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# Photovoltaic Energy Systems

## Program Summary Fiscal Year 1983

January 1984

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# PREFACE

Since 1975, the federal government has conducted a program to provide focus, direction, and funding for the development of terrestrial photovoltaic (solar-electric) technology. The goal of the program is to advance scientific understanding and to establish a technology base which private enterprise can use in developing photovoltaic energy-producing devices or systems for sale in the competitive energy market.

Each year a program summary, such as this, is prepared to provide an overview of government funded activities within the program. This summary highlights tasks conducted in-house by the participating national laboratories or under contract by industrial, academic, or other research institutions. It covers activities initiated, renewed, or completed during Fiscal Year 1983 (FY 1983 — October 1, 1982 through September 30, 1983).

This document is divided into three sections. The first includes introductory information, a list of directing organizations, a list of acronyms and abbreviations, and an index of current contractors. The second section is made up of individual activity summary sheets, grouped by directing organization. The third section is also grouped by directing organization and lists FY 1982 — FY 1983 publications.

# Table of Contents

<b>Introduction</b>	<b>Page</b>
Photovoltaics Program .....	1
Background .....	1
PV Industry .....	1
Research Requirements .....	1
Organizational Relationships .....	2
Status Summary .....	3
Directing Organizations .....	8
Abbreviations and Acronyms .....	9
Index of Current Contractors .....	12
 <b>FY 1983 Contract Descriptions</b>	
Solar Energy Research Institute .....	19
Jet Propulsion Laboratory .....	121
Sandia National Laboratories .....	199
NASA/Lewis Research Center .....	303
Brookhaven National Laboratory .....	311
Battelle Pacific Northwest Laboratories .....	315
Oak Ridge National Laboratory .....	319
DOE Albuquerque Operations Office.....	323
DOE Oak Ridge Operations Office .....	337
Department of Energy .....	341
 <b>FY 1982-FY 1983 Publications</b>	
Solar Energy Research Institute .....	347
Jet Propulsion Laboratory .....	365
Sandia National Laboratories .....	377
NASA/Lewis Research Center .....	385
Brookhaven National Laboratory .....	385
Oak Ridge National Laboratory .....	385
DOE Albuquerque Operations Office.....	385

# Introduction

# Photovoltaics Program

## Background

Since 1975, vast advances have been made in photovoltaic technology; advances that are reflected in terms of performance, reliability, and economics. These gains are a direct result of a continuingly fruitful partnership between government and industry. The conversion efficiency of single-crystal silicon cells produced in the laboratory has increased from 14% to 18%. Flat-plate panel efficiency of 10% or better is now relatively common. Module reliability or lifetime has increased tenfold and can be improved to 20 or 30 years in the near term. Module costs have been reduced tenfold.

A five-year plan\*, prepared in response to the Congressional Appropriations Committee request, outlines federal research and development (R&D) activities that will be pursued in the 1984-1988 time period to achieve the needed technology base from which industry may choose appropriate PV options. This plan is the basis for all future PV planning and reporting. It identifies ten tasks in three major areas (materials research, collector research, and systems research). These tasks will be pursued through 1988 in order to achieve needed technical improvements in a number of PV concepts currently under development. The research concentration will be on the development of promising new approaches such as thin-film and multijunction concepts which offer the potential for long-term improvements in cost and performance.

## PV Industry

As a result of both federal and industrial photovoltaic R&D since 1975, the PV industry has made a number of technical advances which have significantly reduced the cost of producing PV systems. The market potential for PV is large enough that 19 firms are now engaged in the development or production of PV modules. Industry, on its own, is investing in PV technology at a rate that probably exceeds U.S. federal funding.

Today, there are more than 5,000 PV systems operating in the United States, with a total installed capacity greater than 14 megawatts (MW). In the United States, the PV industry continues to grow and sales now exceed \$100 million per annum. The U.S. PV industry still leads the world in photovoltaic exports, for it is in applications distant from a utility-grid that photovoltaic systems are often seen as an attractive option. Distant applications include installations such as water pumping, telecommunications, and village power.

## Research Requirements

Despite the many achievements over the past few years, much more research and development needs to be accomplished to meet certain technical and cost goals. Levelized costs for a 30-year lifetime system have been reduced from an estimated \$15 per kilowatt hour (kWh) in 1975 to \$1.50/kWh. However, to be competitive in domestic U.S. grid-connected systems, costs must be reduced by another factor of ten, to 15¢/kWh. The long-term research goals, established in cooperation with private industry during preparation of the five-year plan, are shown in Table 1.

**Table 1. Federal/Industry Long-Term (Late 1990s) Technical Goals<sup>a</sup>**

Goals	Flat Plate Systems	Concentrator Systems
Module Efficiency <sup>b</sup>	13% - 17%	23% - 29%
Module Cost	\$40 - \$75/m <sup>2</sup>	\$90 - \$160/m <sup>2</sup>
Balance-of-System Costs		
Area-Related	\$50/m <sup>2</sup>	\$100/m <sup>2</sup>
Power-Related	\$150/kW	\$150/kW
System Life-Expectancy	30 years	30 years

<sup>a</sup>1982 dollars

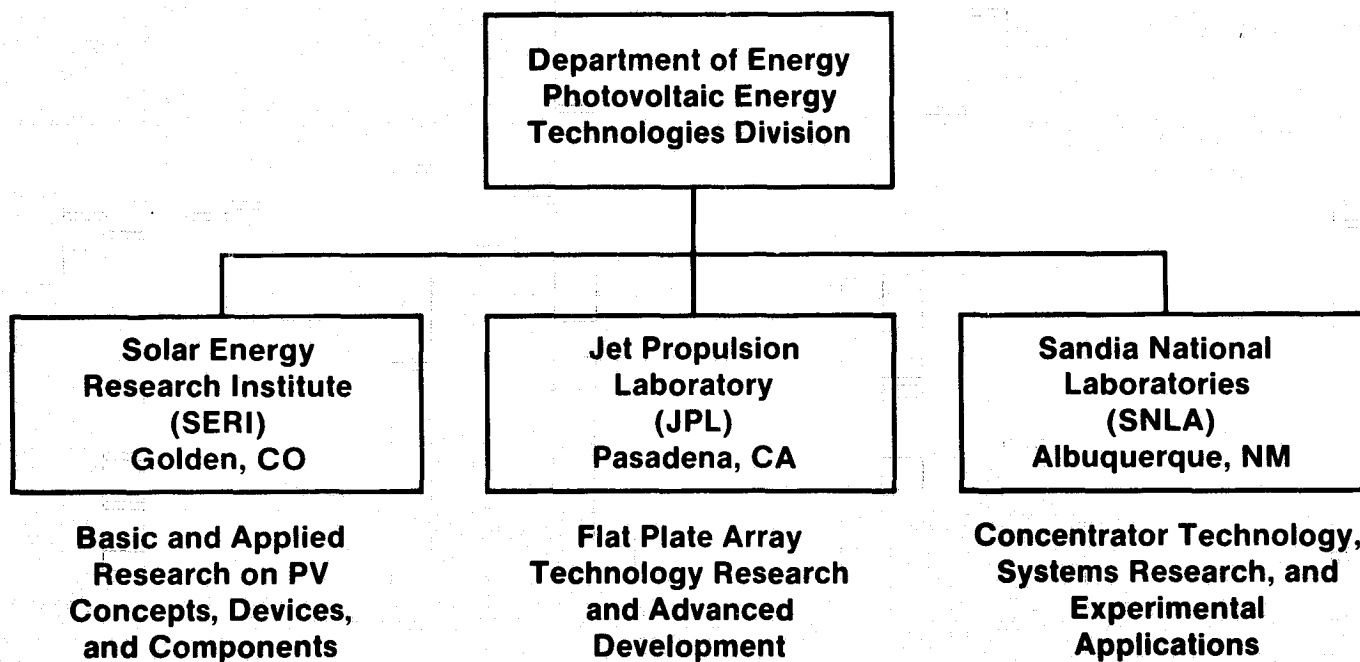
<sup>b</sup>Measured at 28°C and AM 1.5

\*Formally titled, "National Photovoltaics Program: Five-Year Research Plan, 1984-1988."

These planning targets provide guidelines for selecting long-term research, which is the primary focus of federal support. However, it is recognized that interim developments are critical to maintaining momentum in the growth of the PV industry and ensuring its future in competitive energy markets. This requires that the results of technology development be transferred to industry as soon as possible. Technology transfer is promoted by establishing close cooperation with industry in R&D and soliciting significant industrial R&D participation and cost sharing. The federal government also provides tax and regulatory incentives to stimulate private sector investment.

## Organizational Relationships

The federal photovoltaics program is conducted by the U.S. Department of Energy (DOE) and is organizationally assigned to the Assistant Secretary for Conservation and Renewable Energy. Day-to-day research activities are conducted on an in-house or contract basis by three national laboratories. The institutional relationships are shown below:





## Status Summary

Activities carried out in photovoltaics technology are quite diverse. The program has been divided into ten research areas which embody the planning and implementation structure. The ten research areas are:

1. Single-Junction Thin Films
2. High Efficiency Multijunction Concepts
3. Innovative Concepts
4. Silicon Materials
5. Advanced Silicon Sheet
6. Flat-Plate Collectors
7. Concentrator Collectors
8. Module Reliability
9. Array and Balance of Systems Development
10. System Applications

The following is a summary of progress attained in each of these areas in FY 1983.

### 1. Single-Junction Thin Films

Single-junction thin-film cells have two primary advantages: low material requirements (1%-10% of the amounts required in crystalline silicon cells) and the potential for low-cost production techniques, such as the continuous fabrication of entire modules at relatively low temperatures.

In 1983, a significant three-year research program involving cost sharing with industry was initiated by the Solar Energy Research Institute (SERI). The objective of this program is to improve the efficiency and stability of single-junction amorphous silicon (a-Si) solar cells. This three-year phased program is designed to demonstrate efficient, large-area submodules of monolithic solar cells and to design and construct multi chamber deposition systems to reduce cross-contamination between adjacent layers of the cell. The goals of this effort are to demonstrate submodules (1,000 cm<sup>2</sup>) with efficiencies of 8% and small cells (100 cm<sup>2</sup>) with efficiencies of 12%. Chronar Corporation was the first announced, successful competitor in this effort and was awarded a \$6 million cost-shared contract at the end of FY 1983. Two additional contracts were signed with the 3M Company and Solarex Corporation in early FY 1984.

A highlight of the FY 1983 a-Si research effort was the achievement of nearly 5% efficiencies on submodule areas greater than 100 cm<sup>2</sup>. Two SERI contractors, RCA and Chronar, achieved this for submodules of 350 cm<sup>2</sup> and 127 cm<sup>2</sup> respectively. RCA also announced achievement of a 10% a-Si cell in FY 1982. Solarex Corporation has since acquired the RCA a-Si photovoltaic technology and key staff.

In addition to a-Si, several other thin-film materials and devices have shown promise in the development stage. Research progress has been significant enough for polycrystalline compound semiconductors, that a joint venture company was formed in FY 1983 to develop thin-film copper-indium-diselenide (CuInSe<sub>2</sub>) solar cells for commercial markets. The new Seattle-based company, called Sovolco, is operated by the Boeing Engineering Company in partnership with Reading and Bates Development Company of Tulsa, Oklahoma. Under contract to SERI, Boeing improved CuInSe<sub>2</sub> cell efficiency to 11%. Initial work at Sovolco includes the achievement of successful high-efficiency cell deposition on low-cost substrates.

Other thin-film materials of high interest include cadmium telluride (CdTe) and gallium arsenide (GaAs). Several industrial companies are working on each of these materials. In FY 1983, the first self-consistent band structure calculation of several different polycrystalline compounds was completed. Electron density maps were calculated and used to understand the chemical bondings in these systems which exhibit simultaneous covalent (e.g., the Cu-Se bond) and ionic (e.g., the Cu-In bond) bondings.

To support these and other material research tasks, advanced measurement techniques and equipment are developed and maintained for the evaluation and characterization of photovoltaic devices and materials and for conducting insolation resource assessments. SERI's Photovoltaic Devices and Measurements Branch evaluated some 950 materials and device samples. Evaluation criteria ranged from determination of atomic composition to spectral response and cell efficiency. Not surprisingly, interesting research results appear from these evaluation efforts. During this past year, specialized studies on unbaked, oxygen heat-treated and vacuum heat-treated CuInSe<sub>2</sub> solar cells led to the discovery that relationships exist between annealing procedures and the formation of the internal electric fields which drive the photovoltaic process. Significant increases in efficiency are more directly related to oxygen heat-treatment than to other thermal processing techniques.

## 2. High Efficiency Multijunction Concepts

The objective of high efficiency multijunction research is to develop photovoltaic cells capable of achieving 20% to 35% conversion efficiencies. The primary concept entails successively layering different semiconductor materials with differing electronic properties (band gaps), so that each layer more efficiently converts a particular wavelength portion of the solar spectrum into electricity.

Research activities at SERI were focussed in two areas in FY 1983: crystalline multijunction concentrator cells and amorphous thin-film multijunction cells. In the latter category, a three-year research program was initiated to identify and develop new a-Si alloy materials and new multijunction cells. The first funding award from this program was made to Spire Corporation.

SERI's solid-state research efforts produced new understanding of a-Si alloys destined for multijunction cells. An early discovery was that the addition of tin to hydrogenated amorphous silicon (a-Si:H), using a glow-discharge deposition technique, caused a change in the semiconductor material from n-type to p-type with an unwanted loss in photoconductive response. SERI researchers hypothesized, and verified, that the simultaneous addition of phosphorous to the alloy converted it back to n-type with a recovery in photoconductive response.

A highlight of the crystalline multijunction research was the achievement of 21.5% efficiency under concentration ratios of 170 to 380 for a gallium-indium-arsenide (GaInAs) cell fabricated by Varian Associates. These cells (of 1.15 eV band gap) could potentially be used as the bottom cell of a very high-efficiency multijunction structure, or they could be used as single-junction cells in advanced concentrator modules.

A complementary effort is underway at Sandia National Laboratories — Albuquerque (SNLA). This research is focused primarily on the development of mechanically stacked two-junction devices which would consist of a top, high band gap cell ( $\approx 1.75$  eV) having good optical transmission of lower energy radiation to a bottom, crystalline silicon cell. In support of this effort, contracts were placed with Hughes, Spire, and Varian for development of this type of cell.

## 3. Innovative Concepts

The objective of innovative concepts research is to identify new photovoltaic materials, device configurations, and concepts for subsequent preliminary research and development. Under investigation are those high-risk, but potentially high-payoff, ideas which private enterprise is unlikely to pursue because of the costs and risks involved.

In FY 1983, SERI issued a public solicitation requesting letters of interest from potential participants in this program. Nine proposals, primarily from universities, were funded. Two examples of the broad range of concepts funded are research into organic semiconductors and the development of graded band gap materials for solar cells. Other innovative concepts research included studies of photoelectrochemical cells and luminescent dye concentrators.

## 4. Silicon Materials

For the most part, present solar cell technology is based on the use of silicon feedstocks, refined by the Siemens-reactor semiconductor-grade process. The objective of the silicon materials effort, managed by the Jet Propulsion Laboratory (JPL), is to overcome the critical technical and economic barriers to low-cost silicon purification necessary for the widespread use of photovoltaics.

Silicon purification processes involving deposition of the material from silane and dichlorosilane are being pursued because these two substances can be purified relatively easily. Due to their high reactivity, they also can be more readily decomposed or reduced to form silicon than can trichlorosilane, currently used in the Siemens process. Research on two other processes offering promise for less-pure, but potentially solar-cell-grade silicon (by refinement of metallurgical-grade silicon), was recently undertaken because of the potential for further reducing production costs.

A silane pilot plant at the Union Carbide Corporation (UCC) site in Washougal, Washington, was completed and is now in operation under private corporate funding. Silane was successfully produced in early January 1983. 25,000 lbs of silane (a new record) was shipped from this plant. UCC also has achieved complete conversion of silane into silicon during steady-state experiments with a fluidized-bed-reactor (FBR). Under JPL funding, the FBR is now installed and in operation in conjunction with the silane pilot plant. The FBR has continuously operated for more than 20 hours.

An advanced FBR, 6 in. in diameter, has been successfully operated by JPL in studies aimed at the characterization of the silicon deposition process using high concentrations of silane. Early indications are that deposition costs with advanced FBR technology will permit silicon to be produced at a cost in line with research goals.

A second method of silicon refinement, using dichlorosilane (DCS), has been successfully conducted by Hemlock Semiconductor Corporation. The pilot plant, using most of the necessary process steps, continues to function well. Work has just been completed on the last major technical problem, i.e., the deposition of silicon. The results of the cold-wall reactor program indicate that with optimization of reactor operating conditions the goals for deposition rate, conversion of DCS to silicon, and power consumption are attainable, particularly for large-size reactors.

Finally, in a related activity at SERI, researchers invented an improved silicon refining technique, based on earlier electrorefining research, which appears readily adaptable to today's Siemens technology. JPL has initiated technology development activities for this process.

## **5. Advanced Silicon Sheet**

Present solar-cell technology is based on the use of silicon wafers obtained by slicing Czochralski (Cz) ingots which have been grown from molten purified semiconductor-grade silicon. This method of obtaining single-crystal silicon wafers is better tailored to the needs of precision semiconductor device production (e.g., integrated circuit chips and discrete power and control devices) than to the needs of large-area solar cells. The objective of advanced silicon sheet research efforts at JPL is to identify and overcome the critical technical and economic barriers to low-cost silicon sheet growth. Growth of crystalline-silicon sheet material, in a geometry that does not require slicing to achieve proper thickness, is an obvious way to eliminate costly processing and material waste. Ribbon growth techniques such as edge-defined film-fed growth (EFG) and dendritic-web growth are promising methods for producing such solar-cell material. Research is also being conducted on edge-supported pulling (ESP), edge-stabilized ribbon (ESR), and low-angle silicon sheet (LASS) techniques.

Excellent progress has been made in demonstrating the technical feasibility of the dendritic-web and EFG techniques. A new silicon dendritic-web furnace configuration at Westinghouse Electric Corporation has resulted in wider ribbons grown at higher growth rates with less stress. Dendritic-web silicon has been grown at a transient rate of 42 cm<sup>2</sup>/min by Westinghouse, exceeding the JPL contract goals of 35 cm<sup>2</sup>/min.

A comprehensive, multi-organizational research effort is underway, structured to overcome the generic technical barriers that inhibit high-speed production of quality ribbon. Extensive analytical and experimental efforts are designed to examine the interrelationships of heat flow, stress, and deformation at high growth speeds. The theoretical portion focuses on the development of a computer model for temperature field-stress relationships under high-speed growth conditions. The modeling effort will be directed toward defining optimum ribbon-growth conditions that permit high-speed growth with acceptable residual stresses. Experimentally, relevant ribbon-temperature field data and boundary conditions will be obtained from existing sheet-growth equipment and used to confirm or refine the theoretical analyses.

## **6. Flat-Plate Collectors**

The objective of the flat-plate collector research at JPL is to develop the technology base that will increase the efficiency of crystalline silicon flat-plate modules to 15% and reduce their cost to between \$100 and \$135/m<sup>2</sup>. Activities being performed include research in high-efficiency crystalline silicon solar cells, transparent conducting materials, new cell and module processes, and the integration of advanced technologies into new module designs. Prototype modules, designed and fabricated by industry in limited quantities, are periodically procured for test evaluation.

During FY 1983, a non-mass analyzed ion-implantation technique for junction formation was demonstrated by JPL and Spire. This technique results in increased throughput with less expensive ion-implantation equipment. The process also provides better control of junction formation at lower temperatures.

At Westinghouse, a module fabrication pilot line has been converted to the liquid dopant (meniscus coating) method of junction formation. This continuous process technique results in a more uniform, repeatable junction at lower cost, and with a higher throughput rate compared to junctions formed by use of the gaseous diffusion techniques.

The California Institute of Technology and others have shown amorphous titanium nitride to be a very effective diffusion barrier. It avoids shorting of the junction by stopping the diffusion of a contact metal, such as copper,

through the junction. An improved ethelene-vinyl-acetate (EVA) encapsulant was formulated which allows a faster and more reliable cure at a lower temperature. In addition, the material has a longer and more stable shelf life than the EVA formulations previously used.

In a complementary effort, SERI awarded five subcontracts for research to improve the basic understanding of efficiency limits in silicon solar cells, and two subcontracts for research on selected electrically active defects in silicon solar cells. The research into the performance limits of crystalline-silicon solar cells led to cells by Spire Corporation exhibiting up to 18% efficiency.

## **7. Concentrator Collectors**

Concentrator collector research at Sandia Laboratories is directed toward achieving the long-term performance, cost, and reliability goals for concentrator systems indicated in Table 1. Intermediate goals are being pursued through research on silicon concentrator cells, concentrator optics (Fresnel lenses and secondaries), cell assemblies, modules with concentration ratios of 40X to 250X, and full-scale arrays.

Experiments and modeling efforts at Purdue University, Arizona State University, Applied Solar Energy Corporation, and Sandia contributed toward improved understanding of concentrator cell performance. Research continued on several specific silicon concentrator-cell efforts, including the etched multiple-junction cell and the grating cell.

Concentrator lens research resulted in the development of more economical lens fabrication methods, such as Lensfilm by 3M Corporation, injection molding, and acrylic-glass lens laminates.

Concentrator cell assembly research continued to focus on the problems of achieving long lifetime. An improved conformal coating was identified as the preferred encapsulant for point focus assemblies. In addition, titanium nitride (TiN) was identified as a good diffusion barrier under silicon cell metallization because it enables cell processing at elevated temperatures.

In the module research area, Intersol Power Corporation announced development of a commercial point-focus module, based on earlier sponsored DOE research, with peak efficiencies above 15%. Under contract to Sandia, Entech (formerly E-Systems) successfully fabricated their first passively cooled linear Fresnel modules. Finally, an experimental 200X module at Sandia achieved a record module efficiency of 16.7%.

In the area of concentrator array research, Entech delivered a 25kW (electric) concentrator to Sandia for test and evaluation. Delivery, installation, and initial testing of a second generation pedestal mounted, point-focus Fresnel array was also accomplished.

Advanced collector research focused on modules with higher concentration ratios (400X-1000X) and higher efficiency cells. Varian Corporation, under contract to Sandia, fabricated and tested a passively cooled 1000X GaAs module with an efficiency over 17%. The innovative design includes secondary optical elements which relax tracking accuracy requirements to a range equivalent to that needed for 100X Fresnel lens concentrators.

## **8. Module Reliability**

Current module technology is sufficient to predict 10-year lifetime with relative confidence. However, a 30-year lifetime is required for widespread commercial usage. Better encapsulating materials can help extend PV cell life. During FY 1983, accelerated testing of the photothermal characteristics of EVA at JPL revealed no loss of properties for the equivalent of a 20-year exposure. A promising method for improved module encapsulation, utilizing a hermetic edge seal and electrostatic bonding, was completed by Spire. Mild steel, treated with polymeric coatings for use as a module substrate, has withstood 3,000 hr of salt spray without corrosion.

In the latest round (Block V) of JPL module testing and characterization, manufacturers delivered modules designed for higher operating voltages and more rigorous test requirements. All manufacturers chose EVA encapsulation and multiple-redundant cell interconnects. The FY 1983 modules were larger and more efficient than in prior years. One advanced design module included cells made from silicon ribbon.

JPL continued to make progress in identifying, understanding, and correcting module failure mechanisms, and in the defining and designing of life-testing models. Knowledge of electrochemical corrosion effects and the electrical integrity of crystalline silicon modules was significantly advanced. In a complementary effort, SERI initiated outdoor measurements on a-Si modules and stability tests on CdS/CuInSe<sub>2</sub> devices.

## **9. Array and Balance of System Development**

This Sandia activity is divided into three areas: systems research and analysis; array subsystem development; and power conditioning development.

Systems research and analysis includes the definition of system design requirements for systems ranging from small roof-mounted arrays to large, ground-mounted modules and arrays. During FY 1983, an effort to document the large legacy of knowledge and experience on small residential systems was begun. A documentation series of one summary and twelve topical reports is planned. The primary audience is intended to be architects and engineers. The first document summarizes residential PV design in enough detail to define the system. Each subsequent document covers a particular residential PV system design-subject-area that an individual architect might need in order to serve a client considering photovoltaics for his residence. Drafts of six of the twelve topical reports planned were completed and are in review. The summary document is in preparation. Publication of the complete set is scheduled in FY 1984.

The impact of varying PV systems output on utility operations was investigated in FY 1983. A utility system model that analyzes varying levels of PV penetration (proportion of residences or other distributed sites with PV) was developed. Particular focus was on the effects of intermittent cloud cover on the overall performance of the utility system. Both the Salt River Project and Arizona Public Service grids were used as specific grid models. A preliminary conclusion is that system penetrations up to 5%-10% present no significant problems.

Array subsystems development activities were highlighted by the installation of two prototype 30 kW flat-plate array fields at the Sandia Test Facility. One field was designed and developed under contract by Battelle-Columbus Laboratories; the other by Hughes Aircraft Company. Each incorporates unique optimization, low-cost, and integrated structural and design features. Installation and subsequent design verification suggest that, for array field sizes greater than 1 MWp, an array cost of less than \$50/m<sup>2</sup> of collector area is achievable (exclusive of module and power conditioning costs). This figure meets the long-term cost goal established by the DOE Photovoltaics Program.

In addition, design of a modular building block array field operating at high voltage ( $\pm 1000$  Vdc) was completed. Other accomplishments included identification of promising automated installation methods for second generation flat-plate and concentrator array fields, and publication of a comprehensive design guidelines manual on system grounding and fault protection.

A major milestone was reached in the development of advanced residential power conditioners. Several units with efficiencies greater than 90%, excellent power quality and utility interface characteristics were delivered and tested. These advanced designs show promise for achieving the performance and economic goals (30¢ - 40¢/W) of the program, if produced in quantity.

Power conditioning development for central-station applications included completing conceptual design efforts and the definition of baseline design requirements. Plans for the next phase were completed. These included developing a small-scale prototype unit (50 kW) for proof of conversion and control concepts, efficiency, and costs.

## **10. System Applications**

System experiments are conducted on a selected basis to gain operational experience on a systems applications level. These experiments provide information which is used to enhance future component and subsystem development.

The Southeast Residential Experiment Station (RES) began construction of three prototype residential systems. One employs new "ribbon" technology modules by Mobil Solar Corporation. The newly operational Southeast RES joins two others, one in the northeast and one in the southwest. A ninth prototype at the Southwest RES was constructed which also used ribbon modules.

In the intermediate range (20-100 kW), existing experiments using flat-plate arrays continued to demonstrate reliable, moderately efficient performance. A number of these experiments were completed and the hardware was transferred to the private sector. Testing of several intermediate size systems using concentrator technology continued and will extend into FY 1984. Interest continues in monitoring the performance of the tracker mechanisms.

Finally, planning was initiated at Sandia to collect and analyze data from large systems installations such as the Georgetown University National Exemplar Project, the Sacramento Municipal Utility District (SMUD) 1 MWp tracking flat-plate experiment, and the privately funded 1 MWp Arco Solar Facility in Hesperia, California. Data from each of these large experiments provide opportunities for improving our knowledge of the performance of photovoltaic systems in operational settings.

# Directing Organizations

## **Battelle Pacific Northwest Laboratories (PNL)**

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## **Department of Energy**

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## **Brookhaven National Laboratory**

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## **DOE Albuquerque Operations Office**

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## **DOE Oak Ridge Operations Office**

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## **Jet Propulsion Laboratory (JPL)**

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## **NASA/Lewis Research Center (NASA Lewis)**

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## **Oak Ridge National Laboratory (ORNL)**

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## **Sandia National Laboratories (SNLA)**

Albuquerque, NM 87185

## **Solar Energy Research Institute (SERI)**

1617 Cole Boulevard  
Golden, CO 80401

# Abbreviations and Acronyms

A	Angstrom
ac	alternating current
A&E	architects and engineers
AES	auger electron spectroscopy
AGC	automatic generation control
AM	air mass
APS	American Physical Society
AR	anti-reflective
AR&D	advanced research and development
ASEC	American Solar Energy Corporation
a-Si	amorphous silicon
a-Si:H	hydrogenated amorphous silicon
BOS	balance of systems
BSF	back surface field
CLEFT	cleavage of lateral epitaxial film for transfer
C-V	capitance — voltage
CVD	chemical vapor deposition
Cz	Czochralski crystal growth
dc	direct current
DCS	dichlorosilane
DLTS	deep level transient spectroscopy
DOE	Department of Energy
DOE/AL	DOE Albuquerque Operations Office
DOE/OR	DOE Oak Ridge Operations Office
EBIC	electron beam induced current
EFG	edge-defined film-fed growth
ELH	type of lamp used in solar simulators, projectors
EMA	ethylene methyl acrylate
EMVJ	etched multiple vertical junction
EPRI	Electric Power Research Institute
EPR	ethylene-propylene-rubber (encapsulant for terrestrial modules)
EPS	electrochemical photocapacitance spectroscopy
ERDA	Energy Research and Development Administration
ESP	edge-supported pulling
ESR	edge-stabilized ribbon
ESR	electron spin resonance
eV	electron volt
EVA	ethylene vinyl acetate (encapsulant for terrestrial modules)
FAST	fixed abrasive slicing technique
FBR	fluidized bed reactor
FF	fill factor
FIFI	field image feature interface
FSA	flat plate solar array
FTIR	Fourier transform infrared (spectroscopy)
FY	fiscal year
GaAs	gallium arsenide
GD	glow discharge
HEM	heat exchanger method
HOMO	homogenous (as in HOMOCVD)
HWVE	hot-wall vacuum evaporation
IEC	International Electrochemical Commission
IEEE	Institute of Electrical and Electronics Engineers

IR	infrared
ISES	International Solar Energy Society
ITO	indium tin oxide
I-V	current-voltage
J <sub>sc</sub>	short circuit current density
JPL	Jet Propulsion Laboratory
kg	kilogram
kHz	kiloherzt
kW	kilowatt
kWh	kilowatt hour
kWp	kilowatt peak (or the amount of electrical energy generated by a solar system at peak daytime exposure to the sun)
LASS	low angle silicon sheet
LOI	letters of interest
LPCVD	liquid phase chemical vapor deposition
LPE	liquid phase epitaxy
LSC	luminescent solar concentrators
mA	milliamperere
MBE	molecular beam epitaxy
MCM	minority carrier mirror
MEPSDU	Module experimental process system development unit
MINP	metal insulator (n-p silicon)
MIS	metal insulator semiconductor
MIS/IL	metal insulator semiconductor inversion layer
MT	megaton
MW	megawatt
MWp	megawatts peak
MOCVD	metal organic chemical vapor deposition
n	n-doped semiconductor
NASA/	
Lewis	National Aeronautics and Space Administration Lewis Research Center
NEC	National Electrical Code
NE RES	Northeast Residential Experimental Station
n-i-p	three layer device of n, i, and p doping
n-ITO	n-doped indium tin oxide
nm	nanometers
NMA	nonmass analyzed
NMR	nuclear magnetic resonance
NOC	normal operating cell
NOCT	normal operating cell temperature
NTIS	National Technical Information Service
OED	orthogonal experimental design
O&M	operations and maintenance
ORNL	Oak Ridge National Laboratory
p	p-doped semiconductor
PA&I	planning, analysis, and integration
PCS	power conditioning system
PCU	power-conditioning unit
PDU	process development unit
PEC	photoelectrochemical cell
PF (or pF)	power factor
PIM	project integration meeting
p-i-n	three layer device of p, i, and n doping
PMMA	polymethyl methacrylate
PNBA	poly (n-butylacrylate)
PNL	Pacific Northwest Laboratories (Battelle)
PR	photoresist
PRDA	Program Research and Development Announcement
PVAA	photovoltaic array analysis
PVMOC	photovoltaic module optimization code
PV	photovoltaic



PV-T photovoltaic-thermal  
 PVTAP photovoltaic transient analysis computer program  
 QGBF quasi-grain boundary free  
 RBS Rutherford back scattering  
 R&D research and development  
 RF radio frequency  
 RFP request for proposal  
 s second  
 SAMICS solar array manufacturing industry costing standards  
 SAMIS solar array manufacturing industry simultion  
 SCC Standard Coordinating Committee  
 SEM scanning electron microscopy  
 SEMIX a direct sheet growth technique using polycrystalline sheet material  
 SERI Solar Energy Research Institute  
 SIMRAND simulation of research and development  
 SIMS secondary-ion mass spectroscopy  
 SIS semiconductor-insulator-semiconductor  
 SMUD Sacramento Municipal Utility District  
 SNLA Sandia National Laboratory (Albuquerque)  
 SOC silicon-on-ceramic  
 SOLCEL II system analysis program  
 SPV surface photovoltage  
 SRRL Solar Radiation Research Laboratory  
 SS stainless steel  
 SW RES Southwest Residential Experimental Station  
 TAG Technical Advisory Group  
 TCM transparent conducting material  
 TCS trichlorosilane  
 TEM transmission electron microscopy  
 TIR total internal reflection  
 TISES Texas Instruments Solar Energy Systems  
 UCP ubiquitous crystallization process  
 UHV ultra-high vacuum  
 V voltage  
 V<sub>dc</sub> direct current voltage  
 V<sub>oc</sub> open circuit voltage  
 XPS x-ray photoelectron spectroscopy

# Index of Current Contractors

	<b>Page</b>
Abacus Controls, Inc. ....	32, 277
Acurex Corporation .....	247, 323
Aerospace Corporation .....	341
AIA Research Corporation .....	124, 289, 290
Applied Solar Energy Corporation .....	135, 158, 159, 184, 223, 224, 248, 249
ARCO Solar, Inc. ....	136
Arizona Public Service Company .....	324
Arizona State University .....	225, 226, 289
Battelle Columbus Laboratories .....	88, 203, 204
Battelle Memorial Institute .....	53
BDM Corporation .....	250, 278, 290, 325
Bechtel Group, Inc. ....	205
Bernd Ross Associates .....	185
Boeing Aerospace Company .....	89, 90, 91
Boeing Computer Services Company .....	199
Brookhaven National Laboratory .....	36
Brooklyn College of CUNY .....	58
Burt Hill Kosar Rittelmann Associates .....	206
California Institute of Technology .....	19, 186, 227, 228
Chronar Corporation .....	37
Clemson University .....	125
Colorado State University .....	92, 93
Columbia University .....	73
Cornell University .....	20, 74, 160
Crystal Systems, Inc. ....	145
DSET Laboratories .....	251
EER, Inc. ....	303
E-Systems, Inc. ....	211, 212, 213, 256, 326
Energy Materials Corporation .....	75, 146
Entech, Inc. ....	252, 253, 254, 255
Charles Evans and Associates .....	68
Exxon Research and Engineering Company .....	38
Firing Circuits, Inc. ....	279
General Electric Company .....	126, 214, 215, 257, 280, 281, 291, 292
Georgetown University .....	337
Grumman Aerospace Corporation .....	59
Harvard College, President and Fellows of .....	40
Harvard University .....	39
Hemlock Semiconductor Corporation .....	147
Hughes Aircraft Company .....	207, 229, 304, 305
IBM Corporation .....	41
IEEE .....	55, 56
Illinois Tool Works .....	170
Institute of Gas Technology .....	60
Intersol Power Corporation .....	208, 216, 258
L. W. James & Associates .....	259, 260, 261
Jet Propulsion Laboratory .....	282
Kayex Corporation .....	148
Lea County Electric Coop. ....	327
Arthur D. Little, Inc. ....	72
Martin Marietta Corporation .....	217, 218, 262, 263, 264, 293
Massachusetts Institute of Technology .....	42
Materials Research, Inc. ....	161, 162
McDonnell Douglas Astronautics .....	265
Microwave Associates, Inc. ....	230
Mississippi County Community College .....	338
MIT Energy Laboratory .....	331
MIT Lincoln Laboratory .....	21
Mobil Solar Energy Corporation .....	137, 149, 150

NASA/JPL .....	57, 76, 77, 94, 294, 295
National Bureau of Standards .....	43
Naval Research Laboratory .....	44
New Mexico State University .....	328, 332
North Carolina State University .....	45, 95
Oak Ridge National Laboratory .....	78, 319, 320
Oregon State University .....	151
Owens-Illinois, Inc. ....	22
Pennsylvania State University .....	79
Photowatt International .....	138, 187, 231
Poly Solar, Inc. ....	96
Polytechnic Institute of New York .....	171
Power Hybrids .....	232
Princeton University .....	69, 97
Purdue Research Foundation .....	233, 234
Purdue University .....	300
RCA Laboratories .....	46
Rensselaer Polytechnic Institute .....	23
Research Triangle Institute .....	24, 98
Rockwell International Corporation .....	61, 172
Sacramento Municipal Utility District (SMUD) .....	342
C. T. Sah Associates .....	163
San Bernardino West Side Community Development Corporation .....	200
Sandia National Laboratories .....	80
Science Applications, Inc. ....	33, 329
Semix, Inc. ....	343
Solar Energy Research Institute .....	296, 297
Solar Power Corporation .....	306, 330
Solarelectronics, Inc. ....	152
Solarex Corporation .....	139, 188
Solavolt, Inc. ....	140
Solavolt International .....	307
Solenergy Corporation .....	141
Sollos, Inc. ....	189
Southern Methodist University .....	25, 99
Spectrolab, Inc. ....	173, 190
Spire Corporation .....	26, 27, 47, 81, 142, 174, 191, 192, 235
Springborn Laboratories, Inc. ....	175, 266
SRI International .....	62, 100, 101
Stanford University .....	102, 103, 104
State University of New York at Buffalo .....	84
Telic Corporation .....	105
Tennessee Valley Authority .....	219
Teslaco, Inc. ....	283
Texas Instruments, Inc. ....	344
Texas Tech University .....	267
Thermo-Electron, Inc. ....	268
3M Company .....	269, 270
TriSolarCorp. ....	308
Tulane University .....	106
Underwriters Laboratories, Inc. ....	127, 128
Union Carbide Corporation .....	153
United Technologies Research Center .....	28
University of California at Los Angeles .....	164
University of California at Santa Cruz .....	176
University of Central Florida .....	333
University of Colorado .....	48
University of Delaware — Institute of Energy Conversion .....	49, 107, 108, 109
University of Florida .....	82, 83, 165
University of Hawaii at Manoa .....	285
University of Illinois — The Board of Trustees .....	154
University of Kentucky Research Foundation .....	155
University of Massachusetts .....	177
University of Notre Dame .....	70
University of Oregon .....	50

University of Pennsylvania .....	85, 166, 193
University of Southern California .....	167, 178
University of Texas at Arlington .....	110, 298
University of Texas at Austin .....	63
University of Toronto — The Governing Council .....	179
University of Washington — Joint Center for Graduate Study .....	86, 168
University of Wisconsin .....	236
Varian Associates, Inc. ....	29,30, 237, 238, 239, 240, 271, 272
Westinghouse Electric Corporation .....	87, 111, 156, 194, 195, 284
Wyle Laboratories .....	129
Xerox Corporation .....	51
Yeda Research and Development .....	64

**FY 1983**  
**Contract Descriptions**

# **Solar Energy Research Institute**

# SERI

**Title:** Efficient Luminescent Solar Concentrators

**Contractor:**  
California Institute of Technology  
Pasadena, CA 91103

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** A. Zewail  
**Telephone:** (213) 796-6811 ext. 2537

**Project Engineer:** J. Benner  
**Telephone:** (303) 231-1396

**Contract Number:** 1262-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 5/15/79  
**To:** 12/31/82

<b>FY 1979</b>	<b>\$ 144,116</b>	<b>SERI</b>
<b>FY 1980</b>	<b>\$ 126,604</b>	<b>SERI</b>
<b>FY 1981</b>	<b>\$ 42,500</b>	<b>SERI</b>
<b>FY 1982</b>	<b>\$ 41,500</b>	<b>SERI</b>

**Project/Area/Task:** Advanced High Efficiency  
Concepts

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**Objectives:** To produce high efficiency (7-8%) luminescent solar concentrators (LSC) and to investigate the photophysics of energy transfer and energy losses between dye ensembles.

**Approach Tasks:**

- Survey the physical characteristics of the constituents used in LSC devices.
- Study the inter-dye and intra-dye ensemble energy transfer rates as a function of dye concentration, excitation energy, and matrix temperature.
- Build and characterize general LSC systems.
- Evaluate photodegradation rates of dyes in various hosts.

**Status/FY 1983 Accomplishments:**

- Final Report submitted.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Zewail, A.H. (April 1983). *Efficient Luminescent Solar Concentrators; Final Report.*

**Summary Date**  
October 1983

# SERI

**Title:** Investigation of Electronic Properties of Polycrystalline GaAs

**Contractor:**  
Cornell University  
Ithaca, NY 14855

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** K. Wagner  
**Telephone:** (607) 252-3703

**Project Engineer:** J. Benner  
**Telephone:** (303) 231-1396

**Contract Number:** 9316-1 (2163-1)

**Contract Funding:**

**Source:**

**Current Contract Period:** From: 9/29/80  
To: 12/31/82

<b>FY 1980</b>	<b>\$ 109,685</b>	<b>SERI</b>
<b>FY 1981</b>	<b>\$ -0-</b>	<b>SERI</b>
<b>FY 1982</b>	<b>\$ 35,000</b>	<b>SERI</b>

**Project/Area/Task:** Advanced High Efficiency  
Concepts

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**Objectives:** To determine the mechanisms by which grain boundaries degrade the performance of polycrystalline GaAs solar cells.

**Approach/Present Tasks:**

- Fabricate test structures using single grain boundaries in epitaxial GaAs films grown on large grain polycrystalline substrates.
- Using these structures, measure both solar cell and grain-boundary properties resulting from a single grain boundary.
- Routine solar cell characterizations C-V and I-V characteristics across the grain boundary are used to determine the properties of grain boundary defects.

**Status/FY 1983 Accomplishments:**

- Final Report submitted.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Wagner, D.K. (January 1983). *Electrical Characterization of Grain Boundaries in GaAs; Final Report.*

**Summary Date**  
October 1983



# SERI

**Title:** GaAs Thin Film Solar Cells

**Contractor:**  
MIT Lincoln Laboratory  
Lexington, MA 02173

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** J.C.C. Fan  
**Telephone:** (617) 862-5500

**Project Engineer:** J. Benner  
**Telephone:** (303) 231-1396

**Contract Number:** 3021-1 (9158-1, 2071-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 9/30/80  
**To:** 12/31/85

**FY 1980**            \$ 300,573

SERI

**FY 1981**            \$ 182,400

SERI

**FY 1982**            \$ 345,222

SERI

**FY 1983**            \$ 498,058

SERI

**Project/Area/Task:** Advanced High Efficiency  
Concepts

**Objectives:** The intent of this multiyear project is to establish a foundation of scientific understanding of the materials technology required for preparation of thin film, single crystal solar cells using III-V compounds. This will be demonstrated by fabrication of solar cells with conversion efficiencies in excess of 25% at one sun illumination and more than 30% under concentrated sunlight.

#### Approach/Present Tasks:

- Study the initiation and propagation of defects in heteroepitaxial layers of GaAs grown on silicon substrates.
- Investigate vapor phase heteroepitaxial and lateral epitaxial growth of GaAsP and AlGaAs on GaAs substrates in order to establish a baseline material quality for further study.
- Prepare films of AlGaAs and GaAsP for use in conjunction with a silicon bottom cell in a multiple junction structure. These will be either grown directly on the silicon to form a monolithic tandem structure or separated films to be used in a four terminal stacked cascade cell.

#### Status/FY 1983 Accomplishments:

- Lateral overgrowth of AlGaAs achieved.
- One sun efficiencies greater than 12% achieved in AlGaAs solar cells.
- Defect densities in heteroepitaxial GaAs on silicon reduced to  $10^4$  cm<sup>-2</sup>.

#### FY 1984 Milestones:

- Provide an assessment of the relative merits of AlGaAs and GaAsP for use in high efficiency multijunction solar cells — January 1984.
- Demonstrate a CLEFT high bandgap solar cell for use in a multijunction structure — June 1984.

#### Major Project Reports:

- Fan, J.C.C. (February 1982). *GaAs Shallow-Homojunction Solar Cells*. Lexington, MA: Lincoln Laboratory; 82 pp.
- Fan, J.C.C.; Tsaur, B-Y.; Palm, B.J. (1983). "High Efficiency Crystalline Tandem Cells." *Proceedings of the Society of Photo-Optical Instrumentation Engineers: Volume 407 — Photovoltaics for Solar Energy Applications II; Arlington, VA; 5-6 April 1983*. Edited by David Adler. Bellingham, WA: SPIE; pp. 73-87.
- Fan, J.C.C.; Tsaur, B-Y; Palm, B.J. (1983). "Optimal Design of High Efficiency Tandem Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 692-701.
- Tsaur, B-Y; Fan, J.C.C.; Turner, G.W.; Davis, F.M.; Gale, R.P. (1983). "Efficient GaAs/Ge/Si Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1143-1148.

**Summary Date**  
October 1983

# SERI

**Title:** Research Study of Luminescent Solar Concentrators

**Contractor:**

Owens-Illinois Inc.  
Corporate Technology  
P.O. Box 1035  
Toledo, OH 43666

**Principal Investigator:** P.S. Freidman

**Telephone:** (419) 247-9832

**Contract Number:** 2145-1 (9357-1)

**Current Contract Period From:** 2/1/78  
**To:** 4/30/84

**Project/Area/Task:** Advanced High Efficiency  
Concepts

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** J. Benner

**Telephone:** (303) 231-1396

**Contract Funding:**

FY 1978	\$ 130,000
FY 1979	\$ 208,400
FY 1980	\$ 228,642
FY 1981	\$ 168,900
FY 1982	\$ 408,000
FY 1983	\$ 100,000

**Source:**

Sandia
Sandia
SERI
SERI
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SERI

**Objectives:** The objective of this research is to complete the final phase of the study of the thin film approach to Luminescent Solar Concentrator systems. The result will be a demonstration of the state-of-the-art collectors. In addition, this project will compile the results and understanding developed during the last five years of research on these collectors in order to provide a concise description to guide future research.

**Approach/Present Tasks:**

- Complete the investigation of the interaction of organic and inorganic luminescent species in solid hosts.
- Conclude the outdoor and accelerated degradation testing of organic dyes and polymer host materials.
- Conclude the performance screening of combinations of organic dyes, solvents and polymers.
- Using measured characteristics of the best systems identified in the degradation and performance screening, apply the existing performance theory to design of an optimum luminescent solar concentrator plate.

**Status/FY 1983 Accomplishments:**

- Intersystem nonradiative energy transfer was shown to improve plate efficiencies by 20%.
- Theoretical investigations of LSC performance have shown that scaling from 200 cm<sup>2</sup> plates to 2000 cm<sup>2</sup> results in only a 10% relative decrease in collector efficiency.

**FY 1984 Milestones:**

- Fabricate and test a state-of-the-art LSC plate using the best dyes, host polymers and solvents identified in the screening — March 1984.
- Conclude research and submit Final Report — April 1984.

**Major Project Reports:**

- Friedman, P.S. (January 1983). *Luminescent Solar Concentrator Development - II; Final Report*.
- Friedman, P.S.; Parent, C.R. (1983). "Progress on the Development of Organic Dyes and Inorganic Phosphors for Luminescent Solar Concentrators." *Photovoltaics Advanced Research and Development 5th Annual Review Meeting; Denver, CO; 19-21 May 1983*. SERI/CP-311-2011. Golden, CO: Solar Energy Research Institute; pp. 13-18.

**Summary Date**  
October 1983

# SERI

**Title:** Research on Thin Film GaAs Solar Cells

**Contractor:**

Rensselaer Polytechnic Institute  
ESE Department  
Troy, New York 12181

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** S.K. Ghandhi

**Telephone:** (518) 270-6333

**Project Engineer:** J. Benner

**Telephone:** (303) 231-1396

**Contract Number:** 9002-4

**Contract Funding:**

**Source:**

**Current Contract Period From:** 3/1/80

**To:** 11/30/82

**FY 1980**                    \$ 263,454

SERI

**FY 1981**                    \$ 261,994

SERI

**FY 1982**                    \$ 90,000

SERI

**Project/Area/Task:** Advanced High Efficiency  
Concepts

**Objectives:** To develop the materials technology necessary to demonstrate GaAs solar cells of 10% efficiency in polycrystalline films of less than 10  $\mu\text{m}$  thickness which have been deposited by organometallic CVD on low cost substrates.

**Approach/Present Tasks:**

- Investigate MOCVD process parameters to improve the structural and electrical properties of GaAs films.
- Provide definitive structural, compositional, and electrical characterization of the films using electrochemical, DLTS, SEM, and other diagnostic techniques.
- Fabricate and test Schottky barrier solar cells to gauge the progress in improving GaAs films.

**Status/FY 1983 Accomplishments:**

- Final Report submitted.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Borrego, J.M.; Ghandhi, S.K. (February 1983). *Research on Thin Film Gallium Arsenide Solar Cells; Final Report.*

**Summary Date**

October 1983

# SERI

**Title:** Development of High Efficiency Cascade Solar Cells

**Contractor:**

Research Triangle Institute  
P.O. Box 12194  
Research Triangle Park, NC 27709

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** M. Simmons

**Telephone:** (919) 541-5933

**Contract Number:** 8136-1

**Current Contract Period From:** 1/24/78

**To:** 5/31/83

**Project/Area/Task:** Advanced High Efficiency  
Concepts

**Project Engineer:** L.A. Cole

**Telephone:** (303) 231-1841

**Contract Funding:**

FY 1978	\$ 367,140
FY 1979	\$ 297,000
FY 1980	\$ 237,809
FY 1981	\$ 417,347
FY 1982	\$ 56,506

**Source:**

Sandia
SERI
SERI
SERI
SERI

**Objectives:** To perform research on the materials preparation and device technologies needed for the development of high efficiency (30% or more) cascade solar cells.

**Approach/Present Tasks:**

- Theoretically and experimentally investigate the growth techniques, crystalline structure, and device design needed to achieve high conversion efficiency in monolithic, multijunction cascade cells.
- Evaluate four materials systems including GaAlAs/GaAs, AlGaAsSb/GaAsSb, GaAlAs/GaAsSb and GaInP/GaInAs.
- Investigate crystal growth in the AlGaAsSb system using both Liquid Phase Epitaxy (LPE) and Organometallic Chemical Vapor Deposition (MOCVD).

**Status/FY 1983 Accomplishments:**

- Demonstration of superior defect reduction on (100) GaAs as compared to (111) GaAs substrates.
- Achievement of  $10 \text{ \AA} / \text{cm}^2$  GaAsSb tunnel junction.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Timmons, M.J.; et al. (July 1983). *Development of AlGaAsSb/GaAsSb, High Efficiency Cascade Solar Cells*. 224 pp.

**Summary Date**

October 1983

## SERI

**Title:** Thin Film Gallium Arsenide Solar Cell Research

**Contractor:**

Southern Methodist University  
Dallas, TX 75275

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** S.S. Chu

**Telephone:** (214) 692-3024

**Project Engineer:** J. Benner

**Telephone:** (303) 231-1396

**Contract Number:** 9002-3 (2068-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/30/79

**To:** 12/31/83

**FY 1979** \$ 185,740

**FY 1981** \$ 183,800

**FY 1982** \$ 192,000

**FY 1983** \$ 100,000

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SERI

**Project/Area/Task:** Advanced High Efficiency  
Concepts

**Objectives:** To prepare polycrystalline GaAs solar cells of 10% conversion efficiency in films of less than 10  $\mu$ m thickness. The long-term objective is to produce efficiencies approaching 15%.

**Approach/Present Tasks:**

- Investigate the process parameters in organometallic CVD for growth of improved quality polycrystalline GaAs layers. This is being done by improving the grain size of GaAs films by (1) growing them via a liquid-Ga process on GaAs/W/graphite and (2) by growing them on graded Ge/Si substrates.
- Fabricate and characterize solar cells.

**Status/FY 1983 Accomplishments:**

- Discovery of tungsten precipitates in GaAs films grown on W/graphite substrates.
- New laboratory facilities in process of reaching full operation.
- Fabricated a 9.1% efficient polycrystalline GaAs cell on GaAs/W/graphite using a new method in which arsine is passed over molten Ga.

**FY 1984 Milestones:**

- Demonstrate the formation of epitaxial Ge-Si alloy with graded composition.
- Establish the technology of depositing gallium arsenide films on single-crystalline Ge by CVD. Demonstrate a 17%-efficient single-crystal GaAs solar cell.
- Demonstrate the deposition of large grained GaAs films on modified W/graphite substrates.
- Demonstrate crack-free germanium films on Ge-Si/Si substrates.
- Fabricate solar cells on large-grained GaAs films deposited on modified W/graphite substrates.
- Produce polycrystalline GaAs solar cells with greater than 10% efficiency.

**Major Project Reports:**

- Chu, S.S.; Chu, T.L.; Zhang, F.S.; Chen, W.J.; Wang, Q.H. (September 1983). "Thin-Film Arsenide Homojunction Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 1149-1152.

**Summary Date**

October 1983

## SERI

**Title:** Preparation of Silicon Substrate for Gallium Arsenide Solar Cells

**Contractor:**

Spire Corporation  
Patriots Park  
Bedford, MA 01730

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** S. Vernon

**Telephone:** (617) 275-6000

**Project Engineer:** J. Benner

**Telephone:** (303) 231-1396

**Contract Number:** 3033-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 2/18/83

**FY 1983**

**\$ 323,695**

**SERI**

**To:** 4/18/84

**Project/Area/Task:** Advanced High Efficiency  
Concepts

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**Objectives:** The goals of this research are, first, to enhance the quality of GaAs films prepared on germanium-coated silicon substrates; second, to fabricate solar cells in GaAs/Ge/Si structures; and third, to demonstrate the feasibility of AlGaAs/Si cell structures. These goals contribute to achieving the long term goal of increasing the efficiency to more than 20% under one sun illumination.

**Approach/Present Tasks:**

- Study deposition parameters to identify optimum conditions for MOCVD hetero epitaxial growth to achieve minimal-dislocation-density structures.
- Develop a technology for fabrication of efficient GaAs solar cells.
- Fabricate and characterize solar cells in heteroepitaxial GaAs layers.
- Optimize MOCVD growth parameters to achieve high quality heteroepitaxial layers of AlGaAs on silicon substrates.

**Status/FY 1983 Accomplishments:**

- Heteroepitaxial growth achieved for GaAs and AlGaAs directly on silicon as well as on germanium coated silicon.
- GaAs solar cells achieve 20.3% efficiency using MOCVD GaAs layers on GaAs substrates.

**FY 1984 Milestones:**

- Fabricate solar cells in GaAs films heteroepitaxially grown on silicon substrates — February 1984.

**Major Project Reports:**

- Vernon, S.M.; Wolfson, R.G. (1983). "Preparation of Silicon Substrates for Gallium Arsenide Solar Cells." *Photovoltaics Advanced Research and Development 5th Annual Review Meeting; Denver, CO; 19-21 May 1983*. SERI/CP-311-2011. Golden, CO: Solar Energy Research Institute; pp. 23-24.

**Summary Date**  
October 1983

## SERI

**Title:** Preparation of Germanium-on-Silicon Substrates for Gallium Arsenide Solar Cells by Electron Beam Processing

**Contractor:**  
Spire Corporation  
Patriots Park  
Bedford, MA 01730

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** S. Vernon  
**Telephone:** (617) 275-6000

**Project Engineer:** J. Benner  
**Telephone:** (303) 231-1396

**Contract Number:** 2093-1 (9002-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 3/15/80  
**To:** 12/31/82

<b>FY 1980</b>	<b>\$ 164,260</b>
<b>FY 1981</b>	<b>\$ 155,300</b>
<b>FY 1981</b>	<b>\$ 49,000</b>

<b>SERI</b>
<b>SERI</b>
<b>SERI</b>

**Project/Area/Task:** Advanced High Efficiency  
Concepts

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**Objectives:** To prepare high quality crystalline germanium surfaces on silicon substrates for use in heteroepitaxial growth of high efficiency, thin film GaAs solar cells.

**Approach/Present Tasks:**

- Investigate pulsed electron beam processing of germanium-coated silicon substrates to improve crystalline quality.
- Theoretically and experimentally evaluate the effects of lattice mismatch and mismatch of thermal expansion coefficients between Ge and Si.
- Initiate MOCVD growth of GaAs on Ge/Si substrates.

**Status/FY 1983 Accomplishments:**

- Final Report submitted.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Vernon, S. (March 1983). *Preparation of Silicon Substrates for Gallium Arsenide Solar Cells by Electron Beam Processing; Final Report.*

**Summary Date**  
October 1983

# SERI

**Title:** Fabrication of Monocrystalline GaAs Solar Cells Utilizing Sacrificial NaCl Substrates

**Contractor:**

United Technologies Research Center  
East Hartford, CT 06108

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** A.J. Shuskus

**Telephone:** (203) 727-7498

**Project Engineer:** L.A. Cole

**Telephone:** (303) 231-1841

**Contract Number:** 9002-5 (2142-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 8/1/82

**To:** 6/30/84

**FY 1982**

**\$ 177,000**

**SERI**

**FY 1983**

**\$ 264,827**

**SERI**

**Project/Area/Task:** Advanced High Efficiency  
Concepts

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**Objectives:** To establish a process technology for fabrication of high efficiency thin film monocrystalline GaAs photovoltaic cells suitable for application in terrestrial systems.

**Approach/Present Tasks:** Germanium is deposited on a NaCl substrate followed by deposition of molybdenum on the Ge to provide strength after separation from the NaCl. The germanium films are then used as substrates for fabrication of thin single crystal GaAs solar cells. Additional research is underway to grow low temperature (approximately 450°C) GaAs by the plasma-enhanced MOCVD technique, with the ultimate goal of growing GaAs directly on the NaCl.

**Status/FY 1983 Accomplishments:**

- New "clean room" (Class 1000) facilities have been built and the equipment moved in.
- Substrate polishing facilities now reduce surface defects to approximately  $10^6/\text{cm}^2$  (from approximately  $10^{10}/\text{cm}^2$ ).
- A vapour etch techniques has been discovered which further reduces surface defects down to approximately  $10^4/\text{cm}^2$ . Completely specular (both sides) Ge thin films have been produced.
- An annealing technique has been applied to the Ge films, further reducing defects, making the thin film much less brittle, more durable, and increasing the thin film yield.

**FY 1984 Milestones:**

- Demonstrate a 15% efficient thin, separated-film GaAs solar cell.

**Major Project Reports:**

- Shuskus, A.J.; Cowher, M.F. (June 1983). *Final Report*.
- Shuskus, A.J.; Cowher, M.F. (June 1983). *Fabrication of Monocrystalline GaAs Solar Cells Utilizing NaCl Sacrificial Substrates; Final Report*. 52 pp.

**Summary Date**  
October 1983



## SERI

**Title:** Advanced High Efficiency Concentrator Cells

**Contractor:**

Varian Associates, Inc.  
Corporate Solid State Laboratory  
611 Hausen Way  
Palo Alto, CA 94303

**Principal Investigator:** M.J. Ludowise

**Telephone:** (415) 424-5081

**Contract Number:** 3015-1

**Current Contract Period From:** 4/1/83  
**To:** 3/31/84

**Project/Area/Task:** Advanced High Efficiency  
Concepts

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** L.A. Cole

**Telephone:** (303) 231-1841

**Contract Funding:**

**FY 1983**            \$ 295,593

**Source:**

SERI

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**Objectives:** This is a long range research program designed to address those materials areas and concepts with potential photovoltaic conversion efficiencies in excess of 30% under concentrated sunlight.

**Approach/Present Tasks:**

- Theoretically and experimentally investigate techniques to improve multijunction cell technologies based on a high efficiency (21.5%) GaInAs bottom cell.
- Investigate the use of AlGaAs, GaInP, and GaAsP materials for the top cell of a multijunction structure.
- Explore methods of monolithically growing these lattice mismatched top and bottom cells.

**Status/FY 1983 Accomplishments:**

- Linear and step grading techniques have proven successful enough to question the need for superlattice interconnects at this point.
- Mg has been shown to be the preferred dopant in this work. The normal dopant in MOCVD work, Zn, diffuses too rapidly during the growth of the top cell materials; this diffusion degrades or destroys the high efficiency bottom cell. Mg doped materials do not suffer from this problem.
- GaInP has been dropped as a top cell material because it degrades too easily in the presence of small numbers of lattice defects.

**FY 1984 Milestones:**

- Choose a primary material for the top cell (between AlGaAs and GaAsP) by 31 October 1983.

**Major Project Reports:**

- Ludowise, M.J. (August 1983). *Quarterly Progress Report #1*.
- Semi-Annual Report (due November 1983) and Final Report (due April 1983).

**Summary Date**  
October 1983

## SERI

**Title:** Materials for High Efficiency Multijunction Cells

**Contractor:**

Varian Associates, Inc.  
Corporate Solid State Laboratory  
611 Hansen Way  
Palo Alto, CA 94303

**Principal Investigator:** R.L. Bell/M. Ludowise

**Telephone:** (415) 424-5858/5081

**Contract Number:** 8081-1

**Current Contract Period From:** 4/1/79

**To:** 3/31/83

**Project/Area/Task:** Advanced High Efficiency  
Concepts

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** L.A. Cole

**Telephone:** (303) 231-1841

**Contract Funding:**

**FY 1979** \$ 365,668

**FY 1980** \$ 221,273

**FY 1981** \$ 475,682

**FY 1982** \$ 86,264

**Source:**

SERI

SERI

SERI

SERI

**Objectives:** To make available the materials technology necessary to fabricate a two junction monolithic concentrator solar cell with an efficiency goal of 28% (AM2) at concentration of 500 to 1000 suns.

**Approach/Present Tasks:**

- Investigate the MOCVD process parameters needed to prepare high quality semiconductor crystals in the AlGaInAs materials system.
- Theoretically and experimentally develop techniques for fabrication of improved multijunction cells using AlGaInAs top cells on GaInAs bottom cells.

**Status/FY 1983 Accomplishments:**

- Achieved a 21.5% efficient, single junction GaInAs cell (at 172 suns, 1.15 eV bandgap, outdoor test facilities).
- The efficiency of the GaInAs was essentially flat over the concentration range of 113 suns to 380 suns (AM2).
- Improved linear and step-grading technique may eliminate the need for superlattice growths — greatly simplifying the final structures.
- New research, using the GaInAs cell as a high-efficiency basic starting point is being carried out under SERI subcontract number 3015-1 (Varian Associates, Inc.).

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Ludowise, M. (January 1983). *R&D for Perfecting Materials Technology for AlGaInAs and AlInAsSb Mixed Crystal System; Final Report*. 134 pp.

**Summary Date**

October 1983

## SERI

**Title:** Advanced PV Systems Research and Technical Support

**Contractor:**  
Advanced Systems Research Branch — In-House

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** R. DeBlasio  
**Telephone:** (303) 231-1286

**Project Engineers:** E. Witt/T. Surek  
**Telephone:** (303) 231-1042/1371

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82  
**To:** 9/30/83

**FY 1982**            \$ 400,000

DOE

**FY 1983**            \$ 510,000

DOE

**FY 1984**            \$ 595,000

DOE

**Project/Area/Task:** Advanced Systems Research

**Objectives:** To perform in-house research and analysis through experimentation, analysis, and evaluation of advanced PV materials/devices to identify and understand technical issues related to systems adaptations, stability, economics, materials availability, environmental impacts, and safety.

### Approach/Present Tasks:

- Research and analysis is performed utilizing computer methodologies such as PVMOC, PV-TAP, SOLCELL II, SAMICS, PVAA, etc., as well as other techniques.
- Experimentation is performed utilizing PV research outdoor experimental test and simulation facility.
- Technical support to all PV program areas is provided at request of PV Lead Center, program office, and DOE.
- Provide resource management of all support subcontracts regarding advanced PV module/system research.

### Status/FY 1983 Accomplishments:

- Completed transfer of the outdoor PV test facility to the permanent test area and established full operations.
- Designed experiments and fabricated equipment for outdoor stability tests of CdS/CuInSe<sub>2</sub> solar cells.
- Completed system and component level testing of the TI Solar Energy TISES "D" test bed.
- Performed outdoor performance testing of amorphous silicon submodules (RCA, Chronar).
- Performed study on amorphous silicon conceptual module design, laser scribing and module cost.
- Performed experiments utilizing the PV systems simulator to identify systems-related technical issues.

### FY 1984 Milestones:

- Establish a dedicated outdoor test operation at SERI for amorphous silicon solar cell and module testing.
- Perform outdoor stability testing of hydrogen passivated polycrystalline silicon and CdS/CuInSe<sub>2</sub> solar cells.
- Perform a preliminary study of environmental and health hazards as related to the manufacturing of amorphous silicon solar cells and modules.

### Major Project Reports:

- Jackson, B. (September 1983). *Advanced Photovoltaic Module Costing Manual*. SERI/TR-214-1965. Golden, CO: Solar Energy Research Institute.
- Jackson, B. (September 1983). *R&D Decision Methods for Photovoltaic Program Planning*. SERI/TR-214-1743. Golden, CO: Solar Energy Research Institute; 61 pp.
- Lambariski, T.J.; Irby, C.A.; Collaros, G.J.; Anderson, E.R.; Sowa, P.; Schwinkendorf, W.E.; Resnik, W.M. (August 1983). *Design Analysis of Advanced Photovoltaic Technologies*. SERI/STR-214-1997. Golden, CO: Solar Energy Research Institute; 585 pp. Work performed by BDM Corporation, Albuquerque, NM.

**Summary Date**  
October 1983

# SERI

**Title:** Advanced Photovoltaic System Simulator

**Contractor:**

Abacus Controls, Inc.  
80 Readington Road  
Somerville, NJ 08876

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** G.A. O'Sullivan

**Telephone:** (201) 526-6010

**Project Engineer:** L. Mrig

**Telephone:** (303) 231-7178

**Contract Number:** 1070-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 7/8/81  
**To:** 11/30/82

**FY 1981**            \$ 98,222

SERI

**FY 1982**            \$ 32,725

SERI

**FY 1983**            \$ -0-

SERI

**Project/Area/Task:** Advanced Systems Research

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**Objectives:** To design and construct an advanced photovoltaic system simulator for use in characterizing the performance of a simulated total PV system under outdoor conditions based on actual advanced PV cell/module utilization and performance.

**Approach/Present Tasks:**

- System able to simulate actual cell input parameters as well as synthetic parameters based on research laboratory data.
- System adaptable to module and array inputs.
- Major subsystems including PV cell test bed, high gain amplifier-simulator, power conditioner (10 kVA); resistive, inductive/capacitive load. (0.7 pF leading to 0.7 pF lagging, 10 kW); and data acquisition and control equipment.

**Status/FY 1983 Accomplishments:** Outdoor test bed subsystem received November 1982 and wired to total system. Simulation and outdoor testing initiated in December 1983. Test and evaluation experiments in place and operational.

**FY 1984 Milestones:** None. Project completed.

**Major Project Reports:**

- Mrig, L.; DeBlasio, R.; O'Sullivan, G.A.; Tomko, R.P. (May 1983). *An Advanced Photovoltaic System Simulator to Demonstrate the Performance of Advanced Photovoltaic Cells and Devices*. Golden, CO: Solar Energy Research Institute; 6 pp. Paper presented at the Sixteenth IEEE Photovoltaic Specialists Conference; San Diego, CA; 17-30 September 1982.

**Summary Date**

October 1983

# SERI

**Title:** Amorphous Silicon Module Design Study

**Contractor:**

Science Applications, Inc.  
1710 Goodridge Drive  
P.O. Box 1303  
McLean, VA 22012

**Principal Investigator:** Y. Gupta

**Telephone:** (505) 848-5320

**Contract Number:** 1227-1

**Current Contract Period From:** 6/19/81

**To:** 12/82

**Project/Area/Task:** Advanced Systems Research

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** L. Mrig

**Telephone:** (303) 231-5320

**Contract Funding:**

**FY 1981** \$ 10,783

**FY 1982** \$ 8,000

**FY 1983** \$ -0-

**Source:**

SERI

SERI

SERI

**Objectives:** To investigate and develop amorphous silicon integrated module design concepts and to analyze key module design issues and trade-offs.

**Approach/Present Tasks:**

- Develop conceptual designs based on cell circuit configuration as well as cell characteristics and parameters.
- Emphasis will be placed on cell sizes, geometries within the module, interconnect schemes, and module performance parameters.
- Minimum of three designs to be developed, one each for stand alone, residential, commercial, and central station applications.

**Status/FY 1983 Accomplishments:** Final Report disseminated to PV researchers.

**FY 1984 Milestones:** None. Project completed.

**Major Project Reports:**

- *Amorphous Silicon Module Design Study; Final Report.* (April 29, 1982).
- Gupta, Y.; Liers, H.; Wood, S.; Young, S.; DeBlasio, R.; Mrig, L. (1983). "Optimization of a-Si Solar Cell Current Collection." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 1092-1101.

**Summary Date**

October 1983

## SERI

**Title:** Research on High Efficiency Stacked Multi-Junction Amorphous Silicon Alloy Thin Film Solar Cells

**Contractor:**  
To Be Determined

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** To Be Determined  
**Telephone:**

**Project Engineer:** E. Sabisky  
**Telephone:** (303) 231-1483

**Contract Number:** RFP No. RB-3-3055

**Contract Funding:**

**Source:**

**Current Contract Period:** Three Year Subcontract

To Be Negotiated

**Project/Area/Task:** Amorphous Materials

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**Objectives:** To (1) perform research on amorphous silicon alloy materials; (2) to use those materials in the preparation of stacked multijunction amorphous silicon alloy thin film solar cells, (2) to utilize a multi-chamber deposition system for the fabrication of amorphous silicon alloy solar cell devices, and (4) to demonstrate in FY 1986 a stable 16% (AM1) solar conversion efficiency for a solar cell that is at least 1 cm<sup>2</sup> in area and consists of a least two but no more than three stacked cells.

**Approach/Present Tasks:** To be determined by subcontractor.

**Status/FY 1983 Accomplishments:** None. New Program.

**FY 1984 Milestones:** To be negotiated.

**Major Project Reports:** None.

**Summary Date**  
October 1983

## SERI

**Title:** Research on High Efficiency Single-Junction Monolithic Thin Film Amorphous Silicon Solar Cells

**Contractor:**  
To Be Determined

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** To Be Determined  
**Telephone:**

**Project Engineer:** E. Sabisky  
**Telephone:** (303) 231-1483

**Contract Number:** RFP No. RB-3-03056

**Contract Funding:** **Source:**

**Current Contract Period:** Three Year Subcontract

To Be Negotiated

**Project/Area/Task:** Amorphous Materials

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**Objectives:** To provide in FY 1986: (1) a state-of-the-art demonstration of stable, reproducible p-i-n or n-i-p solar cells of at least 12% (AM1) efficiency with areas of at least 1 cm<sup>2</sup>; and (2) a state-of-the-art demonstration of a stable submodule of at least 8% (AM1) efficiency and having a total area of at least 1000 cm<sup>2</sup>. The submodule shall consist of intra-connected, single-junction solar cells. A secondary objective is to design, develop, and operate a multi-chamber deposition system which consists of at least three separate chambers using glow discharge for deposition of state-of-the-art amorphous silicon films over an area of at least 1000 cm<sup>2</sup>.

**Approach/Present Tasks:** To be determined by subcontractor.

**Status/FY 1983 Accomplishments:** None. New program.

**FY 1984 Milestones:** To be negotiated.

**Major Project Reports:** None.

**Summary Date**  
October 1983

## SERI

**Title:** Advanced Amorphous Materials for Photovoltaic Conversion

**Contractor:**  
Brookhaven National Laboratory  
Dept. of Energy and Environment, Bldg. 480  
Upton, Long Island, NY 11973

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** P.E. Vanier  
**Telephone:** (516) 282-3695

**Project Engineer:** A. Mikhail  
**Telephone:** (303) 231-1011

**Contract Number:** 9055-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/78  
**To:** 11/30/84

**FY 1979** \$ 180,000

**DOE**

**FY 1980** \$ -0-

**FY 1981** \$ 310,000

**SERI**

**FY 1982** \$ 240,000

**SERI**

**FY 1983** \$ 316,000

**SERI**

**Project/Area/Task:** Amorphous Materials

**Objective:** To study the characteristics of amorphous silicon hydrogen film deposition by the glow discharge of disilane deposited at high growth rates and determine the effect of cross contamination on device performance.

### Approach/Present Tasks:

- Evaluate amorphous materials deposited by the glow discharge of disilane, at high growth rates.
- Fabricate Schottky barrier and p-i-n devices from materials deposited by the glow discharge of disilane and evaluate their optoelectric properties.

### Status/FY 1983 Accomplishments:

- Prepared microcrystalline n and p layers with conductivities of the order  $2-5 \text{ (ohm-cm)}^{-1}$ .
- Optimized the silane fraction in hydrogen and achieved growth rates, exceeding  $30 \text{ \AA/s}$ .
- p-i-n devices of the structure n-i-p on SS substrates achieved efficiencies in the range of 7-8% (verified by SERI).

### FY 1984 Milestones:

- Deposit undoped by hydrogenated amorphous silicon at growth rates exceeding  $20 \text{ \AA/s}$  by glow discharge of disilane — March 1983.
- Determine the effect of disilane impurities and cross contamination on device qualities — September 1984.
- Fabrication of a disilane-based p-i-n device with AM1 efficiency of at least 6% — September 1984.

### Major Project Reports:

- Delahoy, A.E.; Griffith, R.W.; Kampas, F.J.; Vanier, P.E. (September 1982). "Effects of Monochlorosilane on the Properties of Plasma Deposited Hydrogenated Amorphous Silicon." *Journal of Electronics Materials*. Vol. 11 (No. 5); 869-882.
- Vanier, P.E. (June-July 1983). "The Effects of Light-Soaking on the Low Temperature Photoconductivity of Hydrogenated Amorphous Silicon." *Solar Cells*. Vol. 9 (No. 1-2); pp. 85-93.

**Summary Date**  
October 1983



# SERI

**Title:** Research on PV Devices Using a-Si Produced by CVD from Higher Order Silanes

**Contractor:**

Chronar Corporation  
Princeton, NJ

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** A. Delahoy

**Telephone:** (609) 587-8000

**Project Engineer:** A. Mikhail

**Telephone:** (303) 231-1011

**Contract Number:** 03147

**Contract Funding:**

**Source:**

**Current Contract Period From:** 8/1/81

**To:** 10/31/84

**FY 1981**

**\$ 161,500**

**SERI**

**FY 1982**

**\$ 180,000**

**SERI**

**FY 1983**

**\$ 241,500**

**SERI**

**Project/Area/Task:** Amorphous Materials

**Objectives:** To investigate the use of higher order silanes in the low pressure CVD deposition of hydrogenated amorphous silicon films for production of solar cells.

**Approach/Present Tasks:**

- Investigate various deposition processes of CVD a-Si of higher order silanes by varying the parameters and studying the effect on the material properties. Schottky barrier devices will be used to evaluate the quality of the intrinsic layers.
- Prepare the p and n type layers and analyze their photoelectric properties.

**Status/FY 1983 Accomplishments:**

- Designed, built, and operated at least four independent CVD reactors.
- Achieved growth rates exceeding 10 Å/s in the hot substrate, cold wall reactor.
- Measured external short circuit current of 5.5 mA/cm<sup>2</sup> in the gold Schottky barrier devices without anti-reflection coating.
- An AM1 efficiency of 4% was reported for a three stack p-i-n CVD device.

**FY 1984 Milestones:**

- Fabrication a Schottky barrier with an external short circuit current of at least 9 mA/cm<sup>2</sup> — July 1984.
- Fabrication of a single junction p-i-n device with an AM1 efficient of at least 5% — July 1984.

**Major Project Reports:**

Delahoy, A.E. (1983). "Properties of Hydrogenated Amorphous Silicon Prepared by Chemical Vapor Deposition from Higher Silanes." *Proceedings of the Society of Photo-Optical Instrumentation Engineers: Volume 4-7 — Photovoltaics for Solar Energy Applications II; Arlington, VA; 5-6 April 1983*. Edited by David Adler. Bellingham, WA: SPIE; pp. 47-54.

**Summary Date**

October 1983

# SERI

**Title:** Sputtered Amorphous Silicon Solar Cells

**Contractor:**  
Exxon Research & Engineering Co.  
P.O. Box 8  
Linden, NJ 07036

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** T. Moustakas  
**Telephone:** (201) 474-2051

**Project Engineer:** E. Sabisky  
**Telephone:** (303) 231-1483

**Contract Number:** 9219-1 (2166-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 7/22/80  
**To:** 9/15/83

<b>FY 1980</b>	<b>\$ 280,695</b>	<b>SERI</b>
<b>FY 1981</b>	<b>\$ 389,701</b>	<b>SERI</b>
<b>FY 1982</b>	<b>\$ 380,000</b>	<b>SERI</b>

**Project/Area/Task:** Amorphous Materials

**Objectives:** To further develop the reactive sputtering of a-Si:H, improve material quality and produce solar cell structures with efficiencies in excess of 5%.

**Approach/Present Tasks:**

- Identify deposition parameters which affect the PV properties of the material.
- Understand the mechanism of doping by analyzing amorphous and microcrystalline doped films.
- Understand the operation of a sputtered solar cell by studying the origin of shunt and series resistances and parameters that limit the fill factor.

**Status/FY 1983 Accomplishments:**

- Achieved 5.5% efficiency for single-junction pin solar cell;
- Achieved  $V_{oc} = 1.8$  volts for two stacked p-i-n solar cells;
- Developed methods of depositing amorphous and microcrystalline phosphorus doped amorphous silicon by sputtering from a phosphorus doped target.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Moustakas, J.D. (November 1982). "Studies of Thin-Film Growth of Sputtered Hydrogenated Amorphous Silicon." *Solar Energy Materials*. Vol. 8 (No. 1-3); pp. 187-204.
- Moustakas, J.D. (1983). "High Efficiency Amorphous Silicon Solar Cells Fabricated by Reactive Sputtering." *Electrochemical Society Meeting Proceedings* Vol. 83-11, pp. 291, Symposium "Materials and New Processing Technology for Photovoltaics," 1983, 10 South Main Street, Pennington, NJ 08534.

**Summary Date**  
October 1983

## SERI

**Title:** Investigation of a-Si, a-GaAs and Other Amorphous Semiconductors as Materials for Solar Energy Conversion

**Contractor:**

Harvard University  
Division of Applied Sciences  
Pierce Hall  
Cambridge, MA 02138

**Principal Investigator:** W. Paul

**Telephone:** (617) 495-2853

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** H. Mahan

**Telephone:** (303) 231-1497

**Contract Number:** 9358-1 (2144-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 9/1/83  
**To:** 8/30/84

<b>FY 1979</b>	<b>\$ 239,000</b>	<b>SERI</b>
<b>FY 1980</b>	<b>\$ 236,058</b>	<b>SERI</b>
<b>FY 1981</b>	<b>\$ 180,000</b>	<b>SERI</b>
<b>FY 1982</b>	<b>\$ 125,000</b>	<b>SERI</b>
<b>FY 1983</b>	<b>\$ 90,000</b>	<b>SERI</b>

**Project/Area/Task:** Amorphous Materials

**Objectives:** To produce amorphous silicon-germanium alloys by glow discharge, with the aim of improving material properties such that these materials can be considered for incorporation into tandem cell photovoltaic devices.

**Approach/Present Tasks:**

- Use UHV glow discharge system to deposit hydrogenated amorphous silicon germanium alloys with bandgaps between 1.4-1.5 eV with good photoelectronic properties.
- Fabricate Schottky barrier devices prepared in the UHV glow discharge system and an in situ metal evaporator.

**Status/FY 1983 Accomplishments:**

- Characterized the CVD deposited material by Professor Gordon under Subcontract No. 3071 (President and Fellows of Harvard College).
- Built and operated an UHV glow discharge deposition system.
- Deposited very high quality intrinsic amorphous silicon layers with a density of states less than  $10^{16}/\text{cm}^3$ .

**FY 1984 Milestones:**

- Deposit high quality a-Si Ge<sub>2</sub>H alloy material with bandgap of 1.4-1.5 eV.
- Relate film properties to various deposition conditions and compare it to intrinsic amorphous silicon film.

**Major Project Reports:**

- Meyerson, B.S.; Scott, B.A.; Wolford, D.J. (March 1983). "The Preparation of in-situ Doped Hydrogenated Amorphous Silicon by Homogeneous Chemical Vapor Deposition." *Journal of Applied Physics*. Vol. 54 (No. 3); pp. 1461-1465.

**Summary Date**  
October 1983

## SERI

**Title:** Optimization of Transparent Electrode for Solar Cells

**Contractor:**

President & Fellows of Harvard College  
Office of Research Contracts  
1750 Massachusetts Avenue  
Cambridge, MA 02138

**Principal Investigator:** R.G. Gordon

**Telephone:** (617) 495-4017

**Contract Number:** 9318-1 (3071-1)

**Current Contract Period From:** 9/15/80

**To:** 9/30/84

**Project/Area/Task:** Amorphous Materials

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** E. Sabisky

**Telephone:** (303) 231-1483

**Contract Funding:**

<b>FY 1980</b>	<b>\$ 27,535</b>
<b>FY 1981</b>	<b>\$ 92,000</b>
<b>FY 1982</b>	<b>\$ 16,500</b>
<b>FY 1983</b>	<b>\$ 141,689</b>

**Source:**

SERI
SERI
SERI
SERI

**Objectives:** To investigate fluorine-doped tin oxide as a transparent conductive electrode and to study amorphous silicon films prepared by chemical vapor deposition at atmospheric pressure.

**Approach/Present Tasks:**

- Prepare, by atmospheric pressure CVD, intrinsic layers for use in Schottky barrier devices.
- Investigate anti-reflection coatings, such as titanium nitride, prepared by CVD.
- Prepare films of alumina or silica for use as anti-diffusion coatings and investigate their properties.
- Prepare film of fluorine-doped tin oxide with best possible optoelectronic properties.

**Status/FY 1983 Accomplishments:**

- Grew amorphous silicon films at high growth rates ranging from 30-80 Å/s at atmospheric pressure.
- Fluorine-doped, tin-oxide films, deposited by atmospheric CVD, had an absorption coefficient of 5% with an electrical sheet resistance of 10 ohms/square.

**FY 1984 Milestones:**

- Identification of upper limits of optical transparency of fluorine-doped tin oxide — April 1984.
- Optimization of various deposition conditions to grow amorphous silicon by atmospheric pressure CVD with good photovoltaic properties — October 1984.
- Evaluate the effectiveness of alumina and silica as sodium barriers — August 1984.
- Evaluate the effectiveness of titanium nitride as an anti-reflective coating — January 1984.

**Major Project Reports:**

- Ellis, F.B. et al. 1983. "Properties of Hydrogenated Amorphous Silicon Prepared by Chemical Vapor Deposition." *Journal of Non-Crystalline Solids*, Special issue for Tenth International Conference, Tokyo, 1983.

**Summary Date**

October 1983

# SERI

**Title:** Chemistry and Physics of Silicon-Based Amorphous Semiconductors

**Contractor:**

IBM  
Thomas J. Watson Research Center  
Yorktown Heights, NY 10598

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** M. Brodsky, B.A. Scott

**Telephone:** (914) 945-1338

**Project Engineer:** H. Mahan

**Telephone:** (303) 231-1497

**Contract Number:** 9319-1 (2164-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 9/30/80

**To:** 9/29/83

**FY 1980** \$ 168,143

**FY 1981** \$ 197,674

**FY 1982** \$ 140,000

SERI

SERI

SERI

**Project/Area/Task:** Amorphous Materials

**Objectives:** To use novel deposition methods and novel precursor gases to study the incorporation of hydrogen and dopants into amorphous silicon films in different local configurations in order to improve film transport and stability properties.

**Approach/Present Tasks:**

- Produce films by HOMOCVD deposition process and study film properties.
- Study the chemistry of the deposition process by plasma spectroscopy and novel gas precursors.

**Status/FY 1983 Accomplishments:**

- A solar cell device, fabricated entirely by HOMOCVD, demonstrated an external current of greater than 6 mA/cm<sup>2</sup>.
- A comparison of the ESR spin density and local hydrogen binding (NMR) was made for HOMOCVD, glow discharge (SiH<sub>4</sub>) and glow discharge (Si<sub>2</sub>H<sub>6</sub>) produced films.
- Low ESR spin density (less than 3 x 10<sup>16</sup> cm<sup>-3</sup>), 1.3 V bandgap a-Ge:H material has been produced by HOMOCVD. However, the material exhibits no photoluminescence and poor photoconductivity response. The reasons for the poor photoresponse were investigated but no conclusions were reached.
- Amorphous silicon-carbon alloy films have been produced with carbon incorporated in different local bonding configurations.

**FY 1984 Milestones:** None. Lacking Final Report for program completion.

**Major Project Reports:**

- Meyerson, B.S.; Scott, B.A.; Wolford, D.J. (March 1983). "The Preparation of in-situ Doped Hydrogenated Amorphous Silicon by Homogeneous Chemical Vapor Deposition." *Journal of Applied Physics*. Vol. 54 (No. 3); pp. 1461-1465.
- Scott, B.A.; Reimer, J.A.; Longeway, P.A. "Growth and Defect Chemistry of a-Si:H." *Journal of Applied Physics* (submitted for publication).
- Wolford, D.J.; Scott, B.A.; Reimer, J.A.; Bradley, J.A. (March 1983). "Efficient Visible Luminescence from Hydrogenated Amorphous Silicon." *Proceedings of the 16th International Conference on the Physics of Semiconductors. Montpellier, France; 6-10 September 1982*. Edited by M. Averous. Appears in *Physica B + C; Europhysics Journal*. Vol. 117 & 118 B + C — Part 1; pp. 920-922.

**Summary Date**

October 1983

## SERI

**Title:** Theoretical Investigation of the Origins of Light Induced Effects in Hydrogenated Amorphous Silicon

**Contractor:**

Massachusetts Institute of Technology  
77 Massachusetts Ave.  
Room 13-3050  
Cambridge, MA 02139

**Principal Investigator:** D. Adler

**Telephone:** (617) 253-6868

**Contract Number:** 3117-1

**Current Contract Period From:** 7/1/83  
**To:** 8/31/84

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** H. Mahan

**Telephone:** (303) 231-1497

**Contract Funding:**

FY 1983           \$ 50,000

**Source:**

SERI

**Project/Area/Task:** Amorphous Materials

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**Objectives:** To use the Molecular Orbital Technique to investigate possible mechanisms involved in producing the observed metastable light-induced effects in hydrogenated amorphous silicon.

**Approach/Present Tasks:**

- Calculation of the correlation energy of two dangling bond centers.
- Calculation of the energy states of the H-O-Si complex.

**Status/FY 1983 Accomplishments:**

- None. New program.

**FY 1984 Milestones:**

- Determine if the Staebler-Wronski effect can be explained by the presence of charged dangling bond centers present in amorphous silicon in the absence of light soaking.
- Determine if oxygen could play a role in producing a change in amorphous silicon material properties with light soaking.

**Major Project Reports:**

- None.

**Summary Date**  
October 1983

## SERI

**Title:** Diagnostics of a Glow Discharge Used to Produce Amorphous Silicon Films

**Contractor:**

National Bureau of Standards  
Quantum Physics Division  
Boulder, CO 80303

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** A. Gallagher

**Telephone:** (303) 492-7841

**Project Engineer:** H. Mahan

**Telephone:** (303) 231-1497

**Contract Number:** 1216-1 (2189-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 4/16/81

**To:** 4/14/84

**FY 1981**            \$ 15,500

**FY 1982**            \$ 16,290

**FY 1983**            \$ 25,000

SERI

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**Project/Area/Task:** Amorphous Materials

**Objectives:** To quantify neutral radical specie signals coming from the plasma as a function of deposition conditions and develop a viable model for the discharge.

**Approach/Present Tasks:**

- Modify present detection apparatus to improve the sensitivity for neutral radical species.
- Relate relevant film properties to the neutral radical species observed in the discharge.
- Perform transient neutral radical measurements to distinguish between gas phase and surface reactions.

**Status/FY 1983 Accomplishments:**

- Proved the presence of neutral radical species in glow discharge and successfully distinguished between gas and surface reactions.
- Si, SiH, SiH<sub>2</sub> and SiH<sub>3</sub> radicals were observed in the dc discharge with the SiH<sub>3</sub> as the largest observed signal.
- Identified reaction chain in gas which is responsible for large SiH<sub>3</sub> radical signal observed from CVD reaction.

**FY 1984 Milestones:**

- Detection of difference in radical species signal levels established.
- Report on radical specie measurements for state-of-the-art dc proximity discharge.
- Report results of transient measurements and modeling studies for the dc state-of-the-art material.

**Major Project Reports:**

- Robertson, R.; Hils, D.; Chatham, H.; Gallagher, A. (September 1983). "Radical Species in Argon-Silane Discharges." *Applied Physics Letters*. Vol. 43 (No. 6): pp. 544-546.
- Chatham, H.; Hils, D.; Robertson, R.; Gallagher, A.C. (August 1983). "Reactions of He<sup>+</sup>, Ne<sup>+</sup> and Ar<sup>+</sup> with CH<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, SiH<sub>4</sub> and Si<sub>2</sub>H<sub>6</sub>." *The Journal of Chemical Physics*. Vol. 79 (No. 3); pp. 1301-1311.

**Summary Date**

October 1983

## SERI

**Title:** Spectroscopic Studies of Hydrogenated Amorphous Silicon

**Contractor:**  
Naval Research Laboratory  
Washington, D.C. 20375

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** W. Carlos  
**Telephone:** (202) 767-3357

**Project Engineer:** A. Mikhail  
**Telephone:** (303) 231-1011

**Contract Number:** 9319-2

**Contract Funding:**

**Source:**

**Current Contract Period From:** 3/15/83  
**To:** 3/15/84

**FY 1983**            \$ 62,000

SERI

**Project/Area/Task:** Amorphous Materials

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**Objectives:** To characterize the structural and electronic properties of glow discharge (GD) and CVD amorphous silicon hydrogen material by ESR and NMR techniques.

**Approach/Present Tasks:**

- Perform ESR and NMR measurements on CVD a-Si material prepared by Chronar, Harvard, and Institute of Energy Conversion under SERI subcontracts.
- Study of light induced effects in GD and CVD prepared materials.
- Perform ESR studies of microcrystalline material to determine the doping mechanisms.

**Status/FY 1983 Accomplishments:**

- Identified two principal environments of hydrogen in glow discharge amorphous silicon, namely bulk distributed SiH and hydrogen in various bonding configurations at defect sites.
- Discovered that the majority of boron coordination in p-doped a-Si samples is threefold coordinated.

**FY 1984 Milestones:**

- Complete dopant studies of microcrystalline films — March 1984.
- Investigate light-induced effects in GD and CVD prepared materials — December 1983.

**Major Project Reports:**

- Greenbaum, S.; Taylor, P.C. (March 1983). "Boron and Hydrogen Bonding in P-doped a-Si in NMR Studies." *Proceedings of the 16th International Conference on the Physics of Semiconductors; Montpellier, France; 6-10 September 1982*. Edited by M. Averous. Appears in *Physica B+C; Europhysics Journal*. Vol. 117 & 118 B+C — Part II; pp. 886-888.

**Summary Date**  
October 1983



# SERI

**Title:** Compensation of Dangling-Bond Defects in a-Si, Ge Alloys

**Contractor:**  
North Carolina State University  
Raleigh, NC 27650

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** G. Lucovsky  
**Telephone:** (919) 737-2512

**Project Engineer:** A. Mikhail  
**Telephone:** (303) 231-1483

**Contract Number:** 1071-01 (2065-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 1/15/81  
**To:** 7/31/84

**FY 1981**            \$ 59,000

SERI

**FY 1982**            \$ 56,000

SERI

**FY 1983**            \$ 25,000

SERI

**Project/Area/Task:** Amorphous Materials

**Objectives:** To complete the characterization of a-Si Ge:H alloy material prepared by reactive sputtering and prepare films with device quality photoelectronic properties. To use the UHV magnetron sputtering system to study the effect of impurities on the prepared films.

### Approach/Present Tasks:

- Identify various UHV sputtering conditions that produce high quality a-Si:Ge:H films and study the effect of impurities.
- Conduct theoretical studies of local bonding environment of oxygen.

### Status/FY 1983 Accomplishments:

- Constructed and operated an Ultra High Vacuum dual magnetron sputtering system.
- Films of a-Si:H, a-Ge:H and a-Si:Ge:H were deposited with reasonable dark and photoconductivities.
- Theoretical studies on the infrared absorption of a-Si:O:H and a-Si:N:H films were conducted.

### FY 1984 Milestones:

- Fabricate diagnostic Schottky barrier devices with an a-Si:Ge:H layer — April 1984.
- Determination of local bonding environment of oxygen and nitrogen in a-Si:H alloys and the bonding arrangement of a-Si:Sn:H — July 1984.

### Major Project Reports:

- Rudder, R.A.; Cook, Jr., J.W.; Lucovsky, G. (November 1983). "High Photoconductivity in Magnetron Sputtered Amorphous Hydrogenated Germanium Films." *Applied Physics Letters*. Vol. 43 (No. 9); pp. 871-873.

**Summary Date**  
October 1983

# SERI

**Title:** Amorphous Thin Films Research

**Contractor:**  
RCA Laboratories  
David Sarnoff Research Center  
Princeton, NJ

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** D. Carlson  
**Telephone:** (609) 734-3205

**Project Engineer:** E. Sabisky  
**Telephone:** (303) 231-1483

**Contract Number:** 9372-1 (2044-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/80  
**To:** 5/31/83

<b>FY 1980</b>	<b>\$ 1,241,836</b>	<b>SERI</b>
<b>FY 1981</b>	<b>\$ -0-</b>	<b>SERI</b>
<b>FY 1982</b>	<b>\$ 600,000</b>	<b>SERI</b>

**Project/Area/Task:** Amorphous Materials

**Objectives:** To perform research necessary to achieve a stable a-Si:H solar cell with a conversion efficiency greater than 8%.

**Approach/Present Tasks:**

- Grow doped and undoped amorphous silicon films by means of dc Glow Discharge Deposition Method.
- Construct p-i-n amorphous silicon solar cells to advance the state-of-the-art in small area cells ( $\approx 1.2 \text{ cm}^2$ ).

**Status/FY 1983 Accomplishments:**

- p-i-n solar cells of 7.9% efficiency have been reported using material prepared by dc glow discharge.
- Hole diffusion lengths in undoped a-Si:H of  $1.5 \mu\text{m}$  have been measured under AM2 illumination.
- DLTS has been used to measure density of states of about  $9 \times 10^3 \text{ cm}^{-3} \text{ eV}^{-1}$  near Fermi level of an undoped a-Si:H film.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Carion, F.E.; et al. (1983). *Amorphous-Silicon Process Development; Final Report for the Period 5/31/82 to 5/13/83*. SERI/PR-0-1169-F.
- Carlson, D.E.; Moore, A.R.; Szostals, D.J.; Goldstein, B.; Smith, R.W.; Zanzucchi, P.J.; Frenchu, W.R. (June-July 1983). "Light-Induced Effects in Amorphous Silicon Material and Devices." *Solar Cells*. Vol. 9 (No. 1-2); pp. 19-23.
- Crandall, R.S.; Staedler, D.L. (June-July 1983). "Properties of the Defect Causing Solar Cell Degradation." *Solar Cells*. Vol. 9 (No. 1-2); pp. 63-74.
- Goldstein, D.; Dresner, J.; Moore, A.R.; Szostak, D.J. (May-June 1983). "Diffusion Lengths and Surface Photovoltage." *RCA Engineer*. Vol. 28 (No. 3); pp. 44.

**Summary Date**  
October 1983

# SERI

**Title:** Cost Estimates for Amorphous Silicon Material Deposition Processes

**Contractor:**  
Spire Corporation  
Patriots Park  
Bedford, MA 01730

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** R. Wolfson, S. Shanfield  
**Telephone:** (617) 275-6000

**Project Engineer:** B. Jackson  
**Telephone:** (303) 231-1116

**Contract Number:** 2154-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 8/23/82  
**To:** 12/22/82

**FY 1981**      **\$ 24,500**

**SERI**

**Project/Area/Task:** Amorphous Materials

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**Objectives:** To determine the commercial applicability of three manufacturing processes currently used for the deposition of amorphous silicon cells. The three processes are: 1) glow discharge, both dc proximity and RF diode; 2) sputtering RF diode; and 3) chemical vapor deposition primarily with higher order silanes.

**Approach/Present Tasks:** Contacts will be made with firms manufacturing this and similar types of equipment along with national laboratories, universities, and other private researchers working in this area to learn what factors are expected to determine commercial viability of processes. An investigation will be made of how these factors contribute to cost and the uncertainty about the outlook for the processes.

**Status/FY 1983 Accomplishments:**

- Final Report published.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- *Cost Estimates for Amorphous Silicon Material Deposition Processes; Final Report.* (February 1983). Bedford, MA: Spire Corporation.

**Summary Date**  
October 1983

## SERI

**Title:** Diagnostics of a Glow Discharge Used to Produce Amorphous Silicon Films

**Contractor:**  
University of Colorado  
JILA  
Boulder, CO 80303

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** A. Gallagher  
**Telephone:** (303) 492-7841

**Project Engineer:** H. Mahan  
**Telephone:** (303) 231-1497

**Contract Number:** 9053-1 (2085-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 2/15/80  
**To:** 4/14/84

<b>FY 1980</b>	<b>\$ 99,278</b>	<b>SERI</b>
<b>FY 1981</b>	<b>\$ 105,303</b>	<b>SERI</b>
<b>FY 1982</b>	<b>\$ 43,698</b>	<b>SERI</b>

**Project/Area/Task:** Amorphous Materials

**Objectives:** Quantify-neutral radical specie signals coming from the plasma as a function of deposition conditions and develop a viable model for the discharge.

### Approach/Present Tasks:

- Modify present detection apparatus to improve the sensitivity for neutral radical species.
- Relate relevant film properties to the neutral radical species observed in the discharge.
- Perform transient neutral radical measurements to distinguish between gas phase and surface reactions.

### Status/FY 1983 Accomplishments:

- Proved the presence of neutral radical species in glow discharge and successfully distinguished between gas and surface reactions.
- Observed Si, SiH, SiH<sub>2</sub>, and SiH<sub>3</sub> radicals in the dc discharge with the SiH<sub>3</sub> as the largest observed signal.
- Identified reaction chain in gas which is responsible for large SiH<sub>3</sub> radical signal observed from CVD reaction.

### FY 1984 Milestones:

- Detection of difference in radical specie signal levels as a function of plasma conditions.
- Report on radical specie measurements for state-of-the-art dc proximity discharge.
- Report results of transient measurements and modeling studies for the dc state-of-the-art material.

### Major Project Reports:

- Chatham, H.; Hils, D.; Robertson, R.; Gallagher, A. "Electron Ionization of Methane, Ethane, Silane, and Disilane." *Journal of Chemical Physics* (submitted for publication).
- Chatham, H.; Hils, D.; Robertson, R.; Gallagher, A.C. (August 1983). "Reactions of He<sup>+</sup>, Ne<sup>+</sup>, and Ar<sup>+</sup> with CH<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, SiH<sub>4</sub> and Si<sub>2</sub>H<sub>6</sub>." *Journal of Chemical Physics*. Vol. 79 (No. 3); pp. 1301-1311.
- Robertson, R.; Hils, D.; Chatham, H.; Gallagher, A. (September 1983). "Radical Species in Argon Silane Discharges." *Applied Physics Letters*. Vol. 43 (No. 6); p. 544-546.
- Robertson, R.; Hils, D.; Gallagher, A. "Silane Pyrolysis." *Journal of Chemical Physics* (to be published).

**Summary Date**  
October 1983

## SERI

**Title:** Glow Discharge Deposition of Si:H, Loss Minimization Analysis and Alternative Device Structure

**Contractor:**

University of Delaware  
Institute of Energy Conversion  
One Pike Creek Center  
Wilmington, DE 19808

**Principal Investigator:** R. Rochleau

**Telephone:** (302) 453-6232

**Contract Number:** 9195-1 (2084-1) (3089-1)

**Current Contract Period From:** 11/1/79  
**To:** 6/1/84

**Project/Area/Task:** Amorphous Materials

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** A. Mikhail

**Telephone:** (303) 231-1011

**Contract Funding:**

<b>FY 1979</b>	<b>\$ 256,747</b>
<b>FY 1980</b>	<b>\$ 336,261</b>
<b>FY 1981</b>	<b>\$ 310,001</b>
<b>FY 1982</b>	<b>\$ 248,000</b>
<b>FY 1983</b>	<b>\$ 235,000</b>

**Source:**

<b>DOE</b>
<b>SERI</b>
<b>SERI</b>
<b>SERI</b>
<b>SERI</b>

**Objectives:** To deposit hydrogenated amorphous silicon by low pressure chemical vapor deposition of higher order silanes and fabricate diagnostic Schottky barrier and p-i-n devices. **Approach/Present Tasks:**

- Hydrogenated amorphous silicon, doped and intrinsic, will be prepared by low pressure chemical vapor deposition of high order silanes.
- Conduct theoretical studies on LPCVD kinetic and reactor analysis
- Diagnostic Schottky barriers and p-i-n devices with high short circuit currents will be fabricated and characterized.

**Status/FY 1983 Accomplishments:**

- Designed, built, and operated two reactors.
- The second reactor design produced amorphous silicon films with high hydrogen content at growth rates ranging from 4-30 Å/s.
- The deposited films had majority carrier characteristics such as photo and dark conductive  $\mu\tau$  products that were comparable to glow discharge films.

**FY 1984 Milestones:**

- Selection of deposition parameter space for preparing state-of-the-art intrinsic amorphous silicon layer — July 1983.
- Fabrication of Schottky barrier, or p-i-n devices with an external short circuit current of at least 9 mA/cm<sup>2</sup> — April 1984.
- Verification of model equation of LPCVD of a-Si:H — April 1984.

**Major Project Reports:**

- Rocheleau, R. (1983). *Chemical Vapor Deposition of Amorphous Semiconductor Films; Final Project Report for the Period May 1982 to April 1983.*

**Summary Date**  
October 1983

**SERI**

**Title:** Investigation of Origins of Metastable Light Induced Changes in Hydrogenated Amorphous Silicon

**Contractor:**  
University of Oregon  
Dept. of Physics  
Eugene, OR 97403

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** C.J. David  
**Telephone:** (503) 686-4775

**Project Engineer:** S. Tsuo  
**Telephone:** (303) 231-7682

**Contract Number:** 3101-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 9/1/83  
**To:** 8/31/84

**FY 1983**                      **\$ 50,000**

**SERI**

**Project/Area/Task:** Amorphous Materials

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**Objectives:** To investigate the mechanisms involved in producing the metastable light-induced effects in hydrogenated amorphous silicon.

**Approach/Present Tasks:**

- Correlate the size of the observed light-induced effects and density of gap states with extrinsic impurities and growth parameters.
- Investigate the mechanisms involved in producing the Staebler-Wronski effects such as optical excitation and Fermi energy.

**Status/FY 1983 Accomplishments:** None. New program.

**FY 1984 Milestones:**

- Report on the results of the studies on the extrinsic vs. intrinsic nature of Staebler-Wronski effect and its temperature dependence.
- Complete the DLTS study on the role of impurities and optical excitation on the metastable effect.

**Major Project Reports:**

- None.

**Summary Date**  
October 1983

# SERI

**Title:** Structural and Electronic Studies of Defects in Hydrogenated Amorphous Silicon

**Contractor:**  
Xerox Corporation  
Palo Alto Research Center  
Palo Alto, CA 94304

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** R. Street  
**Telephone:** (415) 494-4120

**Project Engineer:** E. Sabisky  
**Telephone:** (303) 231-1497

**Contract Number:** 9079-1 (2105-1) (3112-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 2/1/79  
**To:** 7/31/84

FY 1979	\$ 91,000
FY 1980	\$ 176,041
FY 1981	\$ 187,641
FY 1982	\$ 187,048
FY 1983	\$ 388,700

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SERI

**Project/Area/Task:** Amorphous Materials

**Objectives:** To investigate and understand the structural origin of light induced effects and study the structural and electronic properties of amorphous silicon alloy materials.

### Approach/Present Tasks:

- Study the mechanisms responsible for light-induced changes in the electronic properties of the intrinsic a-Si:H layers.
- Study properties of amorphous silicon alloy materials with bandgaps below 1.7-1.8 eV.
- Study properties of amorphous silicon alloy materials with bandgaps above 1.7-1.8 eV.

### Status/FY 1983 Accomplishments:

- Reported the highest recorded mobility ( $2.5 \text{ cm}^2/\text{V sec}$ ) for hydrogenated amorphous silicon materials.
- Explained light induced effects in amorphous material by the generation of deep level dangling bonds due to light soaking.
- Obtained evidence of aluminum diffusion in amorphous silicon layers at room temperature.

### FY 1984 Milestones:

- Detailed characterization of amorphous silicon alloys having a bandgap below 1.7-1.8 eV — April 1984.
- Detailed characterization of amorphous silicon alloys having a bandgap above 1.7-1.8 eV — April 1984.
- Complete the studies on the interface between tin oxide, p<sup>+</sup> and i layers — April 1984.
- Report effect of light soaking on the hole and electron  $\mu\tau$  products — April 1984.

### Major Project Reports:

- Street, R.A. (March 1983). "Transient Photoconductivity Studies of Light Soaked State of Hydrogenated Amorphous Silicon." *Applied Physics Letters*. Vol. 42 (No. 6); pp. 507-509.

**Summary Date**  
October 1983

# SERI

**Title:** Insolation Assessment

**Contractor:**  
Renewable Resource Assessment and Instrumentation  
Branch — In-House

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** R.L. Hulstrom  
**Telephone:** (303) 231-1220

**Project Engineer:** C.E. Witt  
**Telephone:** (303) 231-1402

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/81  
**To:** 9/30/83

**FY 1979**            \$ 650,000

**DOE**

**FY 1980**            \$ 800,000

**DOE**

**FY 1981**            \$ 850,000

**DOE**

**Project/Area/Task:** SERI PV Lead Center, Support  
Research, Insolation Assessment

**FY 1982**            \$ 450,000

**DOE**

**FY 1983**            \$ 450,000

**DOE**

**Objectives:** The objectives of this task are to: (1) continue the SERI national center research to evaluate and archive insolation data bases, models, and algorithms; (2) produce terrestrial spectral solar radiation data sets and models; and (3) study small scale spectral variations in insolation. These efforts will lead to an improved understanding of atmospheric effects on photovoltaic device/system performance and they will guide the development of advanced materials.

**Approach/Present Tasks:** SERI solicits and collects high quality insolation data bases representing a range of meteorological conditions. These data bases are archived and used to evaluate and improve insolation models and algorithms in demand by the solar community. Various terrestrial spectral solar radiation models are developed and evaluated with high quality data sets to produce various spectra subsequently utilized to study atmospheric effects on photovoltaic device/system performance.

**Status/FY 1983 Accomplishments:**

- The new National Weather Service 1977-80 global horizontal insolation data set for some 35 sites was utilized to evaluate the various methods (algorithms) used to produce the national SOLMET and ERSATZ data base, and to produce improved models for clear sky and cloudy sky predictions of insolation. Several publications will result which convey the findings of such research to the solar community.
- A permanent Solar Radiation Research Laboratory (SRRL) was developed and established at SERI for the purpose of providing high quality spectral solar radiation and insolation data for the outdoor testing of photovoltaic devices/systems.

**FY 1984 Milestones:**

- Comparison of insolation available to concentrators, fixed flat plates, and tracking flat plates — May 1984.
- Updated and expanded terrestrial spectral data sets — April 1984.

**Major Project Reports:**

- Bird, R.E.; Hulstrom, R.L. (1983). *A Broadband Solar Radiation Model for Clear and Cloudy Days and Extensive Comparisons with Measured Data*. SERI/TP-215-2071. Golden, CO: Solar Energy Research Institute. (Submitted for publication to the *Journal of Solar Energy*).
- Bird, R.E.; Hulstrom, R.L.; Rymes, M. (1983). *An Evaluation of the SOLMET and ERSATZ Data Bases Using Four Years of New Network Data*. SERI/TR-215-2044. Golden, CO: Solar Energy Research Institute.

**Summary Date**  
October 1983



# SERI

**Title:** Joint SERI/PNL Solar-Wind Hybrid Study

**Contractor:**

Battelle Memorial Institute  
Pacific Northwest Laboratories (PNL)  
P.O. Box 999  
Richland, WA 99352

**Principal Investigator:** W.R. Barchet/R.L. Hulstrom  
**Telephone:** (303)231-1220

**Contract Number:** 3049-1

**Current Contract Period From:** 12/1/82  
**To:** 11/30/83

**Project/Area/Task:** SERI PV Lead Center, Support  
Research, Insolation Assessment

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** R.L. Hulstrom  
**Telephone:** (303) 231-1220

**Contract Funding:**

**FY 1983**            **\$ 150,000**

**Source:**

SERI

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**Objectives:** The objectives of this task are to: (1) determine the basic correlation of insolation and wind resources in the U.S. on a temporal (seasonal) and spatial basis; and (2) describe the characteristics of electrical power production by a combined photovoltaics and wind energy conversion system on time scales ranging from minutes to months at selected locations throughout the U.S.

**Approach/Present Tasks:** Extensive insolation data bases from SERI and the wind resource data bases from PNL were utilized to correlate the insolation/wind resources on a temporal (seasonal) and spatial (geographic) basis for the U.S. This effort produced combined resource maps of the U.S. which display the correlation of the two resources. To correlate and describe the electrical power production of a photovoltaic-wind turbine hybrid system PNL and SERI systems analysis/prediction models are being utilized, along with reliable insolation/wind resource data from selected sites.

**Status/FY 1983 Accomplishments:** This study will be completed by 30 November 1983. Maps of the U.S. have been produced which depict the correlation of insolation and wind resources on a seasonal and geographic basis. System simulation models, both static and dynamic, have been utilized to describe the electrical power production from selected sites in the U.S. A final project report is in preparation and will be published as a SERI report.

**FY 1984 Milestones:**

- Final Report — December 1983.

**Major Project Reports:** None.

**Summary Date**  
October 1983

## SERI

**Title:** New Ideas for Photovoltaic Conversion

**Contractor:**

To Be Determined from  
Competitive Respondents to LOI RL-3-03032,  
"New Ideas for Photovoltaic Conversion"

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator: Telephone:**

**Contract Number:**

**Current Contract Period:** TBD

**Project Engineer:** J.B. Milstein

**Telephone:** (303) 231-7299

**Contract Funding:**

**FY 1983**                      \$ 725,000

**Source:**

SERI

**Project/Area/Task:** New Ideas for Photovoltaic  
Conversion

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**Objectives:** The objective of the New Ideas for Photovoltaic Conversion project is to identify, evaluate, and develop new photovoltaic concepts that are high-risk but that also offer the potential for a major advance of understanding and technology leading to the production of low-cost electricity.

**Approach/Present Tasks:** In keeping with this objective, the efforts addressed in response to this solicitation may be quite diverse. However, concepts for conventional single crystal silicon, copper sulfide and copper oxide materials and devices will be rigorously evaluated in this solicitation subject to their long and extensive histories of prior research. In addition, proposed efforts should not be direct extensions of technologies presently being supported by the AR&D Project. A nonexhaustive list of research areas which might be funded as a result of this solicitation includes: new PV conversion concepts, new structures and geometries for the basic conversion elements (e.g., new cell geometries), new materials, new junction formation techniques, new fabrication processes, new material deposition methods, or programs for improved understanding of basic mechanisms or measurement methods. Multiple awards are planned.

**Status/FY 1983 Accomplishments:**

- Solicitation prepared and issued (4 January 1983).
- 100 responses evaluated.
- Approximately 10 awards in negotiation (3 have been completed as of Summary Date, i.e., Louisiana State University, XL-4-03032-2; Poly Solar, Inc., XL-4-03032-5; and Rutgers, The State University of New Jersey, XL-4-03032-7).

**FY 1984 Milestones:**

- Complete negotiations.
- Issue solicitation pending availability of funds.
- Assess progress of FY 1983 awards and renew programs as appropriate.

**Major Project Reports:** None. New program.

**Summary Date**

October 1983

# SERI

**Title:** Support for PV Consensus Standards Development

**Contractor:**

IEEE  
345 E. 47th St.  
New York, NY 10017

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** R. Klein

**Telephone:** (212) 705-7774

**Project Engineer:** G. Nuss

**Telephone:** (303) 231-1287

**Contract Number:** 9160-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 6/2/80  
**To:** 1/1/83

FY 1980          \$ 24,975

SERI

**Project/Area/Task:** Performance Criteria/Test  
Methods

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**Objectives:** To facilitate implementation of photovoltaic interim performance criteria and test methodologies through consensus standards writing activities.

**Approach/Present Tasks:**

- Establish a Standards Coordinating Committee (SCC).
- Provide administrative and logistical support to the SCC and its subcommittees
- Focus on standards development in four areas: (1) array subsystems; (2) power conditioning; (3) storage; and (4) systems.

**Status/FY 1983 Accomplishments:**

- The SCC and its systems subcommittee met several times in FY 1983.
- Three systems standards are under active development.
- One systems standard is ready for approval by the SCC and for transmittal to the IEEE Standards Board. The standard is "Performance Criteria for Terrestrial Photovoltaic Power Systems."

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** Not applicable.

**Summary Date**  
October 1983

## SERI

**Title:** Management and Administration of the IEC/PV/TC Secretariat and U.S. Industrial Participation in International PV Standards Development

**Contractor:**

IEEE  
345 E. 47th St.  
New York, NY 10017

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** R. Klein

**Telephone:** (212) 705-7774

**Contract Number:** 1289-1

**Current Contract Period From:** 9/30/81

**To:** 8/31/84

**Project Engineer:** G. Nuss

**Telephone:** (303) 231-1287

**Contract Funding:**

**FY 1982**            \$ 266,963

**Source:**

SERI

**Project/Area/Task:** PV Quality Assurance and Standards

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**Objectives:** To support an appropriate organization: (1) to manage and to administer secretariat responsibilities for the International Electrotechnical Commission PV Technical Committee (IEC TC-82); and (2) to coordinate and support U.S. technical participation in the IEC TC-82.

**Approach/Present Tasks:**

- Administer IEC TC-82 secretariat.
- Appoint Technical Advisor to the U.S. National Committee.
- Establish a Technical Advisory Group (TAG).
- Assemble appropriate U.S. delegates for international meetings of TC-82 and its working groups.

**Status/FY 1983 Accomplishments:**

- TAG met twice in FY 1983.
- Seven-member U.S. delegation will attend IEC general meeting in Tokyo, 17-29 October 1983.
- U.S. delegates attended two meetings each for Working Groups Two and Three, the first in Europe, the second in New York.

**FY 1984 Milestones:**

- Working group meetings — probably these working groups will meet in FY 1984; schedule uncertain at this time.
- TAG meetings — Second/fourth quarter FY 1984.
- TC-82 annual meeting — Fourth quarter FY 1984.

**Major Project Reports:** Not applicable.

**Summary Date**  
October 1983

# SERI

**Title:** Support for PV Performance Criteria and Test Methods Development

**Contractor:**

NASA-JPL  
M/S 510-200  
4800 Oak Grove Drive  
Pasadena, CA 91103

**Principal Investigator:** D. Otth

**Telephone:** (213) 577-9582

**Contract Number:** 1073-1

**Current Contract Period From:** 5/5/80  
**To:** 5/31/83

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** P. Longrigg/G. Nuss

**Telephone:** (303) 231-1765/1287

**Contract Funding:**

**FY 1981**            \$ 150,000

**Source:**

SERI

**Project/Area/Task:** Performance Criteria/Test  
Methods

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**Objectives:** To provide for a continuation of work undertaken on subcontract No. 9007 in support of the SERI PV Performance Criteria and Test Methods Task; to determine measurement needs for PV array subsystems and elements and to develop measurement methods to meet these needs.

**Approach/Present Tasks:**

- Direct and coordinate SERI's Task Group One (Array Subsystems) to evaluate and develop performance criteria for the following: array field; array (concentrator, receiver, tracker); panel; module; solar cell.
- Document existing test methods for array subsystems and develop priorities for required test method development.
- Study module failure mechanisms under varying levels of environmental stress to refine conditions of environmental tests.

**Status/FY 1983 Accomplishments:**

- Stop work order was placed on subcontract at beginning of FY 1983.
- No work done on contract in FY 1983.
- Remaining funds are being deobligated and contract terminated.

**FY 1984 Milestones:** None. Program terminated.

**Major Project Reports:** None; material incorporated in Performance Criteria document.

**Summary Date**

October 1983

# SERI

**Title:** Electrochemical Photovoltaic Cells

**Contractor:**

Brooklyn College of CUNY  
Bedford Avenue and Avenue H  
Brooklyn, NY 11210

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** M. Tomkiewicz

**Telephone:** (212) 780-5357

**Project Engineer:** W. Wallace

**Telephone:** (303) 231-1380

**Contract Number:** 8312-1 (2098-1)

**Current Contract Period From:** 9/15/79  
**To:** 6/14/84

**Contract Funding:**

<b>FY 1980</b>	<b>\$ 134,177</b>
<b>FY 1981</b>	<b>\$ 294,961</b>
<b>FY 1982</b>	<b>\$ 79,960</b>
<b>FY 1983</b>	<b>\$ 88,308</b>

**Source:**

<b>SERI</b>
<b>SERI</b>
<b>SERI</b>
<b>SERI</b>

**Project/Area/Task:** Photoelectrochemical Cells

**Objectives:** To characterize and develop high efficiency polycrystalline II-VI electrochemical photovoltaic cell devices incorporating aqueous electrolytes and to develop new materials and new advanced characterization techniques for photoelectrochemical cells.

**Approach/Present Tasks:**

- Grow polycrystalline thin films of n-type  $Cd_xHg_{1-x}Se$  and other II-VI materials on metal substrates using electrodeposition techniques.
- Characterize the films using modulated photoluminescence spectroscopy and Raman spectroscopy.
- Investigate limitations on performance of cells with special emphasis on problems affecting the fill factor.

**Status/FY 1983 Accomplishments:**

- Modulated photoluminescence spectroscopy has been used to characterize single crystal and polycrystalline thin film CdSe photoelectrodes. Near the flatband potential, the data fit the "dead layer" theory; however, near the rest potential there is evidence that photoluminescence is due to a transition at the surface, on which adsorbed sulfur ions screen the electric field to facilitate radiative recombination.
- Photoluminescence measurements on aged CdSe photoelectrodes show a shift from CdSe to CdS emission which is consistent with proposed degradation mechanisms for CdSe in a polysulfide aqueous electrolyte.
- The spectral reflectance, solar weighted reflectance and the emittance of electrodeposited CdSe were measured to evaluate the use of CdSe cells as a hybrid photoelectrochemical/thermal system. The results show that CdSe is a selective absorber, but has marginal properties for solar thermal applications.
- Polycrystalline  $Cd_xHg_{1-x}Se$  grown on CdSe shows a maximum external quantum efficiency of 80% at 675 nm and a spectral response that extends to 900 nm. The direct gap was measured to be 1.6 eV.
- Selective passivation of electrodeposited CdSe using a photoresist was shown to improve the open circuit voltage by up to 20% by reducing the dark current. Marginal improvements in the fill factor and short circuit current were also observed.

**FY 1984 Milestones:**

- An evaluation will be performed to determine the relative importance of factors affecting the fill factor of photoelectrochemical cells such as dark current, series resistance, surface and bulk recombination, charge transfer, and unpinning of band edges — April 1984.

**Major Project Reports:**

- Tomkiewicz, M.; Siripala, W.; Tenne, R. "Electrolyte Electroreflectance of Single Crystal  $CdIn_2Se_4$  In a Photoelectrochemical Solar Cell." *Journal of the Electrochemical Society* (submitted for publication).
- Garathara, R.; Tomkiewicz, M.; Silberstein, R. "Electric Field Modulation of Photoluminescence in CdSe Liquid Junction Solar Cells." *Applied Physics Letters* (submitted for publication).

**Summary Date**  
October 1983

# SERI

**Title:** Co-Evaporation of II-VI Films for Photoelectrochemical Cells

**Contractor:**

Grumman Aerospace Corp.  
South Oyster Bay Road  
Bethpage, NY 11714

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** M.A. Russak

**Telephone:** (516) 575-3286

**Project Engineer:** W. Wallace

**Telephone:** (303) 231-1380

**Contract Number:** 8002-8, 2072-1 (03105-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 6/5/79  
**To:** 8/14/84

**FY 1980** \$ 221,696

SERI

**FY 1981** \$ 187,000

SERI

**FY 1982** \$ 93,608

SERI

**FY 1983** \$ 129,483

SERI

**Project/Area/Task:** Photoelectrochemical Cells

**Objectives:** To develop a stable thin film electrochemical photovoltaic cell with a conversion efficiency of 10% (AM1) or greater.

**Approach/Present Tasks:**

- Prepare CdSe thin film photoelectrodes by co-evaporation of Cd and Se.
- Prepare CdSe<sub>x</sub>Te<sub>1-x</sub> thin film photoelectrodes by co-evaporation from Cd, Se, and Te.
- Perform photoelectrochemical measurements on CuInSe<sub>2</sub> photoelectrodes.
- Perform surface analytical, electrical, photoelectrochemical, and optical measurements on the above materials, and surface modified materials, to optimize electrochemical photovoltaic cell efficiency and stability.

**Status/FY 1983 Accomplishments:**

- A detailed study was performed in collaboration with Rockwell to correlate photo electrochemical behavior with deposition parameters using electrochemical photocapacitance spectroscopy.
- A detailed investigation of surface and bulk defects in polycrystalline CdSe thin film photoanodes was also performed using electrochemical photocapacitance spectroscopy.
- A stability of 26 weeks with no degradation was demonstrated for a 4.8% CdSe photoanode in an aqueous basic polysulfide electrolyte.
- Efficiencies up to 7.5% were achieved for CdSe polycrystalline thin film photoelectrodes.
- A detailed surface analysis study was performed for CdSe<sub>x</sub>Te<sub>1-x</sub> photoanodes as a function of various surface treatments and stability tests for optimization studies.
- A preliminary investigation was performed on polycrystalline thin film CuInSe<sub>2</sub> photoelectrodes.

**FY 1984 Milestones:**

- Electrochemical photocapacitance spectroscopy studies will be performed for CdSe<sub>x</sub>Te<sub>1-x</sub> photoelectrodes to investigate the defect structure of this material — May 1984.
- An attempt will be made to achieve a 9% (AM2) efficiency for a thin film CdSe or CdSe<sub>x</sub>Te<sub>1-x</sub> electrochemical photovoltaic cell — June 1984.

**Major Project Reports:**

- Reichman, J.; Russak, M. "I-V Behavior of the CdSe/Sulfide-Polysulfide and CdSe/Ferro-Ferricyanide Photoelectrochemical Systems." *Journal of the Electrochemical Society* (submitted for publication).
- Russak, M.; Creter, C. "CdSe<sub>x</sub>Te<sub>1-x</sub> Thin Films for Electrochemical Photovoltaic Cells." *Journal of the Electrochemical Society* (submitted for publication).

**Summary Date**

October 1983

## SERI

**Title:** Electrochemical Photovoltaic Cells

**Contractor:**

Institute of Gas Technology  
3424 S. State Street  
Chicago, IL 60616

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** A.F. Sammells/P.G. Ang

**Telephone:** (312) 567-5733

**Project Engineer:** W. Wallace

**Telephone:** (303) 231-1380

**Contract Number:** 9175-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 4/15/80

**To:** 9/30/83

**FY 1980**

**\$ 151,737**

**SERI**

**FY 1981**

**\$ 156,424**

**SERI**

**FY 1982**

**\$ 25,000**

**SERI**

**Project/Area/Task:** Photoelectrochemical Cells

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**Objectives:** To experimentally identify semiconductor photoanode/redox couples which show promise of achieving solar energy efficiencies of 10% in four electrode redox storage systems.

**Approach/Present Tasks:**

- Identify candidate semiconductor/redox couples for four-electrode storage.
- Perform electrochemical measurements on selected single crystal/redox couples.
- Evaluate the charge/discharge characteristics of redox couples.

**Status/FY 1983 Accomplishments:**

- An assessment was performed on the approaches being considered for photoelectrochemical storage systems including four electrode storage systems (two photoelectrodes) and the three electrode in situ storage system. The advantages/disadvantages of each approach were analyzed.
- Four electrode photoelectrochemical storage systems incorporating p-InP photocathodes and various photoanodes have been investigated. System efficiencies up to approximately 3% have been demonstrated.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Liu, C.; Ang, P.; Sammells, A. (June 1982). "Surface-Modified p-InP Photocathodes in Sulfide/Polysulfide Electrolyte." *Journal of the Electrochemical Society*. Vol. 129 (No. 6); pp. 1387-1389.

**Summary Date**  
October 1983



## SERI

**Title:** Electrochemical Photovoltaic Cells: Stabilization and Optimization of II-VI Semiconductor Photoanodes

**Contractor:**

Rockwell International  
1049 Camino Dos Rios  
Thousand Oaks, CA 91360

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** D. Tench

**Telephone:** (805) 498-4545

**Project Engineer:** W. Wallace

**Telephone:** (303) 231-1380

**Contract Number:** 9276-1, 2126-1 (3108-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 4/15/80

**To:** 7/5/84

**FY 1980**

**\$ 219,833**

SERI

**FY 1981**

**\$ 169,648**

SERI

**FY 1982**

**\$ 85,000**

SERI

**FY 1983**

**\$ 89,623**

SERI

**Project/Area/Task:** Photoelectrochemical Cells

**Objectives:** To develop new electrolyte redox systems and electrode surface modifications which will stabilize the II-VI compounds against photodissolution without seriously degrading their performance in electrochemical solar cells.

**Approach/Present Tasks:**

- Apply electrochemistry, synthetic chemistry, and materials characterization in concert to evolve a practical compromise between the interfacial chemistry and the device characteristics of high efficiency electrochemical photovoltaic cells.
- Characterize thin film photoelectrode materials using electrochemical photocapacitance spectroscopy.
- Modify the surface of II-VI compounds for stabilization against decomposition.

**Status/FY 1983 Accomplishments:**

- An assessment of electrodeposited conducting polymer films for surface modified photoelectrodes was completed in stabilization studies. Polypyrrole films gave the best stability results and have potential in stability applications.
- Electrochemical Photocapacitance Spectroscopy (EPS) has been developed as a useful routine analytical technique to characterize the intrabandgap electronic state structure of semiconductor photovoltaic materials including bulk and surface electronic state properties.
- EPS has been used to correlate the electronic state structure of co-evaporated polycrystalline CdSe thin films with deposition parameters and I-V characteristics.
- The specialized characterization techniques at Rockwell have been successfully interfaced with other SERI programs to optimize photoelectrode properties.

**FY 1984 Milestones:**

- Characterize electrodeposited CdSe and various CdSe<sub>1-x</sub>Te<sub>x</sub> polycrystalline thin films using EPS — March 1984.
- Complete evaluation of passivation techniques for n-CdSe thin films — July 1984.

**Major Project Reports:**

- Noufi, R.; Nozik, A.J.; White, J.; Warren, L.F. (October 1982). "Enhanced Stability of Photoelectrodes with Electrogenerated Polyaniline Films." *Journal of the Electrochemical Society*. Vol. 129 (No. 10); pp. 2261-2265.
- Haak, R.; Tench, D. "Electrochemical Photocapacitance Spectroscopy Method for Characterization of Deep Levels and Interface States in Semiconductor Materials." *Journal of the Electrochemical Society* (submitted for publication).

**Summary Date**

October 1983

# SERI

**Title:** Investigation of Photoelectrochemical Corrosion of Semiconductors

**Contractor:**  
SRI International  
333 Ravenswood Avenue  
Menlo Park, CA 94025

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** K.W. Frese, Jr.  
**Telephone:** (415) 326-6200

**Project Engineer:** W. Wallace  
**Telephone:** (303) 231-1380

**Contract Number:** 8002-6, 2073-1 (3106-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 4/15/79  
**To:** 7/1/84

FY 1980	\$ 128,425	SERI
FY 1981	\$ 132,945	SERI
FY 1982	\$ 83,012	SERI
FY 1983	\$ 86,517	SERI

**Project/Area/Task:** Photoelectrochemical Cells

**Objectives:** To study the influence of defects such as dislocations and grain boundaries on the photoelectrochemical corrosion of CdSe and related materials. Additionally, redox couples and surface treatments will be investigated that suppress such corrosion.

### Approach/Present Tasks:

- Under potential deposition of metal on semiconductor photoelectrodes will be investigated.
- The effect of surface roughness on stability will be investigated.
- SRI's analytical techniques for investigating stability will be applied to semiconductor/polymer/electrolytes.
- Various crystal faces on stability will be investigated.

### Status/FY 1983 Accomplishments:

- Efficiencies of up to 8% were achieved for polycrystalline CdSe photoelectrodes in alkaline iron cyanide electrolytes. The electrodes were prepared by sintering at 1000°C.
- Rotating Ring Disk Electrode studies support SRI's degradation mechanism for n-CdSe in polysulfide electrolytes, which incorporates a stabilizing charge transfer process involving adsorbed sulfide ion surface state.
- The stabilization efficiency for n-CdSe in the iron cyanide electrolyte was measured with the result that the electrode became more stable on more negative photovoltage. A model was developed for this system.
- The stability of n-CdSe coated with various conducting polymers was investigated showing that polypyrrole has the best stabilizing properties of the materials studied.
- The general corrosion model for photoelectrochemical systems developed by SRI was extended to two electron-equivalent systems and adsorption of redox species, which has a better fit for the n-CdSe system.
- Semiquantitative predictions of electrode stability at high current densities (solar irradiance) were made using a theory developed at SRI. Practical suggestions were made for increasing stability based on the results.

### FY 1984 Milestones:

- An evaluation of the underpotential deposition of metals on semiconductor photoelectrodes to stabilize electrochemical photovoltaic cells will be performed — May 1984.
- An assessment of factors affecting stability such as surface roughness, surface modification, and crystal face will be performed in a quantitative investigation — May 1984.

### Major Project Reports:

- Frese, K.W., Jr. (January 1983). "Electrochemical Studies of Photocorrosion of n-CdSe," *Journal of the Electrochemical Society*. Vol. 130 (No. 1); pp. 28-33.
- Frese, K. (February 1982). "A High Efficiency Single-Crystal CdSe Photoelectrochemical Solar Cell and An Associated Loss Mechanism." *Applied Physics Letters*. Vol. 40 (No. 3); pp. 275-277.

**Summary Date**  
October 1983

# SERI

**Title:** Photorechargeable Electrochemical Solar Cells Based on Semiconductor Electrodes

**Contractor:**

Department of Chemistry  
University of Texas at Austin  
Austin, TX 78712

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** A.J. Bard

**Telephone:** (512) 471-3761

**Project Engineer:** W. Wallace

**Telephone:** (303) 231-1380

**Contract Number:** 9306-1, 2117-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 8/1/80  
**To:** 2/29/84

**FY 1981** \$ 120,592

SERI

**FY 1982** \$ 77,964

SERI

**FY 1983** \$ 29,997

SERI

**Project/Area/Task:** Photoelectrochemical Cells

**Objectives:** To stabilize semiconductor photoelectrodes using surface modification approaches and investigate new materials with the potential for high stability.

**Approach/Present Tasks:**

- Investigate various silicide films on semiconductor photoelectrode surfaces for stabilization purposes.
- Investigate polycrystalline transition metal dichalcogenide layer compounds as photoelectrode materials.

**Status/FY 1983 Accomplishments:**

- It was demonstrated that noble metal silicide coated single crystal n-Si electrodes can be stabilized in aqueous electrolytes and can photo-oxidize halides and water efficiently under appropriate conditions.
- Polycrystalline thin film transition metal dichalcogenide photoelectrodes have been prepared by co-evaporation and were shown to exhibit limited photoactivity.
- Impedance measurements were developed and used to investigate the energetics of photoelectrochemical systems as a function of electrolyte composition and other factors. For layer compounds, Fermi level pinning was observed and ascribed to interface studies.

**FY 1984 Milestones:**

- An assessment will be conducted of silicide films on semiconductor surfaces for stabilizing photoelectrochemical cells and as catalysts on n-type and p-type materials — December 1984.
- Studies will be conducted on polycrystalline WSe<sub>2</sub> materials to assess their potential as high efficiency photoanodes and photocathodes — December 1984.
- The photoelectrochemical storage studies initiated in FY 1982 will be completed — December 1984.

**Major Project Reports:**

- Fan, F-R.F.; Leempoel, P.; Bard, A.J. (September 1983). "Semiconductor Electrodes LI. Efficient Electroluminescence at ZnS Electrode in Aqueous Electrolytes." *Journal of the Electrochemical Society*. Vol. 130 (No. 9); pp. 1866-1875.
- Hope, G.A.; Fan, F-R.F.; Bard, A.J. (July 1983). "Semiconductor Electrodes 52. Photoelectron Spectroscopic Determination of the Structure of Thin Platinum Silicide Layers Formed on Si(100) and Si(111) for Use as Electrodes." *Journal of the Electrochemical Society*. Vol. 130 (No. 7); pp. 1488-1491.
- Nagasubramanian, G.; Wheeler, B.; Bard, A.J. (August 1983). "Semiconductor Electrodes XLIX. Evidence for Fermi Level Pinning and Surface-State Distributions from Impedance Measurements in Acetonitrile Solutions with Various Redox Couples." *Journal of the Electrochemical Society*. Vol. 130 (No. 8); pp. 1680-1688.

**Summary Date**  
October 1983

## SERI

**Title:** High Efficiency Thin Film Cadmium Chalcogenide Photoelectrochemical Cell with In-Situ Storage

**Contractor:**

Yeda Research and Development  
The Weizmann Institute of Science  
Rehovot, Israel

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** J. Manassen

**Telephone:** 011-972-54-70617

**Project Engineer:** W. Wallace

**Telephone:** (303) 231-1380

**Contract Number:** 9010-11, 2096-1 (03107-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/80

**To:** 6/30/84

**FY 1980**

**\$ 97,120**

**SERI**

**FY 1981**

**\$ 61,580**

**SERI**

**FY 1982**

**\$ 89,000**

**SERI**

**FY 1983**

**\$ 109,318**

**SERI**

**Project/Area/Task:** Photoelectrochemical Cells

**Objectives:** To construct and characterize experimental three electrode photoelectrochemical storage cells incorporating n-CdSe<sub>x</sub>Te<sub>1-x</sub> photoanodes, a Sn/SnS storage electrode, a cobalt sulfide counterelectrode, and a sulfide/polysulfide electrolyte.

**Approach/Present Tasks:**

- Evaluate the concept of a three electrode PEC storage cell and construct experimental cells for evaluation.
- Optimize large area thin film CdSe<sub>x</sub>Te<sub>1-x</sub> electrodes.
- Evaluate the storage electrode chemistry.
- Evaluate a three electrode module.

**Status/FY 1983 Accomplishments:**

- CdSe<sub>1-x</sub>Te<sub>x</sub> photoanodes can be prepared by electroplating yielding efficiencies up to 4.5% over 20 cm<sup>2</sup> areas.
- The electrochemistry of the Sn/SnS storage system has been investigated in detail and a storage electrolyte composition has been found in which the Sn<sup>4+</sup> dissolution can be suppressed yielding a stable storage system.
- Preliminary long term stability tests have been conducted for n-CdSe<sub>1-x</sub>Te<sub>x</sub> systems. Although these systems are stable for several months, they are at present less stable than n-CdSe systems.
- Several three electrode storage cell configurations have been investigated. The best cells have operated over 24 hour cycles at a total system efficiency of approximately 3% (solar energy in, dc electrical energy out) with storage. System efficiencies are at present limited by the conversion efficiency of large area photoelectrodes.

**FY 1984 Milestones:**

- A 20 cm<sup>2</sup> photoelectrode will be prepared yielding 300 mA and 350 mV under AM1 simulated solar conditions — June 1984.
- Polarization losses for large area counterelectrodes will be assessed and reduced to acceptable limits — June 1984.

**Major Project Reports:**

- Manassen, J.; Licht, S.; Hodes, G.; Cahen, D.; Lev, M. (October 1983). *A High Efficiency Thin Film Cadmium Chalcogenide Photoelectrochemical Cell with In-Situ Storage; Final Report*. 29 pp.

**Summary Date**  
October 1983

# SERI

**Title:** Cooperative Research

**Contractor:**

PV Devices and Measurements Branch  
In-House

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** L.L. Kazmerski

**Telephone:** (303) 231-1115

**Project Engineer:** L.L. Kazmerski

**Telephone:** (303) 231-1115

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82

**To:** 9/30/83

**FY 1983**

**\$ 564,000**

**DOE**

**Project/Area/Task:** PV Devices and Measurements

**Objectives:** The objectives are to continue, establish, and carry out cooperative research programs with DOE subcontractors and internal SERI researchers for improving the operational characteristics (performance and lifetime) of advanced solar cell technologies. This research will focus primarily on electro-optical measurements, surface and interface analysis, and materials characterization to complement the activities of the cooperating internal and external research groups.

**Approach/Present Tasks:** Task research will complement the research capabilities of DOE subcontractors and internal PV research by providing special measurements, expertise, and evaluations available either uniquely or in a complementary manner using the PV Devices and Measurements Branch facilities and staff. Emphasis will be placed on those materials/devices that are deemed critical to the National Program — including Cu-ternaries, amorphous Si, and GaAs-based concentrators. Research will be performed on an interactive basis to expedite the flow of scientific and technical information.

**Status/FY 1983 Accomplishments:**

- Engaged in more than 50 cooperative projects with DOE subcontractors and internal research.
- Developed understanding of the chemistry, composition, and electrical properties of interfaces in the (CdZn)S/CuInSe<sub>2</sub> solar cell.
- Provided information on the correlated electrical, structural, and compositional properties of polycrystalline Si grain boundaries. Established role of oxygen segregation in grain boundary activation.
- Initiated characterization of a-Si:Sn alloys.
- Published some 20 papers jointly with cooperating groups.

**FY 1984 Milestones:**

- Enhance cooperative projects, especially in a-Si solar cell area.
- Investigate chemistry of hydrogen passivation of Si grain boundaries.
- Provide understanding of contacts to CuInSe<sub>2</sub>.
- Provide interactions with Brazil and Saudi Arabia and solar cell R&D.

**Major Project Reports:**

- Jamjoun, O.; Kazmerski, L.L.; Lichten, D.L.; Bachmann, K.J. (December 1982). "Low Energy Electron Loss Studies of CuInSe<sub>2</sub> Surfaces." *Surface and Interface Analysis*. Vol. 4 (No. 6); pp. 227-229.
- Kazmerski, L.L.; Hallerdt, M.; Ireland, P.J. (April-June 1983). "Optical Properties and Grain Boundary Effects in CuInSe<sub>2</sub>." *Proceedings of the 29th National Symposium of the American Vacuum Society; Baltimore, MD: 16-19 November 1982*. Appears in *Journal of Vacuum Science & Technology A*. Vol. 1 (No. 2, Part 1); pp. 395-398.

**Summary Date**

October 1983

# SERI

**Title:** Internal Research

**Contractor:**  
PV Devices and Measurements Branch  
In-House

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** L.L. Kazmerski  
**Telephone:** (303) 231-1115

**Project Engineer:** L.L. Kazmerski  
**Telephone:** (303) 231-1115

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82  
**To:** 9/30/83

**FY 1983**            **\$ 268,000**

**DOE**

**Project/Area/Task:** PV Devices and Measurements

**Objectives:** The objective is to conduct internal research directed toward the discovery, understanding, correlation, and solution of interfacial electro-optical and chemical problems that limit the performance and operational lifetime of photovoltaic devices.

**Approach/Present Tasks:** Task work will advance and improve the range and reliability of material and solar cell measurements for photovoltaics; increase the understanding of critical materials/device parameters that limit the performance characteristics and operational lifetimes; develop and implement programs aimed at understanding fundamental processes at photovoltaic device interfaces (e.g., grain boundaries, oxide semiconductor, etc.), minimizing surface and interface state densities, producing and analyzing diagnostic device structures, especially in III-V and I-III-V<sub>2</sub> materials, and determining basic cell parameters using advanced laser spectroscopic techniques.

**Status/FY 1983 Accomplishments:**

- Identified mechanisms limiting the performance of ITO/InP heterojunctions.
- Implemented and made optional DLTS system.
- Developed method for topographical corrections for AES and EBIC signals.
- Developed method and hardware for isolating interfaces in PV devices using SIMS/ion etching.
- Developed photoluminescence (high-resolution) facility.
- Developed in-situ temperature-dependent EBIC on SEM.

**FY 1984 Milestones:**

- Provide complete DLTS and photoluminance of CuInSe<sub>2</sub>.
- Initiate interface studies on a-Si:H cells using electron and ion beam characterization techniques.

**Major Project Reports:**

- Kazmerski, L.L.; Russell, P.E. (1983). "Chemical and Electrical Characterization of Polycrystalline Semiconductors." *Journal de Physica*. Vol. C1; p. 171.
- Kazmerski, L.L.; Russell, P.E.; Jamjoun, O.; Ireland, P.J.; Matson, R.J.; Hermann, A.; Ahrenkiel, R.K.; Mickelsen, R.A.; Chen, W.S.; Bachmann, K.J. (1983). "Initial Formation and Development of CdS/CuInSe<sub>2</sub> Solar Cell Interfaces." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 786-790.
- Russell, P.E.; Herrington, C.R.; Matson, R.J. (1983). "Development and Application of Fully-Automated EBIC Techniques for Solar Cell Measurements." *Technology in Review*. Vol. 1; p. 3.
- Sheldon, P.; Russell, P.E.; Ahrenkiel, R.K.; Hayes, R.E. (April-June 1983). "Summary Abstract: p-InP Surface Modification Due to Indium Tin Oxide Deposition." *Journal of Vacuum Science & Technology A*. Vol. 1 (No. 2, Part I); pp. 618-619.

**Summary Date**  
October 1983

# SERI

**Title:** Program Support

**Contractor:**

PV Devices and Measurements Branch  
In-House

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** L.L. Kazmerski

**Telephone:** (303) 231-1115

**Project Engineer:** L.L. Kazmerski

**Telephone:** (303) 231-1115

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82

**To:** 9/30/83

**FY 1983**

**\$ 578,000**

**DOE**

**Project/Area/Task:** PV Devices and Measurements

**Objectives:** The objectives are to develop, implement, and provide state-of-the-art measurement and device capabilities for the improvement of advanced R&D cells and materials that are considered long-term, high-risk, and potentially high payoff solar cell conversion technologies for, in cooperation with, and in support of DOE subcontracted research activities and with SERI internal photovoltaic research programs.

**Approach/Present Tasks:** Task efforts will: support the advancement and improvement of materials/cell properties through the evaluation of photovoltaic materials and devices provided by DOE subcontractors and internal SERI PV researchers; provide, develop, and enhance PV measurement and laboratory support capabilities in the areas of surface and interface analysis, cell performance, electro-optical characterization and materials evaluation to ensure efficient, accurate and quick feedback to interacting research groups; provide light/dark I-V (outdoor and simulator) measurements, spectral response, C-V, photoluminescence, minority-carrier lifetime determination, ellipsometry, surface and bulk analysis, structural characterization, and electrical micro-characterization on a routine basis; and cooperate with SERI program and task managers on establishing priority measurements and areas of investigation.

**Status/FY 1983 Accomplishments:**

- Evaluated approximately 950 cells/materials from DOE subcontractors/internal researchers.
- Published brochure on branch facilities/capabilities.
- Implemented operation of outdoor cell measurement facility.
- Extended spectral response measurement capabilities to 1.5  $\mu\text{m}$ .
- Developed high resolution, multiple-detection digital laser scanner for device investigations.

**FY 1984 Milestones:**

- Extend measurement capabilities provided to subcontractors/internal research to include cathodoluminescence.
- Continue cell/materials evaluation support of DOE subcontractors/internal R&D.
- Implement fully automated spectral response system for advanced cell technologies.
- Establish standard reference cells for (CdZn)S/CuInSe<sub>2</sub>, GaAs, and a-Si:H.

**Major Project Reports:**

- Osterwald, C.R.; Emery, K.A. (October 1983). "Solar Cell Area Considerations." *Solar Cells*. Vol. 10 (No. 1); pp. 1-5.

**Summary Date**  
October 1983

# SERI

**Title:** Procedure for Hydrogen Profiling of Amorphous Films

**Contractor:**

Charles Evans and Associates  
1670 S. Amphlett, Suite 120  
San Mateo, CA 94402

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** C.A. Evans

**Telephone:** (415) 572-1601

**Project Engineer:** J.R. Dick

**Telephone:** (303) 231-1361

**Contract Number:** 1102-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 6/1/81  
**To:** 3/31/83

**FY 1981**           \$ 41,500

SERI

**FY 1982**           \$ -0-

**FY 1983**           \$ -0-

**Project/Area/Task:** PV Devices and Measurements

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**Objectives:** To develop analytical techniques for quantitative depth-profiling of hydrogen in amorphous Si:H films using high-resolution SIMS.

**Approach/Present Tasks:**

- Demonstrate SIMS is capable of performing quantitative analysis of H in a-Si with accuracy of better than 8% in total hydrogen.
- Develop a-Si:H standards.

**Status/FY 1983 Accomplishments:**

- Developed standards (for a-Si:H solar cells).
- Verified method.
- Accomplished routine measurements of DOE subcontractors samples.
- Established standards established for H, B, O, C impurities in a-Si:H.

**FY 1984 Milestones:**

- Extend method to other impurities (B, P, O, C, As) in a-Si:H.

**Major Project Reports:**

- Evans, C.A. *Procedures for Hydrogen Profiling of Amorphous Films; Final Report.*

**Summary Date**  
October 1983



# SERI

**Title:** Identification of Electronic Structure of Grain Boundaries in Polycrystalline  $\text{CuInSe}_2$  and InP

**Contractor:**  
Princeton University  
Office of Research & Project Administration  
Princeton, NJ 08544

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** S. Wagner  
**Telephone:** (609) 452-4631

**Project Engineer:** L.L. Kazmerski  
**Telephone:** (303) 231-1105

**Contract Number:** 1268-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 9/1/81  
**To:** 1/31/83

**FY 1981**            \$ 84,800

SERI

**FY 1982**            \$ -0-

**FY 1983**            \$ -0-

**Project/Area/Task:** PV Devices and Measurements

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**Objectives:** To identify the electronic structure and electrical properties of grain boundaries in  $\text{CuInSe}_2$  and InP.

**Approach/Present Tasks:**

- Prepare bulk polycrystalline  $\text{CuInSe}_2$  and InP with series of donor and acceptor concentrations.
- Determine electrical characteristics (conductivity, concentration, minority carrier lifetime).
- Determine chemical/compositional properties (in cooperation with SERI PV Devices and Measurements Branch).

**Status/FY 1983 Accomplishments:**

- Grain boundaries in n- and p-type InP characterized; fermi-level pinning mechanism reported.
- Laboratory equipment made fully operational.
- Characteristics of grain boundaries in p- $\text{CuInSe}_2$  reported.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Wagner, S. (September 1982). *Identification of Electronic Structure of Grain Boundaries in Polycrystalline  $\text{CuInSe}_2$  and InP; Progress Report.*
- Wagner, S. (April 1983). *Investigations of Polycrystalline InP and  $\text{CuInSe}_2$ ; Final Report.*

**Summary Date**  
October 1983

## SERI

**Title:** Verification of Surface Analysis Results on the Chemistry, Composition of Trace Impurity Content of Thin Conducting Oxides and Insulators on PV Semiconductors

**Contractor:**  
University of Notre Dame  
Notre Dame, IN 46556

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** M. Zeller  
**Telephone:** (219) 239-7865

**Project Engineer:** L.L. Kazmerski  
**Telephone:** (303) 231-1115

**Contract Number:** 2140-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 7/16/82  
**To:** 1/15/84

**FY 1982**           \$ -0-  
**FY 1983**           \$ -0-

**Project/Area/Task:** PV Devices and Measurements

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### Objectives:

- To verify surface analysis results on the chemistry, composition, and trace impurity content of the conducting oxides and insulators on photovoltaic semiconductors, especially GaAs, InP, and CuInSe<sub>2</sub>.
- To provide independent evaluation of oxyfluorides on GaAs.
- To collaborate and verify quantitative surface analytical measurements at SERI.

### Approach/Present Tasks:

- Focus on thermal, anodic, and wet oxides on GaAs, InP, and CuInSe<sub>2</sub>.
- Analysis methods: XPS, AES, SIMS.
- Collaborate results with those of the SERI PV Devices and Measurements Branch.

### Status/FY 1983 Accomplishments:

- Made system operational.
- Made SIMS accessories operational.
- Completed measurements on oxyfluoride/GaAs for standardization.

### FY 1984 Milestones:

- Report full range of XPS, AES, and SIMS measurements for InP, GaAs, and CuInSe<sub>2</sub> oxides.

**Summary Date**  
October 1983

## SERI

**Title:** Investigation of Electrically Active Defects in Silicon

**Contractor:**

Photovoltaic Program Office  
In-House

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** S. Tsuo

**Telephone:** (303) 231-7682

**Project Engineer:** J. Milstein

**Telephone:** (303) 231-7299

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period** From: 10/1/82  
To: 9/31/83

FY 1982           \$ 35,000  
FY 1983           \$ 35,000

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SERI

**Project/Area/Task:** Polycrystalline Silicon

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**Objectives:** To perform studies on electrically active defects, such as grain boundaries and dislocations, in crystalline silicon solar cell materials with the aim of developing methods to passivate them; and to closely coordinate SERI in-house and subcontracted studies in the subject area.

**Approach/Present Tasks:** This involves the investigation of the density and distribution of defects in crystalline silicon solar cell materials, the understanding of the basic mechanisms of defect passivation, and the optimization of the Kaufman ion-beam hydrogen passivation process. An important task is to promote close cooperation among SERI and subcontractors through exchange of samples and complementary measurements.

**Status/FY 1983 Accomplishments:**

- A dominant grain structure in thin edge-supported-pulling silicon sheets has been identified. It is also observed that grains with this structure tend to have less electrically active dislocations than random grains.
- Using dislocation etching, and electron channeling and electron-beam-induced current measurements, we have confirmed that the twin-stabilized planar growth region of the low-angle silicon sheet grown at a speed of 210 cm<sup>2</sup>/min is single crystal.
- The Kaufman ion-beam system at SERI was operational in April 1983. Significant improvements have been observed in the efficiencies of Westinghouse dendritic web and A.D. Little edge-supported pulling silicon solar cells after hydrogen passivation.
- SIMS depth profiling of hydrogen implanted into polycrystalline silicon has been performed.

**FY 1984 Milestones:**

- Initiate study of hydrogen passivated microcrystalline silicon — November 1983.
- Demonstrate the hydrogen passivation of electrically active dislocations in large-grained cast and ribbon silicon materials — September 1984.
- Provide samples to SERI Advanced PV Systems Research Group for stability testing of hydrogen passivated silicon solar cells — March 1984.

**Major Project Reports:**

- Tsuo, Y.S.; Hardy, R.W.; Milstein, J.B. (1983). "Grain Boundary Structures and Properties in Polycrystalline Silicon." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 616-621.
- Tsuo, Y.S.; Milstein, J.B.; Surek, T. (1982). "Grain Boundary Structures and Properties in Polycrystalline Silicon." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981.* Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 155-166.

**Summary Date**  
October 1983

# SERI

**Title:** Investigation of Edge Supported Pulling of Silicon Ribbon

**Contractor:**

Arthur D. Little, Inc.  
20 Acorn Park  
Cambridge, MA 02140

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** E.M. Sachs  
**Telephone:** (617) 864-5770 Ext. 2917

**Project Engineer:** J.B. Milstein  
**Telephone:** (303) 231-7299

**Contract Number:** 1069-1 (3009-1)

**Contract Funding:**

**Source:**

**Current Contract Period** From: 9/29/81  
To: 11/30/83

FY 1981	\$ 319,960
FY 1982	\$ 220,902

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SERI

**Project/Area/Task:** Polycrystalline Silicon

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**Objectives:** To investigate the edge supported pulling technique, developed at SERI, with respect to the rapid growth of large areas of silicon ribbon which can be fabricated into efficient solar cells.

**Approach/Present Tasks:** Technical issues to be investigated include growth in vertical and nonvertical modes at high rates, ribbon quality, and residual stress and ribbon morphology. Tasks include investigation of factors limiting the growth parameters of the ESP process, vertical growth of wide (10 cm) ESP ribbon, investigation of ESP ribbon growth at an angle to the melt surface, investigation of string materials, investigation of thermal stress, material characterization, and solar cell fabrication and evaluation.

**Status/FY 1983 Accomplishments:**

- Ribbon stress has been further reduced by means of moveable radiation shields.
- Melt circulation to improve thermal homogeneity has been implemented, with improvement in ribbon morphology and flatness.
- 10 cm<sup>2</sup> solar cells with reported 7.2% efficiency ( no AR coating) have been fabricated.

**FY 1984 Milestones:** None. Contract completed. To be transferred to JPL.

**Major Project Reports:**

- Sachs, E.; Cook, E.; Smallman, C.R.; Ely, D. (1983). "Edge Stabilized Ribbon Growth." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York, NY: IEEE Publishing Service; p. 1467.

**Summary Date**  
October 1983

# SERI

**Title:** Fundamental Studies of Polycrystalline Silicon for Photovoltaic Application

**Contractor:**

Columbia University  
Dept. of Electrical Engineering  
New York, NY 10027

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** E.S. Yang

**Telephone:** (212) 280-3120

**Project Engineer:** S. Tsuo

**Telephone:** (303) 231-7682

**Contract Number:** 1272-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 1/1/79  
**To:** 8/31/83

**FY 1979** \$ 232,311

DOE

**FY 1980** \$ 149,970

SERI

**FY 1981** \$ 119,199

SERI

**FY 1982** \$ 35,000

SERI

**Project/Area/Task:** Polycrystalline Silicon

**Objectives:** To improve the modeling of polycrystalline silicon solar cells and to increase the understanding of the electrical properties of grain boundaries.

**Approach/Present Tasks:** The project involves: (1) the modeling of polycrystalline silicon solar cells by studying surface recombination, grain boundary recombination, and the behavior of optically generated carriers, and (2) the electrical characterization of grain boundaries by using the photoconductivity transient response method to characterize the electrical properties of silicon grain boundaries that have been characterized by chemical analysis methods at SERI.

**Status/FY 1983 Accomplishments:**

- A theory of the photoconductance transient response has been formulated. Shockley-Read-Hall statistics has been used to describe the emission and capture processes at the grain boundary traps. Under appropriate conditions, the theory predicts that, for discrete grain boundary trap distribution, the photoconductance rise times and decay times correspond exactly to the minority carrier capture and emission time constants of the traps.
- With the "orthogonal experimental design" (OED), dependence of the conductivity and transparency of tin oxide film and open circuit voltage  $V_{oc}$  of SIS solar cells on the spray deposition process factors was studied. Using OED, curves were obtained that depict the effects of each spray deposition process factor on the SIS characteristics. The results of the experiments also illustrate exactly which variation in fabrication technique most affects the sheet resistance,  $V_{oc}$ , and film transparency.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Yang, E.S.; Poon, E.; Evans, H.L.; Hwang, W.; Song, J.S.; Wu, C.M. (1983). "Electronic Properties of Grain Boundaries in Polycrystalline Silicon." *Proceedings of the Society of Photo-Optical Instrumentation Engineers: Volume 381 — Laser Processing of Semiconductor Devices*; Los Angeles, CA; 18-19 January 1983. Edited by Charles C. Tang. Bellingham, WA: SPIE; pp. 59-64.
- Poon, E.; Evan, H.L.; Hwang, W.; Osgood, R.M., Jr.; Yang, E.S. (1983). "Measurement of Grain Boundary Parameters by Laser-Spot Photoconductivity." *Laser Diagnostics and Photochemical Processing for Semiconductors Devices*. Edited by R.M. Osgood, Jr., et al. North-Holland; pp. 103-108.

**Summary Date**

October 1983

## SERI

**Title:** Investigation of Selected Electrically Active Defects in Polycrystalline Silicon Solar Cells

**Contractor:**  
Cornell University  
Ithaca, NY 14853

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** D.G. Ast  
**Telephone:** (607) 256-4140

**Project Engineer:** S. Tsuo  
**Telephone:** (303) 231-7682

**Contract Number:** 2129-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 9/1/83  
**To:** 11/15/84

**FY 1983**      \$ 50,182

**SERI**

**Project/Area/Task:** Polycrystalline Silicon

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**Objectives:** To address basic research aimed at experimentally categorizing and theoretically modeling those selected electrically active defects — grain boundaries and dislocations — that are limiting the performance of polycrystalline silicon solar cells. The specific emphasis of the project is to correlate the structural, chemical, and electrical properties of the electrically active defects in polycrystalline silicon and to get a better understanding and control of the influence of these defects on solar cell performance.

**Approach/Present Tasks:** The program includes correlation between grain boundary structural and electrical properties; correlation between impurities segregated to grain boundaries and their electrical properties and the determination of properties of intragrain dislocations in polycrystalline silicon solar cell materials.

**Status/FY 1983 Accomplishments:** New program.

**FY 1984 Milestones:**

- Thoroughly characterize by high resolution TEM the grain boundary structures of selected poly-Si samples supplied by SERI and correlate them with EBIC studies — June 1984.
- Determine impurities segregated to grain boundaries by energy loss spectroscopy in selected poly-Si samples and correlate them with EBIC studies — September 1984.

**Major Project Reports:** None. New program.

**Summary Date**  
October 1983

# SERI

**Title:** Low Angle Silicon Sheet (LASS) Process

**Contractor:**

Energy Materials Corporation  
P.O. Box 1143  
Sterling Road  
South Lancaster, MA 01561

**Principal Investigator:** D.N. Jewett

**Telephone:** (617) 365-7383

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** J.B. Milstein

**Telephone:** (303) 231-7299

**Contract Number:** 8041-3 (1303-1, 2191-1)

**Current Contract Period From:** 9/15/79

**To:** 11/1/83

**Project/Area/Task:** Polycrystalline Silicon

**Contract Funding:**

<b>FY 1979</b>	<b>\$ 99,700</b>
<b>FY 1980</b>	<b>\$ 166,300</b>
<b>FY 1981</b>	<b>\$ 514,000</b>
<b>FY 1982</b>	<b>\$ 402,059</b>
<b>FY 1983</b>	<b>\$ 349,488</b>

**Source:**

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**Objectives:** To investigate the Low Angle Silicon Sheet (LASS) process with respect to the rapid growth of large areas of silicon ribbon which can be fabricated into efficient solar cells.

**Approach/Present Tasks:** Technical issues to be addressed include growth of flat ribbon capable of being fabricated into efficient solar cells without surface treatment. Tasks include investigation of planar ribbon growth in stable mode, fabrication of efficient solar cells, and electrical characterization of ribbon material.

**Status/FY 1983 Accomplishments:** Growth of regions of (111) oriented twin-stabilized single crystal LASS ribbon as wide as 5 cm at rates of 37 cm/min has been accomplished. The single crystal nature and lack of EBIC-active structural features have been confirmed at SERI, as has solar cell fabrication of 12.7% cells using the SERI baseline process.

**FY 1984 Milestones:**

- Project to be transferred to JPL.
- Final Report — 15 December 1983.

**Major Project Reports:**

- Bates, H.E.; Jewett, D.N.; Keiffer, D.M.; Locher, J.W. (June, 1983). *Low Angle Silicon Sheet Process; Final Report*. SERI/XW-1-1301-1. Golden, CO: Solar Energy Research Institute; 107 p.

**Summary Date**

October 1983

## SERI

**Title:** Electrical and Atomic Transport Properties of Grain Boundaries in Silicon Pertinent to Solar Cell Applications

**Contractor:**

National Aeronautics and Space Administration  
NASA Resident Office — JPL  
4800 Oak Grove Drive  
Pasadena, CA 91109

**Principal Investigator:** Li-Jen Cheng

**Telephone:** (213) 354-3068

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** J.B. Milstein

**Telephone:** (303) 231-7299

**Contract Number:**

**Current Contract Period From:** 8/11/83

**To:** 11/10/84

**Contract Funding:**

FY 1983

\$ 60,000

**Source:**

SERI

**Project/Area/Task:** Polycrystalline Silicon

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**Objectives:** To improve the basic understanding of electrical and atomic transport properties of selected grain boundaries in silicon and to correlate the results with the characterized data of similar boundaries in real photovoltaic materials and solar cells.

**Approach/Present Tasks:** The approach is to investigate electrical and atomic properties of selected grain boundaries in silicon pertinent to solar cell applications. The effort is concentrated on properties of (110) tilt boundaries which form a valuable model system for investigating grain boundaries in silicon. The program is designed to attain the above objectives and includes the following four tasks: (1) preparation of specimens with selected (110) tilt boundaries, (2) investigation of grain boundary electrical transport properties, (3) investigation of atomic transport properties of tilt boundaries, and (4) analysis of data obtained.

**Status/FY 1983 Accomplishments:**

- Growth of bicrystals by the Czochralski technique has been initiated. To date the proper boundaries have proven difficult to prepare.

**FY 1984 Milestones:**

- Preparation and investigation of (110) tilt boundaries, with the goal of improved understanding.

**Major Project Reports:** None. New program.

**Summary Date**  
October 1983



# SERI

**Title:** New High Efficiency Silicon Solar Cells

**Contractor:**

National Aeronautics and Space Administration  
NASA Resident Office — JPL  
4800 Oak Grove Drive  
Pasadena, CA 91109

**Principal Investigator:** T. Daud

**Telephone:** (213) 354-5782

**Contract Number:**

**Current Contract Period From:** 8/11/83  
**To:** 11/10/84

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** J.B. Milstein

**Telephone:** (303) 231-7299

**Contract Funding:**

**FY 1983**            \$ 60,000

**Source:**

**SERI**

**Project/Area/Task:** Polycrystalline Silicon

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**Objectives:** To design and fabricate solar cells with high collection efficiency and reduced dark current. Reduced dark current will result in increased open circuit voltage without any degradation of short circuit current and thus lead to potentially attaining 20% efficiency.

**Approach/Present Tasks:** The approach involves the reduction of saturation current by reducing the ratio of junction area to total cell area, and reduction of surface recombination currents by oxide surface passivation and reduced metallization contact area. Tasks include: (1) design and fabrication of photolithographic masks for attaining p-n junction area to total area ratios of 0.01 to 0.2, (2) fabrication of solar cells using the design principles mentioned above, (3) characterization of solar cells, and (4) modeling the new solar cell design employed.

**Status/FY 1983 Accomplishments:**

- Masks for photolithography have been designed and are being fabricated.

**FY 1984 Milestones:**

- Fabrication, testing, and analysis of solar cells will be carried out, and samples made available to SERI for testing.

**Major Project Reports:** None. New program.

**Summary Date**

October 1983

# SERI

**Title:** Applications of Laser Annealing and Laser-Induced Diffusion to Photovoltaic Conversion

**Contractor:**  
Oak Ridge National Laboratory  
Oak Ridge, TN 37830

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** R.F. Wood  
**Telephone:** (615) 574-5781

**Project Engineer:** S. Tsuo  
**Telephone:** (303) 231-7682

**Contract Number:** 9078-1 (2076-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 3/1/80  
**To:** 7/31/84

<b>FY 1980</b>	<b>\$ 200,300</b>
<b>FY 1981</b>	<b>\$ 250,000</b>
<b>FY 1982</b>	<b>\$ 175,000</b>
<b>FY 1983</b>	<b>\$ 125,000</b>

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**Project/Area/Task:** Polycrystalline Silicon

**Objectives:** To explore the use of laser annealing and laser-induced diffusion techniques in studies of low-cost junction formation in polycrystalline silicon and grain boundary effects in silicon; and to determine the extent to which lasers can be used to induce grain growth and to control the diffusion of impurity and substrate atoms from low-cost substrates into deposited layers.

**Approach/Present Tasks:** This project involves the investigation of pulsed laser processing single-crystalline and polycrystalline silicon solar cells, the design and construction of an advanced gaseous discharge implantation system, and the fabrication of small-grained polycrystalline silicon solar cells using low-temperature processing techniques.

**Status/FY 1983 Accomplishments:**

- Silicon solar cells with efficiencies as high as 16.5% AM1 have been obtained using glow discharge implantation and excimer laser annealing. No back surface fields are created in these cells, no etching of the front surface is done, and no photolithography or surface passivation techniques are employed.
- ORNL's work on the electrical properties of grain boundaries has indicated that conventional one-dimensional treatments of grain boundary scattering of carriers are inadequate to cover the spectrum of cases which can arise in practice. It is not apparent that this conclusion is of particular significance at the doping densities and operating temperatures of polycrystalline silicon solar cells.

**FY 1984 Milestones:**

- Complete the design and construction of an advanced gaseous discharge implantation system — April 1984.
- Fabricate single crystal silicon solar cells with AM1 efficiencies of 17% or larger using glow discharge implantation and pulsed laser processing — July 1984.

**Major Project Reports:**

- Young, R.T.; van der Leeden, G.A.; Sandstrom, R.L.; Wood, R.F.; Westbrook, R.D. (October 1983). "High Efficiency Silicon Solar Cells by Beam Processing." *Applied Physics Letters*. Vol. 43 (No. 7); pp. 666-668.
- Young, R.T.; Narayan, J.; Christie, W.H.; van der Leeden, G.A.; Levatter, J.I.; Cheng, L.J. (November 1983). "Semiconductor Processing with Excimer Lasers." *Solid State Technology*. Vol. 26 (No. 11); pp. 183-189.

**Summary Date**  
October 1983

## SERI

**Title:** Photovoltaic Mechanisms in Polycrystalline Silicon Solar Cells

**Contractor:**

Pennsylvania State University  
Office of Sponsored Programs  
5 Old Main Building  
University Park, PA 16802

**Principal Investigator:** S. Fonash, S. Ashok

**Telephone:** (814) 865-4931

**Contract Number:** 2009-1

**Current Contract Period From:** 12/1/81

**To:** 11/30/82

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** S. Tsuo

**Telephone:** (303) 231-7682

**Contract Funding:**

**FY 1982**

**\$ 78,181**

**Source:**

**SERI**

**Project/Area/Task:** Polycrystalline Silicon

**Objectives:** To improve the performance and stability of MIS, SIS, and MIS-IL solar cells by studying: (1) the damaged surface layer produced by ion beam sputtering; (2) the influence of etching on Schottky barrier formation; (3) the mechanisms of current transport across the insulator; and (4) the effect of grain boundary hydrogen passivation on MIS/SIS solar cell efficiency improvement.

**Approach/Present Tasks:** This project involves the characterization of the damaged surface layer produced by ion-beam sputtering, the determination of the influence of chemical surface etching and ion beam etching on Schottky barrier formation, and studies related to the insulator layer in MIS, SIS, and MIS-IL devices.

**Status/FY 1983 Accomplishments:** The origin of the positive charge in the ion beam modified silicon surface layer has been studied. Chips from ion-beam etched samples were studied by Auger electron spectroscopy (AES), secondary ion mass spectroscopy (SIMS), Rutherford backscattering spectroscopy (RBS), and electron paramagnetic resonance characterization (EPR). It was established that ion beam processing produces silicon sites with dangling bonds. A re-evaluation of the meaning of capacitance plots for Schottky barrier-type diodes has been completed. It is found that most sets of interface state characteristics lead to non-linear  $I/C^2$  plots when an interfacial layer is present. Constant  $I/C^2$  slopes (true straight line plots for all values of reverse bias) are found only if there are no interface states present or only if the states present have a constant density across the gap and follow the metal for all frequencies.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Fonash, S.J. (May 1983). *Photovoltaic Mechanisms in Polycrystalline Silicon Solar Cells; Final Report.*
- Fonash, S.J. (April 1983). "A Reevaluation of the Meaning of Capacitance Plots for Schottky Barrier-Type Diodes." *Journal of Applied Physics*. Vol. 54 (No. 4); pp. 1966-1975.

**Summary Date**

**October 1983**

## SERI

**Title:** Fundamental Studies of Grain Boundary Passivation in Polycrystalline Silicon with Application to Improved Photovoltaic Devices

**Contractor:**  
Sandia National Laboratories  
Albuquerque, NM 87115

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** C.H. Seager/D.L. Ginley  
**Telephone:** (505) 264-9168/8863

**Project Engineer:** S. Tsuo  
**Telephone:** (303) 231-7682

**Contract Number:** (9109-01) 2113

**Contract Funding:**

**Source:**

**Current Contract Period From:** 1/1/79  
**To:** 2/28/84

**FY 1979** \$ 150,000

DOE

**FY 1980** \$ 237,000

SERI

**FY 1981** \$ 247,000

SERI

**FY 1982** \$ 125,000

SERI

**FY 1983** \$ 175,000

SERI

**Project/Area/Task:** Polycrystalline Silicon

**Objectives:** To study the basic physics of charge carrier transport and recombination at silicon grain boundaries, to investigate grain boundary passivation methods, to elucidate the mechanism of action of the passivation agent(s), and to construct theoretical models which are descriptive of the phenomena observed.

**Approach/Present Tasks:** This project involves the optimization of grain boundary hydrogenation processes, the investigation of the basic mechanisms of grain boundary hydrogenation, and the improvement of solar cell efficiencies by both the Kaufman ion source and DC plasma hydrogen passivation processes.

### **Status/FY 1983 Accomplishments:**

- Measurements have been made of the temperature dependence of grain boundary minority-carrier recombination velocities in p-type polycrystalline silicon. This temperature dependence is found to be close to that observed for the dark resistance to across-boundary majority-carrier currents.
- Electrically active defects in edge-defined, film-fed, grown silicon ribbon solar cells have been passivated using a hydrogen-plasma from a Kaufman ion source. Significant improvements in solar cell efficiency for both low diffusion length starting material ( $\approx 20 \mu\text{m}$ ) and high diffusion length ( $\approx 50 \mu\text{m}$ ) material have been obtained. For the former, passivation has produced solar cell efficiency improvements as high as 41% and in the case of the latter, solar cell efficiencies as high as 14.5% (AM1) have been obtained.

### **FY 1984 Milestones:**

- Complete the study of the lateral movement and bonding of hydrogen in various types of polycrystalline silicon using EBIC — February 1984.
- Complete the investigation of the mechanisms of hydrogen passivation by in-situ DC plasma hydrogenation in the variable temperature IR chamber for the FTIR spectroscopy — February 1984.

### **Major Project Reports:**

- Hanoka, J.I.; Seager, C.H.; Sharp, D.J.; Panitz, J.K.G. (April 1983). "Hydrogen Passivation of Defects in Silicon Ribbon Grown by the Edge-Defined Film-Fed Growth Process." *Applied Physics Letters*. Vol. 42 (No. 7); pp. 618-620.
- Seager, C.H. (November 1982). "Temperature Dependence of Minority Carrier Recombination Velocities at Grain Boundaries in Silicon." *Applied Physics Letters*. Vol. 41 (No. 9); pp. 855-857.

**Summary Date**  
October 1983

## SERI

**Title:** Research on Basic Understanding of High Efficiency in Silicon Solar Cells

**Contractor:**

Spire Corporation  
Patriots Park  
Bedford, MA 01730

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** M. B. Spitzer

**Telephone:** (617) 275-6000

**Project Engineer:** J.B. Milstein

**Telephone:** (303) 231-7299

**Contract Number:** 2090-3

**Contract Funding:**

**Source:**

**Current Contract Period From:** 12/23/82

**FY 1982**

**\$ \$117,976**

**SERI**

**To:** 12/31/83

**Project/Area/Task:** Polycrystalline Silicon

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**Objectives:** The objective of this work is to perform fundamental research in the area of silicon solar cell design, experimentation, and analysis, with the goal of developing understanding that will allow the production of cells having conversion efficiencies greater than 18%.

**Approach/Present Tasks:** The approach involves the fabrication, testing, analysis, and demonstration of high efficiency silicon solar cells based on a BSF cell design, and including high-low emitter, thru layer structures and hybrid structure cells. Fabrication employing epitaxy and/or ion implantation with single and multiple dopants is being pursued. Tasks include: (1) innovative cell design, experimentation and analysis, (2) studies of heavy doping effects, and (3) epitaxial fabrication and ion implantation services.

**Status/FY 1983 Accomplishments:**

- Spire has fabricated, tested, and analyzed solar cells which exhibit as much as 18% conversion efficiency, which has been confirmed at SERI. These cells were fabricated using an all ion-implanted, thermally annealed process.

**FY 1984 Milestones:**

- Attainment of 18% efficiency, subject to renewal of subcontract.

**Major Project Reports:**

- Paper to be presented at the 17th IEEE Photovoltaic Specialists Conference — May 1984.
- Annual Report due February 1984.

**Summary Date**

October 1983

## SERI

**Title:** Physical Models for Thin-Film Polycrystalline Solar Cells Based on Measured Grain Boundary and Electronic Parameter Properties

**Contractor:**

University of Florida  
Electrical Engineering Department  
Gainesville, FL 32611

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** F.A. Lindholm

**Telephone:** (904) 392-4929

**Project Engineer:** J.B. Milstein

**Telephone:** (303) 231-7299

**Contract Number:** 8275-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 9/18/78

**To:** 4/14/83

**FY 1978**            \$ 130,000

**FY 1979**            \$ 122,227

**FY 1981**            \$ 199,791

**FY 1982**            \$ 100,000

DOE

SERI

SERI

SERI

**Project/Area/Task:** Polycrystalline Silicon

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**Objectives:**

- To identify and characterize the basic photovoltaic mechanisms that govern the conversion efficiency of thin film polycrystalline solar cells.
- To experimentally determine the electronic parameters related to these photovoltaic mechanisms.
- To relate these mechanisms and parameters to the conversion efficiency through theoretical physical models developed for engineering design.

**Approach/Present Tasks:** The approach involves combined theoretical and experimental efforts. The dominant photovoltaic mechanisms are identified from experimental results from solar cells and test structures made from single-crystal and polycrystalline silicon. Theoretical modeling produces analytic descriptions where possible, but relies on numerical solutions for guidance where necessary. Tasks include development and fabrication of test structures, and theoretical analysis and modeling.

**Status/FY 1983 Accomplishments:** Analysis has been performed which suggests the possibility of producing high efficiency silicon solar cells based on a combination of the Quasi-Grain-Boundary-Free (QGBF) structure with drift field structures.

**FY 1984 Milestones:** None. Contract completed.

**Major Project Reports:**

- Lindholm, F.A. (February 1983). *Physical Models for Thin Film Polycrystalline Solar Cells Based on Measured Grain-Boundary and Electronic Parameter Properties; Annual Report.*
- Lindholm, F.A.; Chen, Y.H. (December 1982). "Current-Voltage Characteristics for Bipolar p-n Junction Devices with Drift Fields, Including Correlation Between Carrier Lifetimes and Shallow-Impurity Concentration." *Journal of Applied Physics*. Vol. 53 (No. 12); pp. 8863-8866.
- Neugroschel, A.; Lindholm, F.A. (January 1983). "Evidence for Low Diffusivity and Mobility of Minority Carriers in Highly Doped Si; and Interpretation." *Applied Physics Letters*. Vol. 52 (No. 2); pp. 176-178.

**Summary Date**  
October 1983

## SERI

**Title:** Research on Basic Understanding of High Efficiency Polycrystalline Silicon Solar Cells

**Contractor:**

University of Florida  
Division of Sponsored Research  
219 Grinter Hall  
Gainesville, FL 32611

**Principal Investigator:** F. A. Lindholm

**Telephone:** (904) 392-4929

**Contract Number:** 2090-2

**Current Contract Period From:** 1/1/83

**To:** 12/31/83

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** J.B. Milstein

**Telephone:** (303) 231-7299

**Contract Funding:**

FY 1982

\$ 94,585

**Source:**

SERI

**Project/Area/Task:** Polycrystalline Silicon

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**Objectives:** The objective of this work is to perform fundamental research in the area of polycrystalline silicon solar cell design, experimentation, and analysis, with the goal of developing understanding that will allow the production of cells having conversion efficiencies greater than 15%.

**Approach/Present Tasks:** The approach involves the fabrication, testing, analysis, and demonstration of high efficiency polycrystalline silicon solar cells employing the Quasi-Grain-Boundary-Free (QGBF) structure with a drift field structure. Tasks include: (1) design and fabrication of polycrystalline silicon solar cells, (2) studies of heavy doping effects, (3) measurement and diagnostic techniques, and (4) theoretical and experimental solar cell analysis.

**Status/FY 1983 Accomplishments:**

- In the course of solar cell fabrication and analysis, it has been observed that minority carriers in As doped ( $1.5 \times 10^{20}/\text{cm}^3$ ) silicon exhibit anomalously low diffusivity and mobility.
- Solar cells of approximately 12% efficiency have been fabricated and reported.

**FY 1984 Milestones:**

- Final Report — February 1984.

**Major Project Reports:** None.

**Summary Date**  
October 1983

# SERI

**Title:** Thin-Film Polycrystalline Silicon Grain Boundary Characterization and Passivation and MIS Stability and Viability Studies

**Contractor:**

State University of New York at Buffalo  
Department of Electrical Engineering  
4232 Ridge Lea Road  
Amherst, NY 14226

**Principal Investigator:** W.A. Anderson  
**Telephone:** (716) 831-3166

**Contract Number:** 9080-1 (2114-1)

**Current Contract Period From:** 1/1/79  
**To:** 6/30/84

**Project/Area/Task:** Polycrystalline Silicon

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** S. TSUO  
**Telephone:** (303) 231-7682

**Contract Funding:**

<b>FY 1979</b>	<b>\$ 60,000</b>
<b>FY 1980</b>	<b>\$ 109,400</b>
<b>FY 1981</b>	<b>\$ 80,039</b>
<b>FY 1982</b>	<b>\$ 60,000</b>
<b>FY 1983</b>	<b>\$ 35,000</b>

**Source:**

DOE
SERI
SERI
SERI
SERI

**Objectives:** The objectives of this work are: (1) to investigate experimentally the concept of reducing minority-carrier recombination at grain boundaries by minority-carrier mirrors, and (2) to study the MINP solar cell structure.

**Approach/Present Tasks:**

- Study the electrical properties of grain boundaries by using the conductance technique that is commonly used in investigating Si-SiO<sub>2</sub> interface states in the semiconductor industry. Study the effects of minority carrier mirror at grain boundaries.
- Optimize the doping profile, junction depth, and oxide quality of the MINP solar cell structure.

**Status/FY 1983 Accomplishments:** Work on Cr-MIS and Yb-MIS cells has been completed. Both cells have an efficiency limit of about 13% due to optical absorption in the metal layers. MINP solar cell research has been initiated. The design consists basically of AR coating/Al-Cr-Yb grid/l-layer/ion implanted n<sup>+</sup>/0.1 Ω-cm p-layer/ohmic contact. The initial design produced a 13% cell. A second computer-aided design has produced a 14.6% (active area) cell which is not yet optimum. Boron diffused into poly-Si has been used to form a minority carrier mirror (MCM) by diffusing from the back. Such MCM has been shown to improve the efficiency of certain poly-Si cells up to about 50%.

**FY 1984 Milestones:**

- Complete the grain boundary study and submit to SERI the Ph.D. thesis of Mr. Francis Kai on this subject — December 1983.
- Fabricate MINP solar cells with 16-17% AM1 total area efficiency — June 1984.

**Major Project Reports:**

- Kai, F.Y. (August 1983). *Grain Boundary Effects and Passivation Studies in Polycrystalline MIS Solar Cells*. Ph.D. Dissertation.
- Kai, F.; Rajeswaran, G.; Jackson, M.A.; Rao, V.J.; Anderson, W.A. (1983). "Grain Boundary Effects and Li Passivation in Polycrystalline Silicon." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 543-547.
- Rajeswaran, G. (January 1983). *Interface and Intergrain Effects in Metal-Insulator-Semiconductor Solar Cells*. Ph.D. Dissertation, State University of New York, Buffalo, NY.

**Summary Date**  
October 1983



# SERI

**Title:** Research on Basic Understanding of High Efficiency in Silicon Solar Cells

**Contractor:**  
University of Pennsylvania  
Department of Electrical Engineering and Science  
Philadelphia, PA 19104

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** M. Wolf  
**Telephone:** (215) 898-4822

**Project Engineer:** J.B. Milstein  
**Telephone:** (303) 231-7299

**Contract Number:** 2090-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/15/82  
**To:** 11/14/83

<b>FY 1982</b>	<b>\$ 147,319</b>	<b>SERI</b>
<b>FY 1983</b>	<b>\$ 100,000 (est.)</b>	<b>SERI</b>

**Project/Area/Task:** Polycrystalline Silicon

**Objectives:** The objective of this work is to perform fundamental research in the area of silicon solar cell design, experimentation, and analysis, with the goal of developing understanding that will allow the production of cells have conversion efficiencies greater than 18%.

**Approach/Present Tasks:** The approach involves the fabrication and analysis of a complex seven-layer solar cell which has been described theoretically in the literature by Professor Wolf. The intention of this program is to investigate means by which recombination in the bulk material, at surfaces, and at contacts may be minimized. In Professor Wolf's analysis heavy doping is to be avoided whenever possible. The research includes a lower-tier subcontract to Spectrolabs for cell fabrication. Tasks include: (1) innovative cell design, experimentation, and analysis, (2) design of an initial process sequence, (3) review of the cell design, (4) fabrication of the first group of test cells, (5) analysis of the test cells, (6) redesign of the process sequence, (7) second review of the cell design, (8) preparation of the second group of test cells, (9) measurement and diagnostic techniques, (10) expansion of the storage relay time method to arbitrary base layer thickness with arbitrary surface recombination velocity, (11) development of methods for determining the front layer material parameters.

**Status/FY 1983 Accomplishments:** This effort has been delayed by difficulties in solar cell fabrication. Some cells have been fabricated with less than the expected efficiencies.

**FY 1984 Milestones:**

- Final Report — 10 January 1984.
- Attainment of 18% efficiency.

**Major Project Reports:**

- Wolf, M. (1983). "Efficiency Improvement in Silicon Solar Cells," *Proceedings of the DOE Annual Photovoltaic Reviews; Arlington, VA; 15-16 February 1983*. CONF-830222; Springfield, VA: National Technical Information Service; pp. 117-131.

**Summary Date**  
October 1983

## SERI

**Title:** Investigation of High Efficiency Silicon MINP Solar Cells

**Contractor:**

University of Washington  
Joint Center for Graduate Study  
Office of Grant and Contract Services  
Room 22, Administration Building M.S. AD24  
Seattle, WA 98195

**Principal Investigator:** L.C. Olsen

**Telephone:** (509) 375-3176

**Contract Number:** 2090-5

**Current Contract Period From:** 10/1/82

**To:** 9/30/83

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** J.B. Milstein

**Telephone:** (303) 231-7299

**Contract Funding:**

FY 1982	\$ 114,010
FY 1983	\$ 125,000 (est.)

**Source:**

SERI
SERI

**Project/Area/Task:** Polycrystalline Silicon

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**Objectives:** The objective of this work is to perform fundamental research in the area of silicon Metal-Insulator-n-p (MINP) solar cell design, experimentation, and analysis, with the goal of developing understanding that will allow the production of cells having conversion efficiencies greater than 18%.

**Approach/Present Tasks:** The approach involves material characterization, cell fabrication using both ion-implanted and diffused p-n junctions between 0.1 and 0.2 microns deep, aluminum BSF, growth of a thin (approximately 15 Å oxide, deposition of a high work function metal, front-grid, deposition of a charged oxide layer, and anti-reflection coating. Tasks include: (1) silicon substrate characterization, (2) MINP cell fabrication, (3) solar cell characterization, and (4) modeling calculations.

**Status/FY 1983 Accomplishments:**

- MINP cells which exhibit 15.4% efficiency have been fabricated, tested, and analyzed. Efficiency measurements have been confirmed at SERI.

**FY 1984 Milestones:**

- Fabrication, testing, analysis, and demonstration of 18% efficient cells — September 1984.
- Renewal of contract (in negotiation).

**Major Project Reports:**

- Annual Report due October 1983.

**Summary Date**  
October 1983

# SERI

**Title:** Research on Basic Understanding of High Efficiency in Silicon Solar Cells

**Contractor:**

Westinghouse Electric Corporation  
Research Development Center  
1310 Beulah Road  
Pittsburgh, PA 15235

**Principal Investigator:** A. Rohatgi

**Telephone:** (412) 256-4019

**Contract Number:** 2090-4

**Current Contract Period From:** 12/1/82  
**To:** 11/30/83

**Project/Area/Task:** Polycrystalline Silicon

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** J.B. Milstein

**Telephone:** (303) 231-7299

**Contract Funding:**

<b>FY 1982</b>	<b>\$ 97,671</b>
<b>FY 1983</b>	<b>\$ 180,000 (est.)</b>

**Source:**

<b>SERI</b>
<b>SERI</b>

**Objectives:** The objective of this work is to perform fundamental research in the area of silicon solar cell design, experimentation, and analysis, with the goal of developing understanding that will allow the production of cells having conversion efficiencies greater than 18%.

**Approach/Present Tasks:** The approach involves the fabrication and evaluation of an advanced solar cell design, which includes such features as an abrupt stepped emitter, MIS contacts, multilayer anti-reflection coating, an optically reflecting back contact, and the use of gallium as a back surface field (BSF) dopant. Tasks include: (1) innovative cell design, experimentation and analysis, (2) modeling and design for high efficiency cells, (3) process verification and device fabrication, (4) device characterization, (5) analysis to correlate theory and experiment, (6) heavy doping effects of various dopants in the base material, and (7) advantages of a gallium-diffused BSF.

**Status/FY 1983 Accomplishments:**

- Fabrication, testing, and confirmation at SERI of 17.1% efficient solar cells.
- Fabrication of GA-diffused BSF cells, with the observation that, to date, gallium does not offer an advantage over boron.

**FY 1984 Milestones:**

- Final Report — January 1984.
- Attainment of 18% efficiency.

**Major Project Reports:**

- Rohatgi, A. (1983). "Research on the Basic Understanding of High Efficiency in Silicon Solar Cells." *Polycrystalline Silicon Solar Cells Review Meeting; Abstracts of Presentations; Golden, CO; 27-28 June 1983*. SERI/CP-211-2025. Golden, CO: Solar Energy Research Institute; pp. 41-58.

**Summary Date**

October 1983

# SERI

**Title:** Stability of Cadmium Sulfide/Copper Sulfide Solar Cells

**Contractor:**  
Battelle-Columbus Laboratories  
505 King Avenue  
Columbus, OH 43201

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** G.T. Noel  
**Telephone:** (614) 424-7481

**Project Engineer:** R.L. Mitchell  
**Telephone:** (303) 231-1379

**Contract Number:** 9169-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 8/12/80  
**To:** 5/31/83

**FY 1980**      \$ 368,061  
**FY 1981**      \$ 314,400

**SERI**  
**SERI**

**Project/Area/Task:** Polycrystalline Thin Films

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**Objectives:** To determine the viability of high efficiency  $\text{Cu}_2\text{S}/\text{CdS}$  and  $\text{CdS}/\text{CuInSe}_2$  solar cells for operational lifetimes of the order of 20 years or more. The project will make projections on the performance of these cells over a 20-year period and assess the potential for producing stable low-cost cells.

**Approach/Present Tasks:**

- Design and implement a matrix stress test of  $\text{Cu}_2\text{S}/\text{CdS}$  and  $\text{CdS}/\text{CuInSe}_2$  cells in dry argon ambient.
- Complete device characterization by I-V, C-V, and laser scan.
- Complete material analysis by SIMS, Auger, and SEM.
- Identify major intrinsic and extrinsic degradation modes.
- Determine physical, chemical, and mechanical processes which lead to device degradation.

**Status/FY 1983 Accomplishments:**

- Testing of Boeing  $\text{CdS}/\text{CuInSe}_2$  cells at 60°C and 90°C in water-saturated air for over 600 hours confirmed that, except for contact degradation, the cells were stable within experimental limits.
- Transferred outdoor test modules to SERI where further testing is to be conducted.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Noel, G.J.; Gaines, G.B.; Richard, N.A. (April 1983). *A Study of the Stability of Cadmium Sulfide/Copper Sulfide Solar Cells; Final Report*. Battelle-Columbus Laboratories.

**Summary Date**  
October 1983

# SERI

**Title:** CdS/CuInSe<sub>2</sub> Solar Cell Research

**Contractor:**

Boeing Aerospace Company  
P.O. Box 3999 M.S. 88-43  
Seattle, WA 98124

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** R. Mickelsen

**Telephone:** (206) 773-1098

**Project Engineer:** K. Zweibel

**Telephone:** (303) 231-7141

**Contract Number:** 8021-1 (2184-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 7/1/83

**To:** 6/30/84

FY 1982 \$ 250,000

FY 1983 \$ 250,000

SERI

SERI

**Project/Area/Task:** Polycrystalline Thin Films

**Objectives:** To develop high-efficiency (over 12%) CuInSe<sub>2</sub>/CdZnS-based devices.

**Approach/Present Tasks:**

- Further optimize CuInSe<sub>2</sub>/CdZnS device to produce the highest possible efficiencies.
- Incorporate Ga atoms into CuInSe<sub>2</sub> films to raise the bandgap and open-circuit voltage.
- Investigate the possibility of developing Ionized-Cluster Beam Deposition of CuInSe<sub>2</sub>.
- Investigate CuInSe<sub>2</sub> device behavior, with emphasis on O<sub>2</sub> heat treatment.

**Status/FY 1983 Accomplishments:**

- A 10.5% efficient CuInSe<sub>2</sub>/CdZnS cell was produced by Boeing and measured at SERI under standard xenon simulation of the solar spectrum (25°C). Boeing also reported an 11% efficient cell, as measured under ELH simulation at 25°C.

**FY 1984 Milestones:**

- Produce a 12.5% efficient 1-cm<sup>2</sup> CdZnS/CuInSe<sub>2</sub> device.
- Assess the feasibility of incorporating Ga in CuInSe<sub>2</sub> films.
- Assess the feasibility of using ion-assisted cluster-beam deposition for CuInSe<sub>2</sub> films.

**Major Project Reports:**

- Mickelsen, R.A.; Chen, W.S.; Buldhaupt, L.F. (August 1982). *CdS/Cu-ternary Heterojunction Cell Research; Final Report*. Seattle, WA: Boeing Aerospace Co.; 106 pp.

**Summary Date**  
October 1983

# SERI

**Title:** CuInSe<sub>2</sub>/CdS Thin Film Solar Cell Research

**Contractor:**

Boeing Aerospace Company  
P.O. Box 3999 M/S 88-43  
Seattle, WA 98124

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** R. Mickelsen

**Telephone:** (206) 773-1098

**Project Engineer:** K. Zweibel

**Telephone:** (303) 231-7141

**Contract Number:** 2038-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 5/14/82  
**To:** 5/13/83

<b>FY 1976</b>	<b>\$ 177,500</b>	<b>ERDA</b>
<b>FY 1978</b>	<b>\$ 177,500</b>	<b>DOE</b>
<b>FY 1979</b>	<b>\$ 185,760</b>	<b>SERI</b>
<b>FY 1980</b>	<b>\$ 521,023</b>	<b>SERI</b>
<b>FY 1981</b>	<b>\$ 250,000</b>	<b>SERI</b>
<b>FY 1982</b>	<b>\$ 250,000</b>	<b>SERI</b>

**Project/Area/Task:** Polycrystalline Thin Films

**Objectives:** To perform research leading to the development of a large area, low cost, stable polycrystalline thin film photovoltaic solar cell based upon the CdS/CuInSe<sub>2</sub> material system.

**Approach/Present Tasks:**

- Lattice-match (Cd,Zn)S to CuInSe<sub>2</sub> to minimize heteroface traps.
- Study effects of heat treatments in oxidizing and reducing atmospheres.
- Improve control of Cu/In ratio.
- Develop a cell model based on experimental parameters.
- Optimize deposition process, grid geometry, and antireflective coating.

**Status/FY 1983 Accomplishments:**

- An 11% efficient (ELH simulation) CdZnS/CuInSe<sub>2</sub> heterojunction was reported by Boeing. A similar device was measured at 10.5% under xenon solar simulation at 25° C.
- Boeing and Reading and Bates formed a joint venture to commercialize their high-efficiency CuInSe<sub>2</sub> cells. This is a direct outgrowth of SERI-supported work and represents an important example of technology transfer.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Hsiao, Y.R.; Chen, W.S.; Mickelsen, R.A.; Stewart, J.M.; Lowe, S.; Olsen, L.C.; Rothwarf, A. (May 1983). *CuInSe<sub>2</sub>/CdS Thin-Film Solar Cell Development; Final Report*. Seattle, WA: Boeing Aerospace Company.

**Summary Date**  
October 1983

# SERI

**Title:** Cadmium Sulfide/Copper Selenide Cell Research

**Contractor:**

Boeing Aerospace Company  
Electronics Technology  
P.O. Box 3999  
Seattle, WA 98124

**Principal Investigator:** J. Stewart

**Telephone:** (206) 773-2429

**Contract Number:** 9216-1 (2183-1)

**Current Contract Period From:** 5/1/79  
**To:** 5/31/84

**Project/Area/Task:** Polycrystalline Thin Films

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** K. Zweibel

**Telephone:** (303) 231-7141

**Contract Funding:**

FY 1979	\$ 77,869
FY 1980	\$ 77,581
FY 1981	\$ 76,609
FY 1982	\$ 80,000

**Source:**

DOE
SERI
SERI
SERI

**Objectives:** To investigate the feasibility of using  $Cu_{2-x}Se$  as a semiconductor material for thin film solar cells. Formed as heterojunctions with CdS, both films are deposited by vacuum evaporation methods onto inexpensive substrates which lead to the possibility of large-scale, low-cost cell production.

**Approach/Present Tasks:**

- Design and build Se sources for uniform depositions.
- Make in-situ film measurements for compositional control.
- Design deposition to avoid Cu and Se source cross-talk and cross-contamination.
- Develop low-resistivity n-ZnSe and form n-ZnSe/p-CuSe<sub>2-x</sub> heterojunctions and Cu<sub>2</sub>Se/ZnSe/CdS SIS devices.

**Status/FY 1983 Accomplishments:**

- Cell efficiency of 5.4% has been demonstrated.
- Stability problems associated with the movement of Cu in the device are being investigated. ZnSe interlayers show good Cu-module suppression and are being used in front- and backwall geometries.

**FY 1984 Milestones:**

- Demonstrate low-resistivity (less than 100 ohm-cm) n-ZnSe films.
- Produce solar cells with 8% efficiency for 1-cm<sup>2</sup> area.

**Major Project Reports:**

- Cross, D.A.; Stewart, J.M; Chen, W.S. (October 1982). *CdS/Cu<sub>2</sub> Cell Research, Copper Selenide-Based Thin Film Solar Cells; Final Report*. Seattle, WA: Boeing Aerospace Co.; 27 pp.

**Summary Date**

October 1983

## SERI

**Title:** Electrodeposited p-CdTe Films for Solar Cell Applications: Photoelectrochemical Acceptor Doping and Characterization

**Contractor:**  
Colorado State University  
Office of Sponsored Research  
Fort Collins, CO 80523

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** K. Rajeshwar  
**Telephone:** (303) 491-8280

**Project Engineer:** R.L. Mitchell  
**Telephone:** (303) 231-1379

**Contract Number:** 3048-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 5/1/83  
**To:** 6/30/84

**FY 1983**                **\$ 29,000**

SERI

**Project/Area/Task:** Polycrystalline Thin Films

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**Objectives:** The objective of this effort is the development of electrodeposition of p-type CdTe films and CdS/CdTe heterojunctions.

**Approach/Present Tasks:**

- Conduct compositional characterizations of CdTe films which have been electrodeposited.
- Conduct performance characterization of electrodeposited CdTe films.
- Optimize the parameters of photoelectrochemical doping of p-type CdTe.
- Fabricate preliminary electrodeposited CdTe devices.

**Status/FY 1983 Accomplishments:**

- Successfully electrodeposited p-type CdTe films.

**FY 1984 Milestones:**

- Transfer project to University of Texas at Arlington.
- Complete characterization of electrodeposited CdTe films and optimization of photoelectrochemical doping parameters.
- Complete fabrication of electrodeposited CdTe devices.

**Major Project Reports:**

- Rajeshwar, K.; Bhattacharya, R.N. (September 1983). *Electrodeposited p-Cd Te Thin Films for Solar Cell Applications: Photoelectrochemical Acceptor Doping and Characterization; Quarterly Progress Report*. Colorado State University.

**Summary Date**  
October 1983



# SERI

**Title:** Transient Measurements on Heterostructure Photovoltaic Cells

**Contractor:**

Colorado State University  
Physics Department  
Fort Collins, CO 80523

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** J. Sites

**Telephone:** (303) 491-5850

**Project Engineer:** R.L. Mitchell

**Telephone:** (303) 231-1379

**Contract Number:** 1237-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 5/18/81

**To:** 5/31/84

**FY 1981** \$ 26,600

**FY 1982** \$ 14,000

**FY 1983** \$ 19,993

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**Project/Area/Task:** Polycrystalline Thin Films

**Objectives:** To improve the performance of  $\text{CuInSe}_2$  cells by experimentally examining their band energy diagrams and developing an analytical model describing cell behavior.

**Approach/Present Tasks:**

- I-V and capacitance-voltage characteristics are to be examined as a function of light intensity, wavelength, and temperature for  $\text{CuInSe}_2/(\text{Cd,Zn})\text{S}$  cells.
- A model of these characteristics are to be developed to show the dependence of cell behavior and to suggest technological improvements.

**Status/FY 1983 Accomplishments:**

- Confirmed the existence of a Schottky barrier at the  $\text{CuInSe}_2/\text{Mo}$  interface of annealed  $\text{CuInSe}_2/\text{CdS}$  cells.
- Identified a barrier shift due to traps at the  $\text{CuInSe}_2/(\text{Cd,Zn})\text{S}$  interface which may degrade the  $V_{oc}$  by as much as 100 mV.

**FY 1984 Milestones:**

- Capacitance-voltage from 1 kHz to 200 kHz will be established on both  $\text{CuInSe}_2(\text{Cd,Zn})\text{S}$ , CdSe, and CdTe solar cells.
- Complete model of band picture for light effects in the junction region.

**Major Project Reports:**

- Potter, R. R.; Sites, J. R.; Wagner, S. (July 1982). "Current-Voltage Response of Tandem Junction Solar Cells." *Journal of Applied Physics*. Vol. 53 (No. 7); pp. 5269-5272.
- Potter, R. R.; Sites, J. R. (1983). "Experimental Nonidealities in Light Response and Quality Factor of Photovoltaic Diodes." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 475-479.
- Potter, R. R.; Sites, J. R. (April-June 1983). "Internal Contacts to Photovoltaic Structures Using Ion Beam Milling." *Proceedings of the 29th National Symposium of the American Vacuum Society; Baltimore, MD; 16-19 November 1982*. Appears in *Journal of Vacuum Science & Technology #A*. Vol. 1 (No. 2, Part I); pp. 331-333.
- Sites, J. R.; Potter, R. R. *Electrical Measurements on  $\text{CuInSe}_2$  Heterojunction Photovoltaic Cells*. SERI Subcontractor Annual Report.

**Summary Date**

October 1983

## SERI

**Title:** Investigation of Magnetron Sputtered ZnSe for Solar Cell Application

**Contractor:**  
NASA/JPL  
4800 Oak Grove Drive  
Pasadena, CA 91109

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** R. Stirn  
**Telephone:** (213) 577-9230

**Project Engineer:** R.L. Mitchell  
**Telephone:** (303) 231-1379

**Contract Number:** 3115-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 8/23/83  
**To:** 10/23/84

**FY 1983**            **\$ 30,000**

**SERI**

**Project/Area/Task:** Polycrystalline Thin Films

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**Objectives:** To conduct research into the feasibility of depositing low resistivity zinc selenide thin films by reactive-mode sputtering.

**Approach/Present Tasks:**

- The sputtering parameters for ZnSe films deposited on glass substrates having electrical resistivities less than 100 ohm-cm shall be optimized, and characterized as to their optical transparency, electrical conductivity, free electron concentration and mobility.
- The optimized ZnSe films shall be deposited on transparent conductive oxide coated glass substrates for subsequent deposition of Zn<sub>3</sub>P<sub>2</sub> films at the University of Delaware.
- The optimized ZnSe films shall be deposited on single crystal Zn<sub>3</sub>P<sub>2</sub> wafers supplied by the University of Delaware. Characterization of the heterojunction properties will then be accomplished.

**Status/FY 1983 Accomplishments:** None. New program.

**FY 1984 Milestones:**

- Produce samples of ZnSe films on conducting transparent substrates with resistivity less than 100 ohm-cm.
- Produce samples of ZnSe films on single crystal Zn<sub>3</sub>P<sub>2</sub> wafers with resistivity less than 100 ohm-cm.
- Complete characterization of heterojunction properties for sample ZnSe/Zn<sub>3</sub>P<sub>2</sub> devices.

**Major Project Reports:** None. New program.

**Summary Date**  
October 1983

## SERI

**Title:** The Preparation and Properties of  $\text{CuInSe}_2$  Crystals

**Contractor:**  
North Carolina State University  
Raleigh, NC 27650

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** K.L. Bachmann  
**Telephone:** (919) 737-2538

**Project Engineer:** K. Zweibel  
**Telephone:** (303) 231-7141

**Contract Number:** 2028-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 4/1/82  
**To:** 5/31/84

<b>FY 1982</b>	<b>\$ 77,302</b>
<b>FY 1983</b>	<b>\$ 78,000</b>

<b>SERI</b>
<b>SERI</b>

**Project/Area/Task:** Polycrystalline Thin Films

**Objectives:** To (1) investigate various  $\text{CuInSe}_2$  crystal growing techniques; (2) grow high-quality  $\text{CuInSe}_2$ ; and (3) supply such material to various cooperative researchers and subcontractors, including Princeton.

### Approach/Present Tasks:

- Characterization of melt/composition/temperature behavior of Cu/In/Se systems.
- Optimization of several crystal growth techniques, including gradient freezing, Bridgman growth, horizontal zone leveling, vertical zone leveling, and Czochralski pulling.
- Growth of sample  $\text{CuInSe}_2$  for various device/research tasks.

### Status/FY 1983 Accomplishments:

- High-quality  $\text{CuInSe}_2$  crystal samples have been grown by the zone-leveling method.
- $\text{CuInSe}_2$  samples have been provided to both SERI in-house researchers and to subcontractors, including Princeton.

### FY 1984 Milestones:

- Grow and characterize off-stoichiometric  $\text{CuInSe}_2$  crystals.
- Grow  $\text{CuInS}_{2y}\text{Se}_{2-2y}$  crystals and use these to make heterojunction solar cells.

### Major Project Reports:

- Bachmann, K.J. (1983). "Efficient and Stable Solar Cell by Interfacial Film Formation: n- $\text{CuInSe}_2/\text{I}=\text{I}_2\text{-Cu-HI/C}$ ." *Nature* (in press).
- Bachmann, K.J.; Fearheily, M. (March 1983). *The Preparation and Properties of  $\text{CuInSe}_2$  Crystals; Annual Report*. Raleigh, NC: North Carolina State University.

**Summary Date**  
October 1983

# SERI

**Title:** CuInSe<sub>2</sub> Thin Film Material Research

**Contractor:**  
Poly Solar Incorporated  
8701 National Drive  
Garland, TX 75041

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** T. Chu  
**Telephone:** (214) 840-1221

**Project Engineer:** K. Zweibel  
**Telephone:** (303) 231-7141

**Contract Number:** 2208-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/82  
**To:** 2/14/85

<b>FY 1982</b>	125,000
<b>FY 1983</b>	\$110,000

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**Project/Area/Task:** Polycrystalline Thin Films

**Objectives:** To develop thin film CuInSe<sub>2</sub> devices using the close-spaced vapor transport method and to investigate various heterojunction partners to CuInSe<sub>2</sub>.

**Approach/Present Tasks:**

- Iodine and HCl carrier gases are being investigated to develop uniform films.
- Various substrates and temperatures are being tried in order to minimize reactions with the carrier gases, which cause contacts to be destroyed.

**Status/FY 1983 Accomplishments:**

- Good quality, uniformly stoichiometric films of CuInSe<sub>2</sub> have been deposited.
- High open-circuit voltages (over 450 mV) have been demonstrated.
- Currents have been low, and difficulties with carrier collection are being examined. Film uniformity and contacting problems are regarded as important areas for improvement.

**FY 1984 Milestones:**

- Fabricate a 4% efficient heterojunction device.
- Assess the potential of various window materials (ZnO, CdO, CdZnS, SnO, ITO) when matched top-CuInSe<sub>2</sub>.

**Major Project Reports:**

- Loh, C.W.; Yu, J.M.; Chu, T.L.; Chu, S.S. (November 1983). *CVD-Deposited CuInSe<sub>2</sub> Thin Film Materials Research; Annual Report*. Garland, TX: Poly Solar, Inc.

**Summary Date**  
October 1983

# SERI

**Title:** Optimization of p-CuInSe<sub>2</sub>/n-(ZnCd)S Solar Cells

**Contractor:**

Princeton University  
Office of Research and Project Administration  
Princeton, NJ 08544

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** S. Wagner

**Telephone:** (609) 452-4631

**Project Engineer:** K. Zweibel

**Telephone:** (303) 231-7141

**Contract Number:** 2075-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 5/2/82

**To:** 1/31/84

**FY 1982**

**\$ 135,386**

**SERI**

**FY 1983**

**\$ 20,000**

**SERI**

**Project/Area/Task:** Polycrystalline Thin Films

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**Objectives:** To fabricate and optimize the efficiency of single-crystal CuInSe<sub>2</sub>/(CdZn)S cells.

**Approach/Present Tasks:** Increase in efficiency (above 12%) will be sought primarily by raising the open-circuit voltage. The voltage will be increased by improving the lattice match and the electron affinity match between the two semiconductors through the introduction of (Zn,Cd)S alloys. A higher bandgap (Zn,Cd)S "window" will also result in higher short-circuit currents. Furthermore, a low-coverage front contact grid will be applied, again to raise the photocurrent averaged over the total cell area to a high value. It is expected that this research will provide information for understanding bulk CuInSe<sub>2</sub>, its interface and defect chemistry, and its potential in terms of various device geometries.

**Status/FY 1983 Accomplishments:**

- Equipment for ZnCdS deposition has been received and is being optimized.

**FY 1984 Milestones:**

- Fabricate a 10% efficient single-crystal CuZnS/CuInSe<sub>2</sub> solar cell — 31 January 1984.

**Major Project Reports:**

- Becker, K.D.; Wagner, S. (1983). "Temperature-Dependent Nuclear Magnetic Resonance in CuInVI<sub>2</sub> Chalcopyrite Compounds." *Physical Review B* (in press).

**Summary Date**

October 1983

## SERI

**Title:** Development of Thin Film Monolithic Cascade ZnSiAs<sub>2</sub> Solar Cells

**Contractor:**

Research Triangle Institute  
P.O. Box 12194  
Research Triangle Park, NC 27709

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** E. Andrews

**Telephone:** (919) 541-5930

**Project Engineer:** K. Zweibel

**Telephone:** (303) 231-7141

**Contract Number:** 2138-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 8/1/82

FY 1982

\$ 137,000

SERI

**To:** 1/31/84

**Project/Area/Task:** Polycrystalline Thin Film

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**Objectives:** To develop a monolithic ZnSiAs<sub>2</sub>/Si two-junction solar cell.

**Approach/Present Tasks:** Difficulties encountered in developing the cascade geometry required to subcontractor to direct attention to the CdS/ZnSiAs<sub>2</sub> component of the device.

**Status/FY 1983 Accomplishments:**

- Several CdS/ZnSiAs<sub>2</sub> heterojunction devices were assembled and demonstrated PV response. Efficiencies remained below about 2%.

**FY 1984 Milestones:**

- None. Program completed.

**Major Project Reports:**

- Andrews, Jr., J.E. (1983). "Development of Thin Film Monolithic Cascade ZnSiAs<sub>2</sub> Solar Cells." *Polycrystalline Thin Film Review Meeting: Abstract of Presentation; Golden, CO; 16-18 May 1983*. SERI/CP-211-1985. Golden, CO: Solar Energy Research Institute; pp. 301-319.

**Summary Date**  
October 1983

# SERI

**Title:** Thin-Film Cadmium Telluride and Zinc Phosphide Solar Cells

**Contractor:**

Southern Methodist University  
Dallas, TX 75275

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** T. Chu

**Telephone:** (214) 692-3014

**Project Engineer:** K. Zweibel

**Telephone:** (303) 231-7141

**Contract Number:** 9286-1 (2097-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 7/1/79  
**To:** 3/31/85

**FY 1979** \$ 140,730

DOE

**FY 1980** \$ 130,000

SERI

**FY 1981** \$ 167,000

SERI

**FY 1982** \$ 295,000

SERI

**FY 1983** \$ 89,000

SERI

**FY 1984** \$ 271,000

SERI

**Project/Area/Task:** Polycrystalline Thin Films

**Objectives:** The objectives of this project are to conduct research and development of thin film polycrystalline cadmium telluride and zinc phosphide solar cells on low-cost substrates and to demonstrate the feasibility of producing thin film cells with a conversion efficiency of 10% or higher.

**Approach/Present Tasks:** The technical approaches consist of the chemical vapor deposition of cadmium telluride and  $Zn_3P_2$  films on graphite and coated graphite substrates, the control of conductivity type and carrier concentration in deposited cadmium telluride films, the characterization of electrical and structural properties of cadmium telluride films, and the fabrication and characterization of thin film cadmium telluride heterojunction solar cells.

**Status/FY 1983 Accomplishments:**

- n-ITO/p-CdTe cells made by CVD had  $J_{sc} = 18 \text{ mA/cm}^2$ ,  $V_{oc} = 0.71 \text{ V}$ ,  $FF = 0.61$ , and an efficiency of 7.8% (1-cm<sup>2</sup> area).
- Lab shutdown 3 August 1982 — 1 May 1983 for safety reasons. New lab in operation May 1983.
- Several new window materials are being investigated, including ZnO, CdO, SnO, and CdZnS. CdTe heterojunctions made with CdO show very similar performance (over 7%) to those made with n-ITO.

**FY 1984 Milestones:**

- Demonstrate a 10% efficient CdTe solar cell.
- Investigate the feasibility of using various window materials on CdTe devices.

**Major Project Reports:**

- Chu, T.I.; Chu, S.S.; Murthy, K.; Stokes, E.D.; Russell, P.E. (April 1983). "Deposition and Properties of Zinc Phosphide Films." *Journal of Applied Physics*. Vol. 54 (No. 4); pp. 2063-2068.
- Chu, T.L.; Chu, S.S.; Pauleau, Y.; Murthy, K.; Stokes, E.D.; Russell, P.E. (January 1983). "Cadmium Telluride Films on Foreign Substrates." *Journal of Applied Physics*. Vol. 54 (No. 1); pp. 398-403.

**Summary Date**

October 1983

## SERI

**Title:** High Temperature Equilibrium Studies of  $\text{CuInSe}_2$

**Contractor:**

SRI International  
333 Ravenwood Ave.  
Menlo Park, CA 94025

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** R. Lamereaux, D. Hildenbraun,  
K. Lau, R. Brittain

**Telephone:** (415) 326-6200

**Contract Number:** 2001-1

**Current Contract Period From:** 1/4/82

**To:** 3/15/83

**Project Engineer:** R.L. Mitchell

**Telephone:** (303) 231-1379

**Contract Funding:**

FY 1981

\$ 65,000

**Source:**

SERI

**Project/Area/Task:** Polycrystalline Thin Films

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**Objectives:** To determine the temperature and pressure conditions under which  $\text{CuInSe}_2$  is chemically stable using mass spectrometric and torsion-effusion measurements. Empirical thermodynamic equations or graphs are to be constructed which will: (1) relate the partial molal Gibbs energies of the elemental components of the  $\text{CuInSe}_2$  phase; (2) relate solid and vapor phase compositions; and (3) relate partial pressure vs. temperature for representative solid phase compositions.

**Approach/Present Tasks:**

- Mass spectrometric measurements on vapor phase in equilibrium with solid  $\text{CuInSe}_2$  to determine species and temperature/pressure diagrams.
- Torsion-effusion measurements on vapor phase in equilibrium with solid  $\text{CuInSe}_2$  to determine vapor pressure.

**Status/FY 1983 Accomplishments:**

- Mass spectrometry shows major vaporization species from  $\text{CuInSe}_2$  are  $\text{Se}_2$  and  $\text{In}_2\text{Se}$ . Minor species are  $\text{InSe}_2$ ,  $\text{In}$ , and  $\text{Se}$  with  $\text{Cu}_2\text{Se}$  as a solid product of vaporization.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Lamoreaux, R.H.; Lau, K.H.; Brittain, R.D. (March 1983). *High Temperature Equilibrium Studies of Copper Indium Diselenide; Final Report*. SRI International.

**Summary Date**

October 1983



# SERI

**Title:** Sprayed CdS/CuInSe<sub>2</sub> and Sintered CdTe Low-Cost Solar Cells

**Contractor:**  
SRI International  
333 Ravenwood Ave.  
Menlo Park, CA 94025

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** J. Mooney  
**Telephone:** (415) 859-2906

**Project Engineer:** R.L. Mitchell  
**Telephone:** (303) 231-1379

**Contract Number:** 8104-4 (2115-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 9/1/79  
**To:** 10/31/83

<b>FY 1979</b>	<b>\$ 173,309</b>	<b>SERI</b>
<b>FY 1980</b>	<b>\$ 97,820</b>	<b>SERI</b>
<b>FY 1981</b>	<b>\$ 243,292</b>	<b>SERI</b>
<b>FY 1982</b>	<b>\$ 163,326</b>	<b>SERI</b>

**Project/Area/Task:** Polycrystalline Thin Films

**Objectives:** (1) To continue the development and characterization of chemically sprayed CdS, CuInSe<sub>2</sub>, and Cd<sub>x</sub>Zn<sub>1-x</sub>S films, (2) to continue analysis of thermodynamics, chemical kinetics, and device physics of the various layers and junctions; and (3) to develop and characterize solar cells formed by chemical spray film techniques with an analysis of the mechanisms which control the photocurrent and junction rectification and limit the photovoltaic efficiency.

**Approach/Present Tasks:** To meet the above objectives, the four following areas are addressed:

- Fabricate solar cell devices using p-CuInSe<sub>2</sub>/CdS and p-CuInSe<sub>2</sub>/Cd<sub>x</sub>Zn<sub>1-x</sub>S layers formed by spray pyrolysis.
- Characterize the above layers with reference to chemical, physical, and electrical properties.
- Characterize the above devices electrically in order to optimize the output.

**Status/FY 1983 Accomplishments:** P-type chalcopyrite CuInSe<sub>2</sub> films with mobilities near 1 cm<sup>2</sup>/v-sec have been deposited by spray pyrolysis.

**FY 1984 Milestones:**

- Complete material and device characterization and conduct efforts for device optimization.
- Complete Final Report in first quarter FY 1984.

**Major Project Reports:**

- Mooney, J.B.; Lamoreaux, R.H.; Bates, C.W. (March 1983). *Spray Pyrolysis of Cadmium Sulfide/ Copper Indium Selenide Cells; Semi-Annual Report*. SRI International.

**Summary Date**  
October 1983

# SERI

**Title:** Photovoltaic Heterodiodes Based on Indium Phosphide

**Contractor:**  
Stanford University  
Material Science and Engineering Dept.  
Stanford, CA 94305

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** R.H. Bube  
**Telephone:** (415) 497-2534

**Project Engineer:** K. Zweibel  
**Telephone:** (303) 231-7141

**Contract Number:** 8087-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 4/1/79  
**To:** 7/31/83

<b>FY 1979</b>	<b>\$ 51,280</b>	<b>SERI</b>
<b>FY 1980</b>	<b>\$ 120,300</b>	<b>SERI</b>
<b>FY 1981</b>	<b>\$ -0-</b>	<b>SERI</b>
<b>FY 1982</b>	<b>\$ 13,343</b>	<b>SERI</b>

**Project/Area/Task:** Polycrystalline Thin Films

**Objectives:** To study heterojunction solar cells based on InP. Prepare and characterize diode solar cells and establish detailed device physics models. Develop optimized heterojunction growth techniques and a quantitative description of these diodes, leading to high-efficiency solar cells.

**Approach/Present Tasks:**

- Heterojunctions are being formed in crystalline p-InP.
- CdS and ZnO window materials are being deposited by variety of techniques.
- Annealing in oxidizing and reducing ambients are being studied.
- Device characterization is being done by I-V, C-V, EBIC, and other techniques.

**Status/FY 1983 Accomplishments:**

- Sprayed n-ZnO with 90% optical transmission and 500-5000 ohms/square sheet resistance after a post-deposition hydrogen anneal.
- Deposited sprayed ZnO on thermally oxidized single crystal InP, forming SIS structure and yielding 14% efficient cells.

**FY 1984 Milestones:**

- Summarize investigations of InP cells in Ph.D. thesis prepared for subcontract final report.

**Major Project Reports:**

- Eberspacher, C.; Fahrenbruch, A.L.; Bube, R.H. "Spray-Deposited ZnO/InP SIS Heterostructure Solar Cells." To be presented at the 17th IEEE Photovoltaic Specialists Conference; 1-4 May 1984.

**Summary Date**  
October 1983

## SERI

**Title:** Photoelectronic Properties of Zinc Phosphide Crystals, Films, and Heterojunctions

**Contractor:**

Stanford University  
Dept. of Materials, Science & Engineering  
Stanford, CA 94035

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** R.H. Bube

**Telephone:** (415) 497-2534

**Project Engineer:** R.L. Mitchell

**Telephone:** (303) 231-1379

**Contract Number:** 1202-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 2/26/79

**To:** 3/31/84

**FY 1979**

**\$ 109,013**

**SERI**

**FY 1981**

**\$ 151,962**

**SERI**

**FY 1982**

**\$ 40,000**

**SERI**

**Project/Area/Task:** Polycrystalline Thin Films

**Objectives:** To investigate the photoelectronic properties of zinc phosphide ( $Zn_3P_2$ ) in single-crystal form, in thin film form, and in heterojunctions in which  $Zn_3P_2$  forms one of the elements. This research is directed towards understanding the role of the interface in  $Zn_3P_2$ .

**Approach/Present Tasks:**

- Work is being concentrated on the unstable metal/ $Zn_3P_2$  structures and MIS- and SIS-like structures. Attempts to stabilize the junction will be made via (1) insulating interlayers, and (2) tying of dangling bonds with reactive metals.
- A minor effort at grain boundary passivation continues.

**Status/FY 1983 Accomplishments:**

- Identified several possible heterojunction partners for  $Zn_3P_2$  including CdS, CdO, ZnO, ITO.
- Enhanced performance through the addition of a thin Mg interlayer at the interface.

**FY 1984 Milestones:**

- Complete an in-depth examination of interfacial passivation schemes.
- Complete the characterization of the density of states at the junction before and after junction formation under various treatments.

**Major Project Reports:**

- Bube, R.H.; Fahrenbruch, A.L. (April 1983). *Photoelectronic Properties of Zinc Phosphide Crystals and Heterojunctions; Quarterly Progress Report*. Stanford University.

**Summary Date**

**October 1983**

# SERI

**Title:** Preparation and Properties of Evaporated CdTe Films Compared with Single Crystal CdTe

**Contractor:**  
Stanford University  
Dept. of Materials, Science & Engineering  
Stanford, CA 94305

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** R.H. Bube  
**Telephone:** (415) 497-2534

**Project Engineer:** R.L. Mitchell  
**Telephone:** (303) 231-1379

**Contract Number:** 2081-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 9/29/80  
**To:** 2/15/84

<b>FY 1981</b>	<b>\$ 130,119</b>	<b>SERI</b>
<b>FY 1982</b>	<b>\$ 118,616</b>	<b>SERI</b>

**Project/Area/Task:** Polycrystalline Thin Films

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**Objectives:** To deposit high quality n- and p-type CdTe thin films via hot wall vacuum evaporation and to make homojunction and heterojunction CdTe thin film cells.

**Approach/Present Tasks:**

- This program is involved with basic research on single-crystal and thin film CdTe.
- Doping effects (with P, As, Sb, Cs, In) and grain boundary effects are being investigated with single-crystal CdTe.
- The hot wall vacuum evaporation (HWVE) technique is being implemented to deposit thin film n- and p-type CdTe layers.

**Status/FY 1983 Accomplishments:**

- Successfully deposited p-type CdTe by Hot Wall Vacuum Evaporation.
- Fabricated a first attempt CdS/pCdTe heterojunction device with 4.2% efficiency.

**FY 1984 Milestones:**

- Complete optimization of the most promising CdTe/p-CdTe junction.
- Complete loss analysis and estimate possible degree of improvement.
- Complete fabrication of an 8% efficient CdTe thin film cell.

**Major Project Reports:**

- Bube, R.H.; Fahrenbruch, A.H. (January 1983). *Preparation and Properties of Evaporated CdTe Films Compared with Single Crystal CdTe; Annual Report*. Stanford University.

**Summary Date**  
October 1983

## SERI

**Title:** CuInSe<sub>2</sub> Solar Cell Research by Sputter Deposition

**Contractor:**

Telic Corporation  
1631 Colorado Avenue  
Santa Monica, CA 94304

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** J.A. Thornton

**Telephone:** (213) 828-7449

**Project Engineer:** K. Zweibel

**Telephone:** (303) 231-7141

**Contract Number:** 2176-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 3/31/82

**FY 1982**

**\$ 333,048**

**SERI**

**To:** 3/31/84

**Project/Area/Task:** Polycrystalline Thin Films

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**Objectives:** To develop a large-area deposition technique and a concomitant high-efficiency cell design for polycrystalline thin-film CuInSe<sub>2</sub> via: (1) the sputtering of CuInSe<sub>2</sub> cells; (2) the development and demonstration of an in-line multistation sputtering system; and (3) the investigation of a p-i-n geometry incorporating a thin (less than 0.5  $\mu$ m) intrinsic layer of CuInSe<sub>2</sub>.

**Approach/Present Tasks:** The approach involved includes the optimization of sputtered CuInSe<sub>2</sub>, the construction of an in-line sputtering system for a multilayered cell, and the investigation of optimal CuInSe<sub>2</sub> cell geometries.

**Status/FY 1983 Accomplishments:**

- A 4% cell efficiency and 33 mA/cm<sup>2</sup> cell current were demonstrated as proof-of-concept for the sputtering system for CdS/CuInSe<sub>2</sub> hybrid devices (vacuum-evaporated CdS).
- The multistation in-line planar magnetron sputtering system has been built and is being tested.

**FY 1984 Milestones:**

- Fabricate a 6%-efficient, all-sputtered CdS/CuInSe<sub>2</sub> on the in-line system.
- Study the feasibility of a p-i-n device geometry for CuInSe<sub>2</sub>.

**Major Project Reports:**

- Thornton, J.A. (1983). "Reactive Sputtered CuInSe<sub>2</sub> Films for PV Applications." *30th National Symposium of the American Vacuum Society* (in press).
- Thornton, J.A.; Cornog, D.G.; Meakin, J.D. (April 1983). *Heterojunction Cell Research by Sputter Deposition; Final Report*. Santa Monica, CA: Telic Corporation.

**Summary Date**

**October 1983**

## SERI

**Title:** Amorphous Silicon Solar Cells and Drift Mobility Research

**Contractor:**  
Tulane University  
Department of Physics  
New Orleans, LA 70118

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** R. Konenkamp/R.D. Purrington  
**Telephone:** (303) 231-1250

**Project Engineer:** R.L. Mitchell  
**Telephone:** (303) 231-1379

**Contract Number:** 1240-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 7/1/81  
**To:** 6/30/84

<b>FY 1981</b>	<b>\$ 10,354</b>
<b>FY 1982</b>	<b>\$ 12,625</b>

<b>SERI</b>
<b>SERI</b>

**Project/Area/Task:** Polycrystalline Thin Films

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### **Objectives:**

- Characterize a-Si:H charge transport and band-tail states.
- Investigate charge transport in a wide range of polycrystalline materials, including CuInSe<sub>2</sub>.

### **Approach/Present Tasks:**

- Perform time of flight measurements on the drift lengths and carrier lifetimes of a-Si:H samples.
- Establish criteria for efficient photovoltaic performance based on diffusion length, lifetime, and mobility data.
- Investigate drift mobility in ZnSe, single crystal CuInSe<sub>2</sub> polycrystalline CuInSe<sub>2</sub>, and polycrystalline Si.

### **Status/FY 1983 Accomplishments:**

- Experimental conditions for observation of dispersive transport in a-Si was investigated.
- First observation of transient space-charge-limited currents in amorphous silicon was made, and a corresponding theory developed.
- First evidence of a photocurrent transient reversal in amorphous silicon was obtained.
- Evidence for non-exponential distribution of band-tail states was obtained.

### **FY 1984 Milestones:**

- Establish criteria for efficient a-Si photovoltaic performance through drift mobility and lifetime studies.
- Complete drift mobility studies for several polycrystalline materials.
- Prepare Ph.D. dissertation of R. Konenkamp.

### **Major Project Reports:**

- Konenkamp, R.; Hermann, A.M.; Madan, A. (October 1983). "On Photocurrent Reversal and Time-of-Flight in Amorphous Silicon-Hydrogen Films." *Philosophical Magazine B*. Vol. 48 (No. 4); pp. L33-L37.

**Summary Date**  
October 1983

## SERI

**Title:** Development of Stable High Efficiency Polycrystalline Thin Film Solar Cells Based on  $\text{CuInSe}_2$

**Contractor:**

University of Delaware  
Institute of Energy Conversion  
One Pike Creek Center, Wilmington, DE

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** J. Meakin

**Telephone:** (302) 453-6243

**Project Engineer:** A. Hermann

**Telephone:** (303) 231-1311

**Contract Number:** 3065-1 (2078-1)

**Contract Funding:**

**Source:**

**Current Contract Period From:** 3/16/82

**To:** 5/15/84

**FY 1982**

**\$ 441,240**

**SERI**

**FY 1983**

**\$ 570,000**

**SERI**

**Project/Area/Task:** Polycrystalline Thin Films

**Objectives:** To develop the optimum design and deposition of  $(\text{Cd,Zn})\text{S}/\text{CuInSe}_2$  thin film photovoltaic devices which maximize cell efficiencies while maintaining high stability, and to develop polycrystalline cascade cells based on  $\text{CuInSe}_2$  bottom cells.

**Approach/Present Tasks:**

- Develop and fabricate  $(\text{CdZn})\text{S}/\text{CuInSe}_2$  solar cell through Knudsen cell deposition and through open-boat deposition.
- Characterize the  $(\text{CdZn})\text{S}/\text{CuInSe}_2$  solar cell through illuminated IV spectral response, capacitance, laser scanning, SEM, and EBIC testing.
- Develop a  $\text{CdS}/\text{CdTe}$  tandem cell using Knudsen sources for  $\text{CdTe}$  deposition and a  $\text{CuInSe}_2$  bottom cell.

**Status/FY 1983 Accomplishments:**

- Successfully fabricated several  $\text{CuInSe}_2/\text{CdS}$  small area cells with efficiencies greater than 7%.
- Preliminary modeling studies completed.
- Stoichiometric  $\text{CdTe}$  films deposited; high resistivities produced by post-deposition anneals.

**FY 1984 Milestones:**

- Demonstrated controlled doping of  $\text{CdTe}$  using Knudsen cell deposition.
- Demonstrated  $\text{CdS}/\text{CdTe}$  cells of at least 5% efficiency.
- Demonstrated tandem junction cells of  $V_{oc}$  of at least 1.0 V.

**Major Project Reports:**

- Birkmire, R.W.; Hall, R.B.; Phillips, J.E. (July 1983). *Development of Stable High Efficiency Polycrystalline Thin Film Solar Cells Based on  $\text{CuInSe}_2$ ; Quarterly Report*. University of Delaware.
- Meakin, J.D.; Russell, T.W.F. (1983). "Laboratory and Commercial Development of Large Area Low Cost Thin Film Solar Cells." *1983 Solar World Congress Extended Abstracts; Perth, Western Australia; 14-19 August 1983*. Edited by S.V. Szokolay. Victoria, Australia: International Solar Energy Society; p. 316.

**Summary Date**  
**October 1983**

## SERI

**Title:** Theory of Thin-Film Photovoltaics

**Contractor:**

University of Delaware  
Institute of Energy Conversion  
Newark, DE 19711

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** K.W. Boer

**Telephone:** (302) 738-8048

**Project Engineer:** K. Zweibel

**Telephone:** (303) 231-7141

**Contract Number:** 9191-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 4/15/79

**To:** 5/1/84

**FY 1980**           \$ 54,500

SERI

**FY 1981**           \$ -0-

**FY 1982**           \$ 26,000

SERI

**Project/Area/Task:** Polycrystalline Thin Films

**Objectives:** (1) To develop the physics of the photovoltaic effect and apply it to thin-film solar cells with the objective to identify important experimental parameters and their optimum range, and (2) to prepare means to measure, monitor, and adjust such parameters in order to provide guidance to obtain solar cells with improved cost efficiency. Understanding of  $\text{CuInSe}_2$  thin film devices are regarded as the main object of study.

**Approach/Present Tasks:**

- Derive current-voltage characteristics of  $\text{CuInSe}_2$  solar cells from basic device physics and postulated or measured junction properties.
- Provide theoretical guidance to experimentalists for higher  $\text{CuInSe}_2$  solar cell efficiencies.

**Status/FY 1983 Accomplishments:**

- Predicted open-circuit voltage increase in  $\text{CuInSe}_2$  devices when the material's resistivity is decreased.
- Developed sophisticated computer model for the  $\text{CdZnS/CuInSe}_2$  device based on fundamental material and electronic properties.

**FY 1984 Milestones:**

- Continued development of computer modeling will be used to project and define the properties and behavior of  $\text{CuInSe}_2$  devices.
- A summary report will suggest strategies for improving  $\text{CuInSe}_2$  devices.

**Major Project Reports:**

- Boer, K.W. (June 15, 1983). *Polycrystalline Semiconductor Heterojunction Modeling ( $\text{CdS/CuInSe}_2$ ); Quarterly Report*. Newark, DE: University of Delaware.

**Summary Date**  
October 1983



# SERI

**Title:**  $Zn_3P_2$  as an Improved Semiconductor for Photovoltaic Solar Cells

**Contractor:**

University of Delaware  
Institute of Energy Conversion  
Wyoming Road  
Wilmington, DE 19808

**Principal Investigator:** J. Meakin

**Telephone:** (302) 995-7155

**Contract Number:** 2048-1 (8062-1)

**Current Contract Period From:** 4/1/82

**To:** 5/31/84

**Project/Area/Task:** Polycrystalline Thin Films

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** R.L. Mitchell

**Telephone:** (303) 231-1379

**Contract Funding:**

**FY 1979** \$ 425,164

**FY 1980** \$ 248,210

**FY 1981** \$ 363,394

**FY 1982** \$ 224,963

**FY 1983** \$ 150,716

**Source:**

SERI

SERI

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SERI

**Objectives:**

- To develop a  $Zn_3P_2$  heterojunction using ZnSe and  $Cd_{1-x}Zn_xS$  with conversion efficiencies in excess of 6%.
- To develop a low-cost substrate.
- To continue theoretical studies to model device/junction behavior.

**Approach/Present Tasks:** Work is being done to optimize the stable ZnSe/ $Zn_3P_2$  and  $Cd_{1-x}Zn_x/Zn_3P_2$  heterojunctions. ZnSe/ $Zn_3P_2$  cells have demonstrated high output voltage (up to 0.8 V), but little current collection, most of which is lost in the  $Zn_3P_2$ . Efforts are underway to reduce the resistivity of the ZnSe and  $Cd_{1-x}Zn_xS$  and thereby extend the collection field into the  $Zn_3P_2$  to collect the light-generated carriers.

**Status/FY 1983 Accomplishments:**

- Fabricated  $Zn_3P_2/ZnSe$  structures with  $V_{oc} = 0.5-0.6$  V and  $J_{sc} = 0.5$  mA/cm<sup>2</sup>.
- Deposited low-resistivity ZnSe on glass (10-100 ohm-cm). Attempts to lower the resistivity of ZnSe on other substrates has not been successful.

**FY 1984 Milestones:**

- Produce low-resistivity (less than 100 ohm-cm)  $Cd_{1-x}Zn_xS$ .
- Match low-resistivity  $Cd_{1-x}Zn_xS$  with  $Zn_3P_2$  to enhance carrier collection and raise efficiencies above 4%.

**Major Project Reports:**

- Bhushan, M. (May 1983).  *$Zn_3P_2$  as an Improved Semiconductor for Photovoltaic Solar Cells*. SERI Subcontractor Annual Report.

**Summary Date**

October 1983

## SERI

**Title:** Electrodeposition of p-Type CdTe and CdS/CdTe Heterojunction Devices

**Contractor:**  
University of Texas at Arlington  
Arlington, TX 76019

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** K. Rajeshwar  
**Telephone:** (817) 273-3810

**Project Engineer:** R. L. Mitchell  
**Telephone:** (303) 231-1379

**Contract Number:** 3140-1

**Contract Funding:**

**Source:**

**Current Contract Period From:** 9/1/83  
**To:** 10/31/84

**FY 1983**            **\$ 47,000**

**SERI**

**Project/Area/Task:** Polycrystalline Thin Films

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**Objectives:** The objective of this effort is the development of electrodeposition of p-type CdTe films and CdS/CdTe heterojunctions.

**Approach/Present Tasks:**

- Conduct compositional characterizations of CdTe films which have been electrodeposited.
- Conduct performance characterization of electrodeposited CdTe films.
- Optimize the parameters of photoelectrochemical doping of p-type CdTe.
- Fabricate preliminary electrodeposited CdTe devices.

**Status/FY 1983 Accomplishments:**

- Transfer of statement of work and subcontract property from Colorado State University subcontract number 3048-1 to this subcontract since principal investigator is now at the University of Texas.

**FY 1984 Milestones:**

- Complete characterization of electrodeposited CdTe films and optimization of photoelectrochemical doping parameters.
- Complete fabrication of electrodeposited CdTe devices.

**Major Project Reports:** None. New program.

**Summary Date**  
October 1983

# SERI

**Title:** Cadmium Sulfide/Copper Sulfide Heterojunction Cell Research

**Contractor:**

Westinghouse Electric Corporation  
R&D Center  
1310 Beulah Road  
Pittsburgh, PA 15235

**Principal Investigator:** J.R. Szidon

**Telephone:** (412) 256-3394

**Contract Number:** 8143-1

**Current Contract Period From:** 9/30/77

**To:** 5/31/83

**Project/Area/Task:** Polycrystalline Thin Films

**Directing Organization:**

Solar Energy Research Institute

**Project Engineer:** R.L. Mitchell

**Telephone:** (303) 231-1379

**Contract Funding:**

<b>FY 1977</b>	<b>\$ 170,500</b>
<b>FY 1978</b>	<b>\$ 170,500</b>
<b>FY 1979</b>	<b>\$ 285,251</b>
<b>FY 1980</b>	<b>\$ 201,849</b>
<b>FY 1981</b>	<b>\$ 144,612</b>

**Source:**

<b>ERDA</b>
<b>DOE</b>
<b>SERI</b>
<b>SERI</b>
<b>SERI</b>

**Objectives:** To identify major solar cell degradation mechanisms, to correlate physical/chemical changes with electrical effects, and to improve intrinsic cell stability in wet-processed CdS/Cu<sub>2</sub>S cells by surface and other treatments.

**Approach/Present Tasks:**

- Cell characterization following stress testing.
- Evaluate results using deep donor tunneling model.
- Attempt stabilization using a variety of surface treatments.

**Status/FY 1983 Accomplishments:**

- Demonstrated surface treatment which significantly increased the stability of CdS/Cu<sub>2</sub>S solar cells. The aging time for a 50% degradation in J<sub>sc</sub> of treated cells was 260 hrs as compared to 35 hrs for untreated cells.

**FY 1984 Milestones:**

- Complete Final Report.

**Major Project Reports:**

- Szidon, J.R.; Krishasnamy, S.V.; McMullin, P.G. (June 1983). *Development of Copper Sulfide/ Cadmium Sulfide Thin Film Solar Cells; Thirteenth Technical Progress Report for July 1 — September 30, 1982.* SERI/PR-8143-1-T12. Pittsburgh, PA: Westinghouse R&D Center; 25 pp.

**Summary Date**

October 1983

## SERI

**Title:** Amorphous Silicon

**Contractor:**  
Solid State Research Branch  
In-House

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** A. Madan  
**Telephone:** (303) 231-7638

**Project Engineer:** S. Deb  
**Telephone:** (303) 231-1105

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82  
**To:** 9/30/83

**FY 1983**      **\$ 830,000**

**DOE**

**Project/Area/Task:** Solid State Research

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**Objectives:** To develop and optimize new amorphous materials and devices for photovoltaic applications and to perform complementary research on novel approaches to materials and device fabrication and characterization.

**Approach/Present Tasks:**

- Fabrication of state-of-the-art p-i-n thin film a-Si:H and Schottky barrier type solar cells by glow discharge methods.
- Deposition and characterization of amorphous Si/Sn/H alloy for use in high efficiency devices.
- Program management support for subcontracted activities.

**Status/FY 1983 Accomplishments:**

- Second glow discharge system designed and made operational.
- ITO system designed and made operational.
- Prepared a-Si:Sn alloys using RF glow discharge technique. Doping achieved with recovery of photo-conductivity.
- a-Si p-i-n junctions fabricated using the following configuration: stainless steel/p<sup>+</sup>/i/n<sup>-</sup>/metal. All the results suggest that it is the state-of-the-art material. Internal device efficiency: 7.6%.
- New techniques developed such as space charge limited current to study materials.
- Existing techniques now computerized such as I(V), (T), spectral response.
- Photocurrent reversal seen in a-Si junctions and thus confirmed mobilities of 1-10 cm<sup>2</sup>s<sup>-1</sup>v<sup>-1</sup> unlike 1000 cm<sup>2</sup>s<sup>-1</sup>v<sup>-1</sup> reported by others.

**FY 1984 Milestones:**

- Assess the suitability of a-Si:Sn:H alloys for solar cell purposes (Report) — January 1984.
- Identify and characterize a wide band gap amorphous alloy for use in a single cell and a tandem cell device (Report) — September 1984.

**Major Project Reports:**

- Madan, A. "Opportunities for High Efficiency a-Si Thin Film Solar Cells." *Solar Energy* (submitted for publication).
- Konenkamp, R.; Hermann, A.H.; Madan, A. "Photocurrent Reversal and Time of Flight in Amorphous Si:H Films." *Philosophical Magazine* (submitted for publication).
- Mahan, A.H.; Williamson, D.L.; Madan, A. "Properties of a-Si:Sn Alloys Produced Using the r.f. Glow Discharge Technique." *Applied Physics Letters* (submitted for publication).

**Summary Date**  
October 1983

# SERI

**Title:** Crystal Growth and Device Fabrication

**Contractor:**  
Solid State Research Branch In-House

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** T. Ciszek  
**Telephone:** (303) 231-1769

**Project Engineer:** S. Deb  
**Telephone:** (303) 231-1105

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82  
**To:** 9/30/83

<b>FY 1982</b>	<b>\$ 496,000</b>
<b>FY 1983</b>	<b>\$ 453,000</b>

<b>DOE</b>
<b>DOE</b>

**Project/Area/Task:** Solid State Research

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## Objectives:

- To devise innovative processes for the crystal growth of bulk or self-supporting thin film semiconductor materials which will advance the understanding and implementation of photovoltaic technology.
- To develop device structures to evaluate and optimize the photovoltaic performance of experimental materials.

**Approach/Present Tasks:** The project involves the investigation of rapid crystal growth kinetics, the effects upon PV cell parameters of impurities and defect structures in high purity crystals, and implementing high-pressure compound semiconductor crystal growth capabilities.

## Status/FY 1983 Accomplishments:

- Facilities for high pressure synthesis/growth of III-V compound semiconductors achieved operation.
- X-ray diffraction topography and X-ray Laue apparatus were installed.
- A new synthesis and crystal growth method for  $\text{CuInSe}_2$  was demonstrated to yield stoichiometric material.
- A low-cost silver contacting system for GaAs solar cells was demonstrated and filed for patent.
- Float-zone and cold crucible techniques were installed and operated for high efficiency Si cells.
- Both (100) and (111) dislocation-free silicon crystals were grown from a cold crucible.
- A comparative analysis of the 15 silicon sheet growth methods was made, based on meniscus geometry.
- The baseline n-on-p Si cell process for evaluation of experimental material was enhanced to 15.5% efficiency.
- A new continuous casting method for silicon was invented.
- The radial growth anisotropies, limiting growth forms, and solid/liquid interface tip morphologies were determined for horizontally growing dislocation-free Si sheets with (100), (110), (111), and (112) sheet planes.

## FY 1984 Milestones:

- Grow device quality single crystals of  $\text{CuInSe}_2$  for material and device characterization — May 1984.
- Achieve high quality Si substrate technology suitable for 18% cells — September 1984.
- Conduct JPL contract 8746 on "Solid/Melt Interface Studies of High-Speed Si Sheet Growth" — July 1984.

## Major Project Reports:

- Ciszek, T.F. "The Growth of Silicon Ribbons for Photovoltaics by Edge Supported Pulling (ESP)." *Silicon Processing for Photovoltaics*. North-Holland (in-press).
- Ciszek, T.F., "Techniques for the Crystal Growth of Silicon Ingots and Ribbons." *Journal of Crystal Growth*. (invited review in-press.)

**Summary Date**  
October 1983

## SERI

**Title:** Material Preparation and Purification

**Contractor:**

Solid State Research Branch  
In-House

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** J. Olson

**Telephone:** (303) 231-1801

**Project Engineer:** S. Deb

**Telephone:** (303) 231-1105

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82  
**To:** 9/30/83

**FY 1983**            \$ 275,000

**DOE**

**Project/Area/Task:** Solid State Research

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**Objectives:** To evaluate the photovoltaic properties of electrorefined silicon and to develop new and innovative methods for producing thin/thick films of high purity, photovoltaic materials.

**Approach/Present Tasks:**

- Studies performed on the electrochemical methods for the extraction, purification, and plating of silicon and other photovoltaic materials.
- Chemical vapor transport growth of transition metal dichalcogenides for PV applications.

**Status/FY 1983 Accomplishments:**

- Demonstrated that electrorefined silicon was of solar-grade quality, yielding solar cells with an efficiency of 12.2% relative to a baseline efficiency of 11.9%.
- Designed, built, and tested a 50 g capacity electrorefining cell.
- Developed an anode casting process.
- Conducted basic studies of the mass transport properties of  $\text{Cu}_3\text{Si}$ .
- Invented and developed an improved silicon refining technique.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Carleton, K.L.; Olson, J.M.; Kibbler, A. (April 1983). "Electrochemical Nucleation and Growth of Silicon in Molten Fluorides." *Journal of the Electrochemical Society*. Vol. 130 (No. 4); pp. 782-786.
- Kibbler, A.; Olson, J.M.; Powell, R. "Mass Transport Properties of  $\text{-Cu}$ ." *Journal of Applied Physics* (submitted for publication).
- Olsen, J.M. (1983). "Silicon Electrorefining and the Transport Properties of  $\text{Cu}_3\text{Si}$ ." "163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983. Vol. 83-1. Pennington, NJ: ECS; p. 335. (Abstract No. 211).
- Olson, J.M.; Powell, R. (September 1983). "A Gravimetric Rate Measurement Technique for Closed Tube, Vapor Transport Crystal Growth." *Journal of Crystal Growth*. Vol. 63 (No. 1); pp. 1-7.

**Summary Date**  
October 1983

## SERI

**Title:** Solid State Theory

**Contractor:**  
Solid State Research Branch  
In-House

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** A. Zunger  
**Telephone:** (303) 231-1172

**Project Engineer:** S. Deb  
**Telephone:** (303) 231-1105

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82  
**To:** 9/30/83

**FY 1983**            **\$ \$600,000**

**DOE**

**Project/Area/Task:** Solid State Research

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**Objectives:** To formulate a self-consistent, quantum-mechanical model for the electronic structures of semi-conductors. Study considers bulk properties, surfaces and interfaces, and point defects and impurities as they relate to PV properties.

**Approach/Present Tasks:**

- Calculation of electronic band structures of new PV materials, including ternary chalcopyrites.
- Determination of factors affecting surface and interface properties — Fermi energy pinning.
- Calculation of electronic structure of impurities in semiconductors and their effects on material properties.

**Status/FY 1983 Accomplishments:**

- Study completed on the electronic structure of all substitutional 3-d transition metal impurities in silicon.
- Band structure of CuAlS, CuGaS<sub>2</sub>, CuInS<sub>2</sub>, CuAlSe<sub>2</sub>, CuGaSe<sub>2</sub>, and CuInSe<sub>2</sub> completed.
- A new analysis of core photoemission processes in semiconductors was completed.
- We moved to a new CYBER 205 computer at CSU; 20% of our programs have been converted.

**FY 1984 Milestones:**

- Convert the computer programs for: (1) plane wave band structure, (2) CuInSe<sub>2</sub> mixed basis bands, (3) the impurity set of programs, to run on CYBER 205 and reproduce results of CDC 7600 — April 1984.
- Theoretical study and analysis of transition metal impurities in III-V semiconductors (Report) — June 1984.
- Develop and test the new theoretical techniques for calculating structurally complex semiconductors such as disordered semiconductors (Report) — September 1984.
- Carry out analysis of optical and structural properties of CuInSe<sub>2</sub>-like ternary semiconductors. (Report) — September 1984.

**Major Project Reports:**

- Jaffe, J.E.; Zunger, A. (April 1983). "Anion Displacements and the Band-Gap Anomaly in Ternary ABC<sub>2</sub> Chalcopyrite Semiconductors." *Physics Review B*. Vol. 27 (No. 8); pp. 5176-5179.
- Singh, V.; Lindefelt, U.; Zunger, A. (April 1983). "Electronic Structure of Substitutional Chalcogen Impurities in Silicon." *Physical Review B*. Vol. 27 (No. 8); pp. 4909-4923.
- Singh, V.A.; Zunger, A.; Lindefelt, U. (January 1983). "Reversal in the Order of Impurity Binding Energies with Atomic Energies." *Physical Review B*. Vol. 27 (No. 2); pp. 1420-1423.
- Zunger, A. (April 1983). "One-Electron Broken-Symmetry Approach to the Core-Hole Spectra of Semiconductors." *Physics Review Letters*. Vol. 50 (No. 16); pp. 1215-1218.
- Zunger, A. (June 1983). "The Origin of Schottky Barriers on the Cleavage Plane of III-V Semiconductors: Review of Theoretical Work." *Thin Solid Films*. Vol. 104 (No. 3/4); pp. 301-316.

**Summary Date**  
**October 1983**

## SERI

**Title:** Thin Film Compound Semiconductors

**Contractor:**  
Solid State Research Branch  
In-House

**Directing Organization:**  
Solar Energy Research Institute

**Principal Investigator:** R. Noufi  
**Telephone:** (303) 231-1390

**Project Engineer:** S. Deb  
**Telephone:** (303) 231-1105

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82  
**To:** 9/30/83

**FY 1982**            \$ 265,000  
**FY 1983**            \$ 450,000

**DOE**  
**DOE**

**Project/Area/Task:** Solid State Research

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**Objectives:** Fabricate and characterize promising thin film solar cell materials and devices.

**Approach/Present Tasks:**

- Study of thin film growth of  $\text{CuInSe}_2$  by three-source evaporation.
- Study composition effects on electrical and structural properties.
- Evaluation of hotwall vacuum deposition of CdTe, and low cost substrates.

**Status/FY 1983 Accomplishments:**

- Characterized the optical and electrical properties and solid state chemistry of  $\text{CuInSe}_2$  films.
- Fabricated and characterized  $\text{CuInSe}_2/\text{CdS}$  PV devices.
- Fabricated and characterized heterojunction and Schottky barrier devices with hotwall vacuum evaporated CdTe.
- In-situ doped p-type thin film CdTe successfully made by electrodeposition.
- Identified cadmium-tin-phosphide as a potential thin film PV material.

**FY 1984 Milestones:**

- Correlate stoichiometry with carrier concentration for  $\text{CuInSe}_2$  (Report) — December 1983.
- Conclude the studies on CdTe deposition by hotwall evaporation process.
- Quantitatively establish the role of two layers of  $\text{CuInSe}_2$  in  $\text{CdS}/\text{CuInSe}_2$  cell (Report) — May 1984.

**Major Project Reports:**

- Fabick, L. "PV Properties of p-CdTe Thin Films Grown by Hotwall Vacuum Evaporation." To be presented at the 17th IEEE Photovoltaic Specialists Conference; Kissimmee, FL; May 1984.
- Noufi, R.; Axton, D.; Cahen, D.; Deb, S.K. "CdS/ $\text{CuInSe}_2$  Heterojunction Cell Research." To be presented at the 17th IEEE Photovoltaic Specialists Conference; Kissimmee, FL; May 1984.
- Noufi, R.; Axton, D.; Cahen, D.; Deb, S.K. (1983). "CdS/ $\text{CuInSe}_2$  Heterojunction Cell Research." *Photovoltaic Advanced Research and Development 5th Annual Review Meeting; Denver, CO; 19-21 May 1983*. SERI/CP-311-2011. Golden, CO: Solar Energy Research Institute; pp. 83-84.

**Summary Date**  
October 1983



## SERI

**Title:** III-V Materials

**Contractor:**

Solid State Research Branch  
In-House

**Directing Organization:**

Solar Energy Research Institute

**Principal Investigator:** G. Blakeslee

**Telephone:** (303) 231-7298

**Project Engineer:** S. Deb

**Telephone:** (303) 231-1105

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82  
**To:** 9/30/83

**FY 1983**            \$ 442,000  
**FY 1983**            \$ 474,000

DOE  
DOE

**Project/Area/Task:** Solid State Research

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**Objectives:** To develop an understanding of those factors which will lead to reliable and economical multijunction III-V compound solar cells with efficiencies greater than 30%.

**Approach/Present Tasks:**

- Evaluation and implementation of schemes for low-resistance interconnects in III-V cascade solar cell structures.
- Demonstration of an improvement in solar cell efficiency by using a superlattice structure to reduce dislocation density.
- Fabrication of single junction and cascade solar cells to develop expertise in device design and processing and to explore alternative routes to high efficiency.

**Status/FY 1983 Accomplishments:**

- Developed process for fabricating MOCVD GaAs shallow homojunction solar cells; non-optimized efficiency 14%.
- Reproducibly grew smooth, planar GaAs<sub>1-x</sub>P<sub>x</sub>/GaAs superlattice structures for x = 0.25.
- Demonstrated novel CVD reactor design that provides thickness and compositional uniformity to within ± 5% over wide area without substrate rotation.
- Proposal funded to perform advanced research on interactions of dislocations in superlattices.

**FY 1984 Milestones:**

- Demonstrate cascade action in GaAsP/Superlattice/GaAs tandem cell — March 1984.
- Produce GaP/Si epitaxial structures — June 1984.

**Major Project Reports:**

- Williamson, D.L.; Rocher, A.; Kowalchik, M.; Gibart, P. (August 1983). "Nature of Defects in Heavily Te-Doped GaAs." *Revue de Physique Appliquee*. Vol. 18 (No. 8); pp. 475-478.

**Summary Date**  
October 1983

# **Jet Propulsion Laboratory**

# JPL

**Title:** Electrochemical Degradation Research

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** G. Mon  
**Telephone:** (213) 577-9242

**Project Engineer:** R. Ross  
**Telephone:** (213) 577-9111

**Contract Number:** Not applicable

**Contract Funding:** **Source:**

**Current Contract Period:**

FY 1982	\$ 50,000	DOE
FY 1983	\$ 250,000	DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Engineering Sciences Area

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**Objectives:**

- Identify corrosion mechanisms involving encapsulated photovoltaic circuitry.
- Determine means of passivation and retardation.
- Establish life prediction capability.

**Approach/Present Task:** The first phase consists of a series of long-term exploratory tests at Wyle Labs (Huntsville, AL) in accelerated temperature and temperature/humidity environments to identify corrosion dependencies, monitor module power loss, and assess degradation rates. The second phase consists of "in-house" laboratory research to identify key degradation controlling parameters, develop quantitative data characterizing degradation rates and integrate knowledge to devise procedures for designing corrosion-resistant modules and arrays.

**Status/FY 1983 Accomplishments:**

- A previously unobserved degradation mechanism referred to as "gridline corrosion" was first identified in an accelerated laboratory environment (at Wyle Labs) and then observed in a field site.
- A parametric study of electrochemical cell corrosion under extremely accelerated test conditions was completed in-house and summarized in an internal Engineering Sciences Group report.
- Extensive parametric testing of various cell metallization systems and encapsulation has been completed. Characterized dielectric and conduction properties of PVB, EVA, and RTV encapsulants as a function of temperature and humidity.

**FY 1984 Milestones:** Report on findings to date.

**Major Project Reports:**

- Mon, G.R. (in publication). "Solar-Cell Electrochemical Corrosion." *FSA Progress Report 22, January 1983 — September 1983*. DOE/JPL-1012-XX. Pasadena, CA: Jet Propulsion Laboratory.

**Summary Date**  
October 1983

# JPL

**Title:** Photovoltaic Array/Power Conditioner Interface Requirements Study

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** C. Gonzalez  
**Telephone:** (213) 577-9115

**Project Engineer:** R. Ross  
**Telephone:** (213) 577-9111

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:** 05/81  
**To:** 06/83

<b>FY 1981</b>	<b>\$ 35,000</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 144,000</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ 20,000</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Engineering Sciences Area

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**Objectives:** To characterize flat-plate arrays by determining significant array operating parameters in order to define the array/power conditioner subsystem interface requirements. Since array output is variable, depending on weather and irradiance availability, the array/PCS interface must be correctly defined in order to optimize array/PCS efficiency. This problem was not previously addressed in the DOE photovoltaics program.

**Approach/Present Task:** Calculate effect of array/power conditioner operational interface parameters on system annual energy production using a computer hour-by-hour simulation. Complete final report on original task; adapt results for another report.

**Status/FY 1983 Accomplishments:** Modifications were made to the draft final report which was published in December 1982. In addition, support was provided for the drafting of the residential photovoltaic array design document being written by JPL.

**FY 1984 Milestones:** Task completed in FY 1983.

**Major Project Reports:**

- Gonzalez, C.C.; Hill, G.M.; Ross, R.G. Jr. (December 1982). *Photovoltaic Array-Power Conditioner Interface Characteristics*. DOE/JPL-1012-79. Pasadena, CA: Jet Propulsion Laboratory; 50 pp.

**Summary Date**  
October 1983

# JPL

**Title:** Voltage Isolation Research

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** G. Mon  
**Telephone:** (213) 577-9242

**Project Engineer:** R. Ross  
**Telephone:** (213) 577-9111

**Contract Number:** Not applicable

**Contract Funding:** **Source:**

**Current Contract Period From:** FY 1981  
**To:** FY 1983

FY 1981	\$ 50,000	DOE
FY 1982	\$ 200,000	DOE
FY 1983	\$ 50,000	DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Engineering Sciences Area

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**Objectives:** The objective of this task is to determine how and why electrical insulations for photovoltaic modules fail (break down) and to determine what design additions and/or modifications are required to minimize the problem. A successful resolution of the problem will result in enhanced module performance — greater product reliability and durability — and favorable cost benefits.

**Approach/Present Task:**

- The task activity involves a multiyear systematic study establishing reliability targets for electrical breakdown and then researching the specific failure mechanisms to provide definitive design data for achieving the reliability targets.
- Key emphasis to date has been on establishing the probability of breakdown versus applied voltage for Mylar, Tedlar, and foil-laminant films commonly used for insulating the module near the surface.
- During FY 1983, emphasis was shifted toward study of the loss of insulation integrity at the module periphery due to electrochemical corrosion and ion-migration between cells and module frames (see separate writeup on JPL in-house electrochemical corrosion research).

**Status/FY 1983 Accomplishments:**

- Initial cost-benefit studies established a breakdown reliability target for the annual fraction of failed modules equal to 0.002. Specific achievements include the development of a cost-optimal laminate design procedure based upon the breakdown probability/voltage characterization of individual layers. Performance ranking of materials has been made possible via this characterization technique. The recent purchases of a sensitive partial discharge detector and a pulse height analyzer have enhanced the capability to detect potential electrical failure sites prior to becoming serious problems.
- FY 1983 activities verified that electrochemical corrosion between module frames and solar cells will lead to breakdown of the insulation at the module periphery. Key parameters include the system voltage between cells and frame (ground) and the ionic conductivity of the module encapsulant as influenced by temperature and humidity.

**FY 1984 Milestones:** Quantification of electrochemical breakdown rate parameter dependencies by end of FY 1984.

**Major Project Reports:** Mon, G. R. (1982). "Voltage Breakdown of PV Insulating Materials." *Flat-Plate Solar Array Project, Progress Report 20 for the Period November 1981 to April 1982 and Proceedings of the 20th Project Integration Meeting*. DOE/JPL-1012-71. Pasadena, CA: Jet Propulsion Laboratory; pp. 487-499.

**Summary Date**  
October 1983

**Title:** Integrated Residential PV Development

**Contractor:**

AIA Research Corporation  
1735 New York Avenue, N.W.  
Washington, DC 20006

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** G. Royal

**Telephone:** (202) 626-7524

**Project Engineer:** R. Sugimura

**Telephone:** (213) 577-9118

**Contract Number:** 955893

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/80

**To:** 12/81

**FY 1981**                 **\$ 391,288**

**DOE**

**FY 1982**                 **\$ (5,137)**

**DOE**

**FY 1983**                 **\$ 10,000**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Engineering Sciences Area

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**Objectives:** The contract objective was to synthesize advanced, integrated, roof-mounted flat-plate array/module concepts to identify performance drivers and technology gaps requiring long-range research. Deliverables included a laboratory mockup and a final report detailing the analyses performed and the identifying technical gaps resulting from this study.

**Approach/Present Task:** Not applicable.

**Status/FY 1983 Accomplishments:** Not applicable.

**FY 1984 Milestones:** Final Report — in publication.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Investigation of Reliability Attributes and Accelerated Stress Factors on Terrestrial Solar Cells

**Contractor:**  
Clemson University  
College of Engineering  
Clemson, SC 29631

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** J. Lathrop  
**Telephone:** (803) 656-3371

**Project Engineer:** E. Royal  
**Telephone:** (213) 577-9580

**Contract Number:** 954929

**Contract Funding:**

**Source:**

**Current Contract Period From:** 12/77  
**To:** 10/84

<b>FY 1978</b>	<b>\$ 123,649</b>	<b>DOE</b>
<b>FY 1979</b>	<b>\$ 110,534</b>	<b>DOE</b>
<b>FY 1980</b>	<b>\$ 81,308</b>	<b>DOE</b>
<b>FY 1981</b>	<b>\$ 105,134</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 119,905</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ 180,334</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Engineering Sciences Area

## Objectives:

- The contractor shall perform research investigations of factors involved in the reliability of terrestrial solar cells and develop a suitable approach for accelerated stress testing of solar cells. The contractor shall also utilize failure analysis methods to ascertain the causes of failure. This shall be performed in conjunction with research within the Reliability and Engineering Sciences Area at JPL.
- The contract was modified to have the contractor initiate a test program for evaluation of encapsulated cell types furnished by JPL; conduct a mid-year contract review; conduct at least two mini-workshop/test result critiques and conduct a joint-failure analysis study. The contract was also modified to instruct the contractor to initiate an R&D program to develop accelerated stress test methods and test measurement methods suitable for use in thin film submodule reliability investigations. Utilize an independent laboratory to support specialized failure analysis requirements and acquire test samples sufficient to support the R&D development and accelerated stress test investigations.

**Approach/Present Task:** Develop new test methods and measurement methods which permit reliability assessment and ranking of thin film cells and submodules.

**Status/FY 1983 Accomplishments:** Interim results from the encapsulated cell testing program indicate that modules which used a foil material on the back for protection against water penetration were found to degrade more than expected. The mechanism believed to cause this degradation is hydrogen penetration through the foil. This will be studied in further investigations.

## FY 1984 Milestones:

- Generate repeatable data on thin film cells and submodules.
- Prove a more detailed data base on encapsulated cell accelerated stress testing.
- Fourth Annual Report.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Bypass Diode Encapsulation Study

**Contractor:**

General Electric Company  
King of Prussia Park  
P.O. Box 527  
King of Prussia, PA 19406

**Principal Investigator:** N. Shepard

**Telephone:** (215) 962-5839

**Contract Number:** 956254

**Current Contract Period From:** 05/82  
**To:** 06/84

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Engineering Sciences Area

**Directing Organization:**

Jet Propulsion Laboratory

**Project Engineer:** R. Sugimura

**Telephone:** (213) 577-9118

**Contract Funding:**

FY 1982	\$ 77,974
FY 1983	\$ 156,848

**Source:**

DOE
DOE

**Objectives:**

- The contract objective is to research techniques for using pn junctions or Schottky diode chips (dies) as bypass diodes within glass-laminate type PV modules with current ratings from 2 to 20 amps. Heat dissipation studies shall consider the effect of module mounting configurations, such as exposed versus thermally insulated rear surface.
- The contract has been modified and extended to include: investigation and identification of factors and conditions related to determining the reliability of rectifying diodes used as PV module bypass diodes; investigation and analysis to determine the extent of current sharing in array circuits consisting of multiple, parallel-connected modules, each containing individual bypass diodes; and experimental thermal-cycle testing of laboratory mockups.
- The contract has been modified further to examine bypass diode/enclosure designs and blocking diode/enclosure designs for externally-mounted diodes.

**Approach/Present Task:** Identify appropriate diodes and their characteristics, then provide detailed designs of diode and heat sink mounting configurations within an appropriately designed enclosure.

**Status/FY 1983 Accomplishments:**

- Completion of a study to examine bypass diode load sharing considerations.
- Completion of a study to examine bypass diode reliability considerations.

**FY 1984 Milestones:** Final Report to be issued in FY 1984.

**Major Project Reports:**

- *Annual Report: Photovoltaic-Module Bypass-Diode Encapsulation.* (June 1983). DOE/JPL/956254-1. Pasadena, CA: Jet Propulsion Laboratory; 149 pp. Work performed by General Electric, Advanced Energy Programs Department, King of Prussia, PA.

**Summary Date**  
October 1983



# JPL

**Title:** Investigation of Solar Array/Module Safety Requirements

**Contractor:**

Underwriters Laboratories, Inc.  
1285 Walt Whitman Road  
Melville, NY 11746

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** A. Levins

**Telephone:** (516) 271-6200

**Project Engineer:** R. Sugimura

**Telephone:** (213) 577-9118

**Contract Number:** 955392

**Contract Funding:**

**Source:**

**Current Contract Period From:** 05/79

**To:** 03/83

<b>FY 1979</b>	<b>\$ 65,730</b>	<b>DOE</b>
<b>FY 1980</b>	<b>\$ 54,100</b>	<b>DOE</b>
<b>FY 1981</b>	<b>\$ 111,689</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 80,000</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Engineering Sciences Area

**Objectives:**

- Contract objectives are to research array subsystem safety schemes; to characterize arcing phenomena related to ignition of materials; and to continue with research pertinent to module and panel safety requirements.
- The contract has been modified and extended to include the following: the results of the development of generic intermodule/array, wire/cable systems consistent with safety requirements for photovoltaic modules and arrays, and generate detailed requirements and detailed conceptual designs for wiring schemes for roof mounted photovoltaic arrays. These requirements and detailed conceptual designs are to be documented in a form suitable for consideration and trial use by the photovoltaic community.
- Based upon previous results definition of and detailed requirements for additional issues concerning module safety, candidate array safety systems and circuits are to be provided.

**Approach/Present Task:** Documentation of research results in program.

**Status/FY 1983 Accomplishments:** Research is complete.

**FY 1984 Milestones:**

- Final Report — Candidate Array Safety Systems and Circuits — FY 1984.
- Final Report — Wiring Schemes and Connection Means — FY 1984.

**Major Project Reports:** No major reports for FY 1983.

**Summary Date**  
October 1983

**JPL**

**Title:** Investigation of Photovoltaic Module and Array Materials

**Contractor:**

Underwriters Laboratories, Inc.  
333 Pfingsten Road  
Northbrook, IL 60062

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** W. Christian

**Telephone:** (312) 272-8800

**Project Engineer:** R. Sugimura

**Telephone:** (213) 577-9118

**Contract Number:** 956368

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/82

**FY 1983**

**\$ 53,051**

**DOE**

**To:** 10/83

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Engineering Sciences Area

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**Objectives:** Investigate and evaluate safety characteristics of emerging photovoltaic module and array construction materials such as encapsulants, dielectrics, and array/module structural materials.

**Approach/Present Task:** To characterize the flammability of flat-plate photovoltaic modules.

**Status/FY 1983 Accomplishments:** Not applicable.

**FY 1984 Milestones:** Test reports — to be issued in FY 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Technical Support in the Development of Durability/Reliability Performance Criteria and Test Methods for Array Subsystem Elements

**Contractor:**  
Wyle Laboratories  
P.O. Box 1008  
Huntsville, AL 35807

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** G. Staton  
**Telephone:** (205) 837-4411

**Project Engineer:** D. Otth  
**Telephone:** (213) 577-9582

**Contract Number:** 955853

**Contract Funding:**

**Source:**

**Current Contract Period From:** 08/80  
**To:** 09/83

<b>FY 1980</b>	<b>\$ 57,400</b>	<b>DOE</b>
<b>FY 1981</b>	<b>\$ -0-</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 147,000</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ 100,000</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Engineering Sciences Area

**Objectives:** The objective of the contract is to perform various environmental tests and related activities supporting the development of performance criteria and test standards for array subsystem elements.

**Approach/Present Task:** Develop degradation rate curves for representative photovoltaic modules for extended exposures in both temperature and temperature/humidity environments.

**Status/FY 1983 Accomplishments:** Completed 85°C and 100°C temperature tests on Block III and Block IV module types.

**FY 1984 Milestones:**

- Complete test series for Block II and Block III modules in 40°C/93% RH environment and Block IV modules in 70°C/85% RH and 85°C/70% RH environments.
- Initiate accelerated test program on Block V module types.

**Major Project Reports:**

- Otth, D.H.; Ross, R.G., Jr. (1983). "Assessing Photovoltaic Module Degradation and Lifetime from Long Term Environmental Tests." *Environmental Technology — A Key to Product Acceptability; Proceedings of the 29th Institute of Environmental Sciences Annual Technical Meeting; Los Angeles, CA; 19-21 April 1983*. Mt. Prospect, IL: IES; pp. 121-126.

**Summary Date**  
October 1983

# JPL

**Title:** Environmental Test and Evaluation

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** J. Griffith  
**Telephone:** (213) 354-6133

**Project Engineer:** L. Runkle  
**Telephone:** (213) 577-9214

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:** FY 1982  
**To:** on-going

FY 1982	\$ 679,000	DOE
FY 1983	\$ 645,000	DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

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**Objectives:** To obtain early indications of module reliability and durability in order to verify that new module designs meet the project goals and are successful enough to warrant procurement of modules for limited field test programs.

**Approach/Present Task:** Modules are subjected to a sequence of environmental and performance tests defined in a pertinent qualification test procedure. The procedure in current use is the Block V Solar Cell Module Design and Test Specification. Failed modules are submitted to the failure analysis activity for diagnosis of the cause of failure, and the results of this analysis and the testing in general are communicated to the module manufacturer to provide guidance in correcting the design or procedure deficiencies.

**Status/FY 1983 Accomplishments:**

- Completed the second round of tests on modules proposed for the Georgetown Photovoltaic Project.
- Completed program of testing Block IV modules to the requirements of the Block V specification.
- Completed testing Block V Group I modules for two of the five manufacturers delivering modules. Late receipt of modules from manufacturers is delaying the completion of this milestone.
- Completed special mechanical integrity test of ARCO Solar modules for the SMUD program.

**FY 1984 Milestones:**

- Complete the testing of Block V Group I modules in order to verify the designs or to identify problems to be solved prior to obtaining Group I modules.
- Complete testing of Block V Group II modules.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

**JPL**

**Title:** Performance Measurements and Standards Research

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** R. L. Mueller  
**Telephone:** (213) 354-4881

**Project Engineer:** L. Runkle  
**Telephone:** (213) 577-9214

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:** FY 1982  
**To:** on-going

<b>FY 1982</b>	<b>\$ 282,000</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ 303,000</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

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**Objectives:** To provide electrical performance measurement standards and consultation for FSA contractors, to develop industry source of reference cell calibration, and to develop techniques for measurement of modules using new photovoltaic materials.

**Approach/Present Task:** Support development of national photovoltaic measurement standards. Transfer reference cell calibration technology to industry. Develop improvements in measurements technology and expansion of techniques to new PV materials. Support testing program by measurements.

**Status/FY 1983 Accomplishments:** Reconfirmed the calibration of the JPL pyrheliometer used in the calibration of reference cells and performed a simultaneous recalibration of six different reference cells. Contract to develop commercial source of calibrated reference cells remains incomplete because of non-performance of contractor. Maintained the operation of the JPL LAPSS and monitored the long time stability of the AM 1.5 filter.

**FY 1984 Milestones:** Develop, document, and implement a procedure for an acceptable secondary calibration of reference cells.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Failure Analysis Research

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** A. Shumka  
**Telephone:** (213) 354-5059

**Project Engineer:** L. Runkle  
**Telephone:** (213) 577-9214

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:** FY 1983  
**To:** on-going

<b>FY 1982</b>	<b>\$ 249,000</b>
<b>FY 1983</b>	<b>\$ 257,000</b>

<b>DOE</b>
<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

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**Objectives:** To determine the causes for module failure during performance test, environmental test, field test, and experimental test applications in order to improve module design and application.

**Approach/Present Task:** Perform analysis of representative modules which fail performance, environment, field, and application tests and report causes of failure. The analysis techniques applied to each failed module depend on the nature of the failure. Among the techniques are laser scanning (to isolate shorted, open, or cracked cells), corona discharge evaluation (to detect and identify contaminants), and varied illumination and elevated temperature application (to assess electrical performance degradation and isolate the cause).

**Status/FY 1983 Accomplishments:** Continuing analysis of problem and failed modules of the Block IV and V vintage, newly designed commercial and experimental test application modules yield valuable information which relate to design, processing, handling, and workmanship problems. These problems are identified and made available to the respective manufacturers together with a cumulative status of failure reports on a quarterly basis. The types of problems identified change as new designs are submitted for test. In addition to previous failure modes such as encapsulant delamination, shorted cells, and high voltage leakage, the discoloration of the PVB and EVA encapsulant was studied and analysis concluded. Several interconnecting system failures were analyzed and cause established. The manufacturers have used this information to make process and design changes and, in one instance, discontinue a design. During the FY 1983 time period, there were approximately 150 problem failure reports written and 100 closed.

**FY 1984 Milestones:** Quarterly issuance of failure analyses and of failure analysis reports to contractors.

**Major Project Reports:** No major report in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Module Development

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** M. Smokler  
**Telephone:** (213) 577-9238

**Project Engineer:** L. Runkle  
**Telephone:** (213) 577-9214

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:** on-going

<b>FY 1982</b>	<b>\$ 362,000</b>
<b>FY 1983</b>	<b>\$ 291,000</b>

<b>DOE</b>
<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

**Objectives:** The basic technology and engineering areas of the FSA Project develop improvements in solar cells, encapsulation, and module design concepts directed toward the capability of producing efficient, reliable, durable, low-cost solar cell modules. The module development task contract is structured to induce industry to combine these advances into modules to enable verification and evaluation of the new technology and design concepts.

**Approach/Present Task:** Implement module design and development contracts embodying the use of new PV technology to meet project objectives of efficiency, reliability, durability, and low cost.

**Status/FY 1983 Accomplishments:**

- Modules built to Block V designs were delivered by four of the original six Block V contractors. One contractor has stopped photovoltaic activities and the other has experienced delays in fabrication. Tests on the modules received are in various stages of completion.
- The Block V program was expanded in FY 1983 to include additional documentation, design reviews, and a second set of modules designated as Block V, Group II modules. Documentation and design reviews for two of the contractors is complete and fabrication of the Group II modules is pending the completion of testing on the first set of modules (Group I).
- The plan to obtain Block VI module design based upon a JPL specification for modules for central station applications was abandoned because of inadequate program funding.
- A contract was implemented to develop and design high efficiency advanced design modules.

**FY 1984 Milestones:**

- Complete contractor delivery of Block V — Group I modules.
- Complete contractor delivery of Block V — Group II modules.
- Complete design review of high efficiency module contract.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Field Test and Evaluation

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** R. Weaver  
**Telephone:** (213) 354-4894

**Project Engineer:** L. Runkle  
**Telephone:** (213) 577-9214

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:** FY 1982  
**To:** on-going

<b>FY 1982</b>	<b>\$ 315,000</b>
<b>FY 1983</b>	<b>\$ 280,000</b>

<b>DOE</b>
<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

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**Objectives:** To determine the reliability and durability of modules in the field environment and to confirm the validity of the module environmental test program.

**Approach/Present Task:** Set up operating module systems in field test environments. Conduct a continuous program of data collection. Analyze and report on module performance, reliability, and durability in the field.

**Status/FY 1983 Accomplishments:** A portable data logger capable of measuring and recording the I-V characteristics of arrays up to 400 volts open circuit and 40 amps short circuit current was developed, and used with numerous arrays around the country to verify performance. Deployment of Block IV module arrays at the JPL field site was completed, and modules were installed at the endurance testing site at the Florida Solar Energy Center. Daily collection of insolation data and module performance continued at the JPL site, and periodic inspection of the other endurance sites, such as at Goldstone, was maintained. The annual field test report was skipped this fiscal year.

**FY 1984 Milestones:** Issue field test report for interval September 1981 to September 1983.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983



**JPL**

**Title:** Intermediate Load Modules

**Contractor:**  
Applied Solar Energy Corporation  
15251 East Don Julian Road  
City of Industry, CA 91746

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** K. Ling  
**Telephone:** (213) 968-6581

**Project Engineer:** M. Smokler  
**Telephone:** (213) 577-9238

**Contract Number:** 955350

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/82  
**To:** 07/83

**FY 1982**            \$ 41,388  
**FY 1983**            \$ -0-

**DOE**  
**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

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**Objectives:** The contractor is to supply 10 modules (referred to as Group I modules). The contractor is also to supply 20 solar cells (same manufacture and performance as Group I modules). Provide documentation, prepare, and present a design review for proposed Group II modules and furnish 10 solar cell modules as Group II modules.

**Approach/Present Task:** Prepare documentation. Present design review. Manufacture and deliver modules. Prepare Final Report.

**Status/FY 1983 Accomplishments:** Documentation and design review completed. Modules delivered.

**FY 1984 Milestones:** Final Report — December 1983.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

**JPL**

**Title:** Block V Documentation and Solar Cell Modules

**Contractor:**  
ARCO Solar, Inc.  
P.O. Box 4400  
Woodland Hills, CA 91365

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** M. Smokler  
**Telephone:** (213) 577-9237

**Contract Number:** 956336

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/82  
**To:** 07/83

**FY 1983**            **\$ 45,667**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

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**Objectives:** The contractor shall deliver 10 ARCO Solar Assembly Drawing No. 1013185 and Interface Control Drawing No. 013194 modules (BQ-754176) referred to as Group I modules. The contractor shall furnish 20 solar cells, provide documentation, prepare and present a design review, visual inspection criteria and the module data package for the Group II modules at JPL and furnish 10 solar cell modules (Group II modules).

**Approach/Present Task:** Deliver Group I modules. Prepare Group II documentation. Present design review. Deliver Group II modules.

**Status/FY 1983 Accomplishments:** Documentation delivered. Design review completed.

**FY 1984 Milestones:** Deliver 10 Group II modules — November 1983.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Block V Documentation and Solar Cell Modules

**Contractor:**

Mobil Solar Energy Corporation  
16 Hickory Drive  
Waltham, MA 02154

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** E. Tornstrum

**Telephone:** (617) 890-0909

**Project Engineer:** M. Smokler

**Telephone:** (213) 577-9237

**Contract Number:** 956335

**Contract Funding:**

**Source:**

**Current Contract Period From:** 01/83

**FY 1983**

**\$ 64,045**

**DOE**

**To:** 01/84

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

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**Objectives:** The contractor shall furnish 20 solar cells of same manufacture and performance as those used in assembly of Group I modules and provide documentation; prepare and present design review, visual inspection criteria, and the module data package proposed for Group II modules at JPL; and furnish 10 solar cell modules, designated as Group II modules.

**Approach/Present Task:** Prepare Group I documentation. Prepare Group II documentation. Present design review. Deliver 10 Group II modules.

**Status/FY 1983 Accomplishments:** Group I documentation delivered.

**FY1984 Milestones:**

- Design review — November 1983.
- Deliver Group II modules — February 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

**JPL**

**Title:** Intermediate Load Modules for Test and Evaluation

**Contractor:**  
Photowatt International  
2414 West 14th Street  
Tempe, AZ 85281

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** M. Keeling  
**Telephone:** (602) 844-9564

**Project Engineer:** M. Smokler  
**Telephone:** (213) 577-9238

**Contract Number:** 956351

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/82  
**To:** 09/83

**FY 1983**            **\$ 19,411**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

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**Objectives:** The contractor is to deliver and provide documentation for 10 modules, referred to as Group I modules. The contractor is also to present a design review, visual inspection criteria, and the module data package proposed for the Group II modules at JPL; present 10 of the Group II modules for evaluation.

**Approach/Present Task:** Prepare documentation. Present design review. Manufacture and deliver 10 modules.

**Status/FY 1983 Accomplishments:** Documentation prepared and delivered.

**FY 1984 Milestones:**

- Design review — November 1983.
- Deliver modules — January 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Block V Documentation and Solar Cell Modules

**Contractor:**  
Solarex Corporation  
1335 Piccard Drive  
Rockville, MD 20850

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** J. Hoelscher  
**Telephone:** (301) 948-0202

**Project Engineer:** M. Smokler  
**Telephone:** (213) 577-9238

**Contract Number:** 956333

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/82  
**To:** 01/84

<b>FY 1982</b>	<b>\$ 83,302</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

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**Objectives:** Under Purchase Order No. BQ754179, the contractor is to deliver 10 each of Solarex Assembly Drawing No. D-1128 and Interface Control Drawing No. D-1131 modules (referred to as Group IA modules) and 10 each Solarex 40-Cell Assembly Drawing No. D-1128 and Interface Control Drawing No. D-1131 modules (referred to as Group IB modules). The contractor is to furnish 20 solar cells of same manufacture and performance as those used in Group IA modules and 20 solar cells of same manufacture and performance as those used in Group IB modules. The contractor is to prepare and present plans for proposed Group II modules. The contractor is to furnish 10 solar cell modules (Group IIA) and 10 solar cell modules (Group IIB).

**Approach/Present Task:** Provide documentation for Group IA and IB modules. Manufacture and deliver Group IA and IB modules. Provide documentation and present design review. Manufacture and deliver Group IIA and IIB modules.

**Status/FY 1983 Accomplishments:** Group IB documentation and modules delivered.

**FY 1984 Milestones:**

- Deliver Group IA modules — November 1983.
- Design review — May 1984.
- Complete module deliveries — July 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

**JPL**

**Title:** Intermediate Load Modules for Test and Evaluation Module Performance and Failure Analysis

**Contractor:**  
Solavolt, Inc.  
P.O. Box 2934  
Phoenix, AZ 85062

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** B. Larson  
**Telephone:** (602) 231-6455

**Project Engineer:** M. Smokler  
**Telephone:** (213) 577-9328

**Contract Number:** 956349

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/82  
**To:** 07/83

**FY 1983**

**\$ 22,488**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

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**Objectives:** The contractor shall provide 20 solar cells of same manufacture and performance as those used in assembly of Group I modules. The contractor shall prepare and present a design review, visual inspection criteria, and the module data package for the Group II modules at JPL. The contractor is then to furnish 10 solar cells designated as Group II modules for evaluation.

**Approach/Present Task:** Prepare documentation. Present design review. Manufacture and deliver modules. Prepare final report.

**Status/FY 1983 Accomplishments:** Documentation and design review completed. Modules delivered.

**FY 1984 Milestones:** Final report — February 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Intermediate Load Modules for Test and Evaluation Module Performance and Failure Analysis

**Contractor:**  
Solenergy Corporation  
171 Merrimac Street  
Woburn, MA 01801

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** R. Hartman  
**Telephone:** (617) 938-0563

**Project Engineer:** M. Smokler  
**Telephone:** (213) 577-9328

**Contract Number:** 956347

**Contract Funding:** **Source:**

**Current Contract Period From:** 09/82  
**To:** 09/83

<b>FY 1982</b>	<b>\$ 16,516</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

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**Objectives:** The objective of the contract is to provide 10 modules, Model No. SG1264-AG delivered under the Purchase Order No. FL733018, which are referred to as Group I modules. The contractor shall also provide 20 solar cells of same manufacture and performance as those used in assembly of Group I modules; provide documentation; prepare and present at JPL a review of the design, visual inspection criteria, and module data package proposed for the Group II modules; furnish 10 solar cell modules, Model No. SG1264-AG designated as Group II modules for evaluation.

**Approach/Present Task:** Provide documentation and deliver 10 Group I modules. Provide documentation and present design review on Group II modules. Deliver Group II modules.

**Status/FY 1983 Accomplishments:** Group I documentation completed. Group I modules delivered.

**FY 1984 Milestones:**

- Design Review — December 1983.
- Deliver Group II modules — March 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

JPL

**Title:** Block V Documentation and Solar Cell Modules

**Contractor:**  
Spire Corporation  
Patriots Park  
Bedford, MA 01730

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** R. Little  
**Telephone:** (617) 275-6000

**Project Engineer:** M. Smokler  
**Telephone:** (213) 577-9237

**Contract Number:** 956334

**Contract Funding:**

**Source:**

**Current Contract Period From:** 12/82  
**To:** 04/84

**FY 1983**                      **\$ 25,640**                      **DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Module Performance and  
Failure Analysis Area

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**Objectives:** The contractor shall provide documentation for and deliver 10 modules, Spire Assembly Drawing No. 058-0008 and Interface Control Drawing No. 058-0147 modules, which shall be referred to as Group I modules.

**Approach/Present Task:** Provide documentation for Group I modules. Manufacture and deliver 10 modules.

**Status/FY 1983 Accomplishments:** Documentation completed and delivered. One module delivered.

**FY 1984 Milestones:**

- Deliver 4 modules — October 1983.
- Deliver 5 modules — January 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983



# JPL

**Title:** FBR In-House Research

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** G. Hsu  
**Telephone:** (213) 354-7428

**Project Engineer:** A. Morrison  
**Telephone:** (213) 354-7200

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/82  
**To:** 12/84

<b>FY 1982</b>	<b>\$ 408,000</b>
<b>FY 1983</b>	<b>\$ 404,000</b>

<b>DOE</b>
<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

## Objectives:

- To establish fundamental understanding of fluidized bed silicon deposition in terms of homogeneous nucleation, chemical vapor deposition, and silicon particle growth mechanism.
- To operate the 6-in. fluidized bed reactor (FBR) to gather data for operating window and deposition kinetics.
- To conduct critical investigations in developing FBR technology as a low-cost photovoltaic material preparation technology.

**Approach/Present Task:** Use fluidized bed reactor to deposit semiconductor grade silicon from silane including scavenging fines into large polysilicon particles; characterize fully the fundamental process including product purity investigation; and develop critical FBR technologies including seed particle generation and product withdrawal.

## Status/FY 1983 Achievements:

- The 6-in. FBR was provided a product particle withdrawal system. A 3 kg/hr rate was demonstrated. This enables a steady state operation of FBR.
- A high silane concentration run with 50% silane at 630° C was successfully conducted for 5 hours. A 4-in. Cz ingot was pulled. Then, baseline cells were made and evaluated.
- 80% silane-in-hydrogen feed for 3 hours was achieved with 3.5 kg/hr deposition rate.

## FY 1984 Milestones:

- Complete seed generation feasibility study — 30 April 1984.
- Complete preliminary purity investigation — 31 October 1984.

## Major Project Reports:

- Hsu, G., et al. "Fines in Fluidized Bed Silane Pyrolysis." *Journal of the Electrochemical Society* (submitted for publication).
- Hsu, G., et al. (1983). *A Technical Report on the Engineering Parametric Study on the 6-in. Jet Propulsion Laboratory Fluidized Bed Reactor.*

**Summary Date**  
October 1983

**Title:** Support and Material Evaluation

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** T. O'Donnell  
**Telephone:** (213) 354-5465

**Project Engineer:** A. Morrison  
**Telephone:** (213) 354-7200

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/81  
**To:** 09/83

<b>FY 1982</b>	<b>\$ 175,000</b>
<b>FY 1983</b>	<b>\$ 178,000</b>

<b>DOE</b>
<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Component  
Research Area; Advanced  
Materials Research Task

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**Objectives:** Overall objective of this effort is to understand the effects of various environments on the mechanical properties of silicon sheet. This understanding should lead to means for reducing silicon damage events.

- To investigate the effect of light on the mechanical strength of silicon sheet.
- To investigate the effect of electric field on the fracture properties of silicon.

**Approach/Present Task:**

- Biaxial strength tests were conducted on silicon wafers [2-in. diameter chemical polished (100) wafers] with in-situ calibrated infrared light exposure and "in the dark".
- Microhardness diamond indentation tests have been conducted on (211) oriented single crystal silicon with and without an applied electric field (6V, 0.1mA).

**Status/FY 1983 Accomplishments:**

- Undamaged wafers approximately 30% stronger in IR light than dark.
- Damaged (by indentation) wafers — approximately 15% weaker in IR light than dark.
- Approximately 15% less indentation fracture damage in silicon in an electric field vs. no field.

**FY 1984 Milestones:** Environmental effects studies terminated. High-temperature testing to be pursued in FY 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Heat Exchanger-Ingot Casting/Slicing Process, Silicon Sheet Growth Development

**Contractor:**  
Crystal Systems, Inc.  
35 Congress Street  
Salem, MA 01970

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** F. Schmid  
**Telephone:** (617) 745-0088

**Project Engineer:** K. Dumas  
**Telephone:** (213) 354-6546

**Contract Number:** 954373

**Contract Funding:**

**Source:**

**Current Contract Period From:** 03/77  
**To:** 06/81

<b>FY 1976</b>	<b>\$ 208,393</b>	<b>DOE</b>
<b>FY 1977</b>	<b>\$ 427,408</b>	<b>DOE</b>
<b>FY 1978</b>	<b>\$ 499,832</b>	<b>DOE</b>
<b>FY 1979</b>	<b>\$ 273,854</b>	<b>DOE</b>
<b>FY 1980</b>	<b>\$ 687,345</b>	<b>DOE</b>
<b>FY 1981</b>	<b>\$ 364,139</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

**Objectives:** Contract objective was to produce large areas of silicon sheet material by the heat exchanger-ingot casting/slicing process suitable for use as solar cells.

- HEM Program. 35-kg ingots (dimensions approximately 30 × 30 × 15 cm) were grown in less than a 48-hour cycle time. Electrical characterization studies showed that the average efficiency of all usable material in the ingot was 85% of simultaneously processed Cz control cells. After completion of the contract goals, the HEM Program was no longer supported.
- FAST Program. The ability to slice 25 wafers/cm of 10-cm diameter ingots was demonstrated. Although the yields are low, the FAST saw is able to slice 15-cm diameter ingots. Work on this program is continued under Contract 956073.

**Approach/Present Task:** Not applicable.

**Status/FY 1983 Accomplishments:** The contract was completed in June 1981 and the ingot growth was no longer supported under any contract. FAST work continued under Contract 956073.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:**

- Schmid, F ; Khattak, C.P. (December 1982). *Silicon Ingot Casting-Heat Exchanger Method (HEM) Multi-Wire Slicing-Fixed Abrasive Slicing Technique (FAST); Phase III-Phase IV; Final Report*. DOE/JPL 554373-81/19. Pasadena, CA: Jet Propulsion Laboratory; 200 pp. Work performed by Crystal Systems, Inc., Salem, MA.

**Summary Date**  
October 1983

**Title:** Electrochemical Production of Silicon

**Contractor:**  
Energy Materials Corporation  
P.O. Box 1143  
Sterling Road South  
Lancaster, MA 01561

**Principal Investigator:** D. Jewett  
**Telephone:** (617) 365-7383

**Contract Number:** 956553

**Current Contract Period From:** 06/83  
**To:** 05/84

**Directing Organization:**  
Jet Propulsion Laboratory

**Project Engineer:** R. Lutwack  
**Telephone:** (213) 354-7648

**Contract Funding:**

**FY 1983**            **\$ 50,000**

**Source:**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

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**Objectives:** The contractor shall establish the conditions for long-term, steady-state operation of a molten salt electrochemical cell for producing high purity silicon using metallurgical-grade silicon as the feed material and evaluate the suitability of the large-scale (1000 MT/yr) electrochemical production of high purity silicon from metallurgical grade silicon.

**Approach/Present Task:** Perform theoretical and experimental studies to determine the conditions for steady-state operation, the characteristics of the reaction system, and the capability of long-term, steady-state runs.

**Status/FY 1983 Accomplishments:** Equipment design began.

**FY 1984 Milestones:** Final report on scalability of electrorefinement of silicon process — November 1984.

**Major Project Reports:** No major reports for FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Development of a Polysilicon Process Based on Chemical Vapor Deposition

**Contractor:**

Hemlock Semiconductor Corporation  
12334 Geddes Road  
Hemlock, MI 48626

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** F. Plahutnik

**Telephone:** (517) 642-5201

**Project Engineer:** A. Briglio

**Telephone:** (213) 354-4883

**Contract Number:** 955533

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/79

**To:** 12/83

**FY 1980** \$ 727,000

DOE

**FY 1981** \$ 783,000

DOE

**FY 1982** \$ 510,450

DOE

**FY 1983** \$ -0-

DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

**Objectives:** To develop a low-cost process for producing polysilicon approaching semiconductor-grade quality by chemical vapor deposition from dichlorosilane (DCS) and/or mixtures of dichlorosilane and trichlorosilane (TCS). The goal is a polysilicon price of less than \$21/kg (1980 dollars, 1000-MT/yr, 20% ROI) for a process having high probability of being successful.

**Approach/Present Task:** Eliminate the excessive deposition of silicon on the inside surfaces of silicon deposition reactors being fed by DCS, so as to allow operation at more optimum conditions, thereby achieving simultaneously the program goals of high silicon deposition rate, high conversion efficiency of DCS to silicon, and low-energy consumption; modify existing cold-metal-wall Siemens-type reactor for operation on DCS, and conduct tests to determine suitable operating parameters; conduct tests to evaluate materials of construction for reactor bell jar; continue operation of DCS process development unit (PDU) to obtain additional information on making DCS from trichlorosilane.

**Status/FY 1983 Accomplishments:**

- Program on cold-metal-wall silicon deposition reactor was completed. Wall temperature was about 300°C compared to temperatures in range of 500°C to 800°C for quartz bell jars. Cooler wall permitted higher silicon deposition rates and lower reactor power consumptions. However, simultaneous achievement of goals for Si deposition rate, conversion efficiency of DCS to Si and power consumption was not attained. Data on Si wall deposition scattered badly, making it impossible to correlate with reactor operating conditions.
- Materials testing indicated that low-carbon alloys should be considered.
- The DCS PDU, integrated with silicon deposition reactors of medium and large size, including the cold-metal-wall type, continued to operate well.
- The draft final report on effort through Phase II was delivered in January 1983.

**FY 1984 Milestones:** None.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**

October 1983

**JPL**

**Title:** Advanced Czochralski Growth Process

**Contractor:**

Kayex Corporation  
1000 Milstead Way  
Rochester, NY 14624

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** R. Lane

**Telephone:** (716) 235-2524

**Project Engineer:** A. Morrison

**Telephone:** (213) 354-7200

**Contract Number:** 955733

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/80

**To:** 05/82

**FY 1980** \$ 153,440

DOE

**FY 1981** \$ 508,479

DOE

**FY 1982** \$ 132,634

DOE

**FY 1983** \$ -0-

DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

**Objectives:**

- Contract objective was to develop a continuous Czochralski growth process capable of producing silicon suitable for use as low-cost solar cells. The cost goal was less than \$799 (1980 dollars) per peak kilowatt by 1986. The goals of this program were: continuous growth of 150 kg or more of multiple ingots, each of approximately 30 kg in weight, from one common crucible with melt-replenishment; resistivity of 1 to 3 ohm-cm; p-type, in all crystals; dislocation density below  $10^4$  per  $\text{cm}^2$ ; diameter of 15 cm for each ingot, growth throughput greater than 2.5 kg per hour of machine operation; orientation: (100); after growth yield of greater than 90%, and prototype equipment suitable for high volume silicon production transferable directly to industry.
- Automation of the growth process has been very successful. Study of silicon/silica reaction and of use of heat shield to accelerate meltdown and growth occupied the remainder of the contract effort.

**Approach/Present Task:** No work is underway nor is any further work planned on this contract.

**Status/FY 1983 Achievements:** Final Report issued.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:**

- Lane, R. (June 1983). *Development of an Advanced Czochralski Growth Process to Produce Low-Cost 150 kg Silicon Ingots from a Single Crucible for Technology Readiness; Final Report Covering the period October 1980 to April 1982.* DOE/JPL/955733-6. Pasadena, CA: Jet Propulsion Laboratory

**Summary Date**

October 1983

# JPL

**Title:** Edge-Defined Film-Fed Growth for Silicon Growth Development

**Contractor:**

Mobil Solar Energy Corporation  
16 Hickory Drive  
Waltham, MA 02156

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** F. Wald

**Telephone:** (617) 890-0909

**Project Engineer:** J. Liu

**Telephone:** (213) 354-6500

**Contract Number:** 954355

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/75

**To:** 03/82

<b>FY</b> 1978	<b>\$</b> 777,010	DOE
<b>FY</b> 1979	<b>\$</b> 965,996	DOE
<b>FY</b> 1980	<b>\$</b> 659,042	DOE
<b>FY</b> 1981	<b>\$</b> 659,042	DOE
<b>FY</b> 1982	<b>\$</b> 129,451	DOE
<b>FY</b> 1983	<b>\$</b> -0-	

**Project/Area/Task:** Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

**Objectives:**

- Contract objective is to develop methods of producing large areas of silicon ribbon by the edge-defined film-fed growth (EFG) technique directed toward minimum cost processing of silicon ribbons of a quality suitable for producing solar cells with a terrestrial efficiency greater than 12.5% and having a potential to be scaled for large quantity production.
- The contract was modified in September 1981 to show that the contractor was to continue the development of methods using the EFG technique to produce silicon ribbons suitable for use as solar cells with ribbon thickness of 8 mil  $\pm$  2 mil and to demonstrate maximum conversion efficiency for large area cell (50 cm<sup>2</sup>) of greater than 12.0%. To achieve these goals, as Phase IV, the contractor is to implement a plan for design, construction, and process testing of Machine 21; perform an economic and technical analysis of Machine 21 and define the Machine 21 system and subsystems on which the analysis is based; perform a detailed design of an integrated Machine 21 system; operate Machine 18 to develop better ribbon guidance, improve ribbon flatness, and continue gas ambient and quality studies for 10 cm wide ribbon to supply information for use in multiple ribbon growth; operate Machine 17 to optimize 10 cm cartridge for growth at 4 cm/min and develop ambient control for use in multiple ribbon growth; deliver residual material characterization and solar cell fabrication; and perform characterizations and tests by making solar cells from EFG samples.
- Contract completed March 1982. Follow-on work under Contract 956312 is underway.

**Approach/Present Task:** Not applicable.

**Status/FY 1983 Accomplishments:** Final Report published.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:**

- Kalejs, J.P. (September 1982). *Large Area Silicon Sheet by EFG; Final Report for the Period October 29, 1975—December 31, 1981*. DOE/JPL/954355/81-21. Pasadena, CA: Jet Propulsion Laboratory; 81 pp. Work performed by Mobil Tyco Solar Energy Corporation, Waltham, MA.

**Summary Date**

October 1983

# JPL

**Title:** Stress Analysis in Edge-Defined Film-Fed Growth (EFG) Ribbons

**Contractor:**

Mobil Solar Energy Corporation  
16 Hickory Drive  
Waltham, MA 02156

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** J. Kalejs

**Telephone:** (617) 890-0909

**Project Engineer:** J. Liu

**Telephone:** (213) 354-6500

**Contract Number:** 956312

**Contract Funding:**

**Source:**

**Current Contract Period From:** 07/82

**To:** 07/84

**FY 1982**

**\$ 156,103**

**DOE**

**FY 1983**

**\$ 65,000**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

**Objective:** The objective of the contract is to perform work specified and related to crystal growth by the edge-defined film-fed growth (EFG) technique. Research and development shall be directed toward improving the quality of silicon ribbon suitable for use as solar cells by solving generic ribbon growth problems. These goals shall be achieved by the performance of research to develop a theoretical model for obtaining temperature field — residual stress relationships in silicon ribbon growth and to test the predictions experimentally in an EFG ribbon growth system. Operation of an existing EFG growth machine (#17) for research and development is also provided to improve quality of grown silicon EFG-ribbon. Deliverables include 75% of usable EFG ribbon produced as well as reports on the theoretical analyses on reduced stress growth configurations.

**Approach/Present Task:** The initial work underway focuses on the development of a computer program to model temperature field-stress relationships in (1) steady-state ribbon growth and then later in (2) realistic dynamic ribbon growth situations. The relevant ribbon temperature field data and boundary conditions will be measured experimentally and integrated into the computer analysis to provide a means for verifying and refining the model. These results will be used to generate a low or no-stress ribbon growth configuration that will be tested experimentally in an EFG ribbon furnace.

**Status/FY 1983 Accomplishments:** Computer code for residual stress calculations is operational. Silicon material data residual stress and ribbon temperature field measurements are being obtained experimentally for input into computer model. Initial results obtained from computer output show qualitative agreement with experimentally observed ribbon stress conditions.

**FY 1984 Milestones:**

- Baseline in-situ ribbon temperature measurements completed — March 1984.
- Initial reduced-stress model for EFG ribbon growth completed — June 1984.

**Major Project Reports:**

- Kalejs, J. P. (August 1983). *Stress Studies in EFG; Fourth Quarterly Progress Report, Covering the Period from April 1, 1983-June 30, 1983*. DOE/JPL/956312-83/04. Pasadena, CA: Jet Propulsion Laboratory; 50 pp. Work performed by Mobil Solar Energy Corporation, Waltham, MA.
- *Stress Studies in EFG, Third Quarterly Progress Report for January 1-March 31, 1983*. (April 1983). DOE/JPL/956312-83/03. Pasadena, CA: Jet Propulsion Laboratory; 40 pp. Work performed by Mobil Solar Energy Corporation, Waltham, MA.

**Summary Date**

**October 1983**



**JPL**

**Title:** Development of Fluidized-Bed Silicon Technology

**Contractor:**  
Oregon State University  
Corvallis, OR 97331

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** O. Levenspiel  
**Telephone:** (503) 754-4791

**Project Engineer:** R. Lutwack  
**Telephone:** (213) 354-7648

**Contract Number:** 956133

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/81  
**To:** 10/83

<b>FY 1981</b>	<b>\$ 30,000</b>
<b>FY 1982</b>	<b>\$ 16,474</b>
<b>FY 1983</b>	<b>\$ -0-</b>

<b>DOE</b>
<b>DOE</b>
<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

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**Objectives:** The contract objective is to obtain experimental data to characterize an internally heated fluidized bed reactor technology for use in converting silane to silicon. The experimental data are intended to provide a basis for determining the applicability of the FBR technology for the silane to silicon conversion.

**Approach/Present Task:** Not applicable.

**Status/FY 1983 Accomplishments:** The effects of the electric heater source power, the bed depth, the reactor geometry, and gas velocity on the effective absorptivity of heat by the bed and on the heat transfer coefficient between the bed and the distributor plate were determined. It was shown that the desired distributor plate temperature can be maintained with a tapered bed, a conical bed with no distributor, or a multiorifice or multicone bed, but not with a square or round bed. An energy-use value of about 40/y kWhr/kg Si (where y = % silane) was calculated. This concept can be scaled up advantageously.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:** *Preliminary Study of a Radiantly Heated Fluidized Bed for the Production of High Purity Silicon; Final Report.* (August 1983). DOE/JPL-956133-83/1. Pasadena, CA: Jet Propulsion Laboratory.

**Summary Date**  
October 1983

# JPL

**Title:** Investigation of Hydrochlorination of  $\text{SiCl}_4$  and Metallurgical-Grade Silicon

**Contractor:**

Solarelectronics, Inc.  
Bellingham Industrial Park  
P.O. Box 141, 21 Rita Lane  
Bellingham, MA 02019

**Principal Investigator:** J. Mui

**Telephone:** (617) 966-1234

**Contract Number:** 956061

**Current Contract Period From:** 07/81

**To:** 02/83

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

**Directing Organization:**

Jet Propulsion Laboratory

**Project Engineer:** N. Rohatgi

**Telephone:** (213) 354-3073

**Contract Funding:**

FY 1981	\$ 35,000
FY 1982	\$ 165,790
FY 1983	\$ (17,885)

**Source:**

DOE
DOE
DOE

**Objectives:**

- Contract objective was to obtain data to define process parameters for the reaction involving hydrochlorination of silicon tetrachloride and metallurgical-grade silicon metal to form trichlorosilane. The engineering data are intended to provide a base for optimizing the economics of the hydrochlorination process by reducing processing costs.

**Approach/Present Task:** Not applicable.

**Status/FY 1983 Achievements:**

- A study on thermodynamic function measurements was completed.
- A plausible hydrochlorination reaction mechanism was proposed.
- A study on reaction kinetics measurements was completed.
- Contract was complete — April 1983.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:**

- Mui, J.Y.P. (April 1983). *Investigation of the Hydrochlorination of  $\text{SiCl}_4$  — Final Report, Covering the Period July 9, 1981 — April 8, 1983.* DOE/JPL-956061-7. Pasadena, CA: Jet Propulsion Laboratory; 101 pp. Work performed by Solarelectronics, Inc., Bellingham, MA.
- Mui, J.Y.P. (January 1983). *Flat-Plate Solar-Array Project, Advanced-Materials Research Task Quarterly Report: Investigation of the Hydrochlorination of  $\text{SiCl}_4$ , Covering the Period October 9, 1982 to January 8, 1983.* DOE/JPL/956061-6. Pasadena, CA: Jet Propulsion Laboratory; 43 pp.
- Mui, J.Y.P. (October 1982). *Investigation of the Hydrochlorination of  $\text{SiCl}_4$  — Fifth Quarterly Report, July 9 — October 8, 1982.* DOE/JPL-956061-5. Pasadena, CA: Jet Propulsion Laboratory; 27 pp. Work performed by Solarelectronics, Inc., Bellingham, MA.

**Summary Date**

October 1983

# JPL

**Title:** Silane to Silicon Process

**Contractor:**

Union Carbide Corporation  
3333 Index Street  
Washougal, WA 98671

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** S. Iya

**Telephone:** (206) 835-8735

**Project Engineer:** G. Hsu

**Telephone:** (213) 354-7428

**Contract Number:** 954334

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/75  
**To:** 12/84

<b>FY 1978</b>	<b>\$ 851,621</b>	<b>DOE</b>
<b>FY 1979</b>	<b>\$ 1,236,000</b>	<b>DOE</b>
<b>FY 1980</b>	<b>\$ 4,354,000</b>	<b>DOE</b>
<b>FY 1981</b>	<b>\$ 5,402,000</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 555,000</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ 430,000</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

**Objectives:** Contract objective is to conduct a program to establish the practicality of a process for high-volume, low-cost production of silane (Step I); and the practicality of the subsequent pyrolysis of silane to semiconductor-grade silicon (Step II). The goal of Step II is to pyrolyze the silane to semiconductor-grade silicon so as to meet the goals of the Advanced Materials Research Task of \$16-20 per kg of silicon in 1983 dollars.

**Approach/Present Task:** The silane production portion is being demonstrated in the Union Carbide's Washougal pilot plant. It has been running since April 1983. The FBR PDU was transferred from Tonawanda to the Washougal site with improvements. It was restarted in May 1983. The present tasks have the objective of establishing a suitable operating window for long-duration tests.

**Status/FY 1983 Accomplishments:**

- Silane EPI data yields resistivity of greater than 200 ohm-cm. Silicon produced exhibits over 2000 ohm-cm with B,P,C, and O meeting the semiconductor grade specifications except hydrogen.
- The operability of FBR PDU was checked out through short-duration experiments. Long-duration tests of 20% silane and 20-24 hr. duration have been conducted for preliminary purity investigation.

**FY 1984 Milestones:**

- Complete seed production design and installation — 29 February 1984.
- Complete feasibility and purity determination runs — 30 September 1984.

**Major Project Reports:**

- *Flat-Plate Solar-Array Project; Experimental Process-System Development Unit for Producing Semiconductor-Grade Silicon Using the Silane-to-Silicon Process; Final Report, Phase III, April 1979-December 1981.* (1983). DOE/JPL/954334-21. Pasadena, CA: Jet Propulsion Laboratory; 354 pp. Work performed by Union Carbide Corporation, Washougal, WA.

**Summary Date**

October 1983

**JPL**

**Title:** Study of the Abrasive Wear Rate of Silicon

**Contractor:**  
The Board of Trustees of the University of Illinois  
Chicago Circle Campus  
Box 4348  
Chicago, IL 60680

**Principal Investigator:** S. Danyluk  
**Telephone:** (312) 996-2437

**Contract Number:** 956053

**Current Contract Period From:** 06/81  
**To:** 08/84

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

**Directing Organization:**  
Jet Propulsion Laboratory

**Project Engineer:** C. Chen  
**Telephone:** (213) 354-5353

**Contract Funding:**

<b>FY 1981</b>	<b>\$ 16,489</b>
<b>FY 1982</b>	<b>\$ 33,750</b>
<b>FY 1983</b>	<b>\$ 46,000</b>

**Source:**

<b>DOE</b>
<b>DOE</b>
<b>DOE</b>

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**Objectives:** To investigate surface "softening" and comparative abrasive wear rates of silicon exposed to light, heat, and various chemical environments and to develop a non-destructive method for measuring residual stresses in sheet silicon.

**Approach/Present Task:** In the course of this contract, it has been determined that there is a mechanism which causes the surface "softening" of silicon in the presence of n-alcohols. The amount of "softening" of the surface is determined by measuring the depth of a groove scratched by a pyramid diamond into the silicon in the presence of the n-alcohol. The scope of the contract was further increased to include the development of a nondestructive technique for measuring residual stresses in sheet silicon by laser interferometry.

**Status/FY 1983 Accomplishments:** The abrasive wear and surface deformation by indentation in the presence of various fluid environments has been characterized.

**FY 1984 Milestones:** Final Report.

**Major Project Reports:** *Study of Abrasive Wear Rate of Silicon Using n-Alcohols.* (February 1983). DOE/JPL-956053-82/4. Pasadena, CA: Jet Propulsion Laboratory.

**Summary Date**  
October 1983

# JPL

**Title:** Stress-Strain Analysis of Silicon Ribbon

**Contractor:**

University of Kentucky Research Foundation  
Kinkead Hall  
Lexington, KY 40506

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** O. Dillon

**Telephone:** (606) 257-3775

**Project Engineer:** T. O'Donnell

**Telephone:** (213) 354-5465

**Contract Number:** 956571

**Contract Funding:**

**Source:**

**Current Contract Period From:** 06/83  
**To:** 07/84

**FY 1983**      **\$ 88,513**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

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**Objectives:** The contractor shall develop stress-strain models for silicon sheet growth processes and evaluate the relationship between silicon growth structure and stress-strain.

**Approach/Present Task:** Development of stress-strain models shall include elastic and elastic-plastic silicon ribbon buckling analysis. Complementary analysis of silicon structure shall focus on establishing the role that defect structures play in creating or relieving ribbon growth stress.

**Status/FY 1983 Accomplishments:**

- Preliminary buckling model developed which describes torsional buckling of grown silicon ribbon.
- Significant amount of high temperature mechanical properties for silicon have been compiled.

**FY 1984 Milestones:**

- Refined ribbon buckling model — April 1984.
- Final Report — July 1984.

**Major Project Reports:** No major report in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Dendritic Web Process Development

**Contractor:**

Westinghouse Electric Corporation  
1310 Beulah Road  
Pittsburgh, PA 15235

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** S. Duncan

**Telephone:** (412) 256-3666

**Project Engineer:** A. Briglio

**Telephone:** (213) 354-4883

**Contract Number:** 955843

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/80  
**To:** 03/84

**FY 1981** \$ 927,266

DOE

**FY 1982** \$ 729,721

DOE

**FY 1983** \$ 499,986

DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Advanced  
Materials Research Task

**Objective:** Solution of generic problems that impede development of a web growth process for processing silicon sheet suitable for use in making low-cost solar cells with a terrestrial efficiency greater than 15% and having potential for scaling to large quantity.

**Approach/Present Task:** The emphasis in FY 1983 was placed on (1) developing thermal stress models so as to understand the parameters that generate stresses in dendritic web silicon ribbon and applying these models to the development of new design concepts of equipment for growing low-stress ribbon, and (2) designing, constructing, and testing equipment, based on these models, that is capable of growing low-stress ribbon at higher area growth rates. The scope of the contract was expanded in FY 1983 to include ribbon growth configurations that employ dynamic control of furnace elements, to allow these elements to be positioned properly for starting growth and then moved to final position for optimum steady-state growth.

**Status/FY 1983 Accomplishments:** Based on results of computer modeling, two ribbon growth configurations incorporating dynamic positioning of thermal elements were defined, built, and tested. Major improvements in linear growth speed at standard ribbon thickness of 150 microns were obtained for low-stress ribbon, the linear growth speed being increased to 3.0 cm/min compared to 1.9 cm/min for the otherwise equivalent static configuration. The speed of 3.0 is the highest attained to date in the dendritic web program. New static growth configurations were designed, built, and tested, one of them giving a growth speed of 2.2 cm/min at 150-micron thickness, the highest ever attained for a static configuration (the highest speed obtained with static configurations prior to these two new designs was 1.9 cm/min). The maximum width of low-stress ribbon was increased to 5.8 cm, compared to a previous width of about 5.5 cm.

**FY 1984 Milestones:** Dendritic web dynamic furnace element program review — May 1984.

**Major Project Reports:**

- Duncan, C.S.; Seidensticker, R.G.; McHugh, J.P. (August 1983). *Large-Area Sheet Task Advanced Dendritic Web Growth Development, Quarterly Report for the Period January 1, 1983 to March 31, 1983*. DOE/JPL/955843-83/10. Pasadena, CA: Jet Propulsion Laboratory; 37 pp. Work performed by Westinghouse R & D Center, Pittsburgh, PA.
- Duncan, C.S.; Seidensticker, R.G.; McHugh, J.P. (March 1983). *Large-Area Sheet Task Advanced Dendritic Web Growth Development, Quarterly Report for the Period October 23, 1982 to December 31, 1982*. DOE/JPL/955843-83/9. Pasadena, CA: Jet Propulsion Laboratory; 31 pp. Work performed by Westinghouse R & D Center, Pittsburgh, PA.

**Summary Date**  
October 1983

**JPL**

**Title:** Device Characterization Research

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:**

**Project Engineer:** T. Daud

**Telephone:**

**Telephone:** (213) 354-5782

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 1982  
**To:** on-going

**FY 1982**           \$ 200,000  
**FY 1983**           \$ 75,000

**DOE**  
**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Device and  
Measurements Research Task

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**Objectives:** Evaluate design variations for silicon solar cells to evolve new device structures for improving cell efficiencies and understanding efficiency limiting loss mechanisms.

**Approach/Present Task:**

- A concept of multijunction silicon solar cell is being evaluated to increase cell open circuit voltage and conversion efficiency. Fabrication and evaluation will be done using molecular beam epitaxy (MBE) technique.
- Characterization techniques such as EBIC, light I-V, dark I-V, SPV, C-V, SIMS, etc. will be used to test MBE-grown silicon layers and solar cell structures.

**Status/FY 1983 Accomplishments:** Calculations of two-junction silicon solar cell has been done. It shows a possible effective backsurface field in the first cell giving voltage increase. Efficiency increase of about 6% is possible.

**FY 1984 Milestones:** Fabricate solar cells and test MBE-grown silicon layers.

**Major Project Reports:** None.

**Summary Date**  
October 1983

# JPL

**Title:** Solar Cell Process Development

**Contractor:**  
Applied Solar Energy Corporation  
15251 East Don Julian Road  
City of Industry, CA 91746

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** D. Leung  
**Telephone:** (213) 968-6581

**Project Engineer:** R. Kachare  
**Telephone:** (213) 354-4583

**Contract Number:** 955089

**Contract Funding:**

**Source:**

**Current Contract Period From:** 05/78  
**To:** 12/82

<b>FY 1978</b>	<b>\$ 223,920</b>	<b>DOE</b>
<b>FY 1979</b>	<b>\$ 113,000</b>	<b>DOE</b>
<b>FY 1980</b>	<b>\$ 302,572</b>	<b>DOE</b>
<b>FY 1981</b>	<b>\$ 250,049</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 112,429</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ 36,158</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Device and  
Measurements Research Task

## Objectives:

- Contract objectives include fabrication of solar cells using reliable and reproducible processes; testing of the solar cells using standardized equipment and techniques; investigate, develop, and utilize technologies appropriate and necessary for improving the efficiency of solar cells made from large area silicon sheets.
- Phase IV of the contract was instituted in the first quarter of FY 1982. The baseline effort of this phase will require fabrication of a maximum of 12 solar cells using standard and reproducible processes. The contractor shall investigate, develop, and utilize technologies appropriate and necessary for improving efficiencies of solar cells made from unconventional silicon.

## Approach/Present Task:

- Small-area diode work being continued to study the effects of grain boundaries on solar cell behavior.
- Small-area light spot scanning technique is established to directly measure local diffusion length in silicon solar cells.

## Status/FY 1983 Accomplishments:

- Small-area light spot scanning technique was established — March 1983.
- Dark diode characteristics of polycrystalline silicon with and without grain boundaries — June 1983.

**FY 1984 Milestones:** Various processing techniques will be used on various ribbon samples to evaluate the material qualities — November 1984.

## Major Project Reports:

- *Solar Cell Process Development, Phase IV Annual Report Covering the Period from July 1, 1981 to December 31, 1982.* DOE/JPL/955089-81/15. Pasadena, CA: Jet Propulsion Laboratory.

**Summary Date**  
October 1983



# JPL

**Title:** Microcrystalline Silicon Growth for Heterojunction for Solar Cells

**Contractor:**

Applied Solar Energy Corporation  
15251 East Don Julian Road  
City of Industry, CA 91746

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** D. Leung

**Telephone:** (213) 968-6581

**Contract Number:** 956369

**Current Contract Period From:** 10/82

**To:** 10/83

**Project Engineer:** T. Daud

**Telephone:** (213) 354-5782

**Contract Funding:**

**FY 1983**            **\$ 61,567**

**Source:**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area: Device and  
Measurements Research Task

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**Objectives:** The contractor shall grow, fabricate, develop, and analyze microcrystalline silicon layer and high-efficiency solar cells.

**Approach/Present Task:** The program is directed toward obtaining a p-type "window" layer of large band-gap microcrystalline silicon on single crystal silicon substrates and to fabricate and test the solar cells and analyze their performance. Further investigation of cell performance as a function of material properties of the layer shall also be performed, which shall, as a goal, result in evolving an improved cell structure.

**Status/FY 1983 Accomplishments:** Low temperature e-beam evaporation technique has been used for deposition of microcrystalline silicon to form heterojunction and heteroface solar cells. Heteroface solar cells, p<sup>+</sup> - p<sup>+</sup>/n, have shown improved V<sub>oc</sub>, but not efficiency.

**FY 1984 Milestones:**

- This one-year effort will be terminated by end of October 1983.
- Final report is due at the end of October 1983, describing evaporation technique and solar cell results.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Investigation of Physical Structure and the Chemical Nature of Defects in the Silicon Sheet Material

**Contractor:**  
Cornell University  
P.O. Box DH  
Ithaca, NY 14853

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** D. Ast  
**Telephone:** (315) 857-1501

**Project Engineer:** L. Cheng  
**Telephone:** (213) 354-3068

**Contract Number:** 956046

**Contract Funding:**

**Source:**

**Current Contract Period From:** 06/81  
**To:** 05/82

<b>FY 1981</b>	<b>\$ 20,000</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 21,210</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ 42,043</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Device and  
Measurements Research Task

**Objectives:** Contract objective is to extend understanding of the structural, electrical, and chemical nature of silicon sheet material. Primary emphasis is on correlation of the structural, electrical, and chemical properties of silicon sheet material leading to a better understanding of their potential to produce high efficiency solar cells.

**Approach/Present Task:** The main effort since the beginning of the contract has been concentrated on structural defects, particularly precipitates and tilt boundaries, in as-grown and processed EFG and HEM materials. Tilt boundaries (including a variety of twin boundaries) are found to be major structural defects in all silicon ribbon and cast materials.

**Status/FY 1983 Accomplishments:**

- It was observed that symmetric grain boundaries in HEM materials were not or only weakly electrically active. In general, the hydrogenation process has no significant effects on electrical activities of grain boundaries in HEM, indicating that the origin of the activities could be related to impurities involved.
- A valuable improvement was made on the understanding of carbon and oxygen behavior in EFG materials, as well as their interactions with intrinsic defects during heat treatments and cell processing.

**FY 1984 Milestones:** An in-depth study on structural defects, impurities, and their interactions of EFG materials will be accomplished.

**Major Project Reports:**

- *Intrinsic Gettering in EFG Ribbons by Pre-Diffusion Anneal at High Temperatures; Quarterly Progress Report.* (September 1983). DOE/JPL-956046-83/8. Pasadena, CA: Jet Propulsion Laboratory.
- *TEM and SEM (EBIC) Investigations of Silicon Bicrystals; Quarterly Progress Report.* (July 1983). DOE/JPL-956046-83/7. Pasadena, CA: Jet Propulsion Laboratory.
- Gleichman, R.; Ast, D.G. (July 1983). *TEM and SEM (EBIC) Investigations of Silicon Bicrystals, Quarterly Report for April 1 — June 31, 1983.* DOE/JPL/956046-83/6. Pasadena, CA: Jet Propulsion Laboratory; 12 pp. Work performed by Cornell University, Department of Materials Science and Engineering, Ithaca, NY.

**Summary Date**  
October 1983

# JPL

**Title:** Analysis of Defect Structure in Silicon

**Contractor:**

Materials Research, Inc.  
790 East 700 South Street  
Centerville, UT 84014

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** R. Natesh

**Telephone:** (801) 298-4000

**Project Engineer:** R. Kachare

**Telephone:** (213) 354-4583

**Contract Number:** 955676

**Contract Funding:**

**Source:**

**Current Contract Period From:** 06/80

**To:** 05/83

**FY 1980** \$ 80,000

**FY 1981** \$ -0-

**FY 1982** \$ 59,700

**FY 1983** \$ 550

DOE

DOE

DOE

DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Device and  
Measurements Research Task

**Objectives:** Contract objective is to perform quantitative defect analysis, using quantitative microscopy equipment, of selected silicon sheet samples. Defect analysis shall include characterization of grain size, dislocation density, twin boundary spacing, twin boundary density, and density of precipitates.

Procedures have been developed for accurate, reproducible, and quantitative analysis of silicon sheet defect structure. A Quantimet (QTM-720) Image Analyzing System, incorporating a PDP 11/03 minicomputer with dual floppy disc drive, high speed printer, field image feature interface (FIFI) module, and an automated X-Y specimen stage control, has been and is being used in this development/evaluation program. A computer program for defect characterization of silicon was developed and submitted to JPL as a new technology item.

The analyses of about 190 silicon sheet samples, approximately 800 cm<sup>2</sup>, for twin boundary density, dislocation pit density, precipitate density, and grain boundary length have been accomplished. One hundred and fifteen (115) of these samples were manufactured by Crystal Systems, Inc. using their heat exchanger method (HEM), 38 by Mobil using edge-defined film-fed growth (EFG), 20 by Honeywell using the silicon-on-ceramic (SOC) process, and 10 by Westinghouse using the dendritic web process. A total of 7 solar cells chosen from the above samples were also step-etched to determine the internal defect distribution on these samples.

**Approach/Present Task:** Not applicable.

**Status/FY 1983 Achievements:** Quantities analyses of precipitates, dislocations, grain boundaries, and twins in Semix UCP material was obtained and correlated with solar cell performance.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:**

- Natesh, R.; Stringfellow, G.B.; Virkar, A.V.; Dunn, J.; Guyer, T. (February 1983). *Analysis of Defect Structure in Silicon, Characterization of Semix Material; Final Report*. DOE/JPL/955676-4. Pasadena, CA: Jet Propulsion Laboratory; 137 pp. Work performed by Materials Research, Inc., Centerville, UT.

**Summary Date**

October 1983

**JPL**

**Title:** Analysis of Defect Structure in Silicon

**Contractor:**

Materials Research, Inc.  
790 East 700 South Street  
Centerville, UT 84104

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** R. Natesh

**Telephone:** (801) 298-4000

**Project Engineer:** R. Kachare

**Telephone:** (213) 354-4583

**Contract Number:** 956406

**Contract Funding:**

**Source:**

**Current Contract Period From:** 04/83

**FY 1983**

**\$ 38,350**

**DOE**

**To:** 03/84

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Device and  
Measurements Research Area

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**Objectives:** The contractor shall perform defect characterization of selected silicon samples supplied by JPL; and perform a detailed analysis of experimental data to extend the understanding of the defect nature of the silicon material.

**Approach/Present Task:** Study the effect on defect density/distribution in materials supplied by JPL which are grown in the Advanced Materials Research Task.

**Status/FY 1983 Accomplishments:** Characterized Semix material.

**FY 1984 Milestones:** Final Report.

**Major Project Reports.** No major reports in FY 1983.

**Summary Date**  
October 1983

**JPL**

**Title:** Study of Relationships of Material Properties and High Efficiency Solar Cell Performance on Material Composition

**Contractor:**  
C. T. Sah Associates  
403 Pond Ridge Lane  
Urbana, IL 61801

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** C. T. Sah  
**Telephone:** (217) 328-1925

**Project Engineer:** L. Cheng  
**Telephone:** (213) 354-3068

**Contract Number:** 956289

**Contract Funding:**

**Source:**

**Current Contract Period From:** 07/82  
**To:** 08/84

<b>FY 1982</b>	<b>\$ 69,853</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Device and  
Measurements Research Task

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**Objectives:** The contract objective is to study the effects of impurities on the properties of silicon materials and the resultant performance of solar cells.

**Approach/Present Task:** Theoretical and experimental studies are used to examine the effects of impurities and cell design on solar cell performance; the studies of the effects on material properties are correlated with the solar cell concepts and experimental results.

**Status/FY 1983 Accomplishments:** A model concerning the cell performance enhancement from deep penetrating back-surface-field (BSF) layer was developed. The results show that significant performance improvements can be realized by extending the BSF layer thickness from 2  $\mu\text{m}$  (18% efficiency) to 40  $\mu\text{m}$  (20% efficiency) and, at the same time, immunity of cell performance to recombination defects can be enhanced by a factor of 2 to 3.

**FY 1984 Milestones:** To complete an in-depth study to identify all the factors that limit the efficiency of silicon solar cells to 20% under AM1 conditions.

**Major Project Reports:** *Study of Relationships of Material Properties and High Efficiency Solar Cell Performance on Material Composition.* (July 1983). DOE/JPL-956289-83/1. Pasadena, CA: Jet Propulsion Laboratory.

**Summary Date**  
October 1983

**JPL**

**Title:** Silicon Sheet With Molecular Beam Epitaxy for High Efficiency Solar Cells

**Contractor:**  
The Regents of the University of California  
Los Angeles  
405 Hilgard Avenue  
Los Angeles, CA 90024

**Principal Investigator:** F. G. Allen  
**Telephone:** (213) 825-2978

**Contract Number:** 956233

**Current Contract Period From:** 03/82  
**To:** 03/83

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Device and  
Measurements Research Task

**Directing Organization:**  
Jet Propulsion Laboratory

**Project Engineer:** T. Daud  
**Telephone:** (213) 354-5782

**Contract Funding:**

<b>FY 1982</b>	<b>\$ 28,834</b>
<b>FY 1983</b>	<b>\$ 59,311</b>

**Source:**

<b>JPL</b>
<b>DOE</b>

**Objectives:** The objective of the contract is to fabricate and deliver, using a molecular beam epitaxial (MBE) system, a set of silicon samples with epitaxial layers; characterize the layers by resistivity and C-V measurements; and fabricate and test solar cells leading to high efficiency solar cell structures.

**Approach/Present Task:** Demonstrate sharp doping profiles. Grow cell structures with potential for high performance. Fabricate solar cells and test at JPL.

**Status/FY 1984 Accomplishments:** Sharp doping profiles of Ga and Sb have been shown. Solid phase epitaxy has been developed for heavier doping. Theoretical analysis of multijunction solar cells has been completed to show enhancement of  $V_{oc}$  and efficiency.

**FY 1984 Milestones:**

- Deliver two MBE-grown p-n junction profiles to fabricate high-efficiency cells.
- Annual report describing growth procedure and test results by April 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

**JPL**

**Title:** Surface and Allied Studies in Silicon Solar Cells

**Contractor:**

University of Florida  
Division of Sponsored Research  
219 Grinter Hall  
Gainesville, FL 32611

**Principal Investigator:** F. Lindholm

**Telephone:** (904) 392-4929

**Contract Number:** 956525

**Current Contract Period From:** 06/83

**To:** 05/84

**Directing Organization:**

Jet Propulsion Laboratory

**Project Engineer:** T. Daud

**Telephone:** (213) 354-5782

**Contract Funding:**

**FY 1983**

**\$ 55,000**

**Source:**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Device and  
Measurements Research Task

**Objectives:** The contractor shall develop theoretical and experimental techniques for measurement of solar cell parameters.

**Approach/Present Task:** A theoretical framework will be developed to unify large-signal transient methods with small-signal, variable-frequency (bridge) methods. Two-part analysis of solar cells will be used to develop new techniques for measurement of surface recombination velocity at silicon surfaces.

**Status/FY 1983 Accomplishments:** Mathematical framework is being developed.

**FY 1984 Milestones:**

- Development of new technique for surface recombination velocity measurement.
- Annual report describing theory and experiments with techniques developed and results of measurements by July 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**

October 1983

**Title:** Development and Analyses of Silicon Solar Cells of Near 20% Efficiency

**Contractor:**  
The Trustees of the University of Pennsylvania  
3451 Walnut Street, 16  
Philadelphia, PA 19104

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** M. Wolf  
**Telephone:** (215) 898-4822

**Project Engineer:** R. Stirn  
**Telephone:** (213) 577-9230

**Contract Number:** 956290

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/82  
**To:** 11/83

<b>FY 1982</b>	<b>\$ 80,000</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Device and  
Measurements Research Task

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**Objectives:** The contractor shall investigate the adequacy of electronic properties of chemical vapor-deposited silicon layers for silicon solar cells having conversion efficiencies approaching 20% under AM1 conditions. Particular attention will be given to the bulk minority carrier properties as a function of deposition parameters and dopant type and concentration, and to the surface recombination rates.

**Approach/Present Task:** Develop a surface recombination velocity and minority carrier diffusion length measurement technique. A reliable technique, particularly to determine minority carrier diffusion length which is greater than the thickness of the material, is not currently existing. A reliable surface recombination velocity measurement technique is required to understand surface phenomena. The technique will be employed to measure surface recombination velocity and minority carrier diffusion length in various silicon sheet materials.

**Status/FY 1983 Accomplishments:** Demonstrated efficacy of light beam induced currents to determine lifetime and surface recombination velocity for 100  $\mu\text{m}$ -thick silicon layers on opposite polarity silicon substrates. Obtained silicon layers with lifetimes of 12 microseconds, adequate for cell efficiencies greater than 18%.

**FY 1984 Milestones:**

- Annual report on development and analyses of silicon solar cells of near 20% efficiency — November 1983.
- Demonstrate modulated light beam method for lifetime measurement in thin Si layers and determine its limitations — October 1984.
- Compare modulated light beam technique with steady state light beam-induced current method for several varieties of Si solar cell structure — December 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983



**JPL**

**Title:** Study of Deep Level Impurities and Defects in Silicon

**Contractor:**

University of Southern California  
Department of Contracts and Grants  
University Park  
Los Angeles, CA 90089-1141

**Principal Investigator:** R. Swimm

**Telephone:** (213) 898-4822

**Contract Number:** 956613

**Current Contract Period From:** 09/83

**To:** 08/84

**Directing Organization:**

Jet Propulsion Laboratory

**Project Engineer:** L. Cheng

**Telephone:** (213) 354-3068

**Contract Funding:**

**FY 1983**

**\$ 68,000**

**Source:**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Device and  
Measurements Research Task

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**Objectives:** The contractor shall develop and demonstrate high sensitive laser calorimetric spectroscopy for the characterization of deep level impurities and defects in silicon material.

**Approach/Present Task:** Experimental evaluation of a laser calorimetric spectroscopy for the characterization of deep level impurities and defects in silicon materials.

**Status/FY 1983 Accomplishments:** Contract started on 6 September 1983.

**FY 1984 Milestones:** Complete the evaluation.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

**JPL**

**Title:** Investigation of Silicon Surface Passivation by SiN<sub>x</sub> Film Deposition

**Contractor:**

University of Washington  
Grants and Contracts Services  
Room 1, Administrative Building, AD-24  
Seattle, WA 98195

**Principal Investigator:** L. Olsen

**Telephone:** (509) 375-3176

**Contract Number:** 956614

**Current Contract Period From:** 08/83  
**To:** 08/84

**Directing Organization:**

Jet Propulsion Laboratory

**Project Engineer:** R. Stirn

**Telephone:** (213) 577-9230

**Contract Funding:**

**FY 1983**            **\$ 86,995**

**Source:**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Device and  
Measurements Research Task

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**Objectives:** The contractor shall develop experimental techniques for passivating silicon surfaces in order to reduce surface recombination losses that may otherwise limit high efficiency performance of silicon solar cells.

**Approach/Present Task:** Silicon nitride layers will be deposited by plasma-assisted chemical vapor deposition and characterized as a function of deposition parameters. Net positive charge in the bulk and interface states of SiN<sub>x</sub> on silicon substrates should reduce surface recombination by inverting the near-surface region of the silicon.

**Status/FY 1983 Accomplishments:** Equipment for silicon nitride deposition has been ordered and computer programs written to determine refractive index of SiN<sub>x</sub> films from transmission and reflectance data.

**FY 1984 Milestones:**

- SiN<sub>x</sub> facility operational — November 1983.
- Deliver test structures and characterization data — August 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Polymer Aging Research

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** R. Liang  
**Telephone:** (213) 354-6314

**Project Engineer:** C. Coulbert  
**Telephone:** (213) 354-2610

**Contract Number:** Not applicable.

**Contract Funding:**

**Source:**

**Current Contract Period From:** FY 1977  
**To:** on-going

FY 1982	\$ 250,000
FY 1983	\$ 150,000

DOE
DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Environmental  
Isolation Research Task

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**Objectives:** Develop theoretical or empirical models for correlating and predicting failure or degradation rates in photovoltaic modules exposed to field and laboratory environments in order to achieve and assure the module life and performance required for economic viability.

**Approach/Present Task:**

- Identify mechanism and rates of photothermal degradations.
- Determine and monitor critical material responses to accelerated aging for EVA, EMA, PMMA, PVB, and RTV.
- Develop diagnostic techniques for early detection of degradation.
- Perform real-time outdoor validation using 2-cell modules.

**Status/FY 1983 Accomplishments:**

- Developing, compiling, and analyzing data base of chemical and physical property changes in pottants (PVB, RTV, EVA, EMA, PU, and PnBA) and cover (Tedlar, Korad, Mylar, and Acrylar) materials as a function of time, temperature, UV intensity, and configuration. Measuring optical, electrical, physical, and geometric changes and relating to chemical molecular changes.
- Research forum on "Quantifying Degradation."
- Photothermal characterization of pottant materials at 135°C.
- Developed photostabilization concepts for glassy polymers.

**FY 1984 Milestones:** Annual Report of new data generated.

**Major Project Reports:**

- Liang, R. H.; Oda, K.L.; Chung, S.Y.; Smith, M.V.; Gupta, A. (May 1983). *Handbook of Photothermal Test Data on Encapsulant Materials*. DOE/JPL-1012-86. Pasadena, CA: Jet Propulsion Laboratory; 159 pp.
- *Proceedings of the Flat-Plate Solar Array Project Research Forum on Quantifying Degradation*. (June 1983). JPL 5101-231, DOE/JPL-1012-89. Edited by E. Cuddihy. Pasadena, CA: Jet Propulsion Laboratory.

**Summary Date**  
October 1983

**JPL**

**Title:** Demonstration of Capability to Metallize Solar Cells by Ion-Plating

**Contractor:**  
Illinois Tool Works, Inc.  
1427 Holmes Road  
Elgin, IL 60120

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** W. Conley  
**Telephone:** (312) 741-6800

**Project Engineer:** E. Cuddihy  
**Telephone:** (213) 354-3188

**Contract Number:** 955506

**Contract Funding:**

**Source:**

**Current Contract Period From:** 12/79  
**To:** 10/82

<b>FY 1980</b>	<b>\$ 120,000</b>	<b>DOE</b>
<b>FY 1981</b>	<b>\$ 100,000</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ -0-</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Environmental  
Isolation Research Task

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**Objectives:** Contract objectives were to investigate, achieve, and demonstrate the capability to produce operational solar cells having front and back metallizations and antireflective (AR) coatings, both deposited by the use and techniques of pure, gasless, ion-plating.

**Approach/Present Task:** Not applicable.

**Status/FY 1983 Accomplishments:** No major accomplishments. Contract completed.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:**

- Conley, W.R. (1982). *Ion-Plating of Solar Cell Arrays Encapsulation Task — LSA Project 32; Final Report for December 1, 1979-October 31, 1982*. DOE/JPL/955506-83-3. Pasadena, CA: Jet Propulsion Laboratory; 32 pp. Work performed by Illinois Tool Works, Inc., Elgin, IL.

**Summary Date**  
October 1983

# JPL

**Title:** Development and Demonstration of Synthetic Procedures for Polymeric Ultraviolet Stabilizers and Absorbers

**Contractor:**  
Polytechnic Institute of New York  
333 Jay Street  
Brooklyn, NY 11201

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** O. Vogl  
**Telephone:** (413) 545-0433

**Project Engineer:** A. Gupta  
**Telephone:** (213) 354-5783

**Contract Number:** 956413

**Contract Funding:**

**Source:**

**Current Contract Period From:** 01/83  
**To:** 09/85

**FY 1983**      \$ 55,000

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Environmental  
Isolation Research Task

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**Objectives:** To test and scale up synthesis of previously developed ultraviolet absorbers and antioxidant additives which can be permanently incorporated into photovoltaic encapsulation materials, and develop encapsulation systems which retain their protective function outdoors for 20 years or more.

**Approach/Present Task:** The formulation and evaluation of synthesis methods for developing scaled-up processes for making candidate UV absorbers and antioxidant additives which were previously identified.

**Status/FY 1983 Accomplishments:** Several vinyl and isopropenyl derivatives of 2HB have been synthesized and their polymerization and copolymerization have been demonstrated. Improved photoaging properties were demonstrated.

**FY 1984 Milestones:** Incorporation of candidate formulations into polyesters and polycarbonates.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

**Title:** Study Program for Encapsulation Materials Interface for Low-Cost Silicon Solar Array

**Contractor:**  
 Rockwell International Corporation  
 Science Center, P.O. Box 1085  
 Thousand Oaks, CA 91360

**Directing Organization:**  
 Jet Propulsion Laboratory

**Principal Investigator:** D. Kaelble  
**Telephone:** (904) 498-4545

**Project Engineer:** D. Coulter  
**Telephone:** (213) 354-3638

**Contract Number:** 954739

**Contract Funding:**

**Source:**

**Current Contract Period From:** 03/77  
**To:** 12/83

FY	Amount	Source
FY 1978	\$ 103,700	DOE
FY 1979	\$ 99,660	DOE
FY 1980	\$ 92,400	DOE
FY 1981	\$ 115,755	DOE
FY 1982	\$ 119,888	DOE
FY 1983	\$ -0-	DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
 Photovoltaic Components  
 Research Area; Environmental  
 Isolation Research Task

**Objectives:**

- Contract objectives are to study encapsulation materials interface problems, through a physical/chemical study of surface and interfacial degradation mechanisms, induced by the singular and combined effects of moisture, temperature, and UV radiation; and to develop necessary theoretical and experimental methods for assuring the quality and life potential of adhesively bonded interfaces, and the requirements of encapsulation systems relative to corrosion protection. An experimental study aimed at developing and then validating one or more corrosive models is to be carried out.
- The scope of the contract was upgraded in FY 1982 to include the generation and validation of the necessary design and process principles for achieving long-term interfacial bonding stability of advanced FSA photovoltaic encapsulation systems and to carry out an experimental program to interpret and relate changes in output electrical characteristics.

**Approach/Present Task:**

- Investigate experimentally the effect of silane primers and their method of application on interface bond strength and durability.
- Evaluate an experimental bond shear test technique which provides statistical strength data using miniature test specimens and a statistical analysis of results.
- Complete a final report.

**Status/FY 1983 Accomplishments:**

- Quantitative relationships using Weibull statistical criteria have been established for bond stability using three different silane coupling agents with novel, shear test set-up.
- Final Report in preparation.

**FY 1984 Milestones:** Complete contract and final report — January 1984.

**Major Project Reports:** Annual Report — draft received.

**Summary Date**  
 October 1983

# JPL

**Title:** The Design, Analysis, and Test Verification of Advanced Encapsulation Systems

**Contractor:**

Spectrolab, Inc.  
12500 Gladstone Avenue  
Sylmar, CA 91342

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** A. Garcia

**Telephone:** (213) 365-4611

**Project Engineer:** E. Cuddihy

**Telephone:** (213) 354-3188

**Contract Number:** 955567

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/79  
**To:** 12/83

<b>FY 1980</b>	<b>\$ 358,000</b>	DOE
<b>FY 1981</b>	<b>\$ 300,000</b>	DOE
<b>FY 1982</b>	<b>\$ 207,584</b>	DOE
<b>FY 1983</b>	<b>\$ 94,558</b>	DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Environmental  
Isolation Research Task

**Objectives:**

- Contract objective is to prepare a prototype encapsulation system design based on recommended material selections and fabrication processes, including a detailed design analysis of the predicted optical, thermal, electrical (isolation), and structural performance of the recommended design.
- To develop optical, thermal, electrical, and structural analytical computer models for the analysis and performance assessment of module encapsulation systems. Parametric and sensitivity studies will provide design and performance optimization criteria relative to encapsulant material selection and material dimensions.
- To represent the complicated structural design behavior of encapsulation systems in the form of reduced-variable master curves.
- An additional task has been added in FY 1984 to develop and evaluate the potential of transparent conducting polymers as PV solar cell coatings to serve as AR layers and current collectors to replating metal grids.

**Approach/Present Task:**

- Use computer models to predict the sensitivity of module design and performance to solar cell shape, and thickness and encapsulation design parameters.
- Fabricate several prototype 4 ft × 4 ft PV modules of a substrate design using both cast urethane and laminated EVA potting. Modules to be tested at JPL.
- For transparent conducting polymers, set up deposition and characterization facilities. Investigate potential materials and deposition techniques and support theoretical modeling effort.

**Status/FY 1983 Accomplishments:**

- Reduced variable master design curves completed.
- Prototype PV module 4 ft × 4 ft with hardboard substrate delivered to JPL.
- Initial electrical and optical measurements made for polypyrrole deposited on a silicon cell.

**FY 1984 Milestones:**

- Assessment of performance of a TCM on solar cells; Final Report draft — December 1983.
- Final Report draft — December 1983.

**Major Project Reports:**

- Garcia, A., III; Kallis, J.M.; Trucker, D.C. (June 1983). *Design, Analysis and Test Verification of Advanced Encapsulation Systems, Triannual Report for the Period Ending 31 March 1983*. DOE/JPL-955567-83-11. Pasadena, CA; Jet Propulsion Laboratory; 48 pp. Work performed by Spectrolab, Inc., Sylmar, CA.

**Summary Date**

October 1983

**JPL**

**Title:** Ion Implantation of Non-Czochralski Silicon

**Contractor:**

Spire Corporation  
Patriots Park  
Bedford, MA 01730

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** R. Little

**Telephone:** (617) 275-6000

**Contract Number:** 956381

**Current Contract Period From:** 12/82  
**To:** 09/83

**Project Engineer:** D. Fitzgerald

**Telephone:** (213) 577-9097

**Contract Funding:**

**FY 1983**            **\$ 103,377**

**Source:**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Environmental  
Isolation Research Task

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**Objectives:** The contractor shall investigate and evaluate the capabilities of the ion implantation process for the production of photovoltaic cells from a variety of present day, state-of-the-art, low-cost silicon sheet materials, including, but not necessarily limited to, dendritic web, edge-defined film-fed growth (EFG) ribbon, semicrystalline (Semix) wafers, and polycrystalline [heat exchanger method (HEM) and Silso] wafers.

**Approach/Present Task:**

- Evaluate ion implanted sheet materials with comparison at pulsed electron beam anneal and thermal anneal.
- Complete Final Report.

**Status/FY 1983 Accomplishments:** Completed evaluation of ion implanted thermal annealed — September 1983.

**FY 1984 Milestones:**

- Complete evaluation of ion implanted sheet materials, compare pulsed electron beam anneal and thermal anneal — November 1983.
- Complete final report — November 1983.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983



# JPL

**Title:** Module Encapsulation Task

**Contractor:**  
Springborn Laboratories, Inc.  
Water Street — Hazardville  
Enfield, CT 06082

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** P. Willis  
**Telephone:** (203) 749-8371

**Project Engineer:** E. Cuddihy  
**Telephone:** (213) 354-3188

**Contract Number:** 954527

**Contract Funding:**

**Source:**

**Current Contract Period From:** 05/76  
**To:** 08/84

FY 1978	\$ 190,000
FY 1979	\$ 100,000
FY 1980	\$ 121,666
FY 1981	\$ 160,000
FY 1982	\$ 112,153
FY 1983	\$ 302,037

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DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Environmental  
Isolation Research Task

## Objectives:

- Contract objectives are to (1) identify, develop, and recommend material or materials and related processes suitable for low cost, automated encapsulation of solar cell modules, said encapsulation to protect the solar cells from terrestrial environment, and (2) develop and characterize specific encapsulation materials, specific encapsulation systems, and associated processes.
- The scope of the contract was expanded in FY 1982 to assess the 20-year life potential of low-cost materials and modules for operation at peak daytime temperatures of 60°C for rack mountings, and at peak daytime temperatures of 85°C for rooftop mountings. Life-limiting failure modes attributable to encapsulation designs and materials are to be identified and necessary modifications for extending life potential are to be undertaken and carried out.

## Approach/Present Task:

- New or modified encapsulant materials and processes are characterized and evaluated experimentally with results communicated to industry.
- Life-assessment studies are carried out with materials and encapsulated solar cells aged in RS/4 UV-accelerometers, air ovens, and on heated outdoor racks. Material properties and module electrical performance are monitored to provide data for extrapolated life predictions and to aid in validation of life prediction models.

## Status/FY 1983 Accomplishments:

- Extended aging time data continue to demonstrate excellent stability of EVA pottant.
- Antisoiling treatments for glass and polymer covers show excellent performance after 2-year outdoor exposure.
- Primers and adhesives for additional interface material combinations have been identified.
- Improved curing agents for EVA and EMA demonstrated extended shelf life and faster cure at lower temperatures.

**FY 1984 Milestones:** Transfer of material and process data to industry via annual report and PIM presentations.

## Major Project Reports:

- Willis, P.B.; Baum, B. (July 1982). *Investigation of Test Methods, Material Properties, and Processes for Solar Cell Encapsulants*. DOE/JPL/954527-82/23. Pasadena, CA: Jet Propulsion Laboratory; 138 pp. Work performed by Springborn Laboratories, Inc., Enfield, CT.

**Summary Date**  
October 1983

**JPL**

**Title:** Time Resolved Spectroscopic Measurements

**Contractor:**  
The Regents of the University of California  
Office of Contracts and Grant Administration  
Santa Cruz, CA 95064

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** D. Kliger  
**Telephone:**

**Project Engineer:** A. Gupta  
**Telephone:** (213) 354-5783

**Contract Number:** 956467

**Contract Funding:**

**Source:**

**Current Contract Period From:** 03/83  
**To:** 01/84

**FY 1983**                 **\$ 12,915**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Environmental  
Isolation Research Task

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**Objectives:** Provide spectroscopic and computer analysis services to facilitate characterizing the kinetic degradation mechanisms in polymeric encapsulants.

**Approach/Present Task:** Perform time resolved spectroscopic analysis on polymeric chromophores; perform computer simulation and deconvolution of transient decay data in order to extract rate constants; assist JPL in interpreting decay data; and modify Photochemical Research Association, Inc. (PRA) subnanosecond N<sub>2</sub> laser to reduce pulse jitter to less than two nanoseconds in order to excite ultraviolet absorbing chromophores.

**Status/FY 1983 Accomplishments:** All tasks performed as services and data transmitted to JPL.

**FY 1984 Milestones:** Continue services on an as-requested basis.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Development of Synthetic Procedures for Polymeric Ultraviolet Stabilizers and Absorbers

**Contractor:**

University of Massachusetts  
Office of Grant and Contract Administration  
Graduate Research Center  
Amherst, MA 01003

**Principal Investigator:** C. Vogl

**Telephone:** (413) 545-0433

**Contract Number:** 955531

**Current Contract Period From:** 08/79  
**To:** 09/83

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Environmental  
Isolation Research Task

**Directing Organization:**

Jet Propulsion Laboratory

**Project Engineer:** A. Gupta

**Telephone:** (213) 354-5783

**Contract Funding:**

<b>FY 1979</b>	<b>\$ 15,000</b>
<b>FY 1980</b>	<b>\$ 32,000</b>
<b>FY 1981</b>	<b>\$ 38,000</b>
<b>FY 1982</b>	<b>\$ 100,000</b>
<b>FY 1983</b>	<b>\$ -0-</b>

**Source:**

<b>DOE</b>
<b>DOE</b>
<b>DOE</b>
<b>DOE</b>
<b>DOE</b>

**Objectives:**

- Contract objectives were to develop synthetic procedures for certain polymerizable ultraviolet stabilizers and absorbers and study their copolymerization with methyl and butyl esters of methacrylic acid; and to develop candidate film materials which may function as outer covers for solar modules, which would meet cost and reliability goals.
- This contract was revised to include the development, testing, and scaling-up of synthesis of ultraviolet absorbers and antioxidant additives which can be permanently incorporated into PV encapsulation material in support of the goal to develop encapsulation systems which retain their protective function outdoors for 20 years or more.

**Approach/Present Task:** Not applicable.

**Status FY 1983 Accomplishments:** Task transferred to Polytechnic Institute of New York under Contract 956413.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:** *Development of Synthetic Procedures for Polymeric Ultraviolet Stabilizers and Absorbers; Final Report.* (December 1982). DOE/JPL-95553/-2. Pasadena, CA: Jet Propulsion Laboratory.

**Summary Date**

October 1983

**JPL**

**Title:** Accelerated Aging and Analyses of Polymers

**Contractor:**

University of Southern California  
Department of Chemistry  
University Park  
Los Angeles, CA 90089-1141

**Principal Investigator:** L. Singer

**Telephone:** (213) 743-4370

**Contract Number:** 956590

**Current Contract Period From:** 06/83

**To:** 09/83

**Directing Organization:**

Jet Propulsion Laboratory

**Project Engineer:** R. Liang

**Telephone:** (213) 354-6314

**Contract Funding:**

FY 1983

\$ 7,500

**Source:**

DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Environmental  
Isolation Research Task

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**Objectives:** Provide testing support services to age and analyze polymeric encapsulants as requested by JPL.

**Approach/Present Task:** Perform accelerated aging of approximately 10 polymer samples (acrylics, polyesters, and fluorocarbons) and analyze the samples for chemical property changes in order to understand the effects of degradation.

**Status/FY 1983 Accomplishments:** Data requested was obtained and supplied to JPL.

**FY 1984 Milestones:** None.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Modeling of Photodegradation in Solar Cell Modules of Substrate and Superstrate Design Made with Ethylene Vinyl Acetate Pottant Material

**Contractor:**

The Governing Council of the University of Toronto  
Office of Research Administration  
Simcoe Hall  
Toronto, Ontario, M5S 1A1, Canada

**Principal Investigator:** J. Guillet

**Telephone:** (416) 978-3591

**Contract Number:** 955591

**Current Contract Period From:** 01/80  
**To:** 08/83

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Environmental  
Isolation Research Task

**Directing Organization:**

Jet Propulsion Laboratory

**Project Engineer:** A. Gupta

**Telephone:** (213) 354-5783

**Contract Funding:**

FY 1980	\$ 55,000
FY 1981	\$ 52,085
FY 1982	\$ 108,100
FY 1983	\$ 20,750

**Source:**

DOE
DOE
DOE
DOE

**Objectives:**

- Contract objectives are to develop an analytical model of photodegradation of ethylene vinyl acetate (EVA) using real time test data on EVA encapsulated solar cell modules and laboratory data on EVA films free standing, under glass, or under other transparent covers/barriers; and to undertake verification and validation of the analytical model of photodegradation of EVA heretofore developed.
- The contract has been revised to reflect measurement by viscometry the rates of degradation of EVA to determine the effect of additives. The contract was further revised for the contractor to develop, test, and validate the computerized analytical model for prediction of changes that may occur within time spans of up to 20 years in the chemical properties of EVA as it is aged outdoors.

**Approach/Present Task:**

- Use analytical computer model to investigate probable chemical changes and mechanisms in EVA as a function of time, temperature, and radiation intensities.
- Assess the possible effects of various stabilization approaches.
- Conduct or utilize the results of experimental tests for validating or modifying the model.

**Status/FY 1983 Accomplishments:**

- Polymer degradation versus UV intensity and temperature calculated.
- Most promising stabilization mechanism for long life identified.

**FY 1984 Milestones:**

- Perform validation experiments to confirm calculated results.
- Summary report of modeling studies

**Major Project Reports:**

- *Modelling of Polymer Photodegradation for Solar Cell Modules; Quarterly Report Covering the Period from 1/1/83-3/31/83. (1983). DOE/JPL-955591-83/6. Pasadena, CA: Jet Propulsion Laboratory.*
- *Modelling of Photodegradation in Solar Cell Modules of Substrate and Superstrate Design Mode with Ethylene-Vinyl Acetate as Pottant Material; Annual Report. (1982). DOE/JPL-955591-83/7. Pasadena, CA: Jet Propulsion Laboratory.*
- *Modelling of Polymer Photodegradation for Solar Cell Modules; Quarterly Report Covering the Period from 4/1/83-6/30/83. (1983). DOE/JPL-955591-83/8. Pasadena, CA: Jet Propulsion Laboratory.*

**Summary Date**  
October 1983

# JPL

**Title:** Dendritic Web Processing (lab support)

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** P. Alexander  
**Telephone:** (213) 577-9324

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:** FY 1981  
**To:** FY 1984

<b>FY 1982</b>	<b>\$ 75,000</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ 34,000</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

**Objectives:** The objective of this task is to support the Westinghouse dendritic web (non-Cz) Contract 955909 by:

- Process verification of dendritic web material.
- Complementing contractor test evaluation with unique JPL diagnostic equipment such as ion microprobe, SEM, etc.

**Approach/Present Task:** The approaches to achieving the stated objectives of contract support are:

- Process selected lots of dendritic web material using liquid dopant solutions and liquid applied masks. Generate test data.
- Perform complementary diagnostic test on selected samples — i.e., junction profile with ion probe, SEM analyses, etc., as appropriate.

**Status/FY 1983 Accomplishments:**

- Completed lab support of liquid dopant studies for front and back junctions — August 1983.
- Presented joint JPL-Westinghouse paper on liquid back junction formation at Electrochemical Society Meeting — May 1983.
- Completed process interface effort on ion implanted web material — September 1983.

**FY 1984 Milestones:**

- Present a least one joint JPL-Westinghouse paper on liquid dopant investigations during FY 1984.
- Start lab support upon execution of new contract — November 1983.

**Major Project Reports:**

- Tarneja, K.S.; Campbell, R.B.; Alexander, P. (1983). "Investigation of Liquid Dopants for High Efficiency Solar Cell Production Using Dendritic Web Material." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA: 8-13 May 1983. Vol. 83-1. Pennington, NJ: ECS; p. 798.*

**Summary Date**  
October 1983

**JPL**

**Title:** Large Scale Lamination Research

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** D. Burger  
**Telephone:** (213) 577-9374

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:** FY 1982  
**To:** FY 1983

<b>FY 1982</b>	<b>\$ 35,000</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ 64,000</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

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**Objectives:** Large area (greater than 1-1/2 ft x 4 ft) PV module vacuum lamination is a new processing area. New equipment and process control concepts are to be developed and verified by experimental testing.

**Approach/Present Task:**

- Design research laminator and control system using innovative concepts and available industrial components.
- Fabricate laminator and control system.
- Check out system operation.
- Laminate test modules.

**Status/FY 1983 Accomplishments:**

- Completed all FY 1983 milestones except process sensitivity which was cancelled due to project redirection.
- Completed final report.

**FY 1984 Milestones:** Task is complete.

**Major Project Reports:**

- Cuddihy, E. (September 1982). *Photovoltaic Module Encapsulation Design and Materials Selection, Volume I (Abridged)*. DOE/JPL-1012-77. Pasadena, CA: Jet Propulsion Laboratory; 33 pp.

**Summary Date**  
October 1983

**Title:** Metallization System Research

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** D. Burger  
**Telephone:** (213) 577-9374

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/82  
**To:** 09/83

<b>FY 1982</b>	<b>\$ 20,000</b>
<b>FY 1983</b>	<b>\$ 92,000</b>

**DOE**  
**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

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**Objectives:** Develop process-oriented technique to measure contact resistance of PV cell metallization system. Present transmission line method (TLM) requires special patterns and has high error potential.

**Approach/Present Task:**

- Measure contact resistance, current linearity, temperature linearity, and current crowding on special test cells and standard process cells.
- Extend measurements to determine potential for use in measuring contact degradation.
- Develop method of probing thick film in cell metallization systems.

**Status/FY 1983 Accomplishments:**

- All FY 1983 milestones were met on time; experimental test station was completed.
- Two addition papers were initiated.
- Computer program CERTLM sent to COSMIC to document measurement methods.

**FY 1984 Milestones:**

- Complete metallization interface degradation studies — January 1984.
- Presentation of measurements paper — April 1984.
- Presentation of degradation paper — May 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983



# JPL

**Title:** Semix Material Processing

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** P. Alexander  
**Telephone:** (213) 577-9324

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:** FY 1981  
**To:** FY 1984

**FY 1982**            \$ 70,000  
**FY 1983**            \$ 28,000

**DOE**  
**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

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**Objectives:** The objective of this task is to support the Solarex polycrystalline processing Contract 955902 by:

- Process verification of Semix material.
- Complementing contractor test evaluation with unique JPL diagnostic equipment such as ion microprobe, SEM, etc.

**Approach/Present Task:** The approaches to achieving the stated objectives of contract support are:

- Process selected lots of Semix material of specified bulk resistivity and thickness. Generate test data.
- Perform complementary diagnostic tests on selected samples — i.e., junction profile with ion probe, SEM analyses, etc., as appropriate.
- Conduct data analyses as appropriate.

#### **Status/FY 1983 Accomplishments**

- Completed lab support of bulk resistivity and silicon substrate experiments — April 1983.
- Presented joint JPL-Solarex paper at Electrochemical Society Meeting on bulk resistivity/thickness experiments — May 1983.

#### **FY 1984 Milestones:**

- Present joint JPL-Solarex paper at 1983 Photovoltaic Solar Energy Conference, Athens, Greece on mechanisms limiting the performance of large grain polycrystalline silicon solar cells — October 1983.
- Start lab support effort upon execution of new contract — November 1983.
- Present at least one joint JPL-Solarex paper during FY 1984.

#### **Major Project Reports:**

- Wohlgemuth, J.H.; Culik, J.S.; Alexander, P. (1983). "Mechanisms Limiting Performance in Polycrystalline Silicon Solar Cells." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1. Pennington, NJ: ECS; pp. 346-347.

**Summary Date**  
October 1983

**JPL**

**Title:** Laboratory Services

**Contractor:**

Applied Solar Energy Corporation  
15251 East Don Julian Road  
City of Industry, CA 91746

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** K. Ling

**Telephone:** (213) 968-6581

**Project Engineer:** D. Burger

**Telephone:** (213) 577-9374

**Contract Number:** 955423

**Contract Funding:**

**Source:**

**Current Contract Period From:** 03/79  
**To:** 10/84

**FY 1979** \$ 135,000

DOE

**FY 1980** \$ -0-

DOE

**FY 1981** \$ 75,000

DOE

**FY 1982** \$ 68,000

DOE

**FY 1983** \$ 27,000

DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

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**Objectives:** Contract objective is to provide laboratory services to perform solar cell and solar module manufacturing process steps and testing as directed by JPL.

**Approach/Present Task:** Present task is to support ion implantation, diffusion barrier, and contact resistivity research programs.

**Status/FY 1983 Accomplishments:** During FY 1983 this contractor supported research efforts in ion implantation, contact resistivity, and base metal thick film ink formulations.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:** No reports are required on this time and material service contract.

**Summary Date**  
October 1983

# JPL

**Title:** Development of an All-Metal Thick Film Cost-Effective Metallization System for Solar Cells

**Contractor:**

Bernd Ross Associates  
2154 Blackmore Court  
San Diego, CA 92109

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** B. Ross

**Telephone:** (714) 274-1391

**Project Engineer:** B. Gallagher

**Telephone:** (213) 577-9255

**Contract Number:** 954688

**Contract Funding:**

**Source:**

**Current Contract Period From:** 05/80

**To:** 01/83

**FY 1980** \$ 113,716

**FY 1981** \$ 20,000

**FY 1982** \$ 69,260

**FY 1983** \$ -0-

DOE

DOE

DOE

DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

**Objectives:** Contract objectives are to develop and perform expert analysis and critical evaluation of an all-metal improved thick film solar cell contact utilizing base metals.

**Approach/Present Task:** All-metal copper-based back contacts have been successfully formulated which have produced solar cells with efficiencies greater than 13%. Original reproducibility problems with formulating the thick film inks have been solved.

**Status/FY 1983 Accomplishments:** Investigations involving the analysis of the possible kinetic reactions occurring at the silicon surface as a function of metal composition, firing schedules, and ambients have been completed. The contract has been completed. The Final Report has been approved.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:**

- Parker, J.; Gallagher, B. (1983). "Application of Thermoanalysis to Thick Film Materials Development." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1. Pennington, NJ: ECS; pp. 352-353.

**Summary Date**

October 1983

**Title:** Diffusion Barrier Studies

**Contractor:**  
California Institute of Technology  
1301 East California  
Pasadena, CA 91125

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** M. Nicolet  
**Telephone:** (213) 795-4801

**Project Engineer:** D. Burger  
**Telephone:** (213) 577-9374

**Contract Number:** Not applicable — Caltech work order No. 61517

**Contract Funding:**

**Source:**

**Current Contract Period From:** 07/82  
**To:** 07/84

<b>FY 1982</b>	<b>\$ 60,000</b>
<b>FY 1982</b>	<b>\$ 10,000</b>
<b>FY 1983</b>	<b>\$ 65,000</b>

Caltech
In-House
DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

**Objectives:** Determine applicability of nitride and amorphous metal films as diffusion barriers for base metal front surface grids on PV cells.

**Approach/Present Task:** Apply titanium nitride (TiN) films to a variety of substrates and cover with a variety of metals. Ion implant through TiN films. Apply amorphous films to a variety of substrates. Ion implant amorphous films. Use backscatter spectrometry to determine condition of all test films.

**Status/FY 1983 Accomplishments:** New insights were gained into ion mixing. Iron-tungsten amorphous film characteristics were investigated and found to be very interesting for further testing. Nine papers were published.

**FY 1984 Milestones:**

- Investigate titanium nitride films as diffusion barriers — July 1984.
- Examine various titanium nitride deposition processes — July 1984.
- Explore barrier height modification in amorphous metal films — July 1984.

**Major Project Reports:**

- Paine, B.M.; Nicolet, M.A. (May 1983). "Shifts of Dilute Pt Impurities in Amorphous Si by Ion Irradiation." *Proceedings of the 3rd International Conference on Ion Beam Modifications of Material; Grenoble, France; 6-10 September 1982.* Appears in *Nuclear Instruments and Methods*. Vol. 209/210 (Part I); pp. 173-177.
- Fernandez, R.; Shreter, U.; Nicolet, M.A. (May 1983). "Temperature and Diffusion Effects in Preferential Sputtering of CrSi<sub>2</sub>." *Proceedings of the 3rd International Conference on Ion Beam Modifications of Materials; Grenoble, France; 6-10 September 1982.* Appears in *Nuclear Instruments and Methods*. Vol. 209/210, (Part I); pp. 513-519.
- Lau, S.S.; Liu, B-X; Nicolet, M.A. (May 1983). "Ion Mixing and Phase Diagrams." *Proceedings of the 3rd International Conference on Ion Beam Modifications of Materials; Grenoble, France; 6-10 September 1982.* Appears in *Nuclear Instruments and Methods*. Vol. 209/210, (Part I); pp. 97-105.
- Scott, D.M.; Nicolet, M.A. (May 1983). "The Effects of Implanted Oxygen on Pd<sub>2</sub>Si Formation." *Proceedings of the 3rd International Conference on Ion Beam Modification of Material; Grenoble, France; 6-10 September 1982.* Appears in *Nuclear Instruments and Methods*. Vol. 209/210, (Part I); pp. 297-301.
- Finetti, M.; Pan, E. T-S.; Suni, I.; Nicolet, M.A. (June 1983). "Electrical Characteristics of Amorphous Iron-Tungsten Contacts on Silicon." *Applied Physics Letters*. Vol. 42 (No. 11); pp. 987-989.
- Shreter, U.; Fernandez, R.; Nicolet, M.A. (August 1983). "Temperature-Dependent Ion Mixing and Diffusion During Sputtering of Thin films of CrSi<sub>2</sub> on Silicon." *Applied Physics Letters*. Vol. 43, (No. 3); pp. 247-249.

**Summary Date**  
October 1983

# JPL

**Title:** Development of Technique for AR Coating and Nickel Copper Metallization of Solar Cells

**Contractor:**  
Photowatt International  
2414 West 14th Street  
Tempe, AZ 85281

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** W. Taylor  
**Telephone:** (602) 894-0564

**Project Engineer:** C. Radics  
**Telephone:** (213) 577-9402

**Contract Number:** 955986

**Contract Funding:**

**Source:**

**Current Contract Period From:** 05/81  
**To:** 10/82

FY 1981	\$ 79,000	JPL
FY 1982	\$ 45,859	JPL
FY 1983	\$ -0-	JPL

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

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**Objectives:** Contract objective is to perform analysis and evaluation of the technical feasibility and cost effectiveness of a system for metallizing silicon solar cells.

**Approach/Present Task:** Frit-containing and frit-less metal ink compositions of nickel tin-base and molybdenum-tin base are being applied to AR coated solar cells. Electroplated copper is being used to reduce gridline resistance. The firing conditions, metal contacts, and the resulting solar cells are being evaluated.

**Status/FY 1983 Achievements:** Final report has been accepted. Project has been completed.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:**

- *Development of Technique for AR Coating and Nickel and Copper Metalization of Solar Cells.* (1983). DOE/JPL-955986-4. Pasadena, CA: Jet Propulsion Laboratory; 35 pp. Work performed by Photowatt International, Inc., Tempe, AZ.

**Summary Date**  
October 1983

**Title:** Process Research of Polycrystalline Silicon Material

**Contractor:**  
Solarex Corporation  
1335 Piccard Drive  
Rockville, MD 20850

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** J. Culik  
**Telephone:** (301) 948-0202

**Project Engineer:** P. Alexander  
**Telephone:** (213) 577-9324

**Contract Number:** 955902

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/80  
**To:** 12/83

<b>FY 1981</b>	<b>\$ 689,000</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 192,154</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

**Objectives:** In August 1982, the contract title was changed from Module Experimental Process Development Unit (MEPSDU) to Process Research of Polycrystalline Silicon Material (PROPSM). The scope of the contract has been changed to reflect the investigation of high-risk, high-payoff research areas on solar cell efficiency mechanisms in processing Semix and other polycrystalline silicon materials. In the performance of this task, the contractor shall design silicon substrate experiments and bulk resistivity experiments; perform data analysis/process investigations; provide comprehensive test matrices; perform cost analyses on processes being investigated and provide to JPL sample solar cells and polycrystalline (Semix) silicon material.

**Approach/Present Task:** Present effort is now research oriented. Key elements of Semix processing, such as surface preparation and diffusion, have been selected to investigate process mechanisms affecting polycrystalline solar cell efficiencies.

**Status/FY 1983 Accomplishments:**

- Completed and distributed MEPSDU (Module Experimental Process System Development Unit) Summary Report — October 1982.
- Completed the silicon substrate and bulk resistivity experiments — January 1983.
- Presented a joint JPL-Solarex paper at Electrochemical Society meeting on bulk resistivity/thickness experiments — May 1983.
- Completed mini-cell experiments (400 cells on 100 cm<sup>2</sup> wafer) — September 1983.

**FY 1984 Milestones:**

- Start new contract on passivation and process sensitivity studies — November 1983.
- Complete and issue final report of Contract 955909 — December 1983.
- Present at least one joint JPL-Solarex paper on process research of polycrystalline silicon material during FY 1984.

**Major Project Reports:**

- Culik, J.S. (1983). *Process Research on Polycrystalline-Silicon Material (PROPSM), Quarterly Report No. 10, April 1, 1983 — June 30, 1983.* DOE/JPL/955902-83/10. Pasadena, CA: Jet Propulsion Laboratory; 60 pp. Work performed by Solarex Corporation, Rockville, MD.
- Culik, J.S. (1983). *Process Research on Polycrystalline-Silicon Material (PROPSM), Quarterly Report No. 9, for January 1 — March 31, 1983.* DOE/JPL/955902-83/9. Pasadena, CA: Jet Propulsion Laboratory; 40 pp. Work performed by Solarex Corporation, Rockville, MD.

**Summary Date**  
October 1983

**JPL**

**Title:** Investigation of Nickel-Silicon Metallization Process

**Contractor:**  
Sollos, Inc.  
1519 Comstock Avenue  
Los Angeles, CA 90024

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** M. Macha  
**Telephone:** (213) 277-2396

**Project Engineer:** C. Radics  
**Telephone:** (213) 577-9402

**Contract Number:** 956276

**Contract Funding:** **Source:**

**Current Contract Period From:** 07/82  
**To:** 12/82

<b>FY 1982</b>	<b>\$ 29,025</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

**Objectives:** The objective of the contract is to perform investigation, analysis and verification of the silicon solar cell metallization systems based on nickel metal layer fired through a predeposited AR coating of Si<sub>3</sub>N<sub>4</sub> (silicon nitride).

**Approach/Present Task:** Investigation of screening ink compositions and firing conditions leading to a cost-effective process for metallization.

**Status/FY 1983 Accomplishments:** Project has been completed. Final Report was accepted July 1983.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:**

- *Investigation of Nickel Silicon Metallization Process; Final Report.* (July 1983). DOE/JPL-956276-1. Pasadena, CA: Jet Propulsion Laboratory; 16 pp.

**Summary Date**  
October 1983

# JPL

**Title:** Development of Metallization Process

**Contractor:**

Spectrolab, Inc.  
12500 Gladstone Avenue  
Sylmar, CA 91342

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** A. Garcia

**Telephone:** (213) 354-4611

**Project Engineer:** B. Gallagher

**Telephone:** (213) 577-9225

**Contract Number:** 956205

**Contract Funding:**

**Source:**

**Current Contract Period From:** 04/82

**FY 1982**            \$ 202,709

DOE

**To:** 11/83

**FY 1983**            \$ -0-

DOE

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

**Objectives:** The objective of the contract is the development and demonstration of a metallization equipment process, or group of processes, which will be capable of being utilized in the baseline process sequence which will result in an improvement in cost performance and/or a reduction in risk.

**Approach/Present Task:** The approach involves formulating a thick film ink utilizing molybdenum, tin, and titanium hydride powders.

**Status/FY 1983 Accomplishments:**

- Demonstration samples of the best combination of coating tests have been completed — May 1983.
- Metallization/conductive transparent coating tests have been completed — May 1983.

**FY 1984 Milestones:**

- Garcia, A., III. (August 1983). *Development of Metallization Process; Quarterly Technical Progress Report for the Period Ending June 30 1983*. DOE/JPL-956205/5. 16 pp. Work performed by Spectrolab, Inc. Sylmar, CA.
- Garcia, A., III. (May 1983). *Development of Metallization Process; FSA Project, Cell and Module Formation Research Area, Quarterly Technical Progress Report for the Period Ending 31 March 1983*. DOE/JPL/956205-83/4. Pasadena, CA: Jet Propulsion Laboratory; 12 pp. Work performed by Spectrolab, Inc., Sylmar, CA.
- Garcia, A., III. (April 1983). *Development of Metallization Process; FSA Project, Cell and Module Formation Research Area, Quarterly Technical Progress Report Ending December 31, 1982*. DOE/JPL/956205-83/3. Pasadena, CA: Jet Propulsion Laboratory; 7 pp. Work performed by Spectrolab, Inc., Sylmar, CA.
- Garcia, A. III; Gallagher, B.D. (1983). "A Non-Noble Front Metallization Process Using Mo/Sn Screen Printed Pastes." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1. Pennington, NJ: ECS; p. 358.
- Garcia, A., III. (November 1982). *Development of Metallization Process; Quarterly Technical Report for the Period Ending 30 September 1982*. DOE/JPL/956205-82/2. Pasadena, CA; Jet Propulsion Laboratory; 14 pp. Work performed by Spectrolab, Inc., Sylmar, CA.

**Summary Date**  
October 1983



**JPL**

**Title:** Development and Fabrication of a Solar Cell Junction Processing System

**Contractor:**  
Spire Corporation  
Patriots Park  
Bedford, MA 01730

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** A. Armini  
**Telephone:** (617) 275-6068

**Project Engineer:** D. Fitzgerald  
**Telephone:** (213) 354-4792

**Contract Number:** 955640

**Contract Funding:**

**Source:**

**Current Contract Period From:** 01/80  
**To:** 02/82

<b>FY 1980</b>	<b>\$ 865,000</b>	<b>DOE</b>
<b>FY 1981</b>	<b>\$ 600,000</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 320,000</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

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**Objectives:** Contract objectives are to develop, construct, and deliver a junction processing system which shall be capable of producing solar cell junctions by means of ion implantation followed by pulsed electron beam annealing. The machine shall be capable of processing 4-in. diameter single crystal Czochralski wafers at a rate of 10 million wafers per year.

**Approach/Present Task:** Complete Final Report.

**Status/FY 1983 Accomplishments:** Completed NMA ion implanter development — January 1983. (Contract was halted due to lack of funds before actual assembly of parts and test. However, design was satisfactorily proven during design test phase solar cell ion implants in FY 1982).

**FY 1984 Milestones:** Complete Final Report — December 1983.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

JPL

**Title:** Hermetic Edge Sealing of Photovoltaic Modules

**Contractor:**  
Spire Corporation  
Patriots Park  
Bedford, MA 01730

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** R. Little  
**Telephone:** (617) 275-6000

**Project Engineer:** D. Burger  
**Telephone:** (213) 577-9374

**Contract Number:** 956352

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/82  
**To:** 06/83

**FY 1983**            **\$ 77,550**

**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

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**Objectives:** The contractor is to investigate the feasibility of using an electrostatic bonding and ultrasonic welding process in air at atmosphere pressure to produce hermetic edge seals on terrestrial photovoltaic solar cell modules.

**Approach/Present Task:** Develop an electrostatic bonding technique for bonding aluminum foil to glass sheet in air. Develop an ultrasonic bonding technique for bonding aluminum foil to foil/glass combination. Demonstrate hermetic seal by testing samples.

**Status/FY 1983 Accomplishments:** Not applicable.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:**

- Nowlan, M.J. (July 1983). *Final Technical Report for: Hermetic Edge Sealing of Photovoltaic Modules*. DOE/JPL/956352-2. Pasadena, CA: Jet Propulsion Laboratory; 29 pp. Work performed by Spire Corporation, Bedford, MA.
- Nowlan, M.J. (February 1983). *Hermetic Edge Sealing of Photovoltaic Modules; Quarterly Technical Report*. DOE/JPL/956352-1. Pasadena, CA: Jet Propulsion Laboratory; 20 pp. Work performed by Spire Corporation, Bedford, MA.

**Summary Date**  
October 1983

# JPL

**Title:** Analyses and Evaluation of Module Experimental Process System Development Unit Processes

**Contractor:**  
The Trustees of the University of Pennsylvania  
3451 Walnut Street, 16  
Philadelphia, PA 19104

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:** M. Wolf  
**Telephone:** (215) 243-4822

**Project Engineer:** B. Gallagher  
**Telephone:** (213) 577-9225

**Contract Number:** 956034

**Contract Funding:**

**Source:**

**Current Contract Period From:** 05/81  
**To:** 05/82

<b>FY 1981</b>	<b>\$ 59,691</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ -0-</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	<b>DOE</b>

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

**Objectives:** Contract objective is to perform expert analysis and critical evaluation of processes as proposed or designed by Module Experimental Process System Development Unit (MEPSDU) contractors including MEPSDU support contractors. An additional objective is to define critical areas requiring research to advance state-of-the-art efficiencies.

**Approach/Present Task:** Not applicable.

**Status/FY 1983 Accomplishments:** Final Report published and distributed.

**FY 1984 Milestones:** Not applicable.

**Major Project Reports:**

- Wolf, M. (April 1982). *Analysis and Evaluation in the Production Process and Equipment Area of the Low-Cost Solar Array Project; Final Report.* DOE/JPL/956034-81/1. Pasadena, CA: Jet Propulsion Laboratory; 61 pp. Work performed by University of Pennsylvania, The Moore School of Electrical Engineering, Philadelphia, PA.

**Summary Date**  
October 1983

# JPL

**Title:** Process Research of Non-Czochralski Silicon Material

**Contractor:**

Westinghouse Electric Corporation  
Advanced Energy Systems Division  
P.O. Box 10864  
Pittsburgh, PA 15236

**Principal Investigator:** R. Campbell

**Telephone:** (412) 892-5600, X5364

**Contract Number:** 955909

**Current Contract Period From:** 11/80

**To:** 11/83

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

**Directing Organization:**

Jet Propulsion Laboratory

**Project Engineer:** P. Alexander

**Telephone:** (213) 577-9324

**Contract Funding:**

<b>FY 1981</b>	<b>\$ 830,000</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 538,886</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	<b>DOE</b>

**Source:**

**Objectives:** The contract has been rescoped to include the investigation of high-risk, high-payoff research areas on advanced processing techniques, specifically ion implantation and liquid dopants and coatings, which indicate promise of improving the cost effectiveness of photovoltaic module production using non-Cz silicon sheet material. There are three studies: a liquid diffusion mask feasibility study to determine the technical feasibility of forming a liquid applied diffusion mask to replace the more costly chemical vapor deposition SiO<sub>2</sub> diffusion mask; another study on antireflective (AR), photoresist (PR) meniscus coating applications to determine the technical feasibility of applying liquid AR and PR solutions using meniscus coating equipment; and a third study on ion implantation compatibility/feasibility to investigate the feasibility of producing uniform high efficiency solar cells from non-Cz silicon using ion implantation junction formation techniques.

**Approach-Present Task:** Present effort is now research oriented. Liquid dopant experiments are well underway and will include liquid applied masks and liquid applied front and back junctions. Ion implantation experiments planned.

**Status/FY 1983 Accomplishments:**

- Presented joint JPL-Westinghouse paper at Electrochemical Society Meeting on liquid dopant back junction formation — May 1983.
- Completed liquid dopant studies and ion implantation studies — August 1983.
- Completed cost analyses of liquid dopant sequentially formed junction formation — September 1983.

**FY 1984 Milestones:**

- Start new contract on simultaneously formed front and back junctions — November 1983.
- Issue final report on liquid dopant studies of Contract 955909 — December 1983.
- Present at least one joint JPL-Westinghouse paper on liquid dopant investigations during FY 1984.

**Major Project Reports:**

- *Process Research on Non-Cz Silicon Material, Quarterly Report No. 5, March 1, 1983 to May 31, 1983. (1983). DOE/JPL/955909-83/10. Pasadena, CA: Jet Propulsion Laboratory; 33 pp. Work performed by Westinghouse Electric Corporation, Advanced Energy Systems Division, Pittsburgh, PA.*
- *Process Research on Non-Cz Silicon Material, Quarterly Report No. 4 for the Period December 1, 1982-February 28, 1983. (1983). DOE/JPL/955909-83/9. Pasadena, CA: Jet Propulsion Laboratory; 29 pp. Work performed by Westinghouse Electric Corporation, Advanced Energy Systems Division, Pittsburgh, PA.*

**Summary Date**  
October 1983

# JPL

**Title:** Laser Assisted Solar Cell Metallization Processing

**Contractor:**

Westinghouse Electric Corporation  
1310 Beulah Road  
Pittsburgh, PA 15235

**Directing Organization:**

Jet Propulsion Laboratory

**Principal Investigator:** S. Dutta

**Telephone:** (412) 256-7281

**Project Engineer:** B. Gallagher

**Telephone:** (213) 354-9225

**Contract Number:** 956615

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/83

FY 1983

\$ 203,421

DOE

**To:** 09/84

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Photovoltaic Components  
Research Area; Process  
Research Task

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**Objectives:** The contractor shall investigate, develop, and characterize the processes required to produce fine line, thin metal grid structures that are required to produce high efficiency solar cells utilizing laser assisted processing techniques.

**Approach/Present Task:** Assess the state-of-the-art. Fabricate cells using both photolytic and pyrolytic decomposition techniques. Characterize the cells, model the process, and determine the effect of transient heating on bulk lifetime and junction characteristics.

**Status/FY 1983 Accomplishments:** Work on this contract did not start until the end of FY 1983.

**FY 1984 Milestones:**

- Fabricate cells — May 1984.
- Characterize cells — July 1984.
- Quarterly technical reports — January, April, July, 1984.

**Major Project Reports:** No major reports in FY 1983.

**Summary Date**  
October 1983

# JPL

**Title:** Project Analysis and Integration

**Contractor:**  
In-House

**Directing Organization:**  
Jet Propulsion Laboratory

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** P. Henry  
**Telephone:** (213) 577-9414

**Contract Number:** Not applicable

**Contract Funding:**

**Source:**

**Current Contract Period From:** 01/75  
**To:** 12/88

**FY 1982**            \$ 591,000  
**FY 1983**            \$ 520,000

**DOE**  
**DOE**

**Project/Area/Task:** Flat-Plate Solar Array Project;  
Project Analysis and Integration  
Area

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**Objectives:** The PA&I Area objective is to provide the FSA Project with the appropriate support in planning integration and decision-making and to establish and maintain the Project standards of economic comparison.

**Approach/Present Task:** The appropriate models are developed for cost projection, budgetary trade-off probability analysis. These models are applied to problems of widespread interest to the photovoltaic industry. Specific operation research problems are also addressed.

**Status/FY 1983 Accomplishments:**

- Dendritic web cost projection: established cost feasibility of less than \$0.60/W<sub>p</sub>. High efficiency crystalline PV.
- SIMRAND analysis of silicon feedstock costs: probabilistic analysis of projected silicon costs. Used to bound sensitivity of PV module cost to silicon cost.
- First use of "efficient frontier" methodology on metallization: presented the family of metallization options in cost/performance space in such a way that optimum metallization systems can be chosen, and future research directions indicated. Combined SAMICS and metallization optimization model.

**FY 1984 Milestones:**

- Complete cell metallization/transparent conducting material optimization methodology.
- Complete ribbon economic assessment.
- Complete subsystem sensitivity to \$0.15/kWh goal.
- Complete Allocation Guideline for \$0.15/kWh goal.
- Complete preliminary multi-junction cell economic analysis.

**Major Project Reports:**

- Daniel, R. E. (February 1982). *Summary Guide to Using SAMIS*. JPL 5101-193. Pasadena, CA: Jet Propulsion Laboratory; 90 pp.
- Miles, R. F., Jr. (July 1982). *The SIMRAND Methodology/Simulation of Research and Development Projects*. JPL 5101-213. Pasadena, CA: Jet Propulsion Laboratory; 35 pp.
- Bard, J. F. (September 1983). *Funding at Redundant R&D Tasks with Probabilistic Outcomes*. JPL 5101-240. Pasadena, CA: Jet Propulsion Laboratory; 33 pp.

**Summary Date**  
October 1983

# SNLA

**Title:** Data Acquisition and Reduction for Intermediate PV Sites

**Contractor:**

Boeing Computer Services Company  
Energy Technology Applications Division  
565 Andover Park West  
Tukwila, WA 98188

**Principal Investigator:** J. Muldoon

**Telephone:**

**Contract Number:** 16-4997

**Current Contract Period From:**

**To:** 01/31/83

**Project/Area/Task:** Array Design and Evaluation

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** T. D. Harrison

**Telephone:**

**Contract Funding:**

FY 1980 \$ 715,266

FY 1981 \$ 836,446

FY 1982 \$ 668,346

FY 1983 \$ 210,000

FY 1984 \$ -0-

**Source:**

SNLA

SNLA

SNLA

SNLA

SNLA

**Objectives:** To acquire performance data from intermediate PV projects; to reduce the data; and to prepare periodic summaries.

**Approach Present Tasks:** Install on-site computers to drive a data collection system, collect, and store the data. Periodically access on-site computers from a data reduction center, collect, store, and reduce the data.

**Status/FY 1983 Accomplishments:** All sites except Georgetown University and SMUD are connected to the data reduction center.

**FY 1984 Milestones:**

- 1 December 1983 — initiate data acquisition from ARCO Solar Lugo facility.
- 1 February 1984 — complete installation of ODAS at Georgetown University.
- 30 September 1984 — receive initial data tapes from SMUD.

**Major Project Reports:** Monthly summaries to each site.

**Summary Date**  
December 1983

# SNLA

**Title:** San Bernardino West Side Community Development Center

**Contractor:**

San Bernardino West Side  
Community Development Corporation  
1736 West Highland Avenue  
San Bernardino, CA 92411

**Principal Investigator:** D. Burgess

**Telephone:** (414) 887-2546

**Contract Number:** 68-1839

**Current Contract Period From:** 04/1/82  
**To:** 06/30/83

**Project/Area/Task:** Array Design and Evaluation

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** M. Thomas

**Telephone:** (505) 844-6111

**Contract Funding:**

FY 1981	\$ 983,400
FY 1982	\$ 56,000
FY 1983	\$ 56,010

**Source:**

SNLA
SNLA
SNLA

**Objectives:** To operate a 35 kW flat-plate PV system on the roof of a light industrial building. The system interfaces with the utility grid, and sellback is 100% of the ac power produced. The system was built using unskilled labor in a CETA training program, with minimal technical supervision. Lessons learned and insights gained will be made available to industry and government.

**Approach Present Tasks:** No further SNLA participation.

**Status/FY 1983 Accomplishments:** System-level experience in operating and maintaining the facility and in selling power back to the utility will be gained. Module mismatch in individual strings has been assessed and corrected. The system operates in full automatic mode. Data are being collected reliably on a regular basis and are being reduced and evaluated.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** Phase II final report by contractor. Phase III final report by contractor.

**Summary Date**  
December 1983



## SNLA

**Title:** Task 2.1 — Subsystem Design and Development

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** H. N. Post  
**Telephone:** (505) 844-2154

**Project Engineer:**  
**Telephone:**

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82  
**To:** 09/30/83

**FY 1983**      \$ 67,000

DOE/PV

**Project/Area/Task:** Array Subsystem Development

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**Objectives:** To define performance requirements for array subsystems incorporated into medium- and large-size photovoltaic applications and to identify and develop approaches which result in the lowest possible life-cycle costs for these subsystems.

**Approach Present Tasks:**

- Develop detailed array subsystem designs and examine design/economic trade-offs.
- Develop building-block (modularized) subsystem designs which minimize life-cycle costs.
- Determine applicability of automated installation methods and develop appropriate hardware.
- Examine subsystem design criteria and determine effect on subsystem cost and performance.

**Status/FY 1983 Accomplishments:**

- System grounding and fault protection design manual completed.
- Automated installation scenarios identified for second-generation array fields.
- Modular designs for large-size systems initiated.

**FY 1984 Milestones:**

- Completion of modular designs for large-size systems — March 1984.
- Expanded system grounding and fault protection manual — May 1984.

**Major Project Reports:**

- Jones, G., ed. (March 1983). *Fourth Photovoltaic Systems Definition and Applications Projects Integration Meeting; Albuquerque, NM; 12-14 April 1983*. SAND83-0603. Albuquerque, NM: Sandia National Laboratories; 271 pp.

**Summary Date**  
December 1983

## SNLA

**Title:** Task 2.2-Engineering Evaluation

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** H. N. Post  
**Telephone:** (505) 844-2154

**Project Engineer:**  
**Telephone:**

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82  
**To:** 09/30/83

**FY 1983**      \$ 83,000

**DOE/PV**

**Project/Area/Task:** Array Subsystem Development

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**Objectives:** To evaluate the performance of array subsystems incorporated into medium and large-size photovoltaic applications and to facilitate the development of reliable, low-cost subsystems through feedback of evaluation results to design activities.

**Approach Present Tasks:**

- Evaluate prototype subsystem hardware in test facilities.
- Analyze operation and maintenance requirements and cost, and develop maintenance strategies.
- Evaluate modular array field building block hardware and verify installation cost.

**Status/FY 1983 Accomplishments:**

- Procurement of concentration building block array field initiated.
- Installation of modular, flat-panel building block array fields completed.

**FY 1984 Milestones:** Installation of concentrator building block array field — December 1983.

**Major Project Reports:**

- Jones, G., ed. (March 1983). *Fourth Photovoltaic Systems Definition and Applications Projects Integration Meeting; Albuquerque, NM; 12-14 April 1983*. SAND 83-0603. Albuquerque, NM: Sandia National Laboratories; 271 pp.

**Summary Date**  
December 1983

## SNLA

**Title:** Modular Designs for Large PV Array Fields

**Contractor:**

Battelle Columbus Laboratories  
505 King Avenue  
Columbus, OH 43201

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** D. C. Carmichael

**Telephone:** (614) 424-6582

**Project Engineer:** H. N. Post

**Telephone:** (505) 844-2154

**Contract Number:** 50-8493

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/13/82  
**To:** 02/5/84

**FY 1983**            **\$ 241,500**

**DOE/PV**

**Project/Area/Task:** Array Subsystem Development

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**Objectives:** The overall objective of this work is to reduce the cost of large-size PV array fields by reducing the cost of structural and electrical subsystem designs, components, and installation.

**Approach Present Tasks:** Modular building-block designs will be developed for flat-plate, ground-mounted arrays that incorporate optimized and integrated subsystems. Detailed analysis of the cost impact of operating voltage on electrical subsystem design will be conducted.

**Status/FY 1983 Accomplishments:** Contract work is 50% completed.

**FY 1984 Milestones:** Modular building block design completed — March 1984.

**Major Project Reports:**

- Carmichael, D.C.; Alexander, G.; Noel, G.T.; Smith, R.W.; Huss, W.R. (November 1982). *Development of a Standard Modular Design for Low-Cost Flat-Panel Photovoltaic Array Fields*. SAND81-7183. Albuquerque, NM: Sandia National Laboratories; 179 pp. Work performed by Battelle Columbus Laboratories, Columbus, OH.

**Summary Date**  
December 1983

## SNLA

**Title:** Modular Array Field Installation

**Contractor:**

Battelle Columbus Laboratories  
505 King Avenue  
Columbus, OH 43201

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** D. C. Carmichael

**Telephone:** (614) 424-6582

**Project Engineer:** H. N. Post

**Telephone:** (505) 844-2154

**Contract Number:** 68-1827

**Contract Funding:**

**Source:**

**Current Contract Period From:** 03/8/82

**To:** 07/15/83

**FY 1982**

**\$ 491,700**

**DOE/PV**

**FY 1983**

**\$ -0-**

**DOE/PV**

**Project/Area/Task:** Array Subsystem Development

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**Objectives:** The objective of this work is the evaluation of the modular building block design through the installation, costing, and functional evaluation of a test array field.

**Approach Present Tasks: The approach to this work consists of three major tasks:**

- Procure and/or fabricate all necessary hardware for the modular array field using specifications and drawings developed during Contract 62-9187.
- Install an array field consisting of three building blocks ( $\approx$  30 kW) in the Sandia Test Facility.
- Test and evaluate the installed array field.

**Status/FY 1983 Accomplishments:** Array field installation is completed.

**FY 1984 Milestones:** Operational evaluation of modular array field — June 1984.

**Major Project Reports:** Final Report (SAND83-7027) in publication.

**Summary Date**  
December 1983

**SNLA**

**Title:** PV System Grounding and Fault Protection Study

**Contractor:**  
Bechtel Group, Inc.  
P.O. Box 3965  
San Francisco, CA 94199

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** W. J. Stolte  
**Telephone:** (416) 768-5834

**Project Engineer:** H. N. Post/D. Chu  
**Telephone:** (505) 844-2154

**Contract Number:** 61-7684

**Contract Funding:** **Source:**

**Current Contract Period From:** 02/15/82  
**To:** 05/15/84

<b>FY 1982</b>	<b>\$ 297,500</b>	<b>DOE/PV</b>
<b>FY 1983</b>	<b>\$ 128,000</b>	<b>DOE/PV</b>

**Project/Area/Task:** Array Subsystem Development

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**Objectives:** The objective of this work is to conduct a detailed investigation of system grounding and fault protection for medium-size and large-size photovoltaic systems.

**Approach Present Tasks:** System grounding, dc fault sensing, availability of fault sensing equipment and dc switchgear, requirements for an isolation transformer, and the impact of existing codes and standards on system electrical protection have been addressed. Additional work was added to contract during FY 1983. These tasks include evaluation of the cost effectiveness of dc fault protection, grounding counterpoise requirements for pedestal-supported arrays, and analysis of lightning protection.

**Status/FY 1983 Accomplishments:** Initial contract work completed.

**FY 1984 Milestones:** Publication of final design guidelines manual — May 1984.

**Major Project Reports:** Interim Report (SAND82-7025) published in July 1983.

**Summary Date**  
December 1983

## SNLA

**Title:** Automated Installation Methods and Equipment Design

**Contractor:**  
Burt Hill Kosar Rittelmann Associates  
400 Morgan Center  
Butler, PA 16001

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** J. R. Oster  
**Telephone:** (412) 285-4761

**Project Engineer:** H. N. Post  
**Telephone:** (505) 844-2154

**Contract Number:** 50-4592

**Contract Funding:**

**Source:**

**Current Contract Period From:** 08/15/82  
**To:** 08/14/83

**FY 1982**            \$ 195,800  
**FY 1983**            \$ -0-

**DOE/PV**

**Project/Area/Task:** Array Subsystem Development

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**Objectives:** The objectives of this work are to identify detailed installation scenarios using both conventional and automated methods for two second-generation array field designs and prepare preliminary designs for the automated equipment.

**Approach Present Tasks:** The automated methods identified during previous work will be applied to specific array designs (one flat-plate and one concentrator) to develop detailed installation plans and costs for these array fields. Preliminary designs of the automated equipment will be developed in sufficient detail for manufacturing analyses.

**Status/FY 1983 Accomplishments:** Automated installation scenarios have been identified for second-generation array fields.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- *Automated Installation Methods for Photovoltaic Arrays.* (November 1982). SAND81-7192. Albuquerque, NM: Sandia National Laboratories; 232 pp. Work performed by Burt Hill Kosar Rittelmann Associates, Research and Solar Applications Division, Butler, PA.

**Summary Date**  
December 1983

## SNLA

**Title:** Modular Array Field Installation

**Contractor:**

Hughes Aircraft Company  
P.O. Box 9399  
Long Beach, CA 90810-0399

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** G. J. Naff

**Telephone:** (213) 513-3487

**Project Engineer:** H. N. Post

**Telephone:** (505) 844-2154

**Contract Number:** 68-3152

**Contract Funding:**

**Source:**

**Current Contract Period From:** 03/19/82

**To:** 07/15/83

**FY 1982**      \$ 467,600

**FY 1983**      \$ 30,200

**DOE/PV**

**DOE/PV**

**Project/Area/Task:** Array Subsystem Development

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**Objectives:** The objective of this work is to evaluate the modular building-block design through the installation, cost analysis, and functional evaluation of a test array field.

**Approach Present Tasks:** The approach to this work consists of three major tasks:

- Procure or fabricate all necessary hardware for the modular array field using specifications and drawings developed under Contract 62-9188.
- Install an array field consisting of three building blocks ( $\approx 30$  kW) in the Sandia Test Facility.
- Test and evaluate the installed array field.

**Status/FY 1983 Accomplishments:** Array field installation is completed.

**FY 1984 Milestones:** Operational evaluation of modular array field — June 1984.

**Major Project Reports:** Final Report (SAND83-7028) in publication.

**Summary Date**  
December 1983

## SNLA

**Title:** Concentrator Building Block Installation

**Contractor:**

Intersol Power Corporation  
11901 W. Cedar Avenue  
Lakewood, CO 80228

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** J. Sanders

**Telephone:** (303) 989-8710

**Project Engineer:** H. N. Post

**Telephone:** (505) 844-2154

**Contract Number:** 37-3058

**Contract Funding:**

**Source:**

**Current Contract Period From:** 03/30/83

**FY 1983**

**\$ 411,700**

**DOE/PV**

**To:** 12/30/83

**Project/Area/Task:** Array Subsystem Development

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**Objectives:** The objective of this work is the evaluation of the modular concentrator building block design through the installation, costing, and functional evaluation of a test array field.

**Approach Present Tasks:** The approach to this work consists of three major tasks:

- Procure and/or fabricate all necessary hardware for the modular array field using specifications and drawings developed during Contract 68-1517.
- Install an array field consisting of one building block ( $\approx 20$  kW) in the Sandia Test Facility.
- Test and evaluate the installed array field.

**Status/FY 1983 Accomplishments:**

- Construction was started on 21 September 1983.
- System checkout is scheduled for December 1983.

**FY 1984 Milestones:** Completion of array field installation — December 1983.

**Major Project Reports:** Reference SAND82-7069.

**Summary Date**  
December 1983



## SNLA

**Title:** Task 6.1 — Array Design and Development

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** A. Maish  
**Telephone:** (505) 844-8771

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

**Project/Area/Task:** Concentrator Arrays

---

**Objectives:** To design, develop, and fabricate experimental arrays for economical energy production. The major emphasis is on array designs which are reliable at low cost.

**Approach Present Tasks:** The primary approach to experimental array design is to integrate promising tracking structure concepts with the latest modules developed under Task 5. Array designs presently include single post (pedestals and heliostats) and tilt-roll structures supporting point- or linear-focus Fresnel lens concentrator modules. Polar-axis trackers are also used for stand-alone arrays.

**Status/FY 1983 Accomplishments:** A new pedestal-mounted tracking structure is under development by Intersol Power. The drive unit has been simplified and strengthened to support a larger array aperture. Six arrays from Intersol and Martin Marietta are being installed for evaluation at Sandia in the building block design developed under Task 2. A building block of E-Systems arrays has been installed at Sandia for testing.

**FY 1984 Milestones:** Complete installation of pedestal building blocks for array testing.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Task 6.2 — Array Evaluation

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** A Maish  
**Telephone:** (505) 844-8771

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

**Project/Area/Task:** Concentrator Arrays

---

**Objectives:** To provide a comprehensive evaluation of the performance, reliability, and durability of photovoltaic concentrator hardware; to facilitate the development of reliable designs through feedback of evaluation results to component and module research activities.

**Approach Present Tasks:** The test process includes initial component and array performance characterization tests, and stress-to-failure tests. Long-term reliability and durability data collected from in-house and worldwide site-installed arrays will be analyzed for potential design improvements and will provide a basis for estimating operational and maintenance costs of concentrator arrays.

**Status/FY 1983 Accomplishments:** Initial tests have been completed on the GE tilt-roll and stand-alone arrays and long-term testing is underway. The Sandia stand-alone array has been fabricated. Controller development is still being completed. Installation and checkout of the E-Systems building block array are nearing completion. Performance characterization tests will follow. Data from the APS, SOLERAS, and DFW arrays is being analyzed for potential design improvements.

**FY 1984 Milestones:** Initial performance characterization tests will be performed on the building-block arrays and on the Sandia stand-alone array. Long-term reliability data from in-house and site-installed arrays will continue to be analyzed.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Second-Generation Array Development

**Contractor:**

E-Systems, Inc.  
Energy Technology Center  
P.O. Box 226118  
Dallas, TX 75266

**Principal Investigator:** M. J. O'Neill  
**Telephone:** (214) 272-0515 ext. 3830

**Contract Number:** 46-5791

**Current Contract Period From:** 10/82  
**To:** 12/83

**Project/Area/Task:** Concentrator Arrays

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** M. Rios, Jr.  
**Telephone:** (505) 844-7812

**Contract Funding:**

FY 1981	\$ 349,000
FY 1982	\$ 143,000
FY 1983	\$ 6,000
FY 1984	\$ 1,940

**Source:**

DOE/PV
DOE/PV
DOE/PV
DOE/PV

**Objectives:** To redesign E-Systems linear Fresnel photovoltaic concentrator modules and arrays for higher performance and lower cost; to build and test prototype collectors; and to build, test, and deliver to Sandia Laboratories a full-scale array.

**Approach Present Tasks:** The basic approach is to redesign the receiver for higher performance and lower manufacturing costs; optimize the size of the module, and design and develop a low-cost tilt-roll two-axis tracking structure.

**Status/FY 1983 Accomplishments:** The E-Systems linear Fresnel module has been redesigned, and a two-axis tracking structure has been built. The array is being tested at E-Systems and has achieved a very high performance. One module has been shipped to Sandia, and testing at Sandia verifies that the module has an efficiency higher than 14% at 28°C cell temperature and 800 W/m<sup>2</sup> insolation.

**FY 1984 Milestones:** An 8-module array has been built and is being tested at E-Systems. The array will be tested at E-Systems over a period of 2 years or more under a mutual benefit loan agreement with Sandia.

**Major Project Reports:** A draft final report is expected in December 1983. Subsequent quarterly reports on the performance will also be provided by E-Systems.

**Summary Date**  
December 1983

## SNLA

**Title:** Stand-Alone Array Development

**Contractor:**

E-Systems Inc.  
Energy Technology Center  
P.O. Box 226118  
Dallas, TX 75266

**Principal Investigator:** M. J. O'Neill

**Telephone:** (214) 272-0515 ext. 3830

**Contract Number:** 62-7219

**Current Contract Period From:** 05/11/81  
**To:** 02/29/84

**Project/Area/Task:** Concentrator Arrays

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** C. Chiang

**Telephone:** (505) 846-3254

**Contract Funding:**

**FY 1981**            **\$ 391,000**

**Source:**

DOE/PV

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**Objectives:** To design, construct, and test a stand-alone PV concentrator array using passively-cooled linear-focus concentrating collectors; to perform a parametric analysis of the module design parameters.

**Approach Present Tasks:** A prototype array is to be fabricated and delivered for testing. The array will be half populated with four modules (the full array holds eight).

**Status/FY 1983 Accomplishments:** The array structure and four modules have been completed. EVA was used initially as a cell encapsulant but was replaced with RTV615 when found to be unsatisfactory. The array is undergoing testing by E-Systems prior to delivery to Sandia for testing. The parametric analysis showed reducing the array width could increase performance by 16%.

**FY 1984 Milestones:** The stand-alone array will be delivered to Sandia for testing.

**Major Project Reports:**

- McDanal, A. J.; O'Neill, M. J.; Waller, R. A. (1983). "Performance Analysis of a Third-Generation Linear Fresnel Lens Passively Cooled Photovoltaic Collector." *Proceedings of the 1983 American Solar Energy Society Meeting: Progress in Solar Energy; Minneapolis, MN; 1-3 June 1983*. Boulder, CO: ASES; Volume 6; pp. 495-500.

**Summary Date**  
December 1983

## SNLA

**Title:** 22 kW Array Development

**Contractor:**

E-Systems, Inc.  
Energy Technology Center  
P.O. Box 226118  
Dallas, TX 75266

**Principal Investigator:** M. J. O'Neill

**Telephone:** (214) 272-0515 ext. 3830

**Contract Number:** 68-1903

**Current Contract Period From:** 12/81  
**To:** 09/83

**Project/Area/Task:** Concentrator Arrays

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** M. Rios, Jr.

**Telephone:** (505) 844-7812

**Contract Funding:**

<b>FY 1982</b>	<b>\$ 252,890</b>
<b>FY 1983</b>	<b>\$ 246,932</b>

**Source:**

<b>DOE/PV</b>
<b>DOE/PV</b>

---

**Objectives:** To develop, fabricate, and deliver to Sandia Laboratories a 22 kW photovoltaic-thermal (PV-T) array that is comprised of E-Systems linear Fresnel PV-T concentrators.

**Approach Present Tasks:** To utilize the technology and expertise that has been developed via other development contracts with emphasis on cost-effective fabrication of 72 modules and corresponding support structures in order to conduct system level PV-T tests at Sandia.

**Status/FY 1983 Accomplishments:** The receivers were fabricated at E-Systems and shipped to Consumer Steel in Wisconsin where the modules and tracking structures were fabricated. Completed arrays were shipped to Sandia Laboratories where the array was installed and checked out.

**FY 1984 Milestones:** Initial performance testing of array at Sandia Laboratories.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Intermediate Field Array Development

**Contractor:**  
General Electric  
Advanced Energy Programs Department  
P.O. Box 527  
King of Prussia, PA 19406

**Principal Investigator:** R. Hodge  
**Telephone:** (215) 296-5949

**Contract Number:** 2-7347

**Current Contract Period From:** 03/15/81  
**To:** 01/15/83

**Project/Area/Task:** Concentrator Arrays

**Directing Organization:**  
Sandia National Laboratories

**Project Engineer:** A. Maish  
**Telephone:** (505) 844-8771

**Contract Funding:**

<b>FY 1981</b>	<b>\$ 497,000</b>
<b>FY 1982</b>	<b>\$ 78,000</b>

**Source:**

<b>DOE/PV</b>
<b>DOE/PV</b>

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**Objectives:** To design and develop a PV concentrator array for intermediate load applications. The array includes a tracking structure, 2.4 kW of modules (20 modules), and a control system.

**Approach Present Tasks:** Point-focus modules, which are similar to the Sandia Baseline I Module, were developed by GE. A tilt-roll two-axis tracking structure and a microprocessor control unit were developed under subcontracts.

**Status/FY 1983 Accomplishments:** Twenty modules were delivered and mounted on the array for testing. Tests conducted by Sandia indicate the modules and array perform reliably. NOC module efficiency is 12%. No further development is planned on this structure.

**FY 1984 Milestones:** GE contract completed. Long-term Sandia testing will continue in FY 1984.

**Major Project Reports:** Final report received. Publication by Sandia is underway.

**Summary Date**  
December 1983

## SNLA

**Title:** Design and Development of Stand-Alone PV Concentrator Array

**Contractor:**

General Electric  
Advanced Energy Programs Department  
P.O. Box 527  
King of Prussia, PA 19406

**Principal Investigator:** R. Hodge  
**Telephone:** (215) 962-5949

**Contract Number:** 67-7220

**Current Contract Period From:** 04/81  
**To:** 10/82

**Project/Area/Task:** Concentrator Arrays

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** M. Rios, Jr.  
**Telephone:** (505) 844-7812

**Contract Funding:**

FY 1981	\$ 344,000
FY 1982	\$ 49,000
FY 1983	\$ 4,600

**Source:**

DOE/PV
DOE/PV
DOE/PV

**Objectives:** To develop a point-focus Fresnel lens concentrator array for low-power, remote, non-grid-connected applications. The stand-alone array should require minimal attendance for daily operation.

**Approach Present Tasks:** To adapt the Sandia baseline module technology and develop a structure and a control system that are potentially cost-competitive with flat-panel PV systems.

**Status/FY 1983 Accomplishments:** Technical effort has been completed; a complete stand-alone array has been delivered and tested at Sandia Laboratories giving a peak efficiency at 28° C heat-sink temperature and 800 W/m<sup>2</sup> of 12.5%.

**FY 1984 Milestones:** None. Program completed:

**Major Project Reports:**

- *Design and Development of a Stand-Alone Concentrator Photovoltaic Array.* SAND82-7131. Albuquerque, NM: Sandia National Laboratories; (in publication).

**Summary Date**  
December 1983

# SNLA

**Title:** Fabricate Modules for Second-Generation Array

**Contractor:**  
Intersol Power Corp.  
11901 West Cedar Ave.  
Lakewood, CO 80228

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** J. Sanders  
**Telephone:** (303) 989-8710

**Project Engineer:** M. Edenburn  
**Telephone:** (505) 844-4003

**Contract Number:** 50-2470

**Contract Funding:**

**Source:**

**Current Contract Period From:** 08/09/82  
**To:** 09/30/83

<b>FY 1982</b>	<b>\$ 445,000</b>
<b>FY 1983</b>	<b>\$ 22,000</b>

<b>DOE/PV</b>
<b>DOE/PV</b>

**Project/Area/Task:** Concentrator Arrays

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**Objectives:** To fabricate a full array for evaluation of array level problems, and to gain experience with production tooling (e.g., plastic housing injection-molding tool).

**Approach Present Tasks:** Intersol has fabricated 70 modules, 60 of which were mounted on the second-generation pedestal tracker at Sandia's test facility.

**Status/FY 1983 Accomplishments:** All modules have been mounted and aligned, and module and array performance data have been taken. The best module tested has a peak efficiency of 15.4% and an NOC efficiency of 14.1%. The array has a peak efficiency of 14.4% and an NOC efficiency of 13.3%. The modules required shimming for alignment (a process that will have to be eliminated for low-cost installation). The contract is being extended to allow Intersol to consider secondary optical units and improved interconnects as a means of reducing alignment requirements and improving cell assembly durability. The 15.4% peak commercial module was tested in August 1983. The second-generation array was assembled and operating in September 1983.

**FY 1984 Milestones:** A module using secondary optical elements and a new interconnect design is to be delivered in March 1984.

**Major Project Reports:** None.

**Summary Date**  
**December 1983**



## SNLA

**Title:** Fabricate Modules for Second-Generation Array

**Contractor:**

Martin Marietta  
Aerospace Division  
P.O. Box 179  
Denver, CO 80201

**Principal Investigator:** N. Pass

**Telephone:** (303) 977-0729

**Contract Number:** 37-2358

**Current Contract Period From:** 11/18/82

**To:** 11/30/83

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** M. Edenburn

**Telephone:** (505) 844-4003

**Contract Funding:**

FY 1983

\$ 460,000

**Source:**

DOE

**Project/Area/Task:** Concentrator Arrays

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**Objectives:** To provide an array for testing and to exercise production tooling for fabricating the modules.

**Approach Present Tasks:** Martin Marietta is fabricating 70 second-generation modules, 60 of which will be mounted on their second-generation tracker at Sandia.

**Status/FY 1983 Accomplishments:** All materials except the injection-molded plastic housings have been delivered to Martin Marietta. An infrared oven for cell assembly soldering is being used. Delivery and mount of the modules is expected in late November 1983.

**FY 1984 Milestones:** The second-generation array is to be assembled in late November 1983.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** PV Tracking Structure Cost Analysis

**Contractor:**

Martin Marietta  
Aerospace Division  
P.O. Box 179  
Denver, CO 80201

**Principal Investigator:** R. Hein

**Telephone:** (303) 977-0115

**Contract Number:** 61-5994

**Current Contract Period From:** 10/15/81  
**To:** 01/15/83

**Project/Area/Task:** Concentrator Arrays

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** A. Maish

**Telephone:** (505) 844-8771

**Contract Funding:**

<b>FY 1981</b>	<b>\$ 183,000</b>
<b>FY 1982</b>	<b>\$ 69,000</b>

**Source:**

<b>DOE/PV</b>
<b>DOE/PV</b>

**Objectives:** To develop detailed fabrication, transportation, and installation costs for three leading two-axis PV tracking structures. The structures are the Martin Marietta pedestal array (second generation), the E-Systems tilt-roll tracker with passively-cooled modules, and a tilt-roll tracker designed by Sandia National Laboratories.

**Approach Present Tasks:** Detailed costs were developed for a production rate of 100,000 square meters of aperture per year. Production tooling, layout and processes were developed in detail.

**Status/FY 1983 Accomplishments:** The study was completed. Costs of all three structures were similar. Installed cost excluding module or site costs but including structure, drive, transportation, foundation, and installation ran between \$1.10 and \$1.35 per peak watt.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** Final report received. Publication by Sandia underway.

**Summary Date**  
December 1983

## SNLA

**Title:** Array Testing

**Contractor:**

Tennessee Valley Authority  
Solar Applications Branch  
Chattanooga, TN 37401

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** J. McKibben

**Telephone:** (615) 751-5183

**Project Engineer:** A. Maish

**Telephone:** (505) 844-8771

**Contract Number:** 58-0093

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/83

**To:** 09/86

**FY 1983**

**\$ 50,000**

**DOE/PV**

**Project/Area/Task:** Concentrator Arrays

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**Objectives:** To obtain test data characterizing the long-term energy collection performance and operational reliability of three tracking photovoltaic arrays in a southeastern United States environment.

**Approach Present Tasks:** The test program will consist of an initial array performance characterization test series, followed by long-term monitoring of energy production performance and array reliability as a function of environmental factors.

**Status/FY 1983 Accomplishments:** None. New Program.

**FY 1984 Milestones:** TVA will procure three arrays and install their monitoring equipment. The initial characterization tests will be performed on the arrays. The arrays are an E-Systems linear-focus actively-cooled array, a point-focus pedestal array, and a tracking flat-panel array.

**Major Project Reports:** None. !

**Summary Date**  
December 1983

## SNLA

**Title:** Subtask 4.1 — Si Concentrator Cell Research

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** D. E. Arvizu  
**Telephone:** (505) 846-0387

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

**FY 1983**      **\$ 610,000**

**DOE**

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** The objective is to investigate the performance potential of single-crystal silicon concentrator cells, verify performance characteristics through experimental cells, and establish designs to perform reliably in the concentrated sunlight environment.

**Approach Present Tasks:** The approach in this subtask is to develop and direct technology toward achieving high efficiency concentrator cells.

**Status/FY 1983 Accomplishments:**

- ASEC has demonstrated n+p concentrator cells with peak efficiencies of 20 % at between 100 and 150 suns illumination.
- Power Hybrids has become the first commercial supplier of p+nn+ concentrator cells developed by Sandia.
- California Institute of Technology has successfully demonstrated reactively sputtered TiN diffusion and electroplated Ag contacts on ASEC cells that withstand heat treatments of 700° C for 15 minutes and 600° C for 1 hour.
- Purdue has continued to improve their cell analysis code to make it more user-independent. In addition, the effect on cell performance of parameters such as grid shadowing, reflective losses, series resistance, and recombination mechanisms have been investigated. Their study indicates that cell efficiencies of 30% at 300X with nonconventional silicon structures are possible.

**FY 1984 Milestones:**

- Achieve a 21% efficiency Si concentrator cell.
- Identify preferred design concepts for advanced Si cells.

**Major Project Reports:** None.

**Summary Date**  
**December 1983**

## SNLA

**Title:** Subtask 4.2 — Advanced Concentrator Cell Research

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** D. E. Arvizu  
**Telephone:** (505) 846-0387

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

**FY 1983**            **\$ 432,000**

**DOE**

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** The objective is to research the performance potential of advanced semiconductor devices including single and multijunction cells for high conversion efficiency in concentrated sunlight.

**Approach Present Tasks:** The approach is to develop and direct technology that leads to better understanding of performance potential of both single and multiple junction devices. High efficiency will be the primary emphasis. The funding in this subtask will be utilized in a two-thirds contract and one-third in-house activities mix.

**Status/FY 1983 Accomplishments:**

- Experiments at Varian have demonstrated a grooved cover glass for parallel grid lines that effectively reduces the obscuration of a concentrator cell by approximately one-half. Testing of deliverables at Sandia has had some absorption loss, reducing this net gain.
- Varian has demonstrated a TIR secondary optical element that allows 0.5 degree off-track error with only 5% loss of power for a 1000X concentration module.
- Hughes has grown nonoptimum large area (2 cm x 2 cm) AlGaAs cells on a GaAs substrate by LPE with approximately 13% electrical conversion efficiency.
- Wisconsin has demonstrated an amorphous silicon-tungsten (90% tungsten) alloy as a corrosion resistant barrier at high temperature (600C for 1 hr) on a GaP Device.

**FY 1984 Milestones:**

- Laboratory demonstration of a mechanically stacked AlGaAs/Si cell.
- Demonstration of a 15% thin AlGaAs cell for use in multijunction device.

**Major Project Reports:** None.

**Summary Date**  
December 1983

**SNLA**

**Title:** Si Concentrator Cell Research

**Contractor:**  
To be determined

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** B. H. Rose  
**Telephone:** (505) 846-4516

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

**FY 1983**            **\$ 200,000**

**DOE/PV**

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** This project is directed toward increasing cell efficiency by investigating new cell designs.

**Approach Present Tasks:** This project is directed toward grating cells, pocket cells, and V-groove cells, although other ideas will be considered.

**Status/FY 1983 Accomplishments:** Contract to be awarded in November. The RFP has been completed and proposals from eight respondents have been received.

**FY 1984 Milestones:** Produce voltage-enhanced, high conversion efficiency silicon concentrator cell.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Silicon Cell Development

**Contractor:**

Applied Solar Energy Corporation  
15251 E. Don Julian Road  
City of Industry, CA 91746

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** K. Ling

**Telephone:** (213) 968-6581

**Project Engineer:** B. H. Rose

**Telephone:** (505) 846-4516

**Contract Number:** 37-1027

**Contract Funding:**

**Source:**

**Current Contract Period From:** 06/82  
**To:** 11/83

**FY 1982**      **\$ 200,000**

**DOE**

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:**

- Design and develop a cell for higher intensity operation (100-200 suns).
- Study front surface passivation.
- Improve metal contacts.
- Participate in cooperative development efforts with Sandia personnel.

**Approach Present Tasks:** Continue with development of techniques to passivate textured cells; fabricate p on n cells via the Sandia recipe; and use double step photoresist to double the height of grid lines.

**Status/FY 1983 Accomplishments:** Cells with textured active area and no junction under peripheral buss area have been fabricated. Cells of 0.15  $\Omega$ -cm material, 1 cm diameter, and MLAR coatings have been measured at 20% at 100X. It was determined that for these n+p cells with no BSF/BSR that a cell thickness of 20 mils is optimum.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** None.

**Summary Date**  
**December 1983**

**SNLA**

**Title:** Diffusion Barrier Technology Transfer

**Contractor:**

Applied Solar Energy Corporation  
15251 E. Don Julian Road  
City of Industry, CA 91746

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** F. Ho

**Telephone:** (213) 968-6581

**Project Engineer:** L. C. Beavis

**Telephone:** (505) 844-2231

**Contract Number:** 47-3966

**Contract Funding:**

**Source:**

**Current Contract Period From:**

FY 1983

\$ 235,000

DOE

**To:**

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** To develop the processes and materials handling technology for reliably in placing titanium nitride diffusion barriers on silicon solar cells. This barrier will allow the solar cells to be processed (e.g., encapsulated; soldered) at 400°C-500°C rather than the 200°C limit presently imposed by silver or copper metallization diffusion into the cell junction.

**Approach Present Tasks:** Adapt research work from Cal Tech to the manufacturing-type environment at ASEC.

**Status/FY 1983 Accomplishments:** None.

**FY 1984 Milestones:** Complete transfer of development of TiN<sub>2</sub> diffusion barrier to ASEC from Cal Tech.

**Major Project Reports:** Final report due at end of contract.

**Summary Date**  
December 1983



## SNLA

**Title:** Cell Module Testing

**Contractor:**

Arizona State University  
College of Engineering Science  
Tempe, AZ 85281

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** C. Backus

**Telephone:** (602) 965-3857

**Project Engineer:** R. D. Nasby

**Telephone:** (505) 844-6137

**Contract Number:** 47-3859

**Contract Funding:**

**Source:**

**Current Contract Period From:** 08/83

**FY 1983**

**\$ 75,000**

**DOE/PV**

**To:** 08/84

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:**

- Continue to act as independent testing laboratory.
- Develop standard test methods.

**Approach Present Tasks:** This contract will continue the work of Contract 50-2591 with emphasis on:

- Linearity of short-circuit current with irradiance.
- Spectral response variation as a function of cell thickness and irradiation.
- Investigation of photoacoustic measurement techniques.

**Status/FY 1983 Accomplishments:** None. New program.

**FY 1984 Milestones:** ASU will provide general concentrator cell research support, especially by conducting cell tests and experiments on a variety of cells under development.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Cell Receiver Testing

**Contractor:**

Arizona State University  
College of Engineering Science  
Tempe, AZ 85281

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** C. Backus

**Telephone:** (602) 965-3857

**Project Engineer:** B. Nasby

**Telephone:** (505) 844-6137

**Contract Number:** 50-2591

**Contract Funding:**

**Source:**

**Current Contract Period From:** 06/1/82

FY 1982

\$ 80,000

DOE/PV

**To:** 03/31/83

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:**

- Continue to act as an independent testing laboratory.
- Develop standard test methods (including reference cell calibration).
- Continue investigation into spectral response behavior.

**Approach Present Tasks:** This contract will continue the work of Contract 40-1356 with emphasis on:

- Cell and receiver testing;
- Investigating the linearity of the short circuit current with intensity;
- Examining cell spectral response and its variation with intensity.

ASU will also provide general concentrator cell research support, especially by conducting cell tests and experiments on a variety of cells under development.

**Status/FY 1983 Accomplishments:** Spectral response was found to increase with irradiance depending on cell base resistivity. The short circuit current to irradiance ratio was seen to increase by as much as 8% over the range 1 to 100 suns for 1.5  $\Omega$ -cm cells. For .15  $\Omega$ -cm cells there was essentially no change in the ratio from 1 to 100 suns.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Diffusion Barrier Technology Transfer

**Contractor:**  
California Institute of Technology  
Electrical Engineering Department  
Pasadena, CA 91125

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** M. Nicolet  
**Telephone:** (213) 356-4803

**Project Engineer:** L. C. Beavis  
**Telephone:** (505) 844-2231

**Contract Number:** 47-3967

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

FY 1983           \$ 35,000

DOE

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** To assist ASEC with the development of the titanium nitride diffusion barrier for silicon concentrator solar cells.

**Approach Present Tasks:** Primarily consulting to ASEC on equipment and processes.

**Status/FY 1983 Accomplishments:** None.

**FY 1984 Milestones:** Complete transfer of development of  $TiN_2$  diffusion barrier to ASEC.

**Major Project Reports:** None.

**Summary Date**  
December 1983

# SNLA

**Title:** Thin Film Barrier

**Contractor:**  
California Institute of Technology  
Electrical Engineering Department  
Pasadena, CA 91125

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** M. Nicolet  
**Telephone:** (213) 356-4803

**Project Engineer:** M. Chamberlain  
**Telephone:** (505) 844-8749

**Contract Number:** 68-0492

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/15/81  
**To:** 05/15/83

<b>FY 1981</b>	<b>\$ 250,000</b>
<b>FY 1982</b>	<b>\$ 70,000</b>

<b>DOE/PV</b>
<b>DOE/PV</b>

**Project/Area/Task:** Concentrator Cell Research

**Objectives:** Investigate thin-film diffusion barriers for metallization schemes by a two-pronged approach; demonstrate relevance of thin-film barrier on devices; further the understanding of thin-film barriers by basic studies.

**Approach Present Tasks:** Cooperate in transfer of technology to industry.

**Status/FY 1983 Accomplishments:** Si concentrator cells fabricated by ASEC with reactively sputtered TiN diffusion and electroplated Ag contacts successfully passed heat treatments at 700°C for 15 minutes and 600°C for 1 hour.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** Final report is in review at Sandia.

**Summary Date**  
December 1983

## SNLA

**Title:** Development of a Thin AlGaAs Solar Cell

**Contractor:**

Hughes Research Labs  
3011 Malibu Canyon Road  
Malibu, CA 90265

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** R. Y. Loo

**Telephone:** (213) 456-6411

**Project Engineer:** J. Gee

**Telephone:** (505) 844-9677

**Contract Number:** 52-7431

**Contract Funding:**

**Source:**

**Current Contract Period From:** 06/83

**To:** 06/84

**FY 1983**

**\$ 63,500**

**DOE/PV**

**FY 1984**

**\$ 168,500**

**DOE/PV**

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** To design and fabricate a high-efficiency, large-bandgap solar cell to be used as the top cell of a mechanically stacked, two-junction concentrator cell.

**Approach Present Tasks:** The device will be an AlGaAs (1.75 eV) solar cell grown by liquid phase epitaxy (LPE) on GaAs substrates. The cell is mounted on a glass superstrate and the GaAs substrate is removed. LPE is a mature technology and is widely used for the production of III-V devices.

**Status/FY 1983 Accomplishments:** Current effort is concentrated on three areas: (1) fabricating high-efficiency AlGaAs solar cells on thick substrates, (2) learning to reliably etch the GaAs substrate off the AlGaAs cell, and (3) investigating the device characteristics of their unique double-front contact design. Some progress has been made in all three areas. Two AlGaAs (1.6 eV) solar cells were delivered to Sandia. The excellent internal quantum efficiencies measured show the cells to be made from good material. The efficiencies were limited to about 13% by absorption in the window layers, which can be made thinner for future cells. Thin AlGaAs material mounted on a glass superstrate has also been delivered to Sandia for transmission measurements.

**FY 1984 Milestones:** Provide Sandia with efficient, thin AlGaAs solar cells.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** High Concentration Cell

**Contractor:**  
Microwave Associates  
43 South Avenue  
Burlington, MA 01803

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** J. Goodrich  
**Telephone:** (617) 272-3000

**Project Engineer:** B. H. Rose  
**Telephone:** (505) 846-4516

**Contract Number:** 73-6298

**Contract Funding:**

**Source:**

**Current Contract Period From:** 04/82  
**To:** 04/83

**FY 1982**                      **\$ 252,000**

**DOE/PV**

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** The objective of this contract is to continue development work for high-concentration advanced silicon cells. To date the etched multiple vertical junction (EMVJ) cell has not performed as expected under high-illumination conditions. Two-dimensional modeling work at Purdue has suggested some areas to investigate. This project is expected to provide insight into the problem areas encountered in previous work and to demonstrate high-efficiency cells.

**Approach Present Tasks:** Areas to be investigated are:

- use of diffusion mask under metal buss area;
- improvement of AR costs by using a thermally grown SiO<sub>2</sub> layer plus a nitride layer for better index matching;
- reduced obscuration by recessing metal grooves.

**Status/FY 1983 Accomplishments:** Some problems with implanting improvements have been encountered. One significant problem is that bulk material minority carrier lifetimes are low. The EMVJ cell still performs at levels that are less than expected.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** None.

**Summary Date**  
December 1983

**SNLA**

**Title:** Solar Cell Development

**Contractor:**  
Photowatt International  
2414 W. 14th Street  
Tempe, AZ 85281

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** B. Taylor  
**Telephone:** (602) 894-9564

**Project Engineer:** B. H. Rose  
**Telephone:** (505) 846-4516

**Contract Number:** 40-0650

**Contract Funding:**

**Source:**

**Current Contract Period From:** 02/1/81  
**To:** 12/15/82

**FY 1981**            **\$ 349,000**

**DOE/PV**

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** The objective of this contract is to transfer the Sandia recipe of a 20% Si solar cell to industry.

**Approach Present Tasks:** Consult with Sandia to transfer cell design fabrication process and deliver 1000 cells to Sandia.

**Status/FY 1983 Accomplishments:** Major difficulties were encountered with the Boron diffusion processing and with bad masking characteristics. Eventually good cells were made with conversion efficiencies of 16% at 10 suns concentration.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** Final report received.

**Summary Date**  
**December 1983**

**SNLA**

**Title:** Si Cell Development

**Contractor:**  
Power Hybrids  
1742 Crenshaw Boulevard  
Torrance, CA 90501

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** J. Meyers  
**Telephone:** (213) 320-6160

**Project Engineer:** B. H. Rose  
**Telephone:** (505) 846-4516

**Contract Number:** 37-3283

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/82  
**To:** 10/83

**FY 1982**      **\$ 200,000**

**DOE/PV**

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** Technology transfer of the Sandia 20% cell recipe to industry.

**Approach Present Tasks:** Complete technology transfer of Sandia cell design and fabrication processing.

**Status/FY 1983 Accomplishments:** Power Hybrids has become the first commercial supplier of state-of-the-art p<sup>+</sup>nn<sup>+</sup> concentrator cells developed by Sandia.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** Awaiting final report.

**Summary Date**  
**December 1983**



# SNLA

**Title:** Solar Cell Modeling

**Contractor:**

Purdue Research Foundation  
School of Electrical Engineering  
Purdue University  
West Lafayette, IN 47907

**Principal Investigator:** R. Schwartz  
**Telephone:** (317) 474-3510

**Contract Number:** 52-5675

**Current Contract Period From:** 04/83  
**To:** 04/84

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** D. E. Arvizu  
**Telephone:** (505) 846-0387

**Contract Funding:**

FY 1983           \$ 75,000

**Source:**

DOE/PV

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** Continue to develop 2-dimensional solar cell modeling capabilities and provide computer simulation of solar cell performance.

**Approach Present Tasks:**

- Incorporate incomplete Choleski gradient method into 2-dimensional code.
- Incorporate automatic mesh selection procedures in codes.
- Implement 2-dimensional code on CYBER 205 and on CRAY 1 (Dan Arvizu at SNLA).
- Investigate bandgap narrowing models.
- Investigate performance and design of conventional, IBC, EMVJ, and pocket cells at high intensity.
- Modify 1-dimensional code to allow modeling of III-V and multijunction solar cells at high intensity.

**Status/FY 1983 Accomplishments:**

- Completed incorporation of incomplete Choleski gradient method into 2-dimensional code and automatic mesh selection procedures in codes.
- Purdue has implemented the 2-dimensional code on their CYBER 205 supercomputer.
- Purdue is concentrating on investigation of bandgap narrowing models and performance and design of conventional, IBC, EMVJ, and pocket cells at high intensity.

**FY 1984 Milestones:** Transfer working user-oriented 2-dimensional code to Sandia's computer and provide a discussion of practical efficiency limits on different cell designs.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** IBC Cell Development

**Contractor:**

Purdue Research Foundation  
School of Electrical Engineering  
Purdue University  
West Lafayette, IN 47907

**Principal Investigator:** R. Schwartz

**Telephone:** (317) 474-3510

**Contract Number:** 73-6299

**Current Contract Period From:** 01/82  
**To:** 01/83

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** D. E. Arvizu

**Telephone:** (505) 846-0387

**Contract Funding:**

FY 1982	\$ 50,000
FY 1983	\$ 24,744

**Source:**

DOE/PV
DOE/PV

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** Continue to act as consultant for development of IBC cells. Continue to provide computer simulation of solar cell performance.

**Approach Present Tasks:** In addition to providing guidance from computer modeling, continue work to improve numerical computation schemes and to assess adequacy of analytical models used in the codes.

**Status/FY 1983 Accomplishments:** A 2-dimensional numerical simulation for silicon solar cells has been developed at Purdue. Several applications of this model were made to devices that are under consideration as concentrator solar cells. These include the Sandia baseline cell, where direct evidence of 2-dimensional effects are observed; but more appropriately, the inherently 2-dimensional IBC and vertical junction were modeled. Results of these calculations will be used to optimize the fabrication methods that are currently being implemented. Transfer of the current 1-dimensional analysis code to Sandia is completed.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** Final report is being prepared for publication.

**Summary Date**  
December 1983

## SNLA

**Title:** Development of a Thin AlGaAs Solar Cell

**Contractor:**  
Spire Corporation  
Patriots Park  
Bedford, MA 01730

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** S. Tobin  
**Telephone:** (617) 275-6000

**Project Engineer:** J. Gee  
**Telephone:** (505) 844-9677

**Contract Number:** 47-2071

**Contract Funding:**

**Source:**

**Current Contract Period From:** 08/83  
**To:** 08/84

<b>FY 1983</b>	<b>\$ 16,000</b>
<b>FY 1984</b>	<b>\$ 84,000</b>

<b>DOE/PV</b>
<b>DOE/PV</b>

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** To design and fabricate a high-efficiency, large-bandgap solar cell to be used as the top cell of a mechanically stacked, two-junction concentrator cell.

**Approach Present Tasks:** The device will be an AlGaAs (1.75 eV) cell grown by organo-metallic-CVD onto a Ge substrate. The device is mounted onto a glass superstrate and the substrate is removed. Germanium is nearly lattice-matched to the AlGaAs and good GaAs cells have been grown in Ge. Substrate removal is expected to be simpler for the AlGaAs/Ge structure.

**Status/FY 1983 Accomplishments:** Effort concentrated on fabricating good GaAs cells on Ge substrates before attempting AlGaAs growth on Ge. Initial growths of GaAs on Ge produced cells with good  $V_{oc}$  but poor electrical characteristics. These growths used the same growth parameters as were used for high-efficiency GaAs cells grown on GaAs substrates. Current experiments are aimed at finding the optimum growth parameters for growth on GaAs substrates.

**FY 1984 Milestones:** To deliver to Sandia high-efficiency AlGaAs solar cells.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Cell Metallization Studies

**Contractor:**  
University of Wisconsin  
Madison, WI 53706

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** J. D. Wiley  
**Telephone:** (608) 263-1643

**Project Engineer:** R. Chaffin  
**Telephone:** (505) 844-2609

**Contract Number:** 68-5071

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/81  
**To:** 09/31/82

<b>FY 1981</b>	<b>\$ 30,000</b>	<b>DOE/PV</b>
<b>FY 1983</b>	<b>\$ 30,000</b>	<b>DOE/PV</b>
<b>FY 1983</b>	<b>\$ -0-</b>	

**Project/Area/Task:** Concentrator Cell Research

**Objectives:** To investigate amorphous metals to be used as diffusion barriers on Si, GaAs, and GaP solar cells.

**Approach Present Tasks:** Develop techniques for producing amorphous metal layers on Si, GaAs, and GaP; demonstrate on actual solar cells.

**Status/FY 1983 Accomplishments:** Deposition and characteristics of an amorphous silicon-tungsten (80% tungsten) alloy was investigated as a metallization for GaP. This metallization scheme was found to have good corrosion resistance at high temperature. The GaP devices with the amorphous metallizations survived 600°C for periods up to an hour. Two patterning technologies were also successfully implemented: plasma etching and wet chemical etching with warm H<sub>2</sub>O<sub>2</sub>. Partial transfer of the technology to Sandia has occurred and is ongoing.

**FY 1984 Milestones:** None.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Development of a Thin AlGaAs Solar Cell

**Contractor:**

Varian Associates  
611 Hansen Way  
Palo Alto, CA 94303

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** M. Ludowise

**Telephone:** (415) 424-5081

**Project Engineer:** J. Gee

**Telephone:** (505) 844-9607

**Contract Number:** 37-5160

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/83

**To:** 09/84

**FY 1983**

**\$ 15,700**

**DOE/PV**

**FY 1984**

**\$ 159,300**

**DOE/PV**

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** To design and fabricate a high-efficiency, large-bandgap solar cell to be used as the top cell of a mechanically stacked, two-junction concentrator cell.

**Approach Present Tasks:** The cell will be an AlGaAs (1.75 eV) cell grown by organo-metallic-CVD onto a GaAs substrate. The cell is mounted on a glass superstrate and the substrate is removed.

**Status/FY 1983 Accomplishments:** Current effort has concentrated on growing epitaxial layers and then removing the GaAs substrate without leaving pinholes in the remaining material. Such pinholes caused large leakage currents in finished devices. Modification of wafer preparation procedures prior to growth was found to nearly eliminate the pinholes. Some tin AlGaAs material mounted on glass superstrates was delivered to Sandia for transmission measurements.

**FY 1984 Milestones:** Provide Sandia with efficient, thin AlGaAs solar cells.

**Major Project Reports:** None.

**Summary Date**

December 1983

## SNLA

**Title:** GaAs/Si Stacked

**Contractor:**

Varian Associates  
611 Hansen Way  
Palo Alto, CA 94303

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** P. Borden

**Telephone:** (415) 493-4000 ext. 2614

**Project Engineer:** R. Chaffin

**Telephone:** (505) 844-2609

**Contract Number:** 68-2264

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/15/81

**To:** 05/1/83

**FY 1982** \$ 302,000

**DOE/PV**

**FY 1983** \$ -0-

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** The objective of this work is to design and fabricate a high efficiency, mechanically stacked, two-junction photovoltaic receiver for concentrator application.

**Approach Present Tasks:** This two-junction device consists of a thin-film (5-10  $\mu\text{m}$ ) AlGaAs (1.65 eV bandgap) solar cell attached to a glass superstrate and mounted on top of a silicon concentrator solar cell. The four electrical terminal assemblies would operate optically and thermally in cascade but electrically independent.

**Status/FY 1983 Accomplishments:** Current efforts are concentrated on developing a high quality, thin-film AlGaAs solar cell. Other efforts are being directed at techniques to mechanically join the solar cells. At present, there are still problems in fabricating the thin-film AlGaAs solar cells with good optical quantum efficiency at good electrical properties. Three cells have been fabricated that have good performance characteristics but yields are quite low. Three thin-film AlGaAs solar cells have been received and tested at Sandia but show poor electrical characteristics.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** Final Report is under review.

**Summary Date**  
December 1983

# SNLA

**Title:** Novel Concentrator Cells

**Contractor:**

Varian Associates  
611 Hansen Way  
Palo Alto, CA 94303

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** P. Borden

**Telephone:** (415) 493-4000 ext. 2614

**Project Engineer:** R. Chaffin

**Telephone:** (505) 844-2609

**Contract Number:** 74-3195

**Contract Funding:**

**Source:**

**Current Contract Period From:** 12/3/80

**To:** 06/82

**FY 1981** \$ 175,000

DOE/PV

**FY 1982** \$ 29,000

DOE/PV

**FY 1983** \$ -0-

**Project/Area/Task:** Concentrator Cell Research

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**Objectives:** The objective of this work was to develop a two-cell photovoltaic concentrator receiver module without the use of a spectral splitting component.

**Approach Present Tasks:** The high bandgap AlGaAs (1.65 eV) solar cell was constructed with a rear surface reflector so that incident optical energy below the 1.65 eV bandgap of the AlGaAs material would be redirected to a lower bandgap, silicon concentrator cell. To reduce effects of substrate absorption, a thin AlGaAs cell was constructed which removed all of the GaAs substrate material. To date Varian has been unsuccessful in consistently fabricating high quality, thin film AlGaAs back surface reflecting concentrator solar cells. Additional work to solve these problems is in progress.

**Status/FY 1983 Accomplishments:** A thin AlGaAs reflecting back cell was fabricated with 13.7% efficiency at 271X. The optical properties were poor indicating this method of beam splitting may not be practical

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** Final Report in review.

**Summary Date**

December 1983

**SNLA**

**Title:** Advanced Cover Glass for GaAs Solar Cells

**Contractor:**  
Varian Associates  
611 Hansen Way  
Palo Alto, Ca 94303

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** P. Borden  
**Telephone:** (415) 493-4000 ext. 2614

**Project Engineer:** R. Chaffin  
**Telephone:** (505) 844-2609

**Contract Number:** 74-6832

**Contract Funding:**

**Source:**

**Current Contract Period From:** 01/15/81  
**To:** 12/10/82

<b>FY 1981</b>	<b>\$ 81,000</b>
<b>FY 1982</b>	<b>\$ 23,000</b>
<b>FY 1983</b>	<b>\$ -0-</b>

<b>DOE/PV</b>
<b>DOE/PV</b>

**Project/Area/Task:** Concentrator Cell Research

**Objectives:**

- To develop a grooved cover-glass for AlGaAs/GaAs and silicon concentrator solar cells. The grooved cover-glass will reduce the optical losses caused by incident optical energy reflecting off the metallic electrical grid on the top surface of the solar cell.
- To develop secondary concentrator cones to be positioned on top of solar cells to increase the concentrator system's allowable tracking error and to improve the collection efficiency of off-axis light rays.

**Approach Present Tasks:** Develop the techniques to produce grooved cover-glasses and demonstrate with actual devices. Develop and demonstrate a TIR secondary concentrator for module application.

**Status/FY 1983 Accomplishments:**

- Developed optically reflecting cover-glass grooves that deflect light originally directed toward the metallic grid to an unobscured active region of the solar cell. Experiments at Varian have shown that cover-glasses fabricated to date can recover one-half of the optical energy normally reflected by the metallic grid.
- Prototype secondary concentrator cones designed and fabricated during this work have been effective at increasing the overall collection efficiency and reducing the tracking requirements.
- Deliverables have been received and tested at Sandia. The grooved cover-glass did recover some light usually reflected from the grid lines but the material of the cover-glass had too much absorption for a net gain to be obtained.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** Final Report in has been published under SAND82-7214.

**Summary Date**  
December 1983



## SNLA

**Title:** Subtask 5.1 — Cell Assemblies Subtask

**Contractor:** In-House

**Directing Organization:** Sandia National Laboratories

**Principal Investigator:** M. Rios, Jr.  
**Telephone:** (505) 844-5259

**Project Engineer:** M. Rios, Jr.  
**Telephone:** (505) 844-5259

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** The objective of this subtask is to identify and evaluate materials for use in concentrating PV cell assemblies that will be durable and inexpensive, and will enhance the performance of concentrating modules.

**Approach Present Tasks:** Sandia is evaluating cell assembly materials and composites including solders, encapsulants, and bonding adhesives in real-time and accelerated environmental tests. Contracts were issued to BDM, Martin Marietta, and ASEC to study various cell assembly materials.

**Status/FY 1983 Accomplishments:** Solders are being extensively evaluated and the field of adhesive and encapsulant candidates has been significantly narrowed. Dow Corning 1-2577 has been identified as a very good cell encapsulant. Metal-loaded silicones look very promising as high-conductivity assembly-to-heat exchanger bonds. Fatigue and tin migration have been identified as likely failure mechanisms in typical interconnect solder bonds. Cell-to-ceramic substrate solder bonds have survived long term, very-severe temperature cycling.

**FY 1984 Milestones:**

- Demonstrate soldered interconnect assemblies with an expected life of 10 years.
- Demonstrate cells bonded to anodized aluminum with a high-conductance adhesive.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Subtask 5.2 — Concentrator Optics Subtask

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** C. B. Stillwell  
**Telephone:** (505) 844-2130

**Project Engineer:** C. B. Stillwell  
**Telephone:** (505) 844-2130

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** The objectives of this subtask are to understand the interplay between concentrator system optical components and photovoltaic cells, explore technologies which have promise in producing high-optical-efficiency low-cost concentrator optics, and assist outside contractors with their optical component design and evaluation.

**Approach Present Tasks:** Use of lens and cell model design codes and experimental analysis hardware to obtain details of optical performance that can be used for design and evaluation. Outside contracts have been placed to develop the injection-molding and the continuous polymeric web (3M) processes for making low-cost high-efficiency Fresnel lenses. Springborn Laboratories has been contracted to develop a bonding system to bond injection-molded lenses to glass superstrates.

**Status/FY 1983 Accomplishments:** 3M's polymeric web lenses show good mold replication but the mold design needs to be improved. A follow-up contract is being issued and lens efficiencies greater than 80% are expected from this process. A procurement for Fresnel lens injection-molding research was initiated. Completed fabrication and laboratory check-out of a new experimental lens analyzer. Sandia lens/cell tester was used to evaluate lenses from GE, Intersol, and Martin Marietta. Intersol and Martin Marietta have received design assistance with the secondary optical elements for their improved module designs.

**FY 1984 Milestones:** To obtain lenses that are greater than 80% efficient from the 3M process by the end of FY 1984 and to place a contract for lens injection-molding early in FY 1984. New optical designs using secondaries are expected to improve module efficiencies by as much as 10% in FY 1984. Springborn will complete their bonding system study which should provide a good acrylic lens-to-glass bonding system.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Subtask 5.3 — Baseline Modules Subtask

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** M. Edenburn  
**Telephone:** (505) 844-4003

**Project Engineer:** M. Edenburn  
**Telephone:** (505) 844-4003

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** To conduct the research necessary to develop high efficiency, durable, low-cost potential photovoltaic concentrator modules that use point-or line-focus Fresnel lenses and silicon cells.

**Approach Present Tasks:** During FY 1983 a detailed analysis of the second-generation prototype Martin Marietta module which identified the module's loss mechanisms was completed. Design improvements to minimize the effects of these mechanisms were identified and are being used to improve the performance of the Intersol Power, Martin Marietta, and Varian backplane modules and to fabricate a high-efficiency Sandia experimental module. Design improvements for linear Fresnel modules are being pursued by E-systems (ENTECH) in their 3rd-generation design (incorporating a crossed lens for 2-dimensional concentration) and in their research and development of Westinghouse dendritic-web cells for incorporation into their module. Sandia has managed and consulted in the design and fabrication of several modules, and followed up with experimental performance and durability evaluation. The modules include those fabricated by Intersol Power, Martin Marietta, E-systems, GE, ASEC, Acurex, and Sandia. As a result, modules have been progressively more efficient and performance has not degraded due to accelerated or real-time environmental exposure tests.

**Status/FY 1983 Accomplishments:** A 14.2% peak actively-cooled E-systems module was tested in December 1982. A 15.4% peak Intersol Power module was delivered and tested in August 1983.

**FY 1984 Milestones:** 16.5% Sandia experimental module to be tested in November 1983. 16% improved commercial point-focus modules to be tested in May 1984. Entech 3rd-generation line-focus module to be tested in July 1984.

**Major Project Reports:**

- Burgess, E. L., ed. (March 1983). *A Bibliography of Reports by the Sandia Photovoltaic Projects*. SAND81-0135 Revision 2. Albuquerque, NM: Sandia National Laboratories; 64 pp. Available from: NTIS.

**Summary Date**  
December 1983

## SNLA

**Title:** Subtask 5.4 — Advanced Modules Subtask

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** M. Edenburn  
**Telephone:** (505) 844-4003

**Project Engineer:** M. Edenburn  
**Telephone:** (505) 844-4003

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** To pursue higher module efficiency through the use of GaAs and multiple junction cells.

**Approach Present Tasks:** Studies conducted at Sandia indicate that GaAs and multiple junction cells will probably be cost effective compared to silicon cells for use in concentrating modules. Stacked or monolithic multiple junction cells are more promising than separate cells that use dichroic filters or reflective high bandgap cells for spectrum splitting because of optical efficiency and packaging considerations. A procurement to obtain 2 kW of GaAs cell modules has been initiated. The module designs will be modifications of baseline module designs.

**Status/FY 1983 Accomplishments:** An RFP for GaAs cell modules was issued and proposals are due in October. Stacked cell module development is awaiting the availability of stacked AlGaAs/Si cells. Varians' 1000X passively-cooled GaAs cell module was delivered to Sandia and tested. Peak module efficiency was above 17%. The module's TIR secondary optical elements are efficient and offer very good alignment and tracking error tolerance.

**FY 1984 Milestones:**

- Develop a 17% to 19% GaAs module breadboard — June 1984.
- Develop a stacked cell module breadboard — September 1984.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** GaAs Cell Modules

**Contractor:**  
To be determined.

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** M. Edenburn  
**Telephone:** (505) 844-4003

**Contract Number:** 47-4129

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:** 06/83

**FY 1983**      **\$ 300,000**

**DOE/PV**

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** To solve design problems related to using GaAs cells in concentrating modules; to procure modules which will require many cells so that GaAs cell production issues can be addressed.

**Approach Present Tasks:** The work has been divided into two phases. In the first, a few cells will be designed and fabricated and an existing module design will be altered to accommodate the high-concentration cells. A module breadboard will be tested. In the second phase, 2 kW of modules will be fabricated, delivered to Sandia, and mounted on a pedestal tracker.

**Status/FY 1983 Accomplishments:** The RFP was issued in August 1983 and proposals are due on 5 October 1983.

**FY 1984 Milestones:** We expect to obtain a 17% to 19% module breadboard by June 1984.

**Major Project Reports:** None.

**Summary Date**  
December 1983

**SNLA**

**Title:** Design and Development of Injection-Molded Fresnel Lenses for Point-Focus PV Systems

**Contractor:**  
To be determined.

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** C. B. Stillwell  
**Telephone:** (505) 844-2130

**Contract Number:** 52-7481

**Contract Funding:**

**Source:**

**Current Contract Period From:** 12/01/83  
**To:** 03/01/85

**FY 1983**            **\$ 100,000**

**DOE/PV**

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** The objectives are to determine if point-focus Fresnel lenses with adequate optical efficiencies can be made by the injection-molding process, and to determine the cost of making such lenses.

**Approach Present Tasks:** The approach will be to study the optimum lens design for the injection-molding process, to make a lens mold master, and to make molding trial runs varying different molding parameters until optimum values are found. Lens samples will be submitted for evaluation.

**Status/FY 1983 Accomplishments:** A statement of work was submitted to approximately 50 potential contractors. Four responses were received in September 1983 and are being evaluated.

**FY 1984 Milestones:** To evaluate the proposals and award a contract to the successful bidder. The successful bidder will select the optimum lens parameters, make the lens masters, and start the molding trials by the end of FY 1984.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Low-Cost PV Concentrator Module Development

**Contractor:**

Acurex Corporation  
485 Clyde Avenue  
Mountain View, CA 94042

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** D. Rafinejad

**Telephone:** (415) 964-3200

**Project Engineer:** C. B. Stillwell

**Telephone:** (505) 844-2130

**Contract Number:** 62-7216

**Contract Funding:**

**Source:**

**Current Contract Period From:** 03/3/81

**To:** 04/30/83

**FY 1981**

**\$ 390,840**

**DOE/PV**

**FY 1982**

**\$ 35,684**

**DOE/PV**

**Project/Area/Task:** Concentrator Module Research

**Objectives:** To advance the maturity of the linear lens PV concentrator module through second-generation development. A PV module was to be developed to exhibit high efficiency, cost effectiveness, durability, reliability, and mass producibility.

**Approach Present Tasks:** None. Program completed.

**Status/FY 1983 Accomplishments:** A 4-module panel was delivered to Sandia in September 1982. A receiver electrical degradation study to determine the cause of a 20% performance degradation on 3 of 4 receivers was conducted; the results were inconclusive because of the small number of cells available for evaluation.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Kull, J.; Maraschin, R.; Rafinejad, D.; Spencer, R.; Sutton, G. (August 1983). *Linear Fresnel Lens Photovoltaic Concentrator Program*. SAND83-7020. Albuquerque, NM: Sandia National Laboratories; 140 pp. Work performed by Acurex Corporation, Mountain View, CA.

**Summary Date**

**December 1983**

## SNLA

**Title:** Low-Cost PV Concentrator Module Development

**Contractor:**

Applied Solar Energy Corporation  
15251 E. Don Julian Road  
City of Industry, CA 91746

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** F. Ho

**Telephone:** (213) 968-6581

**Project Engineer:** L. Beavis

**Telephone:** (505) 844-2231

**Contract Number:** 62-7217

**Contract Funding:**

**Source:**

**Current Contract Period From:** 02/11/81

FY 1981

\$ 270,000

DOE

**To:** 11/30/82

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** Design and construction of 3 × 5 point-focus modules.

**Approach Present Tasks:** ASEC has designed and fabricated 4 point-focus Fresnel lens concentrator modules. The modules use 3 columns of 5 square lenses, 17 cm × 17 cm. The geometric concentration ratio is 150X.

**Status/FY 1983 Accomplishments:** Completed technical work.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- *Design and Development of Low Cost Photovoltaic Concentrator Modules.* (November 1983). SAND83-7022. Albuquerque, NM: Sandia National Laboratories; 46 pp. Work performed by Applied Solar Energy Corporation, City of Industry, CA.

**Summary Date**  
December 1983



## SNLA

**Title:** Substitute Encapsulant for PVB

**Contractor:**

Applied Solar Energy Corporation  
15251 E. Don Julian Road  
City of Industry, CA 91746

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** F. Ho

**Telephone:** (213) 968-6581

**Project Engineer:** L. Beavis

**Telephone:** (505) 844-2231

**Contract Number:** 68-9412

**Contract Funding:**

**Source:**

**Current Contract Period From:** 03/12/82

**FY 1982**

**\$ 33,000**

**DOE**

**To:** 09/30/82

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** Produce substitute encapsulation linear-focus cell strings.

**Approach Present Tasks:** ASEC is studying materials that may be used to replace PVB (which bubbles and turns brown when exposed to high temperatures and UV radiation) in linear PV receivers. RTV looks like the best candidate. The NPE 1677 solid sheet from 3M Company bubbled and partially delaminated when exposed to the -30°C to +90°C environmental cycle.

**Status/FY 1983 Accomplishments:** Technical work is complete.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- *Concentrator Receiver Encapsulant Evaluation.* (February 1983). SAND82-7146. Albuquerque, NM; Sandia National Laboratories; 26 pp. Work performed by Applied Solar Energy Corporation, City of Industry, CA.

**Summary Date**  
December 1983

## SNLA

**Title:** Bonding System Design for Cell Substrates

**Contractor:**  
BDM Corporation  
1801 Randolph Road SE  
Albuquerque, NM 87106

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** B. Schwinkendorf  
**Telephone:** (505) 848-5318

**Project Engineer:** M. Rios, Jr.  
**Telephone:** (505) 844-7812

**Contract Number:** 61-0024

**Contract Funding:**

**Source:**

**Current Contract Period From:** 08/6/81  
**To:** 11/30/83

<b>FY 1981</b>	<b>\$ 145,000</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ 49,348</b>	<b>DOE</b>

**Project/Area/Task:** Concentrator Module Research

**Objectives:** The contract objective has been to develop new bonding (cell laydown) systems with the emphasis on filled organic materials.

**Approach Present Tasks:** Investigate materials and characterize thermal, electrical, and durability properties.

**Status/FY 1983 Accomplishments:** All technical work on this contract was complete as of 30 September 1983. Ten each of experimental cell mount assemblies have been received and a test plan is being completed for them. The most promising material appears to be copper-loaded RTV silicon (e.g., D.C. Sylgard 182) with 90%-94% copper by weight. The thermal conductivity of the material is about 2 W/m<sup>2</sup> K. Bondlines of 0.1 mm-0.15 mm are possible.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** The final report will be completed by 10/31/83 for 1st review.

**Summary Date**  
December 1983

## SNLA

**Title:** Fresnel Lens Aging Testing

**Contractor:**

DSET Laboratories  
Black Canyon Stage  
Box 1850

Phoenix, AZ 85029

**Principal Investigator:** T. Anderson

**Telephone:** (602) 465-7356

**Contract Number:** 61-5641

**Current Contract Period From:** 05/82

**To:** 05/83

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** D. L. King

**Telephone:** (505) 846-8220

**Contract Funding:**

FY 1981

\$ 20,000

**Source:**

DOE

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** Acrylic Fresnel lenses are essential components of current PV concentrator modules. Detailed data concerning the spectral transmittance of acrylic materials following prolonged outdoor exposure have not been well documented. The objectives of this contract are to expose several types of Fresnel lens materials (acrylics and glasses) to both accelerated and real-time outdoor exposure, and to periodically measure the resulting loss in spectral transmittance.

**Approach Present Tasks:** Typical PV-module Fresnel lens materials are currently being exposed to both accelerated and real-time solar radiation. Periodic measurements of spectral transmittance are being made.

**Status/FY 1983 Accomplishments:** Six types of acrylic Fresnel lens material have been exposed for a year and a half (as of October 1983). After washing, the total hemispherical transmittance of these samples was unchanged. However, the near-normal spectral transmittance has degraded for all samples, primarily at wavelengths less than 600 nm. The effect of this transmittance loss is a roughly 2% drop in the solar averaged transmittance. Detailed analyses of test measurements and their implication to PV-concentrator performance are in progress.

**FY 1984 Milestones:** Continue exposure and transmittance measurements.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Development of Actively-Cooled Linear Fresnel Lens Photovoltaic Receivers

**Contractor:**

Entech, Inc.  
P.O. Box 612246  
DFW Airport  
Dallas, TX 75261

**Principal Investigator:** M. J. O'Neill

**Telephone:** (214) 272-0515 ext. 3830

**Contract Number:** 37-7490

**Current Contract Period From:** 12/82  
**To:** 04/84

**Project/Area/Task:** Concentrator Module Research

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** M. Rios, Jr.

**Telephone:** (505) 844-7812

**Contract Funding:**

<b>FY 1983</b>	<b>\$ 97,231</b>
<b>FY 1984</b>	<b>\$ 51,937</b>

**Source:**

<b>DOE/PV</b>
<b>DOE/PV</b>

**Objectives:** The objective of this contract is to evaluate the performance and economic viability of linear Fresnel concentrator receivers which use Westinghouse continuous dendritic-web silicon-process cells. An additional objective is to fabricate and evaluate point-focus concentrator cells made with the same material.

**Approach Present Tasks:** Concentrator cells fabricated from 0.15  $\Omega$ -cm web material have been tested and shown to be low in performance due to poor short-circuit current. The low short-circuit current is probably due to boron precipitation from the heavy base doping. The approach is to determine the optimum performance of the web material by fabricating and testing cells from three separate batches of web material doped in the range of 0.5  $\Omega$ -cm to 1.5  $\Omega$ -cm. Point-focus cells will also be fabricated and tested.

**Status/FY 1983 Accomplishments:** Linear-focus and point-focus concentrator cells have been fabricated and tested. The results indicate that optimum performance for a 50X concentration ratio can probably be achieved with a base resistivity in the range of 0.5  $\Omega$ -cm to 1.5  $\Omega$ -cm.

**FY 1984 Milestones:** Linear- and point-focus concentrator cells will be fabricated from web material with base resistivities of 0.5, 1.0, and 1.5  $\Omega$ -cm. The cells will be tested and a report will be issued.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Third-Generation Module Development

**Contractor:**

Entech, Inc.  
P.O. Box 612246  
DFW Airport  
Dallas, TX 75261

**Principal Investigator:** M. J. O'Neill  
**Telephone:** (214) 272-0515 ext. 3830

**Contract Number:** 52-1485

**Current Contract Period From:** 03/10/83  
**To:** 09/84

**Project/Area/Task:** Concentrator Module Research

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** M. Rios, Jr.  
**Telephone:** (505) 884-7812

**Contract Funding:**

FY 1983	\$ 43,510
FY 1984	\$ 255,759

**Source:**

DOE/PV
DOE/PV

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**Objectives:** To develop an optimized passively-cooled linear Fresnel lens collector with highest performance efficiency at the lowest cost.

**Approach Present Tasks:** A thorough design analysis of a new passively-cooled linear Fresnel lens collector has been completed. A design with an optimum concentration ratio of 55X and an aperture of 18 in. has been developed. A preliminary analysis of a cross-lens concept indicates that the third-generation design can be further improved by superimposing crossed convex acrylic lenses resulting in a linear point-focus receiver, with a concentration ratio of about 150X.

**Status/FY 1983 Accomplishments:** A rigorous design analysis of the linear Fresnel concept has been completed. The results indicate that the performance and cost effectiveness can be improved. Tooling for 55X linear Fresnel lens film has been ordered.

**FY 1984 Milestones:** Complete design and procure and test components — FY 1984.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Low-Cost PV Concentrator Module Development

**Contractor:**

Entech, Inc.  
P.O. Box 612246  
DFW Airport  
Dallas, TX 75261

**Principal Investigator:** A. J. McDanal  
**Telephone:** (214) 272-0515 ext. 3820

**Contract Number:** 62-7218

**Current Contract Period From:** 03/1/81  
**To:** 02/29/84

**Project/Area/Task:** Concentrator Module Research

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** C. Chiang  
**Telephone:** (505) 846-3254

**Contract Funding:**

<b>FY 1981</b>	<b>\$ 236,800</b>
<b>FY 1982</b>	<b>\$ 50,072</b>

**Source:**

<b>DOE</b>
<b>DOE</b>

**Objectives:** To design, construct, and test passively-cooled line-focus photovoltaic modules. The work to be performed includes testing of a new lens design; design fabrication and testing of a new solar cell; design, construction and test of a passively-cooled receiver; and assembly and testing of five prototype modules.

**Approach Present Tasks:** The plan to be followed includes design, component fabrication and testing, prototype fabrication, and prototype testing. Present tasks are completion of prototype fabrication and testing.

**Status/FY 1983 Accomplishments:** Two modules have been constructed and tested. One of these modules uses solar cells of a more advanced design than originally proposed. The efficiency of the module with improved cells was measured at Sandia to be 13.7% at peak conditions of 28°C cell temperature and 800 W/m<sup>2</sup> insolation. The efficiency did not decrease after 8 weeks of temperature and humidity cycling. E-Systems originally proposed using their 3M film lens without a superstrate; however, for adequate structural stiffness, the film lens, .017 inches thick, was found to require lamination to an additional sheet of acrylic .080 inches thick. The dielectric cell bonding technique selected was alumina-loaded RTV 615. The final two modules to be made will use a redesigned heat-exchanger extrusion for improved cooling.

**FY 1984 Milestones:** The remaining three modules to be fabricated and tested will use a heat sink with a wider base for the fins to improve cooling. These modules will be tested and delivered to Sandia for further testing in December 1983.

**Major Project Reports:**

- McDanal, A. J.; O'Neill, M. J.; Waller, R. A. (1982). "Development of a Passively Cooled Linear Fresnel Lens Photovoltaic Concentrator Module." *Proceedings of the 1982 Annual Meeting of the American Solar Energy Society: Progress in Solar Energy — The Renewable Challenge*. Edited by Barbara H. Glenn and William A. Kolar. New York: ASES Publishing Office; pp. 281-286.

**Summary Date**  
December 1983

# SNLA

**Title:** Development of Advanced PV-T Concentrator Module

**Contractor:**

Entech, Inc.  
P.O. Box 612246  
DFW Airport  
Dallas, TX 75261

**Principal Investigator:** M. J. O'Neill  
**Telephone:** (214) 272-0515 ext. 3830

**Contract Number:** 74-0851

**Current Contract Period From:** 04/22/81  
**To:** 04/1/84

**Project/Area/Task:** Concentrator Module Research

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** M. Rios, Jr.  
**Telephone:** (505) 844-7812

**Contract Funding:**

<b>FY 1982</b>	<b>\$ 197,626</b>
<b>FY 1983</b>	<b>\$ 49,403</b>
<b>FY 1984</b>	<b>\$ 46,963</b>

**Source:**

<b>DOE/PV</b>
<b>DOE/PV</b>
<b>DOE/PV</b>

**Objectives:** To develop an advanced linear Fresnel lens photovoltaic-thermal (PV-T) collector capable of operating at fluid temperatures as high as 130°C and able to survive temperature excursions up to 160°C.

**Approach Present Tasks:** Under the current task, Entech will develop a new cell interconnect design that will reduce the stress on the solder joints to acceptable levels while undergoing temperature extremes which occur during environmental cycling; fabricate and deliver a variety of cell assembly test samples for testing at Sandia. The 48 samples to be delivered will vary in parameters such as solder type, cell type, cell superstrate, and nickel plating.

**Status/FY 1983 Accomplishments:** In FY 1983, 10 receiver segments were subjected to a series of environmental tests showing the interconnects could not survive a large number of temperature cycles from -30°C to +160°C.

**FY 1984 Milestones:** In FY 1984 it is anticipated that a new interconnect design will be successfully tested.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Linear Fresnel Lens Development

**Contractor:**

E-Systems, Inc.  
Energy Technology Center  
P.O. Box 22618  
Dallas, TX 75266

**Principal Investigator:** M. O'Neill

**Telephone:** (214) 272-0515

**Contract Number:** 13-2359

**Current Contract Period From:** 01/3/79

**To:** 11/30/83

**Project/Area/Task:** Concentrator Module Research

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** C. R. Stillwell

**Telephone:** (505) 844-2130

**Contract Funding:**

<b>FY 1979</b>	<b>\$ 213,900</b>
<b>FY 1980</b>	<b>\$ -0-</b>
<b>FY 1981</b>	<b>\$ -0-</b>
<b>FY 1982</b>	<b>\$ 50,328</b>

**Source:**

<b>DOE/PV</b>
<b>DOE/PV</b>
<b>DOE/PV</b>
<b>DOE/PV</b>

**Objectives:** The contract objective is to develop a low-cost linear Fresnel lens for photovoltaic concentrators using the extrusion/embossing process.

**Approach Present Tasks:** The contract was extended to remake the lens master embossing roller with 0.075-inch wide facets and to make new extrusion/embossing runs for evaluation.

**Status/FY 1983 Accomplishments:** Trial extrusion embossing runs were made with the remade embossing roller. Several parameters were varied to optimize the embossing process.

**FY 1984 Milestones:** Prepare final report.

**Major Project Reports:** None.

**Summary Date**  
December 1983



## SNLA

**Title:** Laminated Glass-Acrylic Fresnel Lens Development

**Contractor:**

General Electric  
Advanced Energy Programs Department  
P.O. Box 527  
King of Prussia, PA 19406

**Principal Investigator:** R. Hodge

**Telephone:** (215) 962-5949

**Contract Number:** 62-9975

**Current Contract Period From:** 10/20/81

**To:** 07/15/82

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** C. R. Stillwell

**Telephone:** (505) 844-2130

**Contract Funding:**

FY 1981

\$ 172,376

**Source:**

DOE/PV

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** The contract objectives were to extend work on the injection-molded laminated point-focus Fresnel lenses developed under Contract 46-0036 and to fabricate 5 by 6 lens parquets of point-focus photovoltaic concentrator arrays.

**Approach Present Tasks:** During 1981 the lens design was chosen. Work on the injection-molding process and the lens-to-glass lamination machine design was completed during 1982.

**Status/FY 1983 Accomplishments:** During FY 1982 sample injection-molded lenses were received and evaluated. The parquet laminating machine design was completed, and the machine was fabricated. Full lens parquets with injection-molded and compression-molded lenses were fabricated and delivered to Sandia. The injection-molded lenses had poor optical quality (below 80% efficiency). The parquets with compression-molded lenses failed environmental cycling tests. As a result work in this area with GE has not been continued.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Hodge, R. C. (December 1982). *Design and Development of a Laminated Fresnel Lens for Point Focus PV Systems — Phase II*. SAND82-7127. Albuquerque, NM: Sandia National Laboratories; 70 pp. Work performed by General Electric Company, Advanced Energy Programs Department, King of Prussia, PA.

**Summary Date**

December 1983

## SNLA

**Title:** Baseline Concentrator Module Improvement Program

**Contractor:**  
Intersol Power Corporation  
11901 West Cedar Avenue  
Lakewood, CO 80228

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** S. Broadbent  
**Telephone:** (303) 989-8710

**Project Engineer:** C. B. Stillwell  
**Telephone:** (505) 844-2130

**Contract Number:** 37-3136

**Contract Funding:**

**Source:**

**Current Contract Period From:** 04/01/83  
**To:** 06/01/84

**FY 1983**            **\$ 314,926**

**DOE/PV**

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** The contract objectives are to improve the efficiency of Intersol's current baseline PV module and to improve the two-axis tracker on which the module is mounted.

**Approach Present Tasks:** The approach is to use a TIR secondary concentrator, a smaller, more efficient cell, and better interconnects to improve module efficiency. The tracking drive unit is to be simplified for cheaper and easier manufacture. The present effort has been primarily concerned with the tracking drive unit.

**Status/FY 1983 Accomplishments:** The tracking drive unit has been redesigned and new parts ordered. Intersol will assemble a tracking structure in October 1983. The new solar cell for the module has been ordered.

**FY 1984 Milestones:** The new tracking structure will be assembled and evaluated. The module secondary concentrator will be designed and procured. Cell modules will be fabricated and delivered to Sandia for evaluation. A new structure will be delivered.

**Major Project Reports:** None.

**Summary Date**  
**December 1983**

## SNLA

**Title:** Lens/Cell Model Program Documentation

**Contractor:**

L. W. James & Associates  
1525 East County Road 58  
Fort Collins, CO 80524

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** L. W. James

**Telephone:** (303) 484-5296

**Project Engineer:** C. B. Stillwell

**Telephone:** (505) 844-2130

**Contract Number:** 37-2381

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/01/82

**To:** 03/01/83

**FY 1982**

**\$ 7,000**

**DOE/PV**

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** This contract is to furnish documentation on the various lens and cell model programs purchased on previous contracts.

**Approach Present Tasks:** The approach is to describe the various algorithms used in the lens and cell model programs.

**Status/FY 1983 Accomplishments:** Much of the documentation was prepared in draft form; not yet delivered to Sandia.

**FY 1984 Milestones:** Complete the documentation.

**Major Project Reports:** None.

**Summary Date**  
December 1983

**SNLA**

**Title:** Develop Cross-Coupled Linear Lens Program

**Contractor:**

L. W. James & Associates  
1525 East County Road 58  
Fort Collins, CO 80524

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** L. W. James

**Telephone:** (303) 484-5296

**Project Engineer:** C. B. Stillwell

**Telephone:** (505) 844-2170

**Contract Number:** 47-3871

**Contract Funding:**

**Source:**

**Current Contract Period From:** 07/01/83

**To:** 08/01/83

**FY 1983**

**\$ 2,700**

**DOE/PV**

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** The contract objective is to provide a cross-coupled linear lens design program that will run on the HP 9845 desktop computer. The cross-coupled linear lens is the new design proposed by Entech.

**Approach Present Tasks:** The approach is to modify an existing linear lens program to include the cross-coupled lens superstrate features.

**Status/FY 1983 Accomplishments:** Design program started.

**FY 1984 Milestones:** Complete the lens design program and furnish to Sandia.

**Major Project Reports:** None.

**Summary Date**

**December 1983**

**SNLA**

**Title:** Lens-Cell Model Computer Programs

**Contractor:**

L. W. James & Associates  
1525 East County Road 58  
Ft. Collins, CO 80524

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** L. W. James

**Telephone:** (303) 484-5296

**Project Engineer:** C. B. Stillwell

**Telephone:** (505) 844-2130

**Contract Number:** 50-5906

**Contract Funding:**

**Source:**

**Current Contract Period From:** 07/12/82  
**To:** 12/31/82

**FY 1982**      \$ 27,750

DOE/PV

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** The objective of this contract was to update various Fresnel lens and cell model design programs that run on the HP 9845 desktop computer using an array processor to reduce the running time.

**Approach Present Tasks:** None.

**Status/FY 1983 Accomplishments:** The Sandia-ordered array processor was delivered to L. W. James. The array processor was found to have insufficient accuracy to produce acceptable results. The contract was modified to delete remaining work with the array processor. The other contract items were completed and the updated software was delivered in July 1983.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** None.

**Summary Date**  
December 1983

# SNLA

**Title:** Second-Generation Point-Focus Fresnel Lens Module

**Contractor:**

Martin Marietta  
Aerospace Division  
P.O. Box 179  
Denver, CO 80201

**Principal Investigator:** B. Hein

**Telephone:** (303) 977-0510

**Contract Number:** 46-3018

**Current Contract Period From:** 01/31/80

**To:** 04/30/82

**Project/Area/Task:** Concentrator Module Research

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** M. Edenburn

**Telephone:** (505) 844-4003

**Contract Funding:**

**FY 1979** \$ 348,000

**FY 1980** \$ -0-

**FY 1981** \$ 61,000

**FY 1982** \$ 17,000

**Source:**

DOE

DOE

DOE

DOE

**Objectives:** To design and fabricate a prototype module that demonstrates the most recent cell and module technology and leads to a high-efficiency commercial module.

**Approach Present Tasks:** Martin Marietta's second-generation point-focus Fresnel lens module consists of two columns of 7 to 8.16-inch<sup>2</sup> lenses mounted on a molded plastic housing and Si cells mounted on individual passive aluminum heat exchangers. The geometric concentration is 84X.

**Status/FY 1983 Accomplishments:** Three prototype modules were delivered to Sandia and tested. Their peak efficiency was the highest measured at the time for a baseline module — 14.1%.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Broadbent, S.; et al. (December 1982). *Second Generation Photovoltaic Concentrator Array Design*. SAND82-7133. Albuquerque, NM: Sandia National Laboratories; 293 pp. Work performed by Martin Marietta Corporation, Denver, CO.

**Summary Date**

December 1983

## SNLA

**Title:** Baseline Module Improvement

**Contractor:**

Martin Marietta  
Aerospace Division  
P.O. Box 179  
Denver, CO 80201

**Principal Investigator:** L. Marshall

**Telephone:** (303) 977-0139

**Contract Number:** 52-1484

**Current Contract Period From:** 02/24/83

**To:** 11/24/83

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** M. Edenburn

**Telephone:** (505) 844-4003

**Contract Funding:**

**FY 1983**            \$ 70,000

**Source:**

DOE/PV

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** Martin Marietta is making design changes to their second-generation module to improve efficiency by approximately 10%.

**Approach Present Tasks:** Use a smaller cell to obtain full illumination of the cell's active area thereby reducing series resistance and diode loss effects. A reflective secondary optical element will be added to give alignment and tracking error tolerance; a conformal coating will be used to protect the cell and its contacts.

**Status/FY 1983 Accomplishments:** Work in progress.

**FY 1984 Milestones:** A module will be fabricated and delivered — February 1984.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Cell-Substrate Bonding System Development

**Contractor:**

Martin Marietta  
P.O. Box 179  
Mail Station C4000  
Denver, CO 80201

**Principal Investigator:** B. Hein

**Telephone:** (303) 977-0510

**Contract Number:** 68-0490

**Current Contract Period From:** 08/11/81

**To:** 12/30/82

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** L. Beavis

**Telephone:** (505) 844-2231

**Contract Funding:**

FY 1981

\$ 85,000

**Source:**

DOE/PV

**Project/Area/Task:** Concentrator Module Research

**Objectives:** Contract objectives are to develop bonding (cell laydown) systems, with emphasis on loaded thermal greases.

**Approach Present Tasks:** Characterize various thermal greases with various loadings (e.g., SiO<sub>2</sub> spheres) to increase thermal conductivity.

**Status/FY 1983 Accomplishments:** Received the test cell mounts (6 each). Testing of the two linear designs completed. Cover glasses in each case cracked, damaging the cells. This was caused by non-uniform stress applied by the mechanical clips (required when thermal grease is used). Preliminary evaluation on the point-focus mounts does not indicate a similar problem. Evaluation is continuing at Sandia. All loaded thermal greases are Al<sub>2</sub>O<sub>3</sub>-loaded (e.g., E:C:TC-8M). D.C. 3110 adhesive is also used to hold the point-focus cell mounts to the aluminum heat sink. The cell substrate is either alumina ceramic or epoxy-coated copper-clad invar.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Marshall, L. S. (August 1983). *Cell-Substrate Bonding System Design and Development*. SAND83-7021. Albuquerque, NM: Sandia National Laboratories; 99 pp. Work performed by Martin Marietta Corporation, Solar Energy Systems, Denver, CO.

**Summary Date**  
December 1983



## SNLA

**Title:** Environmental Degradation of Solar Optical Materials

**Contractor:**

McDonnell Douglas Astronautics  
5301 Bolsa Avenue  
Huntington Beach, CA 92647

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** C. A. Smith

**Telephone:** (714) 896-5287

**Project Engineer:** D. L. King

**Telephone:** (505) 844-8220

**Contract Number:** 68-4729

**Contract Funding:**

**Source:**

**Current Contract Period From:** 12/81

**FY 1982**      \$ 110,000

DOE/PV

**To:** 06/83

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** A great deal of information concerning the weathering and durability of both reflecting and transmitting solar optical materials has been generated by various organizations over the last several years. The objective of this effort was to conduct an extensive literature survey and consolidate, in a computer data base, all quantifiable data relating to the environmental degradation of these materials.

**Approach Present Tasks:** A statistical sorting of data was conducted in an attempt to isolate specific materials and/or site parameters that were particularly influential to optical degradation.

**Status/FY 1983 Accomplishments:** A survey of published literature, 1960 to present, was conducted, as was a telephone survey of organizations currently conducting related research. Optical degradation data and associated site parameters information were used to generate a large computer data base after statistical sorting and evaluation of data.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Morris, V. L. (November 1982). *Environmental Degradation of Solar Optical Materials: Volume I. Literature Survey*. SAND82-7068/1. Albuquerque, NM: Sandia National Laboratories; 126 pp. Work performed by McDonnell Douglas Astronautics Company, Huntington Beach, CA.

**Summary Date**  
December 1983

## SNLA

**Title:** Design and Development of Laminated Fresnel Lens Parquet for Point-Focus PV Systems

**Contractor:**  
Springborn Laboratories, Inc.  
Enfield, CT 06082

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** B. Baum  
**Telephone:** (203) 749-8371

**Project Engineer:** C. B. Stillwell  
**Telephone:** (505) 844-2130

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/01/82  
**To:** 02/01/84

**FY 1983**            **\$ 244,275**

**DOE/PV**

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** The contract objective is to develop an adhesive system and a bonding process which will bond glass superstrate/acrylic Fresnel lens parquets for use in point-focus PV modules.

**Approach Present Tasks:** The approach is to explore various adhesives, develop a bonding system from the most promising ones, evaluate samples and then select the best. A lamination machine will be devised to manufacture lens parquets. The present task is to screen the various candidate bonding systems.

**Status/FY 1983 Accomplishments:** Many adhesive systems were screened and the selection was narrowed to about 5. Glass and acrylic surface preparation studies have been carried out.

**FY 1984 Milestones:** Identify and recommend a bonding system and complete the parquet fabrication machine design task.

**Major Project Reports:** None.

**Summary Date**  
**December 1983**

# SNLA

**Title:** Hail Storm Monitoring

**Contractor:**

Texas Tech University  
Department of Industrial Engineering  
5210 16th Street  
Lubbock, TX 79409

**Principal Investigator:** M. L. Smith

**Telephone:** (806) 742-3543

**Contract Number:** 16-0895

**Current Contract Period From:** 10/1/81  
**To:** 09/30/84

**Project/Area/Task:** Intermediate PV System  
Experiments

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** T. D. Harrison

**Telephone:** (505) 844-6394

**Contract Funding:**

FY 1982 \$ 22,100

FY 1983 \$ 23,000

**Source:**

SNLA

SNLA

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**Objectives:** To determine the frequency of hail storms at intermediate PV projects; to determine the size and velocity of hail stones associated with the storms; and to correlate any resulting damage to the PV system with the data acquired.

**Approach Present Tasks:** To establish in the laboratory the size of dents in pads made by hail stones of varying sizes, impacting at various velocities; to furnish similar pads to the PV project; to return pads to the laboratory for analysis subsequent to each hail storm.

**Status FY 1983 Accomplishments:** Subsequent to all observed hail storms in FY 1982, the pads were returned to the laboratory and analyzed. Data sheet obtained for each hail incident.

**FY 1984 Milestones:** Submit report summarizing hail storms at intermediate PV sites, 30 September 1984.

**Major Project Reports:** None.

**Summary Date**  
December 1983

**SNLA**

**Title:** Domed Fresnel Lens

**Contractor:**  
Thermo Electron, Inc.  
101 First Avenue  
Waltham, MA 02154

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** A. Moffatt  
**Telephone:** (617) 890-8700 ext. 385

**Project Engineer:** M. Edenburn  
**Telephone:** (505) 844-4003

**Contract Number:** 68-9463

**Contract Funding:**

**Source:**

**Current Contract Period From:** 02/24/82  
**To:** 01/31/84

<b>FY 1982</b>	<b>\$ 49,500</b>
<b>FY 1983</b>	<b>\$ 8,400</b>

<b>DOE/PV</b>
<b>DOE/PV</b>

**Project/Area/Task:** Concentrator Module Research

**Objectives:** The objective of this contract was to fabricate domed Fresnel point-focus lenses that can be injection-molded and used at high concentration with an efficiency of  $\geq 85\%$ .

**Approach Present Tasks:** Fabrication of a multipiece collapsible tool for injection-molding domed point-focus Fresnel lenses. Several lenses were to be made from the tool.

**Status/FY 1983 Accomplishments:** An injection-molded tool was made and some lenses were molded, but their quality was poor because of errors in the tool. An attempt was made to correct the errors by nickel plating and recutting the tool, but the attempt was unsuccessful. Technical work on the contract has been stopped.

**FY 1984 Milestones:** None.

**Major Project Reports:** A final report will be written.

**Summary Date**  
December 1983

# SNLA

**Title:** Point Focus Polymeric Web Lens Development Phase II

**Contractor:**

3M Company  
Optical Technology Center  
3M Center  
St. Paul, MN 55144

**Principal Investigator:** S. Cobb  
**Telephone:** (612) 733-6913

**Contract Number:** 47-5883

**Current Contract Period From:**  
**To:**

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** C. B. Stillwell  
**Telephone:** (505) 844-2130

**Contract Funding:**

**FY 1983**                      \$ 160,000

**Source:**

DOE/PV

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** The objective of this contract will be to continue the design and development effort started in Contract 74-1349, utilizing a 3M proprietary process (polymeric web) to make point-focus Fresnel lenses for PV application.

**Approach Present Tasks:** The approach is to use the Martin Marietta second-generation module lens parameters to make a new master for the polymeric web process and to attempt to improve lens efficiency.

**Status/FY 1983 Accomplishments:** A statement of work for a 15-month effort was prepared and sent to 3M for a quote.

**FY 1984 Milestones:** Place a contract with 3M to prepare a new lens master, translate the design to the polymeric web process, and start making lens film.

**Major Project Reports:** None.

**Summary Date**  
December 1983

# SNLA

**Title:** Development of a Laminated Fresnel Lens with Polymeric Web Process

**Contractor:**  
3M Company  
Optical Technology Center  
3M Center  
St. Paul, MN 55144

**Principal Investigator:** S. Cobb  
**Telephone:** (612) 733-6913

**Contract Number:** 74-1349

**Current Contract Period From:** 04/28/81  
**To:** 10/28/82

**Project/Area/Task:** Concentrator Module Research

**Directing Organization:**  
Sandia National Laboratories

**Project Engineer:** C. B. Stillwell  
**Telephone:** (505) 844-2130

**Contract Funding:**

<b>FY 1981</b>	<b>\$ 189,204</b>
<b>FY 1982</b>	<b>\$ -0-</b>
<b>FY 1983</b>	<b>\$ -0-</b>

**Source:**

DOE/PV

**Objectives:** To develop a low-cost point-focus Fresnel lens using 3M's polymeric web process. In this process thin sheets of point-focus lenses, 3 lenses wide by 5 lenses long, are made as a continuous lens film. The cost is expected to be about \$0.50/ft<sup>2</sup> in volume runs. The films are to be bonded to a superstrate to form lens parquets.

**Approach Present Tasks:** To make a new lens master compatible to the polymeric web process and then adapt the masters to the process and fabricate lens film. The film would be solvent-bonded to an acrylic superstrate.

**Status/FY 1983 Accomplishments:** During FY 1983, 3 × 5 lens films were delivered and evaluated. These lenses performed to within 2% of the compression-molded lenses made from the master, however, the master lens exhibited only about 80% efficiency. Eight-degree facet draft angles (most compression-molded lenses have a 2% draft angle) were identified as the major loss mechanism in the lens master. 3M purposely chose the 8 angle for the first development work to assure lens formability. Reducing the draft angle will be major goal in the future. During December 1982, 20 each of 5 × 6 laminated lens parquets were delivered.

**FY 1984 Milestones:** Publish final report.

**Major Project Reports:** None.

**Summary Date**  
December 1983

# SNLA

**Title:** Point-Focus Back Panel Design

**Contractor:**  
Varian Associates  
611 Hansen Way  
Palo Alto, CA 94303

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** N. Kaminar  
**Telephone:** (415) 424-5090

**Project Engineer:** L. Beavis  
**Telephone:** (505) 844-2231

**Contract Number:** 37-0052

**Contract Funding:**

**Source:**

**Current Contract Period From:** 03/1/83  
**To:** 06/1/84

**FY 1983**                    **\$ 164,200**

**DOE**

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** To develop an integrated point-focus PV receiver; including cell design, cell interconnects, electrical insulation, heat sink, and all attachments.

**Approach Present Tasks:** To reduce the number of parts and assembly steps via integration of the electrical insulation onto the heat sink, etc.; to reduce the cost of producing modules and possibly improvement in performance.

**Status/FY 1983 Accomplishments:** The anodize coatings have proven to be effective and have passed the environmental testing.

**FY 1984 Milestones:** A review of the cost studies and the first experimental partial module assembly will take place on 10 November 1983.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** High Efficiency, Low Cost, Passively-Cooled PV Concentrator Module Development

**Contractor:**

Varian Associates  
611 Hansen Way  
Palo Alto, Ca 94303

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** N. Kaminar

**Telephone:**(415) 424-5090

**Project Engineer:** D. E. Arvizu

**Telephone:**(505) 846-0387

**Contract Number:**74-2999

**Contract Funding:**

**Source:**

**Current Contract Period From:** 05/1/81

**To:** 02/1/83

**FY 1981** \$ 320,000

**FY 1982** 74,000

DOE

DOE/PV

**Project/Area/Task:** Concentrator Module Research

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**Objectives:** To design and fabricate a low cost, efficient, durable, passively-cooled photovoltaic module using high concentration (1000X) and GaAs cell technology.

**Approach Present Tasks:** Tasks include lens/cell optimization study; lens/secondary concentrator design; cell design; module design; component fabrication/module assemble; and module testing.

**Status/FY 1983 Accomplishments:** Test results at Varian for the best single lens/cell secondary combination showed an 18.8% conversion efficiency. Tests conducted at Sandia indicate at  $15.7\% \pm 0.3\%$  conversion efficiency for the module at NOCT (i.e., 28°C ambient and 880 W/m<sup>2</sup> DNI) with a peak efficiency (i.e., 28°C cell temperature and 800 W/m<sup>2</sup> DNI) of  $17.2\% \pm 0.3\%$ . A 3 m/s wind increases efficiency by 2% with no apparent effect of wind direction. The optical design (flat Fresnel lens with TIR secondary) tolerates a 0.5 degree tracking error with only a 5% power loss. These results meet the FY 1983 milestones for the program.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** Final report due.

**Summary Date**  
December 1983



## SNLA

**Title:** PV Systems Experiment Project

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** T. D. Harrison  
**Telephone:** (505) 844-6394

**Project Engineer:**  
**Telephone:**

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82  
**To:** 09/30/83

**FY 1983**      \$ 420,000

**DOE/PV**

**Project/Area/Task:** PV Systems Experiment Project

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**Objectives:** To complete fabrication of all PV experiments; to establish criteria for evaluating the experiments; to oversee operation of completed experiments; to assure availability of needed resources; and to acquire and disseminate technical information which emerges from the experiments.

### **Approach Present Tasks:**

- Design, implement, test, and evaluate components and subsystems.
- Design, construct, and operate full-scale systems tests.
- Seek active industry involvement in all phases of the project; provide for timely and broad-based data dissemination.
- Aid in establishment of appropriate codes, standards, and certifications.
- To expand and implement phase-out plans for experiments which have achieved their objectives or which have outlived their usefulness.

### **Status/FY 1983 Accomplishments:**

- Phase out of Natural Bridges and San Bernadino sites.
- Agreement with EPRI to assume 85% of cost of data acquisition (Boeing); agreement with ARCO to acquire performance data.
- SE RES prototypes built and operational; ninth prototype installed at SW RES.
- Draft Residential Plan completed.

### **FY 1984 Milestones:**

- Close out Lovington Square and Beverly High School by 30 September 1984; Newman Power Station by 30 June 1984.
- Establish minimum human intervention operation at APS by March 1984; conclude DOE involvement by March 1984; assess further program involvement.
- Conclude DOE involvement at ORSA and DFW by June 1984; assess further program involvement.
- Establish operation of flexible prototypes at SW RES and NE RES by January 1984.
- Define thermal analysis — March 1984; initial performance analyses — June 1984; summarize O&M experiment — September 1984.

**Major Project Reports:** Final reports from each contractor and Sandia topical reports due.

**Summary Date**  
December 1983

# SNLA

**Title:** PCS Development

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** T. S. Key  
**Telephone:** (505) 844-3043

**Project Engineer:** T. S. Key  
**Telephone:** (505) 844-3043

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/81  
**To:** 09/83

<b>FY 1982</b>	<b>\$ 200,000</b>
<b>FY 1983</b>	<b>\$ 200,000</b>
<b>FY 1984</b>	<b>\$ 200,000</b>

<b>DOE/PV</b>
<b>DOE/PV</b>
<b>DOE/PV</b>

**Project/Area/Task:** Power Conditioning and Control

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**Objectives:** The primary objective is to assure that PCS concepts are compatible with PV collectors and the utility grid. Specific objectives include definition of performance requirements for the PCS, initiation of research activities, and conducting engineering evaluation which will support industrial development of PCS hardware suitable for PV applications.

**Approach Present Tasks:**

- Monitor power electronics research activities.
- Identify advanced power processing techniques.
- Develop to demonstrate feasibility for PV.
- Test, modify, and improve hardware.
- Initiate supporting activities related to safety codes, utility interface, grounding, etc.

**Status/FY 1983 Accomplishments:**

- Small, high efficiency 4-kW PCS using several different design approaches.
- Utility interface models and dynamic simulation verification completed — August 1983.
- Central station hardware development 3-year plan.

**FY 1984 Milestones:**

- High voltage large PCS conceptual design — January 1984
- Small transformerless PCS prototype — June 1984.
- Advanced specification approved for SMUD Phase III central station PCS.

**Major Project Reports:** None.

**Summary Date**  
December 1983

# SNLA

**Title:** PCS Engineering Evaluation

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** T. S. Key  
**Telephone:** (505) 844-3043

**Project Engineer:** W. Bower  
**Telephone:** (505) 844-5206

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 12/81  
**To:** 09/84

<b>FY 1982</b>	<b>\$ 239,000</b>
<b>FY 1983</b>	<b>\$ 557,000</b>
<b>FY 1984</b>	<b>\$ 450,000</b>

<b>DOE/PV</b>
<b>DOE/PV</b>
<b>DOE/PV</b>

**Project/Area/Task:** Power Conditioning and Control

**Objectives:** Characterize photovoltaic power conditioners with respect to performance, safety, reliability, maintenance, and survival under various operating conditions and extremes; identify potential operating problems (particularly with respect to unique-PV-array or grid-connection interface problems) and work with the manufacturer in correcting these problems; develop strawman uniform test procedures and maintain baseline specification documents; and provide a consistent set of evaluation data for candidate PCS designs.

**Approach Present Tasks:** Purchase off-the-shelf power conditioners as well as inverters developed in the program. Test at Sandia's facility and publish reports.

**Status/FY 1983 Accomplishments:**

- Engineering evaluation plan completed (SAND82-0209).
- Identification of tests and preliminary test procedures completed (SAND83-1802 draft).
- Testing of residential units completed.

**FY 1984 Milestones:**

- Complete and publish SAND83-1802.
- Publish test reports on residential units.

**Major Project Reports:** One for each unit evaluated. SAND83-2317, DECC 6 kW. SAND83-2318, ABACUS 4 kW.

**Summary Date**  
December 1983

## SNLA

**Title:** Innovative Approaches for UI PCS (Three-Phase)

**Contractor:**  
To be determined.

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** D. Chu  
**Telephone:** (505) 846-2457

**Contract Number:** 47-5638 and 47-5639

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/83  
**To:** 11/84

**FY 1982**            **\$ 200,000**

**DOE/PV**

**Project/Area/Task:** Power Conditioning and Control

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**Objectives:** Development and analysis of innovative PCS topologies for large and intermediate photovoltaic applications.

**Approach Present Tasks:** The designs should emphasize future low cost and performance potential. Substitution of solid state switching devices to accomplish functions which have in the past utilized inductive and capacitive elements is suggested, since the cost of the solid state devices is coming down. High efficiency, small size, and minimal weight are also desirable. A trade-off analysis should be done to determine the best design. A proof-of-concept of the best design should be developed. A final report should detail the evaluations, trade-offs, and proof of concept for the best design.

**Status/FY 1983 Accomplishments:** None. New Program.

**FY 1984 Milestones:** Publish final report.

**Major Project Reports:** None.

**Summary Date**  
**December 1983**

## SNLA

**Title:** Design Modification and Production Engineering

**Contractor:**  
Abacus Controls, Inc.  
P.O. Box 893  
Somerville, NJ 08876

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** G. O'Sullivan  
**Telephone:** (201) 526-6010

**Project Engineer:** W. Bower  
**Telephone:** (505) 844-3043

**Contract Number:** 68-1406

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/82  
**To:** 08/83

<b>FY 1982</b>	<b>\$ 129,228</b>
<b>FY 1983</b>	<b>\$ 107,000</b>

<b>DOE/PV</b>
<b>DOE/PV</b>

**Project/Area/Task:** Power Conditioning and Control

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**Objectives:** The objectives are to further develop existing PCS hardware to assure short-term availability with acceptable performance and price for early systems. Two 4-kW inverters and a battery interface option will be delivered.

**Approach Present Tasks:** Develop and construct advance 4-kW inverter with battery option. The following improvements are anticipated:

- Redesign and repackage to reduce fabrication labor and improve repairability (5:1 material-to-labor cost ratio).
- Reduce size and weight approximately 50%.
- Increase efficiency from 88% to 90%.
- Project quantity price is \$0.05/W.

**Status/FY 1983 Accomplishments:** Advanced design of 4-kW inverter completed and currently under test at Sandia. Battery interface option is 90% completed.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** SAND 83-7038.

**Summary Date**  
December 1983

## SNLA

**Title:** Determination of Detail Residential Load Profile and Harmonics

**Contractor:**  
BDM Corporation  
1801 Randolph Road SE  
Albuquerque, NM 87106

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** G. C. Collaros  
**Telephone:** (505) 848-5000

**Project Engineer:** M. G. Thomas  
**Telephone:** (505) 844-6111

**Contract Number:** 62-3977

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/14/80  
**To:** 11/30/82

FY 1982

\$ -0-

DOE/PV

**Project/Area/Task:** Power Conditioning and Control

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**Objectives:** To obtain and characterize harmonics at the Southwest Residential (SW RES) project. To obtain and evaluate the need for instantaneous load data for the determination of PV economic value.

**Approach Present Tasks:** Measurement and analysis of harmonics at the SW RES. Measurement of instantaneous loads incorporated into a statistical model.

**Status/FY 1983 Accomplishments:**

- Measurement of harmonics at SW RES completed.
- Load statistical model completed and Solcel performance adapted for using instantaneous data.

**FY 1984 Milestones:**

- Complete analysis of instantaneous loads and measurement of voltage harmonics.

**Major Project Reports:** Interim report on load; final reports and reproduction masters received for loads and harmonics.

**Summary Date**  
December 1983

## SNLA

**Title:** Utility Interactive PCS for Intermediate Applications (60 kW)

**Contractor:**

Firing Circuits, Inc.  
Muller Avenue  
P.O. Box 2007  
Norwalk, CT 06852

**Principal Investigator:** N. S. Andersson

**Telephone:** (203) 846-1633

**Contract Number:** 52-1419

**Current Contract Period From:** 08/15/83

**To:** 08/15/84

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** D. Chu

**Telephone:** (505) 846-2457

**Contract Funding:**

FY 1983

\$ 205,000

**Source:**

DOE/PV

**Project/Area/Task:** Power Conditioning and Control

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**Objectives:** Develop, build, and test a photovoltaic-compatible and utility line interactive power conditioning system in the 40-100 kW range.

**Approach Present Tasks:** Start with an existing design from some complimentary application. Modify this design for PV and utility interaction and specifications:

- dc — 400 V, range 575-675;
- ac — 480 V, 0.95 pF, 5%  $I_{THD}$ ;
- Efficiency —  $\geq 92\%$ ;
- Temperature — zero to 49°C.

**Status/FY 1983 Accomplishments:** Completed early design phase; first review meeting held 19 October 1983.

**FY 1984 Milestones:** Deliver 60-kW unit for test.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Design of PCS for Central Station

**Contractor:**  
General Electric R&D Center  
P.O. Box 43  
Schenectady, NY 12301

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** F. Turnbull  
**Telephone:** (518) 385-2211

**Project Engineer:** D. Chu  
**Telephone:** (505) 846-2457

**Contract Number:** 37-0194

**Contract Funding:**

**Source:**

**Current Contract Period From:** 04/5/83  
**To:** 03/31/84

**FY 1983**            **\$ 294,400**

**DOE/PV**

**Project/Area/Task:** Power Conditioning and Control

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**Objectives:** Provide an advanced conceptual design with low-cost and high-efficiency potential.

**Approach Present Tasks:**

- Review and assess the state-of-technology for megawatt power conditioners.
- Define dc and ac interface requirements.
- Define design requirements.
- Develop conceptual design.
- Program management and reports.

**Status/FY 1983 Accomplishments:**

- Completed review and assessment of the state-of-technology for megawatt power conditioners.
- Definition of dc and ac interface requirements is 90% completed.

**FY 1984 Milestones:** Complete conceptual design and report.

**Major Project Reports:** None.

**Summary Date**  
December 1983



## SNLA

**Title:** Design and Construction of Advanced PCS for Small PV Applications

**Contractor:**

General Electric R&D Center  
P.O. Box 8  
Schenectady, NY 12301

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** R. L. Steigerwald

**Telephone:** (518) 385-5467

**Project Engineer:** T. S. Key

**Telephone:** (505) 844-3043

**Contract Number:** 68-4806

**Contract Funding:**

**Source:**

**Current Contract Period From:** 08/12/82

**To:** 11/12/83

**FY 1982**

**\$ 492,000**

**DOE/PV**

**Project/Area/Task:** Power Conditioning and Control

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**Objectives:** The contract objective is to use an existing conceptual design (shown to be promising with respect to performance and production) to design and build an advanced PCS that meets a modified version of Sandia's baseline specifications.

**Approach Present Tasks:** Construction of two 4-kW high-frequency link PCS units.

**Status/FY 1983 Accomplishments:** Ninety-five percent of the fabrication, debugging, and factory testing has been completed.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** SAND83-7037.

**Summary Date**  
December 1983

## SNLA

**Title:** JPL Federal Agency Order

**Contractor:**

Jet Propulsion Laboratory  
4800 Oak Grove Drive  
Pasadena, CA 91109

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** J. Klein

**Telephone:** (213) 577-9629

**Contract Number:** 68-4728

**Current Contract Period From:** 11/81

**To:** 10/83

**Project Engineer:** T. S. Key

**Telephone:** (505) 844-3043

**Contract Funding:**

**FY 1982**           \$ 400,000

**FY 1983**           \$ 260,000

**Source:**

DOE/PV

DOE/PV

**Project/Area/Task:** Power Conditioning and Control

**Objectives:** The contract objectives are the definition and specification of PCS/utility interface requirements and the analysis and improvement of inverter topologies and PCS hardware.

**Approach Present Tasks:** Proof-of-concept hardware development for advanced intermediate topology delivery — May 1984; Purdue Dynamic Simulation lessons learned — January 1984; transformer loss requirements report — December 1983; and central station hardware lessons learned — February 1984.

**Status/FY 1983 Accomplishments:** Studies completed include intermediate PCS technical issues report and baseline specification; recommended PCS tests and an intermediate PCS/utility interface issues document; 60-kW PCS development and transformerless requirements report are underway.

**FY 1984 Milestones:** Complete project.

**Major Project Reports:** SAND82-7108; SAND83-7039.

**Summary Date**  
December 1983

## SNLA

**Title:** Advanced PCS Concepts Study

**Contractor:**

Teslaco, Inc.  
490 South Rosemead Blvd., Suite 6  
Pasadena, CA 91107

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** R. D. Middlebrook

**Telephone:** (213) 795-1699

**Project Engineer:** T. S. Key

**Telephone:** (505) 844-3043

**Contract Number:** 74-5898

**Contract Funding:**

**Source:**

**Current Contract Period From:** 07/1/81

**To:** 11/30/83

**FY 1981**                 \$ 162,200

**FY 1982**                 \$ 14,500

**FY 1983**                 \$ 112,000

DOE/PV

DOE/PV

DOE/PV

**Project/Area/Task:** Power Conditioning and Control

**Objectives:** The contract objectives are to select the optimal module size and topology for residential size inverters; to build and test breadboard; to provide a detailed design including control circuitry and maximum power tracking; to build and evaluate the final unit; and, to publish a final report.

**Approach Present Tasks:** A wide range of topology options are to be compared with respect to efficiency, simplicity, overall performance, and low-cost potential. No size or voltage restrictions within the constraints of a residential array (10 W-10 kW and 5 Vdc-200 Vdc) will be imposed. Current tasks are the development of closed-loop stability analysis techniques and hardware evaluation.

**Status/FY 1983 Accomplishments:** The topology and optimal module size have been selected. The prototype has been built and operated for demonstration at the Southwest Residential Experiment site at Las Cruces. These units were repackaged and improvements incorporated. Final testing at Sandia is currently underway.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** SAND83-7017.

**Summary Date**  
December 1983

## SNLA

**Title:** Design of PCS for Central Station

**Contractor:**

Westinghouse Electric Corp.  
Advanced Energy Systems Division  
P.O. Box 10864  
Pittsburg, PA 15236

**Principal Investigator:** P. Wood

**Telephone:**

**Contract Number:** 37-3011

**Current Contract Period From:** 05/3/83  
**To:** 03/31/84

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** D. Chu

**Telephone:** (505) 846-2457

**Contract Funding:**

**FY 1983**            \$ 191,760

**Source:**

DOE/PV

**Project/Area/Task:** Power Conditioning and Control

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**Objectives:** Provide an advanced conceptual design with low-cost and high-efficiency potential.

**Approach Present Tasks:**

- Review and assess the state-of-technology for megawatt power conditioners.
- Define dc and ac interface requirements.
- Define design requirements; develop conceptual design.
- Program management and reports.

**Status/FY 1983 Accomplishments:**

- Completed review and assessment of the state-of-technology for megawatt power conditioners.
- Definition of dc and ac interface requirements is 90% completed.

**FY 1984 Milestones:** Complete conceptual design and report.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Hawaiian Photovoltaic Residential Systems Operation and Evaluation

**Contractor:**  
University of Hawaii at Manoa  
Hawaii National Energy Institute  
Honolulu, HI 96822

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** G. Curtis  
**Telephone:** (808) 948-8788

**Project Engineer:** M. Thomas  
**Telephone:** (505) 844-6111

**Contract Number:** 37-4534

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/15/82  
**To:** 01/15/84

<b>FY 1980</b>	<b>\$ 100,000</b>
<b>FY 1981</b>	<b>\$ 185,284</b>
<b>FY 1982</b>	<b>\$ 75,000</b>

<b>MIT/LL</b>
<b>MIT/LL</b>
<b>SNLA</b>

**Project/Area/Task:** Residential PV Systems

**Objectives:** To operate and evaluate the three PV residences funded by DOE in Hawaii. The three residences are occupied. Two of the residences are on the island of Oahu; one is on the island of Molokai.

**Approach Present Tasks:** In addition to routine data collection and analysis, some system modifications are planned.

**Status/FY 1983 Accomplishments:** The three systems have been operated since July 1981. New power conditioning units in two of the systems and reconfiguration of the system wiring of one system to serve an entire quadruplex were accomplished.

**FY 1984 Milestones:** None.

**Major Project Reports:** A final report on system operation is expected November 1983.

**Summary Date**  
December 1983

## SNLA

**Title:** Task 1 — Systems Research of Sandia PV Projects

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** J. Stevens  
**Telephone:** (505) 846-4516

**Project Engineer:**  
**Telephone:**

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/1/82  
**To:** 09/30/83

**FY 1982**            **\$ 650,000**

**SNLA**

**Project/Area/Task:** Systems Research

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**Objectives:** To aid in the development of effective photovoltaic systems by contributing to the understanding of overall system operation and value, and transfer of this understanding to the user.

**Approach Present Tasks:** Prepare documentation of previous efforts defining general system design requirements and guidelines, subsystem requirements, and discussion of specific options and issues. Develop and refine analytical models and computer simulations. Define requirements to facilitate allocation of program resources.

**Status/FY 1983 Accomplishments:**

- Documentation of residential design topics and issues nearing completion.
- Utility-related research being documented to allow summation and analysis for further direction.
- Energy scenario effects study completed.

**FY 1984 Milestones:**

- Complete residential documentation effort — March 1984.
- Award utility research contract — December 1983.

**Major Project Reports:** Jones, G. ed. (March 1983). *Fourth Photovoltaic Systems Definition and Applications Projects Integration Meeting; Albuquerque, NM; 12-14 April 1983*. SAND83-0603. Albuquerque, NM: Sandia National Laboratories; 271 pp.

**Summary Date**  
December 1983

## SNLA

**Title:** Simplified Design Software for Small Computers

**Contractor:**

AIA Foundation  
1735 New York Avenue NW  
Washington, DC 20006

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** G. C. Royal

**Telephone:** (202) 626-7524

**Project Engineer:** G. J. Jones

**Telephone:** (505) 844-2433

**Contract Number:** 50-0680

**Contract Funding:**

**Source:**

**Current Contract Period From:** 01/1/82  
**To:** 12/31/82

**FY 1982**      \$ 19,600

**DOE**

**Project/Area/Task:** Systems Research

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**Objectives:** To simplify the design evaluation process for small applications by providing architects a tool capable of running on office microcomputers.

**Approach Present Tasks:** Final report preparation.

**Status/FY 1983 Accomplishments:** A computer code for use on small minicomputers has been developed. This code is based on previous hand calculation methods and is intended for use by system designers and architects. It yields performance estimates and economic assessment. The original codes have been modified for use on an IBM/PC. In addition, a more sophisticated energy flow/economic evaluation technique has been added.

**FY 1984 Milestones:**

- Publish revised users manual.

**Major Project Reports:** The users manual will be issued.

**Summary Date**  
December 1983

## SNLA

**Title:** Residential Topical Report Preparation

**Contractor:**

AIA Foundation  
1735 New York Avenue NW  
Washington, DC 20006

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** G. C. Royal

**Telephone:** (202) 626-7524

**Project Engineer:** G. J. Jones

**Telephone:** (505) 844-2433

**Contract Number:** 50-5802

**Contract Funding:**

**Source:**

**Current Contract Period From:** 05/27/82

FY 1982

\$ 143,100

DOE/PV

**To:** 05/31/83

**Project/Area/Task:** Systems Research

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**Objectives:** To aid in the preparation of reports summarizing the understanding of residential PV spheres for use by the potential system designer.

**Approach Present Tasks:** Residential photovoltaic system design status and guidelines are being summarized in a series of topical reports now being prepared. The effort involves outside contractors as well as program field centers. The series, which will be edited by Sandia, is intended for use by architects and designers.

**Status/FY 1983 Accomplishments:** An initial draft of the design tool document was delivered in late September 1982.

**FY 1984 Milestones:**

- Complete printing of reports — March 1984.

**Major Project Reports:** None.

**Summary Date**  
December 1983



# SNLA

**Title:** Stochastic Effects of PV Systems

**Contractor:**

Arizona State University  
Academic Services Bldg., Rm. 101  
Tempe, AZ 85281

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** P. Anderson

**Telephone:** (602) 965-6569

**Project Engineer:** M. Thomas

**Telephone:** (505) 844-6111

**Contract Number:** 68-1871

**Contract Funding:**

**Source:**

**Current Contract Period From:** 03/22/82  
**To:** 03/31/83

**FY 1982**            **\$ 200,000**

**DOE/PV**

**Project/Area/Task:** Systems Research

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**Objectives:** The objective of this study is to determine the effects of the inherent stochastic nature of PV on utility operation control and general dispatch. The scope of the project includes modeling and analytical evaluation of PV and the development of possible solutions to identified problems.

**Approach Present Tasks:** Utility automatic generation control for the WSCC Region is modeled using a DOE computer simulation (which replaces an inadequate EPRI code). By following frequency control errors (and other regulated variables of the utility industry), the effects of PV variability due to cloud passage are estimated.

**Status/FY 1983 Accomplishments:** Obtained the EPRI simulation on AGC and developing an input cloud model.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** A draft describing utility AGC was delivered at the completion of Task 1. Final report received and distributed for review — September 1983. Final review and publication prior to December 1983. A Monte Carlo simulation will be performed to establish any possible totally random synergistic effects during final draft review.

**Summary Date**  
December 1983

## SNLA

**Title:** Analysis of Concentrating PV-T Systems for the Commercial/Industrial Sector

**Contractor:**

BDM Corporation  
1801 Randolph Road SE  
Albuquerque, NM 87106

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** W. E. Schwinkendorf

**Telephone:** (505) 848-5313

**Project Engineer:** M. Rios, Jr.

**Telephone:** (505) 844-7812

**Contract Number:** 68-0361

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/9/81

**To:** 11/9/82

**FY 1982**

**\$ 395,400**

**DOE/PV**

**FY 1983**

**\$ 53,000**

**DOE/PV**

**Project/Area/Task:** Systems Research

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**Objectives:** The objectives of this project are to make feasibility assessments and to develop design procedures and reference designs for total energy systems that use actively-cooled concentrating photovoltaic collectors for commercial and industrial application. Ten application-site pairs were selected following initial assessment. These were evaluated for the impact of technical issues, and design guidance was developed. Three of the ten were then carried through to the detailed design phase.

**Approach Present Tasks:** The approach is to select the ten most promising application-site pairs. Of these ten choices, the three most cost effective have been chosen for trade-off analysis and detailed designs. Currently, more accurate design nomographs are being developed, and an application analysis of laundromats is being conducted.

**Status/FY 1983 Accomplishments:**

- The original scope of work has been completed.
- A four-volume draft report has been reviewed and approved.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- *Analysis of Concentrating PV-T Systems for the Commercial/Industrial Sector, Volume 1 — Executive Summary, Volume 2 — PV-T State of the Art Survey and Site/Application Pair Selection, Volume 3 — Technical Issues and Design Guidance, and Volume 4 — PV-T Design Analysis.*

**Summary Date**  
December 1983

## SNLA

**Title:** Energy Scenario Effects Study

**Contractor:**

General Electric  
1 River Road  
Schenectady, NY 12345

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** G. J. Bonk

**Telephone:** (518) 385-4097

**Project Engineer:** G. J. Jones

**Telephone:** (505) 844-2433

**Contract Number:** 13-9482

**Contract Funding:**

**Source:**

**Current Contract Period From:** 04/1/81  
**To:** 09/30/82

<b>FY 1983</b>	<b>\$ 401,600</b>
<b>FY 1982</b>	<b>\$ 72,000</b>

<b>DOE/PV</b>
<b>DOE/PV</b>

**Project/Area/Task:** Systems Research

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**Objectives:** The objective of this project is to analyze the impact of future energy contingencies on the value of photovoltaic energy.

**Approach Present Tasks:** None. Program completed.

**Status/FY 1983 Accomplishments:** The results treat the continental U.S. on a regional basis, following the electric reliability councils. Results indicate the regional variation in PV energy worth, the impact of future fuel mixes, and the role of capacity credit. This work has led to a reassessment of system design issues and better understanding of utility impact. During FY 1983 the contractor's submitted final report was extensively rewritten for increased clarity. The revised document was published as a Sandia report.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:**

- Bonk, G.J.; Jones, G.J.; Thomas, M.G.. (August 1983). *The Effects of Future Energy Scenarios on Photovoltaic Energy Value*. SAND83-1283. Albuquerque, NM: Sandia National Laboratories, 96 pp. Work performed by General Electric Company, Electric Utility Systems Engineering Department, Schenectady, NY and Sandia National Laboratories.

**Summary Date**  
December 1983

## SNLA

**Title:** Technology Transfer Documentation

**Contractor:**

General Electric  
Advanced Energy Programs Dept.  
P.O. Box 527  
King of Prussia, PA 19406

**Principal Investigator:** E. Mehalick

**Telephone:** (215) 962-5842

**Contract Number:** 50-8426

**Current Contract Period From:** 09/2/82  
**To:** 05/1/83

**Project/Area/Task:** Systems Research

**Directing Organization:**

Sandia National Laboratories

**Project Engineer:** M. G. Thomas

**Telephone:** (505) 844-6111

**Contract Funding:**

FY 1982           \$ 163,700

**Source:**

DOE/PV

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**Objectives:** To analyze and prepare draft technology transfer documents for the A&E community on energy storage and dc loads, design and design alternatives, PV/T flat plate collectors, and PV economics.

**Approach Present Tasks:** State-of-the-art concepts were reviewed and analyzed to prepare presentation to the PV design community, current and future.

**Status/FY 1983 Accomplishments:**

- Analysis and draft reports completed.

**FY 1984 Milestones:**

- Revision of design report and review of other technology transfer documents.

**Major Project Reports:** All draft reports received.

**Summary Date**  
December 1983

## SNLA

**Title:** Reference Design for Photovoltaic Central Power Station

**Contractor:**  
Martin Marietta  
P.O. Box 179  
Denver, CO 80201

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** R. Hein  
**Telephone:** (303) 977-0510

**Project Engineer:** G. Jones  
**Telephone:** (505) 844-2433

**Contract Number:** 62-9142

**Contract Funding:**

**Source:**

**Current Contract Period From:** 06/11/81  
**To:** 12/31/82

**FY 1982**            **\$ 383,000**

**DOE/PV**

**Project/Area/Task:** Systems Research

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**Objectives:** The contract objective was to design a central power station plant, located adjacent to the Arizona Public Service Saguaro Power Station.

**Approach Present Tasks:** Project complete.

**Status/FY 1983 Accomplishments:** Two designs for a 10 MW station were developed: one flat-panel, one concentrator. The key issues were identified and recommendations given for future work. The contractor's final report was received on schedule but needed extensive revisions. The second draft also required revision. Publication has been delayed for 6 months.

**FY 1984 Milestones:** Publication of final report.

**Major Project Reports:**

- The two design summaries and the final report should be available in early 1984 as SAND82-7147, 7148, and 7149.

**Summary Date**  
December 1983

## SNLA

**Title:** Technology Transfer Documentation

**Contractor:**

NASA/JPL  
4800 Oak Grove Drive  
Pasadena, CA 91103

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** R. Sugimura

**Telephone:** (213) 577-9118

**Project Engineer:** M. G. Thomas

**Telephone:** (505) 844-6111

**Contract Number:** 37-6475

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/28/82

**FY 1983**

**\$ 100,000**

**DOE/PV**

**To:** 05/2/83

**Project/Area/Task:** Systems Research

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**Objectives:** To analyze and prepare draft technology transfer documents for the A&E community on PV fundamentals and array design.

**Approach Present Tasks:** All past and current state-of-the-art concepts were to be reviewed, analyzed, and presented as concise design and design-related treaties.

**Status/FY 1983 Accomplishments:**

- Analysis and draft reports completed.

**FY 1984 Milestones:**

- Revision of the array design document — November 1983.
- Review of other technology transfer documents.

**Major Project Reports:** Draft reports were received on the fundamentals and array design reports.

**Summary Date**  
December 1983

## SNLA

**Title:** Technology Transfer Documentation

**Contractor:**  
NASA/JPL  
4800 Oak Grove Drive  
Pasadena, CA 91103

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** K. Volkmer  
**Telephone:** (213) 577-9170

**Project Engineer:** G. J. Jones  
**Telephone:** (505) 844-2433

**Contract Number:** 37-7345

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/4/82  
**To:** 06/30/83

**FY 1983**      **\$ 150,000**

**DOE/PV**

**Project/Area/Task:** Systems Research

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**Objectives:** To assist in the preparation of residential technology transfer documents.

**Approach Present Tasks:** The effort consisted of four tasks: 1) to prepare the installation, operation and maintenance topical report; 2) to provide environmental health and safety input to the institutional issues topical report; 3) to publish *Photovoltaic Environmental Health and Safety Issues Status Report*; and 4) to provide editorial support to the overall residential documentation effort.

**Status/FY 1983 Accomplishments:**

- The installation topical report draft was completed and sent for outside review — September 1983.
- The input for the institutional issues report was included in that topical report currently being prepared for review.

**FY 1984 Milestones:** *Photovoltaic Environment Health and Safety Issues Status Report* will be published by JPL in early FY 1984.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Photovoltaic Bibliography

**Contractor:**  
Solar Energy Research Institute  
1617 Cole Boulevard  
Golden, CO 80401

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** K. Weber  
**Telephone:** (303) 231-7067

**Project Engineer:** G. J. Jones  
**Telephone:** (505) 844-2433

**Contract Number:** 37-5047

**Contract Funding:**

**Source:**

**Current Contract Period From:** 10/11/82  
**To:** 01/31/83

**FY 1983**                      **\$ 50,000**

**DOE/PV**

**Project/Area/Task:** Systems Research

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**Objectives:** The preparation of a comprehensive list of documents pertaining to residential photovoltaic systems. This work supports residential photovoltaic technology transfer documentation.

**Approach Present Tasks:** An extensive survey of published literature was performed using several topical listings, and each of the PV laboratories was asked to provide titles and review the final listings. Selected titles were abstracted and evaluated to provide further background data.

**Status/FY 1983 Accomplishments:** Both the basic bibliography and the abstracted reports documents were received on schedule in FY 1983.

**FY 1984 Milestones:** None.

**Major Project Reports:** None.

**Summary Date**  
December 1983



## SNLA

**Title:** Technology Transfer Documentation

**Contractor:**

Solar Energy Research Institute  
1617 Cole Boulevard  
Golden, CO 80401

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** W. Short

**Telephone:** (303) 231-7721

**Project Engineer:** G. D. Jones

**Telephone:** (505) 844-2433

**Contract Number:** 52-0271

**Contract Funding:**

**Source:**

**Current Contract Period From:** 01/12/83  
**To:** 09/30/83

**FY 1983**      **\$ 70,000**

**DOE/PV**

**Project/Area/Task:** Systems Research

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**Objectives:** A document to aid the residential PV system designer in determining the feasibility of a given application.

**Approach Present Tasks:** The principal factors determining PV system feasibility were identified and techniques for communicating these to the architectural community were developed. A draft feasibility assessment report was provided to the technology transfer documentation team.

**Status/FY 1983 Accomplishments:** The draft document was provided on schedule.

**FY 1984 Milestones:** The feasibility assessment document will be published as part of the residential PV design series.

**Major Project Reports:**

- Residential Photovoltaic Systems: Should I Be Interested?

**Summary Date**  
December 1983

## SNLA

**Title:** Impact of Residential Grid-Connected Photovoltaic Power Systems on the Utility

**Contractor:**

University of Texas at Arlington  
West 6th at Speer Street  
Arlington, TX 76019

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** J. Fitzer

**Telephone:** (817) 273-2268

**Contract Number:** 50-5811

**Current Contract Period From:** 15/15/82  
**To:** 01/15/84

**Project Engineer:** J. Stevens

**Telephone:** (505) 846-2457

**Contract Funding:**

FY 1982           \$ 79,748

**Source:**

DOE/PV

**Project/Area/Task:** Systems Research

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**Objectives:** The contract objectives are to determine the effect of varying power factors on distribution feeders due to PV power and to evaluate the cumulative effect of inverter harmonic currents on distribution line voltage harmonics.

**Approach Present Tasks:** Refinement of harmonic models of household loads and distribution transformers is being completed. Final feeder voltage profiles are being run.

**Status/FY 1983 Accomplishments:** Completed most data acquisition and analysis. Upon first analysis, it was determined that a clearer picture would be given if another feeder was monitored. An extension was granted to accomplish this.

**FY 1984 Milestones:** Project completion — January 1984.

**Major Project Reports:** Final Report due — January 1984.

**Summary Date**  
December 1983

# SNLA

**Title:** Task 9 — Technology Evaluation

**Contractor:**  
In-House

**Directing Organization:**  
Sandia National Laboratories

**Principal Investigator:** H. Gerwin  
**Telephone:** (505) 844-0112

**Project Engineer:**  
**Telephone:**

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

FY 1983      \$ 500,000

DOE/PV

**Project/Area/Task:** Technology Evaluation

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**Objectives:** To establish an extensive testing capability to support the system development and evaluation efforts in power conditioning and array BOS; and to provide support performance testing of components, especially those involved in the concentrator development program.

**Approach Present Tasks:** To provide a fully staffed test facility capable of needed testing. The staff will develop test procedures as required as well as provide technical support for development projects.

**Status/FY 1983 Accomplishments:**

- Installation of Hughes and Battelle flat-plate building blocks.
- Initiation of RES PCU testing program.
- Fix of grounding problem at BDM PRDA and structured experiments support of OCSA experiment.
- Installation of PV-T building block.
- Testing of baseline, Intersol, Varian, and other concentrator modules.

**FY 1984 Milestones:**

- Complete RES PCU testing program.
- Publish PCU performance reports and test procedures.
- Design and implement automated annunciator system for field experiments.
- Operate building block arrays and continue concentrator component testing.

**Major Project Reports:** None.

**Summary Date**  
December 1983

## SNLA

**Title:** Dynamic Simulation of Dispersed Grid-Connected Photovoltaic Power Systems

**Contractor:**

Purdue University  
School of Electrical Engineering  
West Lafayette, IN 47907

**Directing Organization:**

Sandia National Laboratories

**Principal Investigator:** O. Wasynczuk

**Telephone:** (317) 494-3475

**Project Engineer:** J. Stevens

**Telephone:** (505) 846-4516

**Contract Number:** 62-4092

**Contract Funding:**

**Source:**

**Current Contract Period From:** 06/1/81  
**To:** 12/31/82

<b>FY 1982</b>	<b>\$ 301,200</b>
<b>FY 1983</b>	<b>\$ 148,769</b>

<b>DOE/PV</b>
<b>DOE/PV</b>

**Project/Area/Task:** Utility Interface

---

**Objectives:** To develop PV system models simulation and to interpret the PV system both individually and collectively on typical distribution networks.

**Approach Present Tasks:** Develop models, identify case studies of interest, run simulations and verify results with actual hardware tests.

**Status/FY 1983 Accomplishments:**

- The models and simulations have been defined and verified.
- Simulation case studies have been run and reporting is underway.

**FY 1984 Milestones:** Dynamic simulation results to be reported.

**Major Project Reports:** SAND83-7018, Dynamic Simulation — Modeling of Control. SAND83-7019, Dynamic Simulation — Results.

**Summary Date**  
December 1983

# **Sandia National Laboratories**

# **NASA/Lewis Research Center**

## NASA/Lewis

**Title:** Assessment of Hybrid PV Systems

**Contractor:**

EER, Inc.  
1951 Kidwell Drive  
Vienna, VA 22180

**Directing Organization:**

NASA-Lewis Research Center

**Principal Investigator:** A. Cabraal

**Telephone:** (703) 893-8600

**Project Engineer:** L.R. Scudder

**Telephone:** (216) 433-4000 ext. 5328

**Contract Number:** DEN3-299

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/10/82

**To:** 9/10/83

**FY 1982**

**\$ -0-**

**DOE**

**FY 1983**

**\$ 193,206**

**DOE**

**Project/Area/Task:** PV Hybrid System Assessment

---

**Objectives:** The objective of this activity is to provide a comprehensive assessment of the potential of PV hybrid systems (PV/Wind, PV/Diesel, etc.) for stand-alone applications.

**Approach/Present Tasks:** Define and assess hybrid concepts and societal issues to determine appropriate hybrid techniques; develop typical hybrid conceptual designs; evaluate technical and economic viability.

**Status/FY 1983 Accomplishments:**

- Task I — Completed definition of candidate PV hybrid concepts — February 1983.
- Task II — Completed assessment of PV hybrid systems — June 1983.
- Task III — Completed conceptual design of hybrid systems — September 1983.

**FY 1984 Milestones:** None.

**Major Project Reports:** Final Report. NASA CR-168264. To be issued November 1983.

**Summary Date**

October 1983

## NASA/Lewis

**Title:** Modular Stand-Alone System Development

**Contractor:**

Hughes Aircraft Company  
Building A1, M/S 4C843  
P.O. Box 9399  
Long Beach, CA 90810-0399

**Directing Organization:**

NASA-Lewis Research Center

**Principal Investigator:** G.J. Naff

**Telephone:** (213) 513-3487

**Project Engineer:** R. DeLombard

**Telephone:** (216) 433-4000 ext. 331

**Contract Number:** DEN3-207

**Contract Funding:**

**Source:**

**Current Contract Period From:** 11/80  
**To:** 7/83

FY 1980	\$ 457,900
FY 1981	\$ -0-
FY 1982	\$ -0-
FY 1983	\$ -0-

DOE
DOE
DOE
DOE

**Project/Area/Task:** Stand-Alone Applications/System  
Development

---

**Objectives:** The objective of this activity is to develop a family of modular PV stand-alone power systems covering the range from 1 kW to 15 kW which are adaptable to different environments.

**Approach/Present Tasks:** Design, build and evaluate a low-cost, multi-purpose prototype modular PV stand-alone system.

**Status/FY 1983 Accomplishments:**

- Completed prototype evaluation.
- Completed and issued Phase I and II Final Reports.

**FY 1984 Milestones:** None.

**Major Project Reports:**

*Phase I; Final Report.* (February 1983). DOE/NASA/0207-1.

*Phase II; Final Report.* (July 1983). DOE/NASA/0207-2.

**Summary Date**  
October 1983



## NASA/Lewis

**Title:** Utrik Island Photovoltaic Village Power Project

**Contractor:**

Hughes Aircraft Company  
Building A1, M/S 4C843  
P.O. Box 9399  
Long Beach, CA 90810-0399

**Principal Investigator:** G. J. Naff

**Telephone:** (213) 513-3487

**Contract Number:** DEN3-349

**Current Contract Period From:** 10/11/83

**To:** 6/10/86

**Project/Area/Task:** Stand-Alone Applications

**Directing Organization:**

NASA-Lewis Research Center

**Project Engineer:** L. R. Scudder

**Telephone:** (216) 433-4000 ext. 5328

**Contract Funding:**

**FY 1982**

\$ -0-

**FY 1983**

\$ 170,634

**Cost Sharing:** \$100,000, Republic of the Marshall Islands

**Source:**

DOE

DOE

**Objectives:** The objective of this work is to field test and evaluate a modular PV system in a salt spray environment typical of the Pacific Islands and to develop a Marshallese understanding and capability in the application of PV technology.

**Approach/Present Tasks:** Establish joint, cost-shared project with the Marshall Islands; install and operate a complete integrated village PV system; instruct Rep Mar\* personnel in operation/maintenance of system.

**Status/FY 1983 Accomplishments:**

- Memorandum of Understanding and Implementation Plan developed and signed by all parties.
- Contract for implementation of project awarded to Hughes Aircraft.

**FY 1984 Milestones:**

- Install system and train Republic of the Marshall Islands personnel — second and third quarter of FY 1984.

**Major Project Reports:** None.

**Summary Date**

October 1983

\*Republic of the Marshall Islands

**NASA/Lewis**

**Title:** PV Medical Refrigerator/Freezer Project

**Contractor:**  
Solar Power Corporation  
20 Cabot Road  
Woburn, MA 01801

**Directing Organization:**  
NASA-Lewis Research Center

**Principal Investigator:** B. Huskey  
**Telephone:** (617) 935-4600

**Project Engineer:** J. Toma  
**Telephone:** (216) 433-4000 ext. 331

**Contract Number:** DEN3-238

**Contract Funding:**

**Source:**

**Current Contract Period From:** 01/19/82  
**To:** 11/19/83

<b>FY 1982</b>	<b>\$ 92,999</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	<b>DOE</b>

**Project/Area/Task:** Stand-Alone Applications

**Cost Sharing:** \$39,685 (DHHS/CDC)

---

**Objectives:** The objective of this task is to demonstrate the use of PV-powered refrigerator/freezers for the preservation of vaccines at remote medical centers in developing countries.

**Approach/Present Tasks:** Procure from industry small PV-powered refrigerator/freezer systems, meeting CDC/World Health Organization requirements; install and field-test units at remote medical posts in India, Maldives Islands, Gambia (2), Ivory Coast (2), Colombia, and Peru.

**Status/FY 1983 Accomplishments:**

- Refrigerator/freezer units installed and operating at all sites.

**FY 1984 Milestones:** None.

**Major Project Reports:** Final Report due April 1984.

**Summary Date**  
October 1983

## NASA/Lewis

**Title:** PV Power Systems for Remote Villages in Gabon

**Contractor:**  
Solavolt International  
3646 E. Atlanta Avenue  
Phoenix, AZ 85062

**Directing Organization:**  
NASA-Lewis Research Center

**Principal Investigator:** W. J. Kaszeta  
**Telephone:** (602) 231-6439

**Project Engineer:** A. F. Ratajczak  
**Telephone:** (216) 433-4000 ext. 6816

**Contract Number:** DEN3-347

**Contract Funding:** **Source:**

**Current Contract Period From:** 8/29/83  
**To:** 8/29/85

**FY 1982** \$ -0- DOE  
**FY 1983** \$ 500,000 DOE

**Project/Area/Task:** Stand-Alone Applications

**Cost Sharing:** \$134,000 (Contractor), \$500,000 (Gabon)

---

**Objectives:** The objective of this activity is to demonstrate the value of PV power for a variety of rural development applications of interest to Gabon.

**Approach/Present Tasks:** Establish a joint, cost-shared project with the government of Gabon; conduct field experiments in four villages with PV systems powering loads selected by Gabonese; install standardized systems for each application (health, potable water, education and public lighting).

**Status/FY 1983 Accomplishments:**

- Implementation plan developed and signed by all parties.
- Contract for implementation of activity awarded.
- Site visits completed.
- Assisted local university personnel in developing methodology for impact assessment.

**FY 1984 Milestones:**

- Install system and train Gabonese personnel.
- Conduct technical seminar in Gabon, September-October — 1984.

**Major Project Reports:** None.

**Summary Date**  
October 1983

## NASA/Lewis

**Title:** Microprocessor Controller Development

**Contractor:**

TriSolarCorp  
10 DeAngelo Drive  
Bedford, MA 01730

**Directing Organization:**

NASA-Lewis Research Center

**Principal Investigator:** A. Millner

**Telephone:** (617) 275-1200

**Project Engineer:** R. DeLombard

**Telephone:** (216) 433-4000 ext. 331

**Contract Number:** DEN3-310

**Contract Funding:**

**Source:**

**Current Contract Period From:** 1/26/83

**To:** 1/31/84

**FY 1982**

**\$ -0-**

**DOE**

**FY 1983**

**\$ 341,413**

**DOE**

**Project/Area/Task:** Stand-Alone Applications/System  
Development

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**Objectives:** The objective of this work is to develop a generalized, microprocessor technology-based photovoltaic control subsystem which shall lower the cost of energy from stand-alone photovoltaic systems.

**Approach/Present Tasks:** An assessment of the technical and economic considerations involved in the design of a control subsystem will be performed. Conceptual designs will be developed from this assessment and a developmental design will be selected from the range of conceptual designs. A prototype controller will be constructed and tested according to the developmental design.

**Status/FY 1983 Accomplishments:**

- Complete assessment survey.
- Conceptual design review conducted — June 1983.
- Prototype controller under construction at end of FY 1983.

**FY 1984 Milestones:**

- Factory testing completed — November 1983.
- Complete STF testing — mid-January 1984.

**Major Project Reports:** Final Report due January 1984.

**Summary Date**

October 1983

# **Brookhaven National Laboratory**

## Brookhaven

**Title:** Health and Environmental Effects of Photovoltaics

**Contractor:**  
In-House

**Directing Organization:**  
Biomedical and Assessment Division  
Brookhaven National Laboratory

**Principal Investigator:**  
**Telephone:**

**Project Engineer:** L. D. Hamilton/P. D. Moskowitz  
**Telephone:** (516) 282-2017

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

<b>FY 1980</b>	<b>\$ 200,000</b>
<b>FY 1981</b>	<b>\$ 225,000</b>
<b>FY 1982</b>	<b>\$ 120,000</b>
<b>FY 1983</b>	<b>\$ 250,000</b>

<b>DOE/Solar</b>
<b>DOE/Solar</b>
<b>DOE/Solar</b>
<b>DOE/Solar</b>

**Project/Area/Task:** PV Health and Safety

**Objectives:** The objective of this project is to identify and analyze health and environmental concerns related to development of photovoltaic energy systems.

**Approach/Present Tasks:** Examine health and environmental risks and control technology needs for near-term photovoltaic cell processing alternatives.

- 1.1 — Process/Material Alternatives: identify processing alternatives, gather process information, examine risks, and identify areas of control technology needs and uncertainty associated with fabrication of thin film amorphous silicon and gallium arsenide photovoltaic cells.
- 1.2 — Control Technology: identify control equipment, and capital and operating costs for the manufacture of dentritic web photovoltaic cells. Compare costs of integrated control vs. individual work-stations.

**Status/FY 1983 Accomplishments:**

- Task 1.1 completed, report in review.
- Task 1.2 completed, report in preparation.

**FY 1984 Milestones:**

- Examination of new process and material alternates — September 1984.
- Characterization of specific hazards — September 1984.

**Major Project Reports:**

- Moskowitz, P.D.; Coveney, E.A.; Rabinowitz, S.; Barancik, J.I. (September 1983). "Rooftop Photovoltaic Arrays: Electric Shock and Fire Health Hazards." *Solar Cells*. Vol. 9 (No. 4) ; pp. 327-336.
- Fthenakis, V.M.; et al. (October 1983). *Amorphous Silicon and Gallium Arsenide Thin Film Technologies for Photovoltaic Cell Production: An Identification of Potential Health and Safety Hazards*. Upton, NY: Brookhaven National Laboratory.

**Summary Date**  
October 1983

# **Battelle Pacific Northwest Laboratories**

**PNL**

**Title:** Photovoltaic Technology Assessment

**Contractor:**  
In-House

**Directing Organization:**  
Battelle Pacific Northwest Laboratories

**Principal Investigator:** R. L. Watts  
**Telephone:** (509) 376-4348

**Project Engineer:** R. L. Watts  
**Telephone:** (509) 376-4348

**Contract Number:**

**Contract Funding:**

**Source:**

**Current Contract Period From:**  
**To:**

**FY 1984**

**\$ 95,000**

**DOE**

**Project/Area/Task:** Photovoltaic Technology  
Assessment

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**Objectives:** To provide the information on the current economic and technical developments and trends of the photovoltaics industry. This information will be used by the DOE Photovoltaics Division in planning long-term R&D projects.

**Approach Present Tasks:** Provide information on the current and near-term status of various technological developments including the advances in single crystal silicon production techniques and in amorphous silicon; also provide information on firms entering and exiting the market, as well as the status of various markets.

**Status/FY 1983 Accomplishments:** The project is active. Achievements include providing DOE with quarterly presentations on the developments of the industry and the preparation of a report that summarized the status of these developments during 1982.

**FY 1984 Milestones:** Publish status report — January 1984.

**Major Project Reports:** None.

**Summary Date**  
December 1983



# **Oak Ridge National Laboratory**

# ORNL

**Title:** Technical Assistance to PV Grant Projects

**Contractor:**

Oak Ridge National Laboratory  
P.O. Box Y  
Oak Ridge, TN 37830

**Directing Organization:**

Department of Energy  
Photovoltaic Energy Systems Division  
Washington, D.C. 20585

**Principal Investigator:** S. I. Kaplan

**Telephone:** (615) 574-5819

**Project Engineer:** V. N. Rice

**Telephone:** (202) 252-1694

**Contract Number:** W-7405-eng-26, FTP/A No. 00007

**Contract Funding:**

**Source:**

**Current Contract Period From:**

**FY 1983**

**\$ 78,000**

**DOE**

**To:**

**FY 1984**

**\$ 35,000**

**DOE**

**Project/Area/Task:**

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**Objectives:** To provide technical assistance to DOE and to the grantees at Georgetown University (GU) and Mississippi County Community College (MCCC). Specifically, this includes monitoring work progress, technical review of major commitments, coordinating technical assistance from DOE Laboratories, and system performance analysis.

**Approach/Present Tasks:**

- ORNL is assisting DOE in formulating and evaluating alternatives for termination of grant support at MCCC. The approach is to leave the school with a low-maintenance, cost-effective system, to the extent possible.
- The GU system is under construction; completion is expected in September 1984.

**Status/FY 1983 Accomplishments:** System diagnostics were continued at MCCC. Collector subfield I-V measurements, optical alignment checks and shadowing tests were performed by the staff. Bid evaluations were coordinated and summarized for the GU Project. Block V-level tests of candidate modules at JPL were arranged. ORNL participated in 2 major design reviews following the award of the project of Hughes Aircraft Co.

**FY 1984 Milestones:** Draft Final Report on MCCC — March 1984.

**Major Project Reports:**

- Kaplan, S. I. (December 1982). *Evaluation of Mississippi County Community College and Northwest Mississippi Junior College Solar Power Systems*. ORNL/TM-8396. Oak Ridge, TN: Oak Ridge National Laboratory; 37 pp.

**Summary Date**  
December 1983

# ORNL

**Title:** Effect of Weathering and Atmospheric Contamination on PV Cells in Concentrators

**Contractor:**

Oak Ridge National Laboratory  
P.O. Box Y  
Oak Ridge, TN 37830

**Directing Organization:**

Department of Energy  
Photovoltaic Energy Systems Division  
Washington, D.C. 20585

**Principal Investigator:** S. I. Kaplan

**Telephone:** (615) 574-5819

**Project Engineer:** V. N. Rice

**Telephone:** (202) 252-1694

**Contract Number:** W-7405-eng-26, FTP/A No. 00017

**Contract Funding:**

**Source:**

**Current Contract Period From:**

FY 1983

\$ 78,000

DOE

**To:**

FY 1984

\$ 75,000

DOE

**Project/Area/Task:**

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**Objectives:** To study the ability of atmospheric contaminants to form adherent deposits on concentrator PV cells, which would interfere with light transmission to the cells by filtering, blocking or reflecting light, by modifying cell surfaces, or by other means.

**Approach/Present Tasks:** Single-crystal Si cells are exposed to concentrated sunlight in ambient atmosphere in a reflective ( $\approx 30X$ ) concentrator in a 2-axis tracking mount at ORNL.

**Status/FY 1983 Accomplishments:**

- Sample irradiations were performed covering spans of 1 month and 6 months between inspections. No significant permanent degradation of light transmission occurred.

**FY 1984 Milestones:** Relocate the concentrator at Atlanta Airport for a new test series — April 1984.

**Major Project Reports:** None.

**Summary Date**  
December 1983

# **DOE Albuquerque Operations Office**

**DOE/AL**

**Title:** G. N. Wilcox Hospital Experiment

**Contractor:**

Acurex Corporation  
Alternate Energy Division  
485 Clyde Avenue  
Mountain View, CA 94042

**Principal Investigator:** D. Rafinejad

**Telephone:** (415) 964-3200

**Contract Number:** DE-AC04-79ET20633

**Current Contract Period From:** 09/28/79

**To:** 03/1/83

**Project/Area/Task:** Array Design and Evaluation

**Directing Organization:**

DOE-Albuquerque Operations Office

**Project Engineer:** D. C. Graves

**Telephone:** (505) 846-5202

**Contract Funding:**

**FY 1979-1980** \$ 1,368,927

**FY 1981** \$ 422,315

**FY 1982** \$ 45,104

**FY 1983** \$ -0-

**Cost Sharing:** \$412,000

**Source:**

DOE

DOE

DOE

**Objectives:** To assess parabolic trough concentrating PV systems as a viable PV technology in a non-optimum climatic region.

**Approach Present Tasks:** DOE participation in this experiment has been completed.

**Status/FY 1983 Accomplishments:** Steady-state operation was not achieved. System performed at 15-20 kWp,  $\approx$  50% of rating. Westinghouse power conditioner was shown to be inadequate for reliable operation required for PV systems.

**FY 1984 Milestones:** None.

**Major Project Reports:** Evaluation to be included in Sandia report on experiments.

**Summary Date**

December 1983

## DOE/AL

**Title:** Sky Harbor Airport Experiment

**Contractor:**  
Arizona Public Service Co.  
P.O. Box 21666  
Phoenix, AZ 85036

**Directing Organization:**  
DOE-Albuquerque Operations Office

**Principal Investigator:** T. Lepley  
**Telephone:** (602) 271-2964

**Project Engineer:** D. C. Graves  
**Telephone:** (505) 846-5202

**Contract Number:** DE-AC04-80ET20624

**Contract Funding:**

**Source:**

**Current Contract Period From:** 03/19/80  
**To:** 06/30/84

<b>FY 1980</b>	<b>\$ 3,088,176</b>	<b>DOE</b>
<b>FY 1981</b>	<b>\$ 3,412,877</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 274,965</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	

**Project/Area/Task:** Array Design and Evaluation

**Objectives:** To establish highly reliable unattended operation for linear focus concentrating array compatible with utility operation.

**Approach Present Tasks:** Retrofitting all arrays to avoid slippage and potentiometer problems. Analyze PCU tripping and array tracking errors.

**Status/FY 1983 Accomplishments:** Established high efficiency operation (greater than 10%) and compatibility with utility operations.

**FY 1984 Milestones:** Steady-state operation, establish O&M requirements.

**Major Project Reports:**

- *Airport Solar Photovoltaic Concentrator, Phase III.* DOE/ET/20624-T4. Washington, D.C.: U.S. Department of Energy; 22 pp. Work performed by Arizona Public Service Company, Phoenix, AZ.

**Summary Date**  
December 1983

## DOE/AL

**Title:** BDM Office Building Experiment

**Contractor:**

BDM Corporation  
1801 Randolph Road SE  
Albuquerque, NM 87106

**Directing Organization:**

DOE-Albuquerque Operations Office

**Principal Investigator:** W. Kauffman

**Telephone:** (505) 848-5223

**Project Engineer:** D. C. Graves

**Telephone:** (505) 846-5202

**Contract Number:** DE-AC04-79ET20625

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/28/79

**To:** 09/30/83

**FY 1979-1980** \$ 1,111,421

**FY 1981** \$ 550,219

**FY 1982** \$ -0-

**FY 1983** \$ 49,971

DOE

DOE

DOE

**Project/Area/Task:** Array Design and Evaluation

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**Objectives:** To assess concentrating parabolic trough concentrators in an optimum southwest climate and to gain experience in a rooftop facility.

**Approach Present Tasks:** DOE involvement in the experiment has been completed.

**Status/FY 1983 Accomplishments:** Steady-state operation not attained. Rooftop facility proved to be expensive and resulted in wind damage to the array. Peak power less than 35 kWp for a 47-kWp design. Westinghouse inverter was particularly troublesome.

**FY 1984 Milestones:** None.

**Major Project Reports:** Final Phase III report.

**Summary Date**  
December 1983

**DOE/AL**

**Title:** Dallas-Fort Worth Airport Experiment

**Contractor:**

E-Systems, Inc.  
Energy Technology Center  
P.O. Box 226118  
Dallas, TX 75266

**Principal Investigator:** M. O'Neill

**Telephone:** (214) 272-0515

**Contract Number:** DE-AC04-79ET20626

**Current Contract Period From:** 09/28/79

**To:** 07/31/84

**Project/Area/Task:** Array Design and Evaluation

**Directing Organization:**

DOE-Albuquerque Operations Office

**Project Engineer:** D. C. Graves

**Telephone:** (505) 846-5202

**Contract Funding:**

**FY 1979-1980** \$ 784,552

**FY 1981** \$ 345,572

**FY 1982** \$ 339,409

**FY 1983** \$ -0-

**Source:**

DOE

DOE

DOE

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**Objectives:** To establish steady-state operation of a small PV-T linear focus Fresnel concentrating array.

**Approach Present Tasks:** To operate modified system without maintenance, to establish importance of lens soiling, and to establish needed O&M procedures for this type of facility.

**Status/FY 1983 Accomplishments:** Underwent modifications to alleviate shadowing and use of thermal output. Obtained efficiencies for the PV system in excess of 9% and total system efficiencies approaching 50%.

**FY 1984 Milestones:** Steady-state high efficiency operation and O&M assessment requirements.

**Major Project Reports:** Phase II report complete; O&M and Phase III reports in preparation.

**Summary Date**  
December 1983



**DOE/AL**

**Title:** Lovington Shopping Center Experiment

**Contractor:**  
Lea County Electric Coop.  
P.O. Drawer 1447  
Lovington, NM 88260

**Directing Organization:**  
DOE-Albuquerque Operations Office

**Principal Investigator:** E. R. Felfe  
**Telephone:** (505) 396-3631

**Project Engineer:** D. C. Graves  
**Telephone:** (505) 846-5202

**Contract Number:** DE-AC04-79ET20628

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/30/79  
**To:** 08/31/83

**FY 1979-1980** \$ 2,663,358

DOE

**FY 1981** \$ 220,738

DOE

**FY 1982** \$ 186,571

DOE

**FY 1983** \$ -0-

**Cost Sharing:** \$51,000

**Project/Area/Task:** Array Design and Evaluation

**Objectives:** To operate and maintain a large fixed flat-plate array compatibly with the utility and to assess power conditioning units designed for PV use in the Southwest.

**Approach Present Tasks:** DOE funding has ceased. A memorandum of understanding with Lea County Electric is under negotiation to continue system and insolation data collection.

**Status/FY 1983 Accomplishments:** Establishment of steady-state and highly reliable operation at designed power level.

**FY 1984 Milestones:** None.

**Major Project Reports:** Phase III report.

**Summary Date**  
December 1983

**DOE/AL**

**Title:** El Paso Newman Power Station Experiment

**Contractor:**

New Mexico State University  
New Mexico Solar Energy Institute  
P.O. Box 3SOL  
Las Cruces, NM 88003

**Principal Investigator:** V. Risser  
**Telephone:** (505) 646-3948

**Contract Number:** DE-AC04-79ET20626 and  
DE-AC04-81AL17093

**Current Contract Period From:** 09/28/79  
**To:** 06/30/84

**Project/Area/Task:** Array Design and Evaluation

**Directing Organization:**

DOE-Albuquerque Operations Office

**Project Engineer:** D. C. Graves  
**Telephone:** (505) 846-5202

**Contract Funding:**

**FY 1979-1980**     \$ 470,870  
**FY 1981**         \$ 233,082  
**FY 1982**         \$ -0-  
**FY 1983**         \$ -0-  
**Cost Sharing:** \$5,000

**Source:**

DOE  
DOE

**Objectives:** To operate a 17-kW flat-plate PV system which supplies energy to the El Paso Newman Power Station.

**Approach Present Tasks:** The system operated during FY 1983 with no major problems. Operation and continued system and insolation data collection are ongoing.

**Status/FY 1983 Accomplishments:** System-level experience has been gained in the operation and maintenance of the facility since 15 February 1981, providing a benchmark for dc (no power conditioning) operation of a PV system.

**FY 1984 Milestones:** DOE participation terminates — June 1984.

**Major Project Reports:**

- *20-Kilowatt El Paso Photovoltaic System; Phase III, Initial Operation, January 27, 1981, through April 23, 1982.* (May 1982). DOE/ET/17093-T7. Washington, D.C.: U.S. Department of Energy; 72 pp. Work performed by New Mexico State University, New Mexico Solar Energy Research Institute, Las Cruces, NM and El Paso Electric Company, El Paso, TX.

**Summary Date**  
December 1983

**DOE/AL**

**Title:** Oklahoma City Science and Arts Center Experiment

**Contractor:**

Science Applications, Inc.  
1710 Goodridge Drive  
P.O. Box 1303  
McLean, VA 22102

**Principal Investigator:** Y. Gupta

**Telephone:** (703) 827-4782

**Contract Number:** DE-AC04-79ET20630

**Current Contract Period From:** 09/28/79

**To:** 04/26/84

**Project/Area/Task:** Array Design and Evaluation

**Directing Organization:**

DOE-Albuquerque Operations Office

**Project Engineer:** D. C. Graves

**Telephone:** (505) 846-5202

**Contract Funding:**

**FY 1979-1980** \$ 2,516,912

**FY 1981** \$ \$-0-

**FY 1982** \$ 434,661

**FY 1983** \$ -0-

**Cost Sharing:** \$327,0000

**Source:**

DOE

DOE

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**Objectives:** To operate a large flat-plate mirror enhanced PV system which supplies energy to the Oklahoma City Science and Arts Center.

**Approach Present Tasks:** System-level experience has been gained in the operation and maintenance of the facility since 02/1/82. Evaluation of mirror enhancement and semicrystalline devices is the focus of the R&D.

**Status/FY 1983 Accomplishments:** Data at summer solstice shows system power and maximum power tracker anomalies. Evaluation and analysis is ongoing.

**FY 1984 Milestones:** DOE participation terminates — April 1984.

**Major Project Reports:** Phase III report.

**Summary Date**  
December 1983

**DOE/AL**

**Title:** Beverly High School Experiment

**Contractor:**  
Solar Power Corporation  
20 Cabot Road  
Woburn, MA 01801

**Directing Organization:**  
DOE-Albuquerque Operations Office

**Principal Investigator:** R. R. Addiss  
**Telephone:** (617) 935-4600

**Project Engineer:** D. C. Graves  
**Telephone:** (505) 846-5202

**Contract Number:** DE-AC04-79ET20631

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/28/79  
**To:** 11/30/83

<b>FY 1979-1980</b>	<b>\$ 2,747,288</b>	<b>DOE</b>
<b>FY 1981</b>	<b>\$ 376,266</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 22,875</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ -0-</b>	
<b>Cost Sharing:</b>	<b>\$131,000</b>	

**Project/Area/Task:** Array Design and Evaluation

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**Objectives:** To operate and maintain a fixed flat plate array in the Northeast as a twin to the Lovington experiment.

**Approach Present Tasks:** DOE funding stage completed. A time and materials contract from SNLA is in negotiations to continue system data and insolation data collection.

**Status/FY 1983 Accomplishments:** Establish steady-state operation. Ground fault trips related to oversensitive GFIs rather than array problems.

**FY 1984 Milestones:** None.

**Major Project Reports:** None.

**Summary Date**  
December 1983

**DOE/AL**

**Title:** NE Residential Experiment Station

**Contractor:**

MIT Energy Laboratory  
77 Massachusetts Avenue  
Cambridge, MA 02139

**Directing Organization:**

DOE-Albuquerque Operations Office

**Principal Investigator:** E. C. Kern

**Telephone:** (617) 863-5770

**Project Engineer:** D. C. Graves

**Telephone:** (505) 846-5202

**Contract Number:** DE-AC02-76ET20279

**Contract Funding:**

**Source:**

**Current Contract Period From:** 06/30/84

**To:** 09/30/84

**FY 1983**

**\$ 384,000**

**DOE**

**Project/Area/Task:** Residential Project

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**Objectives:** Continued operation of existing facility and implementation of retrofit evaluation experimentation.

**Approach Present Tasks:** Construction of retrofit prototypes to optimize PV design for retrofit design.

**Status/FY 1983 Accomplishments:** Completion of evaluation of first one-and-a-half years of NE RES activities and initiation of retrofit evaluation program.

**FY 1984 Milestones:** Analysis of load monitoring activities, evaluation of retrofit schemes, analysis of data collection methods.

**Major Project Reports:**

- Russell, M. C. (January 1983). *Photovoltaic-System Evaluation at the Northeast Residential Experiment Station; November 1980 — May 1982; Final Report*. DOE/ET/20279-219. Washington, D.C.: U.S. Department of Energy; 163 pp. Work performed by Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, MA.

**Summary Date**  
December 1983

**DOE/AL**

**Title:** SW Residential Experiment Station

**Contractor:**  
New Mexico State University  
New Mexico Solar Energy Institute  
P.O. Box 3SOL  
Las Cruces, NM 88003

**Principal Investigator:** J. Schaefer  
**Telephone:** (505) 646-4240

**Contract Number:** DE-AC04-82AL20090

**Current Contract Period From:** 05/1/82  
**To:** 09/30/84

**Project/Area/Task:** Residential Project

**Directing Organization:**  
DOE-Albuquerque Operations Office

**Project Engineer:** D. C. Graves  
**Telephone:** (505) 846-5202

<b>Contract Funding:</b>		<b>Source:</b>
<b>FY 1982</b>	<b>\$ 802,497</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ 950,000</b>	<b>DOE</b>

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**Objectives:** To construct, operate and evaluate small systems in a southwest climate.

**Approach Present Tasks:** Primary focus for current year include the thermal behavior of mounting schemes utilizing a flexible prototype under construction, the testing of new ribbon technology on the ninth prototype, and continued analysis of system reliability.

**Status/FY 1983 Accomplishments:** Continued operation of 8 prototypes and the construction and installation of a ninth prototype; evaluation of thermal behavior of existing prototypes; evaluation of harmonics on a local utility feeder.

**FY 1984 Milestones:** Mounting scheme thermal analysis, climatic variation analysis and reliability evaluation.

**Major Project Reports:** None.

**Summary Date**  
December 1983

**DOE/AL**

**Title:** SE Residential Experiment Station

**Contractor:**  
University of Central Florida  
Division of Sponsored Research  
Orlando, FL 32816

**Directing Organization:**  
DOE-Albuquerque Operations Office

**Principal Investigator:** G. Ventre  
**Telephone:** (305) 783-0300

**Project Engineer:** D. C. Graves  
**Telephone:** (505) 846-5202

**Contract Number:** DE-FC04-82AL20729

**Contract Funding:**

**Source:**

**Current Contract Period From:** 09/30/82  
**To:** 09/30/84

**FY 1982**            \$ 2,000,000

**DOE**

**FY 1983**            \$ -0-

**Cost Sharing:** \$1,842,896

**Project/Area/Task:** Residential Project

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**Objectives:** To install and operate 3 prototypes in a southeastern climate and to study the effects of regional building trends on PV systems.

**Approach Present Tasks:** Operation of existing facilities, improvement of tracking equipment and expansion of facility to provide the ability to perform structured experiments.

**Status/FY 1983 Accomplishments:** Construction of 3 prototypes, 2 integral mounts and 1 standoff mount and continued operation of the SE PV house.

**FY 1984 Milestones:** Assist in performance modelling, acquire data on tracking enhancement, and conceptualize modular building approaches.

**Major Project Reports:** Annual reports and topicals on milestones; annual experimental plans.

**Summary Date**  
December 1983

# **DOE Oak Ridge Operations Office**



**DOE/ORO**

**Title:** Georgetown University Intercultural Center

**Contractor:**

Georgetown University  
37th and O Streets, N.W.  
Washington, D.C. 20057

**Directing Organization:**

DOE — Oak Ridge Operations Office

**Principal Investigator:** T. B. Collins

**Telephone:**

**Project Engineer:** N. Lingle

**Telephone:** (615) 576-5580

**Contract Number:** DE-FG05-80CS83014

**Contract Funding:**

**Source:**

**Current Contract Period From:** 8/80

**FY 1981-1986**    \$ 23,680,000

**DOE**

**To:** 6/85

**Project/Area/Task:**

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**Objectives:** To build an academic facility that will integrate flat-plate photovoltaic roof modules with an optimally oriented solar architecture.

**Approach/Present Tasks:** The project is broken down into three phases. Phase I, Contractor Selection, included testing of prospective photovoltaic modules and establishment of a project management approach. Phase II, System Installation, included completing the system design, manufacturing the photovoltaic roof components and the associated systems, and installing the system into the Intercultural Center. Phase III, Test and Acceptance, includes testing of the installed components and systems, training operators and maintenance personnel, documenting operation and maintenance procedures, and conducting a safety analysis and systems audit.

**Status/FY 1983 Accomplishments:**

- Solar array construction contract was awarded to Hughes Aircraft Corporation — March 1983.
- Performance testing of sample modules (Block V Tests) was completed and report issued — 1983.
- A purchase order was placed with Solarex to supply the photovoltaic modules.
- Final design review was held at Georgetown — August 1983.

**FY 1984 Milestones:**

- Define systems requirements.
- Develop systems analysis/preliminary design.
- Develop subsystem analysis/detail design.

**Major Project Reports:** *Block V Test Report*. Pasadena, CA: Jet Propulsion Laboratory.

**Summary Date**

October 1983

**DOE/ORO**

**Title:** A Total Energy Photovoltaic Conversion System

**Contractor:**  
Mississippi County Community College  
Blytheville, AR 72315

**Directing Organization:**  
DOE — Oak Ridge Operations Office

**Principal Investigator:** J. Sullen  
**Telephone:** (501) 762-1020  
**Contract Number:** DE-AC05-810R20846  
**Current Contract Period From:** 7/81  
**To:** 7/86

**Project Engineer:** N. Lingle  
**Telephone:** (615) 576-5580  
**Contract Funding:**  
FY 1981-1986 \$ 343,302

**Source:**  
DOE

**Project/Area/Task:**

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**Objectives:** To provide operating and maintenance support for the Photovoltaic Total Energy System installed under DOE Grant No. DE-FG05-77ET20347.

**Approach/Present Tasks:** The contractor has continued to monitor photovoltaic performance and provide required maintenance for the installation. Investigations are being made into converting the system from photovoltaic to thermal collection.

**Status/FY 1983 Accomplishments:**

- Contractor has provided summary reports of operational and maintenance data for DOE use; photovoltaic performance less than planned for the duration of the period; maintenance requirements proved high, especially for the tracking drive system.

**FY 1984 Milestones:** None.

**Major Project Reports:** Final Report.

**Summary Date**  
October 1983

# Department of Energy

DOE

**Title:** Photovoltaic Utility Applications Project

**Contractor:**  
The Aerospace Corporation  
2350 East El Segundo Boulevard  
El Segundo, CA 90045

**Directing Organization:**  
Department of Energy

**Principal Investigator:** S.L. Leonard  
**Telephone:** (213) 648-7040

**Project Engineer:** M. Pulsak  
**Telephone:** (202) 252-1726

**Contract Number:** DEAI01-81CS30622

**Contract Funding:**

**Source:**

**Current Contract Period From:** 1/16/81  
**To:** 9/30/83

FY 1981	\$ 550,000	DOE
FY 1982	\$ 450,000	DOE
FY 1983	\$ 100,000	DOE

**Project/Area/Task:** Utility Applications

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**Objectives:** The objective of this project is to support the development of utility-scale PV power generation through analysis and system design; information exchange with industry; and technical support of the planning and conducting of MW-scale PV projects.

**Approach/Present Tasks:** Present tasks include maintenance of a two-way exchange of information with industries that would be involved in utility applications of large PV systems; support of the Sacramento Municipal Utility District PV project as part of the DOE Technical Assistance Team; and, phase out analyses and technology transfer activities.

**Status/FY 1983 Accomplishments:**

- Conducted sensitivity study of third party financing.
- Established data requirements for SMUD project.
- Summarized Aerospace involvement in the DOE Photovoltaic Program over the period 1975-1983.

**FY 1984 Milestones:**

- None.

**Major Project Reports:**

- *Third Party Arrangements for Financing Photovoltaic Power Plants.* (December 1982).
- *Photovoltaic Energy Systems Summary Report.* (June 1983).

**Summary Date**  
October 1983

## DOE

**Title:** Sacramento Municipal Utility District (SMUD) Photovoltaic Power Plant Project

**Contractor:**

SMUD  
2601 S. Street, Box 15830  
Sacramento, CA 95813

**Directing Organization:**

DOE/San Francisco Operations Office

**Principal Investigator:** M. Anderson (SMUD)

**Telephone:** (916) 452-3211

**Project Engineer:** Mitchell Wool (Acurex)

**Telephone:** (415) 964-3200

**Contract Number:** DE-FC03-83CE11968

**Contract Funding:**

**Source:**

**Current Contract Period From:** 8/22/83

**To:** 9/1/86

FY 1982 \$ 6,800,000 DOE

FY 1983 \$ 6,800,000 DOE

**Project/Area/Task:** Photovoltaic Powerplant

**Cost Sharing:** FY 1982 \$3,200,000 (SMUD); \$2,000,000 (CEC), FY 1983 \$3,600,000 (SMUD)

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**Objectives:** To design, procure, construct, operate, and monitor a MW-scale photovoltaic system at the SMUD Rancho Seco Nuclear Generating Station near Sacramento, California.

**Approach Present Tasks:**

- Design standardization.
- Civil and architectural plant design.
- PV array structure design.
- Electrical and balance of system design.
- Procurement, site preparation and plant construction.
- System turnover and monitoring.

**Status/FY 1983 Accomplishments:**

- Completed all procurement actions for engineering, equipment and general contracting.

**FY 1984 Milestones:**

- Complete construction of Phase 1 (1 MW) — 1984.
- Checkout system and start-up of Phase 1 (1 MW) — July 1984.
- Complete civil and architectural design of Phase 2 (1 MW) — January 1984.
- Panel award of Phase 2 (1 MW) — December 1983.
- Begin construction of Phase 2 (1MW) — November 1983.

**Major Project Reports:**

- System Design Selection Criteria; Technical Report.
- Conceptual System Design Selection; Technical Report.
- Critical Component Procurement Readiness Review; Technical Report.
- Construction Readiness Review; Technical Report.

**Summary Date**  
October 1983

# DOE

**Title:** Semicrystalline Casting Process Development and Verification

**Contractor:**  
Semix Inc.  
15801 Gaither Road  
Gaithersburg, MD 20877

**Directing Organization:**  
Department of Energy  
Division of Photovoltaic Energy Technology

**Principal Investigator:** G. Storti  
**Telephone:** (301) 948-4680

**Project Engineer:** M. Prince  
**Telephone:** (202) 252-1725

**Contract Number:** DE-FC01-80ET 23197

**Contract Funding:**

**Source:**

**Current Contract Period From:** 6/19/80  
**To:** 9/30/83

<b>FY 1980</b>	<b>\$ 1,669,000</b>	<b>DOE</b>
<b>FY 1981</b>	<b>\$ 900,000</b>	<b>DOE</b>
<b>FY 1982</b>	<b>\$ 840,000</b>	<b>DOE</b>
<b>FY 1983</b>	<b>\$ 400,000</b>	<b>DOE</b>

**Project/Area/Task:** Advanced Materials Research

**Cost Sharing:** \$1,086,915 Semix

**Objective:** To improve the crystalline quality of large, cast semi-crystalline silicon ingots (square in cross-section) and the performance of photovoltaic wafer cells cut and fabricated from ingots grown under various conditions. The R&D project can lead to reduced silicon material cost compared to Czochralski-grown, single-crystal silicon and potentially lower cost delivered electrical energy per cell.

**Approach/Present Tasks:** The project involves proving the entire photovoltaic cell production process including the initial metallurgical-grade silicon material; the crystal-growth and purification phases to form semi-crystalline, square ingots (bricks); the cutting of ingots into square wafers; cell processing; and, measurement and characterization of semi-crystalline silicon materials structure and of fabricated cells to correlate their performance characteristics as a function of ingot growth conditions. This project is formed around the Semix Ubiquitous Crystallization process (UCP) developed by Solarex Corporation. Present tasks include further materials and cell characterizations, development of a contactless technique for measuring the minority carrier lifetime for material in the brick stage, and investigation of the influence of thermal control on the crystal solidification rates and the density of crystal dislocation and grain boundaries.

**Status/FY 1983 Accomplishments:**

- The size of macro-crystals growing along the length of the square ingot has been increased dramatically —filament-type, single-crystal, cross-sectional areas ranging up to about a square centimeter in area over a 4-in<sup>2</sup> ingot.
- Cells fabricated from the wafers sliced from an ingot range up to 16% efficiency for small cells made from sections of a slice and up to about 14% for some 4-in<sup>2</sup> cells.

**FY 1983 Milestones:**

- Complete a final report.

**Major Project Reports:**

- Quarterly Report 1 (June 19 — September 19, 1980) to Quarterly Report 8 (March 19-June 19, 1982).
- Proof-of-Concept Report (March 11, 1982).
- Multi-Blade slurry wafering (July, 1982).

**Summary Date**  
October 1983

## DOE

**Title:** "Development of a Solar Energy System"

**Contractor:**

Texas Instruments, Inc.  
Corporate Research, Development and Engineering  
P.O. Box 225303, MS 158  
Dallas, TX 75265

**Principal Investigator:** E.L. Johnson

**Telephone:** (214) 995-4872

**Contract Number:** DE-AC-1-79ER10000

**Current Contract Period From:** 10/1/78

**To:** 9/30/82

**Directing Organization:**

DOE Collector R&D Branch  
Lloyd Herwig  
(202) 252-1692

Assisted by: SERI

**Project Engineer:** W. Wallace

**Telephone:** (303) 231-1380

**Contract Funding:**

FY 1979 \$ 12,500,000

**Cost Sharing:** \$5,300,000 (T1)

**Source:**

DOE

**Project/Area/Task:** Photoelectrochemical

**Objectives:** To develop a unique system for solar energy utilization based upon photoelectrochemical conversion of sunlight, storage of chemical reactants, and recombination of reactant on demand to provide electrical and thermal power for residential applications.

**Approach/Present Tasks:** The system has four main components which were developed and tested under this project; namely, the solar chemical converter, hydrogen storage, fuel cell, and thermal management system. Energy conversion is accomplished by means of small spherical silicon cells imbedded in a glass matrix and immersed in hydrogen bromide electrolyte. The current generated by the cells is applied to separate the electrolyte into hydrogen gas and a bromine solution. These chemical reactants are stored separately until needed and then recombined in a fuel cell to produce electrical energy.

**Status/FY 1983 Accomplishments:**

- The project has been completed.
- Assembled and tested a complete TISES (Texas Instruments of Solar Energy System) development module, which evolved from 3 years of development and tests of each of the major system components.
- Solar cell conversion efficiencies of about 13% were achieved.
- The TISES D prototype system was demonstrated to have a 7% overall efficiency — about 2.4% electrical and 5.3% thermal.
- Further component improvements in FY 1983 can currently project overall system efficiencies of about 11% — approximately 4.5% electrical and 6% thermal.

**FY 1984 Milestones:** None. Program completed.

**Major Project Reports:** *Development of a Solar Energy System; Final Report.* (May 1983). DOE/TI-ER10000.

**Summary Date**

October 1983

**FY 1982 - FY 1983  
Publications**



# Solar Energy Research Institute

Abruna, H.D.; Hope, G.A.; Bard, A.J. (October 1982). "Semiconductor Electrodes: XLV — Photoelectrochemistry of n- and p-Type  $\text{MoTe}_2$  in Aqueous Solutions." *Journal of the Electrochemical Society*. Vol. 129 (No. 10); pp. 2224-2228.

Adams, J. (January 1983). *EMI from Solar Panels and Inverters*. SERI/STR-214-1730. Golden, CO: Solar Energy Research Institute; 20 pp. Available from: NTIS.

Ahrenkiel, R.K.; Kazmerski, L.L. (1982). "Passivation of Surface States on p-Type GaAs." *Proceedings of the Third Symposium on Materials and New Processing Technologies for Photovoltaics; Montreal, Canada; May 1982*. Vol. 82-8. Edited by J.P. Dismukes, E. Sirtl, P. Rai-Choudhury, and L.P. Hunt. Pennington, NJ: Electrochemical Society; pp. 469-476.

Ahrenkiel, R.K.; Kazmerski, L.L.; Matson, R.J.; Osterwald, C.; Massopust, T.P. Mickelsen, R.A.; Chen, W.S. (1 October 1983). "Heterojunction Formation in (CdZn)s/CuInSe<sub>2</sub> Ternary Solar Cells." *Applied Physics Letters* Vol. 43 (No. 7); pp. 658-660.

Ahrenkiel, R.K.; Sheldon, P.; Hayes, R.E.; Dunlavy, D.J.; Roybal, L.L. (1 October 1983). "Surface Compensation of p-Inp as Observed by Capacitance Dispersion." *Applied Physics Letters*. Vol 43 (No. 7); pp. 675-676.

Ahrenkiel, R.K.; Wagner, R.S.; Pattillo, S.; Dunlavy, D.; Gervis, T.; Ireland, P.J.; Russell, P.E.; Kazmerski, L.L. (July/August 1982). "Reduction of Surface States on GaAs by the Plasma Growth of Oxyfluorides." *Journal of Vacuum Science and Technology*. Vol. 21 (No. 2); pp. 434-437.

Akhtar, M. (15 December 1982). "Electronic and Optical Properties of a-Si:H Films Deposited by CVD." *Applied Physics Letters*. Vol. 41 (No. 12); p. 1146.

Anderson, D.A.; Paul, W. (1982). "Transport Properties of a-Si:H Alloys Prepared by r.f. Sputtering II. The Effects of Doping." *Philosophical Magazine B*. Vol. 45 (No. 1); pp. 1-23.

Anderson, W.W. (October 1982). "Dielectric Relaxation Contribution to Dispersion of Junction Admittance." *Solid-State Electronics*. Vol. 25 (No. 10); pp. 1033-1044.

Andrews, J.E., Jr. (1983). "Development of Thin Film Monolithic Cascade ZnSiAs<sub>2</sub> Solar Cells." *Polycrystalline Thin Film Review Meeting: Abstracts of Presentation; Golden, CO; 16-18 May 1983*. SERI/CP-211-1985. Golden, CO: Solar Energy Research Institute; pp. 301-319.

Bates, C.W., Jr.; Uekita, M.; Nelson, K.F.; Abernathy, C.; Mooney, J.B. (1983). "The Effect of pH on the Production of Chalcopyrite CuInSe<sub>2</sub> Prepared by Spray Pyrolysis." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1427-1428. Available from: IEEE.

Bell, R.L. (March 1983). "Advanced Cell Research at Varian." *Tenth Photovoltaic Concentrator Project Integration Meeting; Albuquerque, NM; 6-7 April 1983*. SAND83-0604. Albuquerque, NM: Sandia National Laboratories; pp. 172-174.

Benner, J. (June 1983). *Materials and Cells for High Efficiency Solar to Electric Conversion*. SERI/TP-211-1988. Golden, CO: Solar Energy Research Institute; 3 pp. Presented at the 18th IECEC; Orlando, FL; 21-26 August 1983.

Benner, J.P. (1983). "Materials and Cells for High Efficiency Solar to Electric Conversion." *Proceedings of the 18th Intersociety Energy Conversion Engineering Conference; Orlando, FL; 21-26 August 1983*. New York: American Institute of Chemical Engineers; Vol. 3, pp. 1331-1333.

Benner, J.P.; Blakeslee, A.E. (1982). "Effects of Grain Boundaries in GaAs Solar Cells." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 205-216.

Bhushan, M. (1982). "Zn<sub>3</sub>P<sub>2</sub> Thin-Film Solar Cells." *Fourth EC Photovoltaic-Solar Energy Conference; Proceedings of the International Conference; Stresa, Italy; 10-14 May 1982*. Edited by W.H. Bloss and G. Grassi. Boston, MA: D. Riedel Publishing Company; pp. 844-847.

Bhushan, M.; Pawlikowski, J.M.; Pereyra, I. (1982). "Zinc Phosphide for Solar Cell Applications." *Proceedings of the Third Symposium on Materials and New Processing Technologies for Photovoltaics; Montreal, Canada; May 1982*. Vol. 82- 8. Edited by J.P. Dismukes, E. Sirtl, P. Rai-Choudhury, and L.P. Hunt. Pennington, NJ: Electrochemical Society; pp. 505-513.

Biegelsen, D.K. (1983). "Defects in Amorphous Silicon." *Materials Research Society Symposia Proceedings; Volume 14 - Defects in Semiconductors II; Boston, MA; November 1982*. Edited by Subhash Mahajan and James W. Corbett. New York: North-Holland, pp. 75-86.

Biegelsen, D.K.; Street, R.A. Jackson, W.B. (March 1983). "Distribution of Recombination Lifetimes in Doped a-Si:H." *Proceedings of the 16th International Conference on the Physics of Semiconductors; Montpellier, France; 6-10 September 1982*. Edited by M. Averous. Appears in: *Physica B+C*. Vol. 117 & 118 B+C (Part II); pp. 899-901.

Bird, R. E. (December 1982). *A Beers-Law-Based, Simple Spectral Model for Direct Normal and Diffuse Horizontal Irradiance*. SERI/TR-215-1781. Golden, CO: Solar Energy Research Institute; 46 pp. Available from: NTIS.

Bird, R.E.; Hulstrom, R.L. (1983). "Availability of SOLTRAN 5 Solar Spectral Model." *Solar Energy*. Vol. 30 (No. 4); p. 379.

Bird, R.E.; Hulstrom, R.L.; Lewis, L.J. (1983). "Terrestrial Solar Spectral Data Sets." *Solar Energy*. Vol. 30 (No. 6); pp. 563-573.

Bornan, C.G.; Bienstock, S.; Zawadzki, A.; Gordon, R.G. (1982). "Gas Phase Diagnostics and Modelling of Tin Oxide Chemical Vapor Deposition." *162nd Electrochemical Society Meeting Extended Abstracts; Detroit, MI; 17-21 October 1982*. Vol. 82-2. Pennington, NJ: ECS; pp. 297-298 (Abstract No. 188).

Branz, H.M. (1983). "The Effect of Operating-Point-Control Strategy on the Annual Energy Production of Degraded Photovoltaic Arrays." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists' Conference - 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 525-531. Available from: IEEE.

Bratin, P.; Tomkiewicz, M. (November 1982). "Transport Properties of Nafion Membranes for Use in Three-Electrode Photoelectrochemical Storage Cells." *Journal of the Electrochemical Society*. Vol. 129 (No. 11); pp. 2469-2473.

Bube, R.H. (1983). "Cadmium Telluride Solar Cells." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1. Pennington, NJ: ECS; p. 360 (Abstract No. 230).

Buonaquisti, A.D.; Matson, R.J.; Russell, P.E. (1983). "The Application of Electron Beam Techniques (EBIC and EBIV) to Electrically Characterize Magnetron Sputtered Au-GaAs Devices." *12th Annual Symposium - Applied Vacuum Science & Technology; Clearwater, FL; 14-16 February 1983*. New York: American Vacuum Society; p. 27.

Burk, D.E.; Kanner, S.; Muyschondt, J.E.; Shaulis, D.S.; Russell, P.E. (January 1983). "Determination of Surface Recombination Velocity at a Grain Boundary Using Electron-Beam-Induced Current." *Journal of Applied Physics*. Vol. 54 (No. 1); pp. 169-173.

Carleton, K.L.; Olson, J.M.; Kibbler, A. (April 1983). "Electrochemical Nucleation and Growth of Silicon in Molten Fluorides." *Journal of the Electrochemical Society*. Vol. 130 (No. 4); pp. 782-786.

Carlos, W.E.; Taylor, P.C. (1 October 1982). "H NMR in a-Si." *Physical Review B*. Vol. 26 (No. 7); pp. 3605-3616.

Carlson, D.E. (November 1982). "Effects of Prolonged Illumination on the Properties of Hydrogenated Amorphous Silicon." *Solar Energy Materials*. Vol. 8 (Nos. 1-3); pp. 129-140.

Carlson, D.E.; Moore, A.R.; Szostak, D.J.; Goldstein, B.; Smith, R.W.; Zanzucchi, P.J.; Frenchu, W.R. (June-July 1983). "Light-Induced Effects in Amorphous Silicon Material and Devices." *Solar Cells*. Vol. 9 (Nos. 1-2); pp. 19-23.

Carlson, D.E.; Smith, R.W.; Zanzucchi, P.J.; Frenchu, W.R. (1983). "Light-Induced Effects in Amorphous Silicon Films and Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference - 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1372-1375. Available from: IEEE.

- Catalano, A.; D'Aiello, R.V.; Dresner, J.; Faughnan, B.; Firester, A.; Kane, J.; Schade, H.; Smith, Z.E.; Swartz, G.; Triano, A. (1983). "Attainment of 10% Conversion Efficiency in Amorphous Silicon Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1421-1422. Available from: IEEE.
- Chatham, H.; Hils, D.; Robertson, R.; Gallagher, A.C. (1 August 1983). "Reactions of He<sup>+</sup>, Ne<sup>+</sup>, and Ar<sup>+</sup> with CH<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, SiH<sub>4</sub>, and Si<sub>2</sub>H<sub>6</sub>." *The Journal of Chemical Physics*. Vol. 79 (No. 3); pp. 1301-1311.
- Chu, S.S.; Chu, T.L.; Zhang, F.S.; Chen, W.J.; Wang, Q.H. (1983). "Thin Film Gallium Arsenide Homo Junction Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1149-1152. Available from: IEEE.
- Chu, S.S.; Chu, T.L.; Zhang, F.S.; Chen, W.J.; Wang, Q.H. (1983). "Thin Film Gallium Arsenide Solar Cells." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol 83-1. Pennington, NJ: ECS; pp. 363-364 (Abstract No. 233).
- Chu, T.L.; Chu, S.S. (February 1983). "Partial Purification of Metallurgical Silicon by Acid Extraction." *Journal of the Electrochemical Society*. Vol. 130 (No. 2); pp. 455-457.
- Chu, T.L.; Chu, S.S.; Murthy, K.; Stokes, E.D.; Russell, P.E. (April 1983). "Deposition and Properties of Zinc Phosphide Films." *Journal of Applied Physics*. Vol. 54 (No. 4); pp. 2063-2068.
- Chu, T.L.; Chu, S.S.; Murthy, K.; Yang, Y.T.; Yi, X.J.; Lin, S.C.; Yu, J.M.; Russell, P.E.; Herrington, C. (1983). "Thin Film Cadmium Telluride Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 922-927. Available from: IEEE.
- Chu, T.L.; Chu, S.S.; Pauleau, Y.; Murthy, K.; Stokes, E.D.; Russell, P.E. (January 1983). "Cadmium Telluride Films on Foreign Substrates." *Journal of Applied Physics*. Vol. 54 (No. 1); pp. 398-403.
- Chu, T.L.; Chu, S.S.; Ray, R.L. (October 1982). "Germanium Arsenide Iodide: A Clathrate Semiconductor." *Journal of Applied Physics*. Vol. 53 (No. 10); pp. 7102-7103.
- Chu, T.L.; Chu, S.S.; Yang, Y.T.; Yi, X.J.; (1983). "Thin Film Cadmium Telluride Solar Cells." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol 83-1. Pennington, NJ: ECS; p. 367 (Abstract No. 238).
- Ciszek, T.F. (1983). "Orientation and Morphology Effects in Rapid Silicon Sheet Solidification." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 21.
- Ciszek, T.F. (1983). "Silicon Crystal Growth and Device Research at SERI." *Polycrystalline Silicon Review Meeting; Abstracts of Presentations; Golden, CO; 27-28 June 1983*. SERI/CP-211-2025. Golden, CO: Solar Energy Research Institute; pp. 207-224.
- Ciszek, T.F. (1983). "Silicon Sheet Technologies." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 316-326. Available from: IEEE.
- Ciszek, T.F.; Hurd, J.L.; Schietzelt, M. (December 1982). "Filament Materials for Edge-Supported Pulling of Silicon Sheet Crystals." *Journal of the Electrochemical Society*. Vol. 129 (No. 12); pp. 2838-2843.
- Cody, G.D.; Brooks, B.G.; Abeles, B. (November 1982). "Optical Absorption Above the Optical Gap of Amorphous Silicon Hydride." *Solar Energy Materials*. Vol. 8 (Nos. 1-3); pp. 231-240.
- Cole, L.A. (March 1983). "SERI's Advanced High Efficiency Concepts Task." *Tenth Photovoltaic Concentrator Project Integration Meeting; Albuquerque, NM; 6-7 April 1983*. SAND83-0604. Albuquerque, NM: Sandia National Laboratories; p. 170.
- Cooper, J.; Turner, J.A.; Nozik, A.J. (1982). "Mott-Schottky Plots and Flat-Band Potentials for Single Crystal Rutile Electrodes." *Proceedings of the Symposia on Photoelectrochemical Processes and Measurement Techniques*. Edited by W.L. Wallace, A.J. Nozik, S.K. Deb, and R.H. Wilson. Vol. 82-3. Pennington, NJ: The Electrochemical Society; pp. 456-469.
- Cooper, G.; Turner, J.A.; Parkinson, B.A.; Nozik, A.J. (November 1983). "Hot Carrier Injection of Photogenerated Electrons at Indium Phosphide-Electrolyte Interfaces." *Journal of Applied Physics*. Vol. 54 (No. 11); pp. 6463-6473.

- Corderman, R.R.; Vanier, P.F. (July 1983). "Mass Spectrometric Studies of Impurities in Silane and Their Effects on the Electronic Properties of Hydrogenated Amorphous Silicon." *Journal of Applied Physics*. Vol. 54 (No. 7); pp. 3987-3992.
- Cornog, D.G.; Hall, R.B.; Meakin, J.D.; Thornton, J.A. (1983). "Preparation of  $\text{CuInSe}_2$  Films by Reactive Co-Sputtering." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1. Pennington, NJ: ECS; p. 366. (Abstract No. 236).
- Coutts, T.; Kazmerski, L.L.; Wagner, S. (January 1983). "Amorphous Silicon Bibliography 1981." *Solar Cells*. Vol. 7 (No. 4); pp. 347-425.
- Crandall, R.S.; Staebler, D.L. (June-July 1983). "Properties of the Defect Causing Solar Cell Degradation." *Solar Cells*. Vol. 9 (Nos. 1-2); pp. 63-74.
- Dalal, V.L.; Akhtar, M.; Delahoy, A.; Gau, S.C.; Cambridge, J.A.; Ramaprasad, K.R. (1983). "Photovoltaic Properties of CVD Amorphous Silicon." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1384-1388. Available from: IEEE.
- Daniels, R.R.; Katnani, A.D.; Zhao, T-X; Margaritondo, G.; Zunger, A. (20 September 1982). "Initial Adsorption State for Al on GaAs(110) and Its Role in the Schottky Barrier Formation." *Physical Review Letters*. Vol. 49 (No. 12); pp. 895-898.
- DeBlasio, R. (October 1982). "Photovoltaic Systems Measurements Status and Perspectives." *Solar Cells*. Vol. 7 (No. 1); pp. 159-163.
- Deckman, H.; Wronski, C.; Witzke, H.; Yablonovitch, E. (1983). "Optical Enhancement of a-SiH<sub>x</sub> Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1425-1426. Available from: IEEE.
- Delahoy, A.E. (1983). "Properties of Hydrogenated Amorphous Silicon Prepared by Chemical Vapor Deposition from Higher Silanes." *Proceedings of the Society of Photo-Optical Instrumentation Engineers: Volume 407 — Photovoltaics for Solar Energy Applications II; Arlington, VA; 5-6 April 1983*. Edited by David Adler. Bellingham, WA: SPIE; pp. 47-54.
- Delahoy, A.E.; Griffith, R.W.; Kampas, F.J.; Vanier, P.E. (September 1982). "Effects of Monochlorosilane on the Properties of Plasma Deposited Hydrogenated Amorphous Silicon." *Journal of Electronic Materials*. Vol. 11 (No. 5); pp. 869-882.
- de Rosny, G.; Mosburg, E.R., Jr.; Abelson, J.R.; Devaud, G.; Kerns, R.C. (May 1983). "Evidence for a Time Dependent Excitation Process in Silane Radio Frequency Glow Discharges." *Journal of Applied Physics*. Vol. 54 (No. 5); pp. 2272-2275.
- Devaud, G.; Kerns, R.C.; Abelson, J. (1982). "BF<sub>3</sub>-Doped Amorphous Silicon Thin Films." *Proceedings of the Third Symposium on Materials and New Processing Technologies for Photovoltaics; Montreal, Canada; May 1982*. Vol. 82-8. Edited by J.P. Dismukes, E. Sirtl, P. Rai-Choudhury, and L.P. Hunt. Pennington, NJ: Electrochemical Society; pp. 384-390.
- Ellis, F.B., Jr.; Gordon, R.G. (September 1983). "A Simple Method for Preparing Hydrogenated Amorphous Silicon Films by Chemical Vapor Deposition at Atmospheric Pressure." *Journal of Applied Physics*. Vol. 54 (No. 9); pp. 5381-5384.
- Ellis, F.B., Jr.; Gordon, R.G.; Paul, W.; Yacobi, B.G. (1983). "Properties of Hydrogenated Amorphous Silicon Prepared by Chemical Vapor Deposition." *Proceedings of the 10th International Conference on Amorphous and Liquid Semiconductors; Tokyo, Japan; 22-26 August 1983*. Appears in: *Journal of Non-Crystalline Solids*, Vol. 59/60; pp. 719-722.
- Emery, K.; Withey, P.; Russell, P.E.; Cheek, G.; Mertens, R.; Van Overstraeten, R. (1983). "Electro-Optical Properties of Screen Printed Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 947-951. Available from: IEEE.
- Fan, F-R.F.; Leempoel, P.; Bard, A.J. (September 1983). "Semiconductor Electrodes LI. Efficient Electroluminescence at ZnS Electrode in Aqueous Electrolytes." *Journal of the Electrochemical Society*. Vol. 130 (No. 9); pp. 1866-1875.

- Fan, J.C.C. (1983). "High-Efficiency Tandem Cells." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1. Pennington, NJ: ECS; p. 361 (Abstract No. 231).
- Fan, J.C.C.; Tsaur, B.-Y.; Palm, B.J. (1983). "High Efficiency Crystalline Tandem Cells." *Proceedings of the Society of Photo-Optical Instrumentation Engineers: Volume 407 — Photovoltaics for Solar Energy Applications II; Arlington, VA; 5-6 April 1983*. Edited by David Adler. Bellingham, WA: SPIE; pp. 73-87.
- Fan, J.C.C.; Tsaur, B.-Y.; Palm, B.J. (1983). "Optimal Design of High-Efficiency Tandem Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 692-701. Available from: IEEE.
- Firor, K.; Hogan, S.J.; Barrett, J.M.; Coyle, R.T. (1983). "Series Resistance Associated with Thick-Film Contacts to Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 824-827. Available from: IEEE.
- Fletcher, R.M.; Wagner, D.K.; Wicks, G.W.; Ballantyne, J.M. (1982). "High-Spatial-Resolution Diffusion Length Measurements in Polycrystalline GaAs." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier — North Holland; pp. 205-216.
- Fonash, S.J. (April 1983). "A Reevaluation of the Meaning of Capacitance Plots for Schottky-Barrier-Type Diodes." *Journal of Applied Physics*. Vol. 54 (No. 4); pp. 1966-1975.
- Frank, A.J. (1982). "Photoelectrochemical Solar Cells: Stabilization of Small Band Gap Semiconductor in Aqueous Solution by Surface-Attached Organic Conducting Polymer." *Proceedings of the International Conference on Low-Dimensional Conductors; Boulder, CO; 9-14 August 1981*. New York: Gordon and Breach Science Publishers; Part D, pp. 1373-1384. Appears in: *Molecular Crystals & Liquid Crystals*. Vol. 83 (Nos. 1-4); pp. 341-352.
- Frank, A.J.; Cooper, J.; Noufi, R.; Turner, J.A.; Nozik, A.J. (1982). "Solar Energy Conversion: Photoelectrochemical and Electrochemical Studies of Organic Conducting Polymer-Coated Electrodes." *Proceedings of the Symposia on Photoelectrochemical Processes and Measurement Techniques*. Edited by W.L. Wallace, A.J. Nozik, S.K. Deb, and R.K. Wilson. Vol. 82-3. Pennington, NJ: The Electrochemical Society; pp. 248-255.
- Frese, K.W., Jr. (January 1983). "Electrochemical Studies of Photocorrosion of n-CdSe." *Journal of the Electrochemical Society*. Vol. 130 (No. 1); pp. 28-33.
- Frese, K.W., Jr. (1982). "Electrochemical Studies of the Photocorrosion of n-CdSe." *Proceedings of the Symposium on Photoelectrochemical Processes and Measurement Techniques*. Edited by W.L. Wallace, A.J. Nozik, S.K. Deb, and R.H. Wilson. Vol. 82-3. Pennington, NJ: The Electrochemical Society; pp. 157-171.
- Friedman, P.S.; Parent, C.R. (1983). "Progress on the Development of Organic Dyes and Inorganic Phosphors for Luminescent Solar Concentrators." *Photovoltaics Advanced Research and Development 5th Annual Review Meeting; Denver, CO; 19-21 May 1983*. SERI/CP-311-2011. Golden, CO: Solar Energy Research Institute; pp. 13-18.
- Fulop, G.F.; Meyers, P.V.; Liu, C.H.; So, S.M.; Hwang, W.; Yang, E.S. (1983). "Electrical Characterization of Electrodeposited CdTe Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 917-921. Available from: IEEE.
- Garunara, R.; Tomkiewicz, M.; Silberstein, R.P. (November 1983). "Electric Field Modulation of Photoluminescence in Cadmium Selenide Liquid Junction Solar Cells." *Journal of Applied Physics*. Vol. 54 (No. 11); pp. 6787-6789.
- Goldstein, B.; Dresner, J.; Moore, A.R.; Szostak, D.J. (May/June 1983). "Diffusion Length and Surface Photovoltage." *RCA Engineer*. Vol. 28 (No. 3); pp. 45-49.
- Greenbaum, S.G.; Carlos, W.E.; Taylor, P.C. (March 1983). "Boron and Hydrogen Bonding in B-Doped a-S:H — an NMR Study." *Proceedings of the 16th International Conference on the Physics of Semiconductors; Montpellier, France; 6-10 September 1982*. Edited by M. Averous. Appears in: *Physica B+C*. Vol. 117 & 118 B+C (Part II); pp. 886-888.
- Gupta, Y.; Liers, H.; Woods, S.; Young, S.; DeBlasio, R.; Mrig, L. (1983). "Optimization of a-Si Solar Cell Current Collection." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1092-1101. Available from: IEEE.

- Haak, R.; Ogden, C.; Tench, D. (1982). "Characterization of Semiconductors by Electrochemical Photocapacitance Spectroscopy." *Proceedings of the Symposia on Photoelectrochemical Processes and Measurement Techniques*. Edited by W.L. Wallace, A.J. Nozik, S.K. Deb, and R.H. Wilson. Vol. 82-3. Pennington, NJ: The Electrochemical Society; pp. 486-495.
- Hack, M.; McGill, J.; Czubytyj, W.; Singh, R.; Shur, M.; Madan, A. (September 1982). "Minority Carrier Diffusion Lengths in Amorphous Silicon-Based Alloys." *Journal of Applied Physics*. Vol. 53 (No. 9); pp. 6270-6275.
- Hanak, J.J.; Korsun, V. (1983). "Optical Stability Studies of a-Si:H Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1381-1383. Available from: IEEE.
- Hanoka, J.I.; Seager, C.H.; Sharp, D.J.; Panitz, J.K.G. (1 April 1983). "Hydrogen Passivation of Defects in Silicon Ribbon Growth by the Edge-Defined Film-Fed Growth Process." *Applied Physics Letters*. Vol. 42 (No. 7); pp. 618-620.
- Hayes, R.E.; Chevrier, J.; Kowalchik, M. (1982). "Tunnel Diode Interconnects for High Efficiency Multijunction Solar Cells." *161st Meeting of the Electrochemical Society Extended Abstracts; Montreal, Canada; 9-14 May 1982*. Vol. 82-1. Pennington, NJ: ECS; p. 555 (Abstract No. 339).
- Hermann, A.M. (1983). "Semiconducting Polymers." *Applied Physics Communications*. Vol. 3 (No. 1-2); pp. 59-82.
- Hermann, A.M. (1982). "Luminescent Solar Concentrators — a Review." *Solar Energy*. Vol. 29 (No. 4); pp. 323-329.
- Hermann, A.M.; Fabick, L. (April/May 1983). "Research on Polycrystalline Thin-Film Photovoltaic Devices." *Journal of Crystal Growth*. Vol. 61 (No. 3); pp. 658-664.
- Hermann, A.M.; Fabick, L.; Zweibel, K.; Hardy, R. (1983). "Progress in Polycrystalline Thin-Film Photovoltaic Device Research: The DOE/SERI Program." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 840-845. Available from: IEEE.
- Hermann, A.M.; Zweibel, K. (1983). "Progress in Copper Indium Diselenide Thin-Film Photovoltaic Device Research." *Proceedings of the Society of Photo-Optical Instrumentation Engineers: Volume 407 — Photovoltaics for Solar Energy Applications II; Arlington, VA; 5-6 April 1983*. Edited by David Adler. Bellingham, WA: SPIE; pp. 96-105.
- Hogan, S.; Firor, K. (May 1983). *A Simplified Contacting Scheme for GaAs Solar Cells Using Silver*. SERI/TP-212-1970. Golden, CO: Solar Energy Research Institute; 11 pp. Presented at the 163rd Electrochemical Society Meeting; San Francisco, CA; 8-13 May 1983.
- Hogan, S.J.; Firor, K. (1983). "A Simplified Contacting Scheme for GaAs Solar Cells Using Silver." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1. Pennington, NJ: ECS; p. 364 (Abstract No. 234).
- Hope, G.A.; Fan, F.-R.F.; Bard, A.J. (July 1983). "Semiconductor Electrodes 52. Photoelectron Spectroscopic-Determination of the Structure of Thin Platinum Silicide Layers Formed on Si(100) and Si(111) for Use as Electrodes." *Journal of the Electrochemical Society*. Vol. 130 (No. 7); pp. 1488-1491.
- Hulstrom, R.L. (July 1983). *Meteorologic/Atmospheric Effects on the Performance of Solar Photovoltaic Energy Conversion Devices*. SERI/TP-215-2049. Golden, CO: Solar Energy Research Institute; 5 pp. Presented at the 5th Conference on Atmospheric Radiation; Baltimore, MD; 31 October-3 November 1983.
- Hulstrom, R.L. (June 1983). *Spectral Solar Radiation — New Data*. SERI/TP-215-1999. Golden, CO: Solar Energy Research Institute; 7 pp. Available from: SERI; NTIS. Presented at the 1983 Annual Meeting of the American Solar Energy Society; Minneapolis, MN; 1-3 June 1983.
- Hurd, J.L.; Cizek, T.F. (October 1982). "Semicontinuous Edge-Supported Pulling of Silicon Sheets." *Journal of Crystal Growth*. Vol. 59 (No. 3); pp. 499-506.
- Hwang, H.L.; Yang, M.H.; Shen, C.S.; Liu, L.M.; Chen, J.S.; Chen, P.Y.; Peng, C.K.; Loferski, J.J. (1983). "Compositional and Trace-Elemental Analysis of CuInS<sub>2</sub>, CuInSe<sub>2</sub> and Related Ternary Alloys." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 867-871. Available from: IEEE.

Ireland, P.J.; Jamjoum, O.; Kazmerski, L.L.; Ahrenkiel, R.K.; Russell, P.E.; Stanchina, W.; Wager, J.F. (April-June 1983). "Surface and Interface Analysis of GaAs-oxyfluorides." *Proceedings of the 29th National Symposium of the American Vacuum Society; Baltimore, MD; 16-19 November 1982*. Appears in: *Journal of Vacuum Science & Technology A*. Vol. 1 (No. 2, Part I); pp. 653-656.

Jackson, B. (September 1983). *R&D Decision Methods for Photovoltaic Program Planning*. SERI/TR-214-1743. Golden, CO: Solar Energy Research Institute; 61 pp. Available from: NTIS.

Jackson, W.B.; Biegelsen, D.K.; Nemanich, R.J.; Knights, J.C. (1 January 1983). "Optical Absorption Spectra of Surface on Interface States in Hydrogenated Amorphous Silicon." *Applied Physics Letters*. Vol. 42 (No. 1); pp. 105-107.

Jackson, W.B.; Nemanich, R.J. (1983). "The Absolute Luminescence Quantum Efficiency in Hydrogenated Amorphous Silicon." *Proceedings of the 10th International Conference on Amorphous and Liquid Semiconductors; Tokyo, Japan; 22-26 August 1983*. Appears in: *Journal of Non-Crystalline Solids*. Vol. 59/60; pp. 353-356.

Jackson, W.B.; Street, R.A.; Thompson, M.J. (August 1983). "Anomalous Surface Photoconductivity in Hydrogenated Amorphous Silicon." *Solid State Communications*. Vol. 47 (No. 6); pp. 435-438.

Jackson, W.B.; Thompson, M.J. (March 1983). "The Effects of Band Bending on the Photoconductivity in a-Si:H." *Proceedings of the 16th International Conference on the Physics of Semiconductors; Montpellier, France; 6-10 September 1982*. Edited by M. Averous. Appears in: *Physica B+C*. Vol. 117 & 118 B+C (Part II); pp. 883-885.

Jaffe, J.E.; Zunger, A. (15 April 1983). "Anion Displacements and the Band-Gap Anomaly in Ternary ABC<sub>2</sub> Chalcopyrite Semiconductors." *Physical Review B*. Vol. 27 (No. 8); pp. 5176-5179.

Jamjoum, O.; Kazmerski, L.L.; Lichtman, D.L.; Bachmann, K.J. (December 1982). "Low Energy Electron Loss Studies of CuInSe<sub>2</sub> Surfaces." *Surface and Interface Analysis*. Vol. 4 (No. 6); pp. 227-229.

Jewett, D.N.; Bates, H.E.; Locher, J.W. (1983). "Progress in Growth of Silicon Ribbon by a Low Angle, High Rate Process." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 86-89. Available from: IEEE.

Johnson, N.M. (1983). "Deep-level Distributions in Hydrogenated Amorphous Silicon." *Proceedings of the 10th International Conference on Amorphous and Liquid Semiconductors; Tokyo, Japan; 22-26 August 1983*. Appears in: *Journal of Non-Crystalline Solids*, Vol. 59/60; pp. 265-268.

Kai, F.; Rajeswaran, G.; Jackson, M.A.; Rao, V.J.; Anderson, W.A. (1983). "Grain Boundary Effects and Li Passivation in Polycrystalline Silicon." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 543-547. Available from: IEEE.

Kai, F.; Rao, V. J.; Rajeswaran, G.; Anderson, W.A. (1982). "Characterization of Grain Boundaries Before and After Passivation." *161st Meeting of the Electrochemical Society Extended Abstracts; Montreal, Canada; 9-14 May 1982*. Vol. 82-1. Pennington, NJ: ECS; pp. 114-115 (Abstract No. 71).

Kampas, F.J. (May 1983). "An Optical Emission Study of the Glow-Discharge Deposition of Hydrogenated Amorphous Silicon from Argon-Silane Mixtures." *Journal of Applied Physics*. Vol. 54 (No. 5); pp. 2276-2280.

Kampas, F.J.; Corderman, R.R. (1983). "Optical Emission and Mass Spectrometric Studies of Plasma Deposition." *Proceedings of the 10th International Conference on Amorphous and Liquid Semiconductors; Tokyo, Japan; 22-26 August 1983*. Appears in: *Journal of Non-Crystalline Solids*; Vol. 59/60; pp. 683-686.

Kang, E.T.; Bhatt, A.P.; Villaroel, E.; Anderson, W.A.; Ehrlich, P. (1982). "Electrical Properties of Thin Films of Polyphenylacetylene Doped with Iodine or Arsenic Pentafluoride." *Proceedings of the International Conference on Low-Dimensional Conductors, Molecular Crystals and Liquid Crystals; Boulder, CO; 9-14 August 1981*. Appears in: *Molecular Crystals and Liquid Crystals*. Vol. 83 (Nos. 1-4); pp. 307-308.

Kazmerski, L.L. (1982). "X-ray Photoelectron Spectroscopy Applications in Photovoltaics Research." *Applied Electron Spectroscopy for Chemical Analysis*. Edited by H. Windawi and F. Ho. New York: John Wiley & Sons, Inc.; pp. 61-87.

Kazmerski, L.L.; Ahrenkiel, R.K.; Matson, R.J.; Dick, J.R.; Massopust, T.P.; Ireland, P.J.; Herrington, C.R.; Osterwald, C.R. (May 1983). "Cd(Zn)S/CuInSe<sub>2</sub> Solar Cells." *Polycrystalline Thin-Film Review Meeting; Abstracts of Presentation; Golden, CO; 16-18 May 1983*. SERI/CP-211-1985. Golden, CO: Solar Energy Research Institute; pp. 181-196.

- Kazmerski, L.L.; Hallerdt, M.; Ireland, P.J. (April-June 1983). "Optical Properties and Grain Boundary Effects in  $\text{CuInSe}_2$ ." *Proceedings of the 29th National Symposium of the American Vacuum Society; Baltimore, MD; 16-19 November 1982*. Appears in: *Journal of Vacuum Science & Technology A*. Vol. 1 (No. 2, Part I); pp. 395-398.
- Kazmerski, L.L.; Ireland, P.J.; Jamjoun, O.; Clark, A.H. (1981). "Microanalysis of Oxide/ $\text{CuInSe}_2$  Interfaces." *Scanning Electron Microscopy/1981/1*. O'Hare, IL: SEM, Inc.; pp. 285-290.
- Kazmerski, L.L.; Jamjoun, O.; Wager, J.F.; Ireland, P.J. (April-June 1983). "Summary Abstract: Oxidation of  $\text{CuInSe}_2$ ." *Proceedings of the 29th National Symposium of the American Vacuum Society; Baltimore, MD; 16-19 November 1982*. Appears in: *Journal of Vacuum Science & Technology A*. Vol. 1 (No. 2, Part I); pp. 668-669.
- Kazmerski, L.L.; Russell, P.E.; Ireland, P.J.; Herrington, C.R.; Dick, J.R.; Matson, R.J.; Jones, K.M. (1983). "Grain Boundaries in Silicon Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 622-626. Available from: IEEE.
- Kazmerski, L.L.; Russell, P.E.; Jamjoun, O.; Ireland, P.J.; Matson, R.J.; Hermann, A.; Ahrenkiel, R.K.; Mickelsen, R.A.; Chen, W.S.; Bachmann, K.J. (1983). "Initial Formation and Development of  $\text{CdS/CuInSe}_2$  Solar Cell Interfaces." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 786-790. Available from: IEEE.
- Keeney, R.P.; Shastry, S.K.; Reep, D.H.; Sundaram, L.M.G.; Bhat, K.N.; Ghandi, S.K.; Borrego, J.M. (1982). "Spectral Response of Thin-Film Poly-GaAs Solar Cells." *161st Meeting of the Electrochemical Society Extended Abstracts; Montreal, Canada; 9-14 May 1982*. Vol. 82-1. Pennington, NJ: ECS; p. 90 (Abstract No. 56).
- Kendelwicz, T.; Petro, W.G.; Babalola, I.A.; Silberman, J.A.; Lindau, I.; Spicer, W.E. (July-September 1983). "Room Temperature Exchange Reaction at the Al-InP(110) Interface: Soft X-Ray Photoemission Studies." *Proceedings of the 10th Annual Conference on the Physics and Chemistry of Semiconductor Interfaces; Santa Fe, NM; 25-27 January 1983*. Appears in: *Journal of Vacuum Science & Technology B*. Vol. 1 (No. 3); pp. 623-627.
- Kendelewicz, T.; Rossi, G.; Petro, W.G.; Babalola, I.A.; Lindau, I.; Spicer, W.E. (July-September 1983). "Similarities in Chemical Intermixing at the Cu/InP and Cu/Si Interfaces." *Proceedings of the 10th Annual Conference on the Physics and Chemistry of Semiconductor Interfaces; Santa Fe, NM; 25-27 January 1983*. Appears in: *Journal of Vacuum Science & Technology B*. Vol. 1 (No. 3); pp. 564-569.
- Khan, A.A.; Woollam, J.A.; Hermann, A.M. (1982). "Minority Carrier Diffusion Length Measurements: A Review and Comparison of Techniques." *Applied Physics Communications*. Vol. 2 (No. 1 & 2); pp. 17-56.
- Kibbler, A.E.; Carleton, K.L.; Olson, J.M. (1982). "Electrodeposition of Silicon from a High-Purity Silicon Copper Anode." *161st Meeting of the Electrochemical Society Extended Abstracts; Montreal, Canada; 9-14 May 1982*. Vol. 82-1. Pennington, NJ: ECS; pp. 88-89 (Abstract No. 53).
- Konenkamp, R.; Hermann, A.M.; Madan, A. (October 1983). "Photocurrent Reversal and Time-of-Flight in Amorphous Silicon-Hydrogen Films." *Philosophical Magazine B*. Vol. 48 (No. 4); pp. L33-L37.
- Kwietniak, M.; Warminski, T.; Beaulieu, R.; Kazmerski, L.L.; Loferski, J.J. (1982). "RF-Sputtering of Low-Resistivity  $\text{CdS}$  Thin Films." *161st Meeting of the Electrochemical Society Extended Abstracts; Montreal, Canada; 9-14 May 1982*. Vol. 82-1. Pennington, NJ: ECS; pp. 130-131 (Abstract No. 80).
- Lamberski, T.J.; Irby, C.A.; Collaros, G.J.; Anderson, E.R.; Sowa, P.; Schwinkendorf, W.E.; Resnik, W.M. (August 1983). *Design Analysis of Advanced Photovoltaic Technologies*. SERI/STR-214-1997. Golden, CO: Solar Energy Research Institute; 585 pp. Work performed by BDM Corporation, Albuquerque, NM. Available from: NTIS.
- Lamberski, T.J.; Irby, C.A.; Semmens, M.G.; Mrig, L.; DeBlasio, R. (1983). "Guidelines and Methodology for Design and Analysis of Advanced PV Technology Systems." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 289-294. Available from: IEEE.
- Langmuir, M.E.; Michells, R.H.; Boudreau, R.A.; Rauh, R.D. (1982). "Laser Spot Scanning of Photoelectrochemical Cells." *Proceedings of the Symposia on Photoelectrochemical Processes and Measurement Techniques*. Edited by W.L. Wallace, A.J. Nozik, S.K. Deb, and R.H. Wilson. Vol. 82-3. Pennington, NJ: The Electrochemical Society; pp. 598-607.
- Langmuir, M.E.; Parker, M.A.; Rauh, R.D. (1982). "Photoelectrochemical Cells Based on n-GaAs and the Cu(II)/Cu(I) Redox Couple in Acetonitrile." *Proceedings of the Symposia on Photoelectrochemical Processes and Measurement Techniques*. Edited by W.L. Wallace, A.J. Nozik, S.K. Deb, and R.H. Wilson. Vol. 82-3. Pennington, NJ: The Electrochemical Society; pp. 315-326.



LaRue, R.A.; Borden, P.G.; Ludowise, M.J.; Gregory, P.E.; Dietze, W.T. (1983). "The Metal Interconnected Cascade Solar Cell." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 228-230. Available from: IEEE.

Leopold, D.J.; Boyce, J.B.; Fedders, P.A.; Norberg, R.E. (December 1982). "Deuteron and Proton Magnetic Resonance in a-Si:(D,H)." *Physical Review B*. Vol. 26 (No. 11); pp. 6053-6066.

Lester, P.A.; Singh, R.; Rice, D.A.; Pangborn, R.N.; Ashok, S.; Fonash, S.J. (1982). "Chemical and Ion Beam Etch Studies of Polycrystalline Silicon." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 199-204.

Lindholm, F.A.; Chen, Y.H. (December 1982). "Current-Voltage Characteristic for Bipolar p-n Junction Devices with Drift Fields, Including Correlation between Carrier Lifetimes and Shallow-Impurity Concentration." *Journal of Applied Physics*. Vol. 53 (No. 12); pp. 8863-8866.

Lindholm, F.A.; Neugroschel, A.; Sah, C.T. (1983). "Design Principles for High Efficiency Small-Grain Polysilicon Solar Cells, with Supporting Experimental Studies." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 644-647. Available from: IEEE.

Longrigg, P. (October 1982). "DC-to-AC Inverters for Photovoltaics." *Solar Cells*. Vol. 6 (No. 4); pp. 343-356.

Lucovsky, G. (November 1982). "A Structured Interpretation of the Infrared Absorption Spectra of a-Si:H:O Alloys." *Solar Energy Materials*. Vol. 8 (No. 1-3); pp. 165-175.

Lucovsky, G. (September/October 1982). "An XTS Study of Sputtered a-Si-Ge Alloys." *Journal of Vacuum Science & Technology*. Vol. 21 (No. 3) pp. 838-844.

Lyon, S.A.; Nemanich, R.J. (March 1983). "Raman Scattering from Hydrogenated Amorphous Silicon." *Proceedings of the 16th International Conference on the Physics of Semiconductors; Montpellier, France; 6-10 September 1982*. Edited by M. Averous. Appears in: *Physica B+C*. Vol. 117 & 118 B+C (Part II); pp. 871-873.

Madan, A. (June 1983). *Opportunities for High Efficiency Amorphous Silicon Thin Film Solar Cells*. SERI/TP-212-1989. Golden, CO: Solar Energy Research Institute; 19 pp. Presented at the 1983 Annual Meeting of the American Solar Energy Society; Minneapolis, MN; 1-3 June 1983.

Mahan, A.H.; Kerns, R.C.; Devaud, G. (November 1983). "BF<sub>3</sub>-Doped Amorphous Silicon Thin Films." *Journal of Electronic Materials*. Vol. 12 (No. 6); pp. 1033-1049.

Mahan, A.H.; Stone, J.L.; eds. (January 1983). "Silicon Bibliography 1981." *Solar Cells*. Vol. 7 (No. 4); 425 pp.

Matson, R.J. (25 August 1983). "Modifications to, and Applications of, the JEOL JSM-35C Scanning Microscope for EBIC Analysis of Photovoltaic Devices." *JEOL News*. Vol. 21E (No. 2); pp. 10-13.

May, E.F.; Leboeuf, C.M.; Waddington, D. (December 1982). *Conceptual Design of the Truscott Brine Lake Solar Pond System*. SERI/TR-253-1833. Golden, CO: Solar Energy Research Institute; 69 pp. Available from: NTIS.

McMahon, T.J.; Konenkamp, R. (1983). "Diffusion Length and Collection Width for the Evaluation of a-Si." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1389-1393. Available from: IEEE.

Meakin, J.D.; Russell, T.W.F. (1983). "Laboratory and Commercial Development of Large Area Low Cost Thin Film Solar Cells." *1983 Solar World Congress Extended Abstracts; Perth, Western Australia; 14-19 August 1983*. Edited by S.V. Szokolay. Victoria, Australia: International Solar Energy Society; p. 316. Available from: ISES, c/o CSIRO; Victoria, Australia.

Meyerson, B.S.; Scott, B.A.; Wolford, D.J. (March 1983). "The Preparation of in situ Doped Hydrogenated Amorphous Silicon by Homogeneous Chemical Vapor Deposition." *Journal of Applied Physics*. Vol. 54 (No. 3); pp. 1461-1465.

Mickelsen, R.A.; Chen, W.S. (1983). "Polycrystalline Thin-Film CuInSe<sub>2</sub> Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 781-785. Available from: IEEE.

Mickelsen, R.A.; Chen, W.S. (August 1982). *Cadmium Sulfide/Copper Ternary Heterojunction Cell Research, Final Report*. SERI/TR-8021-1-T1. Golden, CO: Solar Energy Research Institute; 110 pp. Work performed by Boeing Aerospace Company, Seattle, WA. Available from: NTIS.

Milstein, J.B.; Hardy, R.W.; Tsuo, Y.S. (1983). "Research on Polycrystalline Silicon Solar Cells: Goals and Accomplishments." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 119-122. Available from: IEEE.

Milstein, J.B.; Tsuo, Y.S. (1983). "Review of Research on Polycrystalline Silicon Solar Cells." *Proceedings of the Society of Photo-Optical Instrumentation Engineers: Volume 407 — Photovoltaics for Solar Energy Applications II; Arlington, VA; 5-6 April 1983*. Edited by David Adler. Bellingham, WA: SPIE; pp. 115-120.

Milstein, J.B.; Tsuo, Y.S. (June 1983). *Review of Research on Polycrystalline Silicon Solar Cells*. SERI/TP-211-1952. Golden, CO: Solar Energy Research Institute; 13 pp. Presented at the Society of Photo-Optical Instrumentation Engineers Conference; Arlington, VA; 5-6 April 1983.

Mitchell, K.W. (1982). "Status of New Thin-Film Photovoltaic Technologies." *Annual Review of Materials Science*. Palo Alto, CA: Annual Reviews, Inc.; Vol. 12; pp. 401-415.

Morrison, S.R. (1982). "Grain Boundary Shunt Currents Across a p-n Junction." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 193-198.

Moustakas, T.D. (November 1982). "Studies of Thin-Film Growth of Sputtered Hydrogenated Amorphous Silicon." *Solar Energy Materials*. Vol. 8 (Nos. 1-3); pp. 187-204.

Moustakas, T.D.; Maruska, H.P. (1 December 1983). "Effects of Power and Hydrogen in the Discharge on the Photovoltaic Properties of Sputtered Amorphous Silicon." *Applied Physics Letters*. Vol. 43 (No. 11); pp. 1037-1039.

Mrig, L.; DeBlasio, R.; O'Sullivan, G.A.; Tomko, R.P. (May 1983). *An Advanced Photovoltaic System Simulator to Demonstrate the Performance of Advanced Photovoltaic Cells and Devices*. SERI/TP-214-1937. Golden, CO: Solar Energy Research Institute; 6 pp. Paper presented at the Sixteenth IEEE Photovoltaic Specialists Conference; San Diego, CA; 27-30 September 1982.

Mrig, L.; DeBlasio, R.; O'Sullivan, G.A.; Tomko, R.P. (1983). "An Advanced Photovoltaic System Simulator to Demonstrate the Performance of Advanced Photovoltaic Cells and Devices." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 199-204. Available from: IEEE.

Nagasubramanian, G.; Wheeler, B.L.; Bard, A.J. (August 1983). "Semiconductor Electrodes XLIX. Evidence for Fermi Level Pinning and Surface-State Distributions from Impedance Measurements in Acetonitrile Solutions with Various Redox Couples." *Journal of the Electrochemical Society*. Vol. 130 (No. 8); pp. 1680-1688.

Nagasubramanian, G.; Wheeler, B.L.; Hope, G.A.; Bard, A.J. (February 1983). "Semiconductor Electrodes XLVII. A-C Impedance Technique for Evaluating Surface State Properties of n-MoTe<sub>2</sub> in Acetonitrile Solutions Containing Various Redox Couples." *Journal of the Electrochemical Society*. Vol. 130 (No. 2); pp. 385-391.

Nemanich, R.J.; Thompson, M.J.; Jackson, W.B.; Tsai, C.C.; Stafford, B.L. (1983). "Interface Kinetics at Metal Contacts on a-Si:H." *Proceedings of the 10th International Conference on Amorphous and Liquid Semiconductors; Tokyo, Japan; 22-26 August 1983*. Appears in: *Journal of Non-Crystalline Solids*. Vol. 59/60; pp. 513-516.

Nemanich, R.J.; Thompson, M.J.; Jackson, W.B.; Tsai, C.C.; Stafford, B.L. (July-September 1983). "Initial Reactions at the Interface of Pt and Amorphous Silicon." *Proceedings of the 10th Annual Conference on the Physics and Chemistry of Semiconductor Interfaces; Santa Fe, NM; 25-27 January 1983*. Appears in: *Journal of Vacuum Science & Technology B*. Vol. 1 (No. 3); pp. 519-526.

Neugroschel, A.; Lindholm, F.A. (15 January 1983). "Evidence for Low Diffusivity and Mobility of Minority Carriers in Highly Doped Si and Interpretation." *Applied Physics Letters*. Vol. 42 (No. 2); pp. 176-178.

Noel, G.T.; Gaines, G.B.; Richard, N.A. (1983). "A Study of the Stability of Cadmium Sulfide/Copper Sulfide Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 723-730. Available from: IEEE.

Noufi, R. (1983). "Applications of Electrogenerated Conducting Polymers in Electrochemical Photovoltaic Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1293-1298. Available from: IEEE.

Noufi, R. (1983). "Electro-Generated Conducting Polypyrrole Polymers and Applications in Photoelectrochemical Cells." *Applied Physics Communications*. Vol. 3 (No. 1-2); pp. 33-57.

- Noufi, R. (October 1983). "The Incorporation of Ruthenium Oxide in Polypyrrole Films and the Subsequent Photooxidation of Water at n-GaP Photoelectrode." *Journal of the Electrochemical Society*. Vol. 130 (No. 10); pp. 2126-2128.
- Noufi, R.; Axton, D.; Cahen, D.; Deb, S.K. (1983). "CdS/CuInSe<sub>2</sub> Heterojunction Cell Research." *Photovoltaics Advanced Research and Development 5th Annual Review Meeting; Denver, CO; 19-21 May 1983*. SERI/CP-311-2011. Golden CO: Solar Energy Research Institute; pp. 83-84.
- Noufi, R.; Nozik, A.J.; White, J.; Warren, L.F. (1982). "Enhanced Stability of Photoelectrodes with Electrogenerated Polyaniline Films." *Proceedings of the Symposia on Photoelectrochemical Processes and Measurement Techniques*. Edited by W.L. Wallace, A.J. Nozik, S.K. Deb, and R.H. Wilson. Vol. 82-3. Pennington, NJ: The Electrochemical Society; pp. 256-263.
- Noufi, R.; Nozik, A.J.; White, J.; Warren, L.F. (October 1982). "Enhanced Stability of Photoelectrodes with Electrogenerated Polyaniline Films." *Journal of the Electrochemical Society*. Vol. 129 (No. 10); pp. 2261-2265.
- Olsen, L.C.; Addis, F.W.; Miller, W.A.; Dunham, G.C. (1983). "Silicon MIS/Inversion-Layer Solar Cells Utilizing SiO Deposition." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1223-1230. Available from: IEEE.
- Olson, J.M. (1983). "Silicon Electrorefining and the Transport Properties of Cu<sub>3</sub>Si." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1. Pennington, NJ: ECS; p. 337. (Abstract No. 211).
- Olson, J.M. (February 1983). "Kinetics of Silicon Electrodeposition." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 279-292.
- Olson, J.M.; Carleton, K.; Kibbler, A. (1983). "Silicon Electrorefining Using a Semipermeable Cu<sub>3</sub>Si:Si Anode." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York, NY: IEEE Publishing Service; pp. 123-127. Available from: IEEE.
- Olson, J.M.; Powell, R. (September 1983). "A Gravimetric Rate Measurement Technique for Closed Tube, Vapor Transport Crystal Growth." *Journal of Crystal Growth*. Vol. 63 (No. 1); pp. 1-7.
- Osterwald, C.R.; Emery, K.A. (October 1983). "Solar Cell Area Considerations." *Solar Cells*. Vol. 10 (No. 1); pp. 1-5.
- Pawlikowski, J.M. (1982). "High-Efficiency Photo-Generation Processes." *161st Meeting of the Electrochemical Society Extended Abstracts; Montreal, Canada; 9-14 May 1982*. Vol. 82-1. Pennington, NJ: ECS; pp. 92-94 (Abstract No. 58).
- Photovoltaics Advanced Research and Development 5th Annual Meeting; Denver, CO; 19-21 May 1983*. (May 1983). SERI/CP-311-2011. Golden, CO: Solar Energy Research Institute; 137 pp.
- Pirouz, P.; Echigoya, J.; Edington, J.W. (1982). "A Structure Image Study of Defects in Cadmium Sulfide." *Institute of Physics Conference Series 61: Electron Microscopy and Analysis 1981; Cambridge, England; 7-10 September 1981*. Edited by M.J. Goringe. Bristol, England: Adam Hilger; pp. 531-534.
- Pollard, W.B.; Lucovsky, G. (15 September 1982). "Phonons in Polysilane Alloys." *Physical Review B*. Vol. 26 (No. 6); p. 3172.
- Polycrystalline Silicon Solar Cells Review Meeting; Abstracts of Presentations; Golden, CO; 27-28 June 1983*. (June 1983). SERI/CP-211-2025. Golden, CO: Solar Energy Research Institute; 248 pp.
- Polycrystalline Thin Film Review Meeting; Abstracts of Presentation; Golden, CO; 16-18 May 1983*. (May 1983). SERI/CP-211-1985. Golden, CO: Solar Institute; 362 pp.
- Poon, E.; Evans, H.L.; Hwang, W.; Osgood, R.M., Jr.; Yang, E.S. (1983). "Measurement of Grain Boundary Parameters by Laser-Spot Photoconductivity." *Laser Diagnostics and Photochemical Processing for Semiconductor Devices*. Edited by R.M. Osgood, Jr., S.R.J. Brueck, and H.R. Schlossberg. New York: North-Holland; pp. 103-108.
- Poon, E.; Yang, E.S.; Evans, H.L.; Hwang, W.; Osgood, R.M., Jr. (1 February 1983). "Determination of Grain Boundary Barrier Height and Interface States by a Focused Laser Beam." *Applied Physics Letters*. Vol. 42 (No. 3); pp. 285-287.
- Potter, R.R.; Sites, J.R. (1983). "Experimental Nonidealities in Response and Quality Factor of Photovoltaic Diodes." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 475-479. Available from: IEEE.

- Potter, R.R.; Sites, J.R. (April-June 1983). "Internal Contacts to Photovoltaic Structures Using Ion Beam Milling." *Proceedings of the 29th National Symposium of the American Vacuum Society; Baltimore, MD; 16-19 November 1982*. Appears in: *Journal of Vacuum Science & Technology A*. Vol. 1 (No. 2, Part I); pp. 331-333.
- Rajeswaran, G. (January 1983). *Interface and Intergrain Effects in Metal Insulator Semiconductor Solar Cells*. Ph.D. Dissertation, State University of New York, Buffalo, NY.
- Rajeswaran, G.; Anderson, W.A. (1982). "Design of Stable Metal-Insulator-Semiconductor (MIS) Solar Cells by Oxide Thickness Compensation." *Fourth EC Photovoltaic Solar Energy Conference; Proceedings of the International Conference; Stresa, Italy; 10-14 May 1982*. Edited by W.H. Bloss and G. Grassi. Boston, MA: D. Riedel Publishing Company; pp. 532-536.
- Rajeswaran, G.; Thayer, M.; Rao, V.J.; Anderson, W.A. (1982). "Advantages of MIS Processing on Passivated Polycrystalline Silicon." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 235-240.
- Rajeswaran, G.; Vanier, P.E.; Kampas, F.J.; Corderman, R.R.; Wiesemann, H. (1983). "The Effect of Silane Fraction on the Optoelectronic and Photovoltaic Properties of rf Glow Discharge a-Si:H Prepared from SiH<sub>4</sub> + H<sub>2</sub> Mixtures." *Proceedings of the 10th International Conference on Amorphous and Liquid Semiconductors; Tokyo, Japan; 22-26 August 1983*. Appears in: *Journal of Non-Crystalline Solids*. Vol. 59/60; pp. 1131-1134. Vol. 59/60; pp. 1131-1134.
- Rao, V.J.; Anderson, W.A.; Kai, F. (1982). "Grain Boundary Passivation and Analysis for Solar Cell Applications." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 229-234.
- Rao, V.J.; Anderson, W.A.; Rajeswaran, G. (August 1982). "The Role of Hydrogen in Improving Photovoltaic Response of Solar Cells on Polycrystalline Silicon." *Physica Status Solidi (a)*. Vol. 72 (No. 2); pp. 745-749.
- Redfield, D. (1983). "Incompatible Models of a-Si:H Films." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1327-1330. Available from: IEEE.
- Robertson, R.; Hils, D.; Chatham, H.; Gallagher, A. (15 September 1983). "Radical Species in Argon-Silane Discharges." *Applied Physics Letters*. Vol. 43 (No. 6); pp. 544-546.
- Rohatgi, A. (1983). "Research on the Basic Understanding of High Efficiency in Silicon Solar Cells." *Polycrystalline Silicon Solar Cells Review Meeting; Abstracts of Presentations; Golden, CO; 27-28 June 1983*. SERI/CP-211-2025. Golden, CO: Solar Energy Research Institute; pp. 41-58.
- Rothwarf, A. (1983). "A p-i-n Heterojunction Model for the Thin Film CuInSe<sub>2</sub>/CdS Solar Cell." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 791-793. Available from: IEEE.
- Russak, M.; Reichman, J. (1982). "Photocurrent Spectroscopy of CdSe Electrodes in Polysulfide Electrolyte." *Proceedings of the Symposia on Photoelectrochemical Processes and Measurement Techniques*. Edited by W.L. Wallace, A.J. Nozik, S.K. Deb, and R.H. Wilson. Vol. 82-3. Pennington, NJ: The Electrochemical Society; pp. 496-504.
- Russak, M.; Reichman, J.; DeCarlo, J. (1982). "Investigation of Zinc Treated CdSe Thin Film Electrodes by Auger Spectroscopy and I-V Measurements." *Proceedings of the Symposia on Photoelectrochemical Processes and Measurement Techniques*. Edited by W.L. Wallace, A.J. Nozik, S.K. Deb, and R.H. Wilson. Vol. 82-3. Pennington, NJ: The Electrochemical Society; pp. 496-504.
- Russak, M.; Reichman, J.; DeCarlo, J. (1982). "Investigation of Zinc Treated CdSe Thin Film Electrodes by Auger Spectroscopy and I-V Measurements." *Proceedings of the Symposia on Photoelectrochemical Processes and Measurement Techniques*. Edited by W.L. Wallace, A.J. Nozik, S.K. Deb, and R.H. Wilson. Vol. 82-3. Pennington, NJ: The Electrochemical Society; pp. 505-516.
- Russell, P.E.; Herrington, C.R. (1983). "Microanalysis of Candidate Thin and Thick Film Photovoltaic Materials." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82H1821-8. New York: IEEE Publishing Service; pp. 1051-1056.
- Russell, P.E.; Herrington, C.R. (1982). "Development and Application of Fully Automated EBIC Techniques for Solar-Cell Measurements." *Microbeam Analysis — 1983*. Edited by K.F.J. Heinrich. San Francisco, CA: San Francisco Press, Inc.; pp. 449-454.

Russell, P.E.; Herrington, C.R.; Burke, D.E.; Holloway, P.H. (1982). "The Effect of Heat Treatment on Grain Boundary Properties in Cast Polycrystalline Silicon." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 185-191.

Russell, P.E.; Herrington, C.R.; Matson, R.J. (August 1983). "Development and Application of Fully Automated EBIC Techniques for Solar-cell Measurements." *Technology in Review*. Vol. 1 (No. 2); pp. 3-7.

Sabisky, E.; Mahan, H.; McMahon, T. (1983). "Amorphous Silicon Materials and Solar Cells: Progress and Directions." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1106-1110. Available from: IEEE.

Sachs, E.; Cook, E.; Smallman, C.R.; Ely, D. (1983). "Edge Stabilized Ribbon Growth." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; p. 1467. Available from: IEEE.

Salerno, J.P.; McClelland, R.W.; Fan, J.C.C.; Vohl, P.; Bozler, C.O. (1983). "Growth and Characterization of Oriented GaAs Bicrystal Layers." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1299-1303. Available from: IEEE.

Seager, C.H. (1982). "The Electronic Properties of Semiconductor Grain Boundaries." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 85-98.

Seager, C.H. (1 November 1982). "Temperature Dependence of Minority-Carrier Recombination Velocities at Grain Boundaries in Silicon." *Applied Physics Letters*. Vol. 41 (No. 9); pp. 855-857.

Shastry, S.K. (1 November 1982). "Metalorganic Chemical Vapor Deposition of Very Thin ( $\approx 2 \mu\text{m}$ ), Oriented GaAs Layers on Tungsten Substrates." *Applied Physics Letters*. Vol. 41 (No. 9); pp. 836-838.

Sheldon, P.; Ahrenkiel, R.K.; Hayes, R.E.; Russell, P.E. (15 October 1982). "Interfacial Properties of Indium Tin Oxide/Indium Phosphide Devices." *Applied Physics Letters*. Vol. 41 (No. 8); pp. 727-729.

Sheldon, P.; Ahrenkiel, R.K.; Hayes, R.E.; Russell, P.E.; Nottenburg, R.N.; Kazmerski, L.L. (1983). "Junction Characteristics of Indium Tin Oxide/Indium Phosphide Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1284-1287. Available from: IEEE.

Sheldon, P.; Russell, P.E.; Ahrenkiel, R.K.; Hayes, R.E. (April-June 1983). "Summary Abstract: p-InP Surface Modification Due to Indium Tin Oxide Deposition." *Proceedings of the 29th National Symposium of the American Vacuum Society; Baltimore, MD; 16-19 November 1982* Appears in: *Journal of Vacuum Science & Technology A*. Vol. 1 (No. 2, Part I); pp. 618-619.

Sher, A.; Hoffman, H.J.; Su, P.; Tsuo, Y.H. (September 1983). "Techniques for Improving the Si-SiO<sub>2</sub> Interface Characterization." *Journal of Applied Physics*. Vol. 54 (No. 9); pp. 5183-5198.

Sillman, S. (1983). "On-Site Use and Sellback in Residential Photovoltaic Systems, Based on Monitored Residential Load Data." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 182-187. Available from: IEEE.

Singh, R.; Fonash, S.J.; Ashok, S.; Caplan, P.J.; Shappirio, J.; Hage-Ali, M.; Ponpon, J. (April-June 1983). "Electrical, Structural and Bonding Changes Induced in Silicon by H, Ar, and Kr Ion-Beam Etching." *Proceedings of the 29th National Symposium of the American Vacuum Society; Baltimore, MD; 16-19 November 1982*. Appears in: *Journal of Vacuum Science & Technology A*. Vol. 1 (No. 2, Part I); pp. 334-336.

Singh, V.A.; Lindefelt, U.; Zunger, A. (15 April 1983). "Electronic Structure of Substitutional Chalcogen Impurities in Silicon." *Physical Review B*. Vol. 27 (No. 8); pp. 4909-4923.

Singh, V.A.; Zunger, A.; Lindefelt, U. (15 January 1983). "Reversal in the Order of Impurity Binding Energies with Atomic Energies." *Physical Review B*. Vol. 27. (No. 2); pp. 1420-1423.

Spencer, M.G.; Schaff, W.J.; Wagner, D.K. (1982). "Characterization of Grain Boundaries in Polycrystalline GaAs." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 125-129.

- Stoffel, T.L. (November 1982). *Catalog of Automatic Sun-Following Trackers*. SERI/TR-215-1490. Golden, CO: Solar Energy Research Institute; 151 pp.
- Stone, J.L. (1983). "Promising Thin Film Solar Cells — An Overview." *Proceedings of the Society of Photo-Optical Instrumentation Engineers: Volume 407 — Photovoltaics for Solar Energy Applications II; Arlington, VA; 5-6 April 1983*. Edited by David Adler. Bellingham, WA: SPIE; pp. 2-4.
- Street, R.A. (15 April 1983). "Measurement of Depletion Layers in Hydrogenated Amorphous Silicon." *Physical Review B*. Vol. 27 (No. 8); 4924-4932.
- Street, R.A. (15 March 1983). "Transient Photoconductivity Studies of the Light Soaked State of Hydrogenated Amorphous Silicon." *Applied Physics Letters*. Vol. 42 (No. 6); pp. 507-509.
- Street, R.A. (1 December 1982). "Trapping Parameters of Dangling Bonds in Hydrogenated Amorphous Silicon." *Applied Physics Letters*. Vol. 41 (No. 11); pp. 1060-1062.
- Street, R.A. (18 October 1982). "Doping and the Fermi Energy in Amorphous Silicon." *Physical Review Letters*. Vol. 49 (No. 16); pp. 1187-1190.
- Street, R.A.; Zesch, J. (1983). "Time-of-Flight Photoconductivity in a-Si:H." *Proceedings of the 10th International Conference on Amorphous and Liquid Semiconductors; Tokyo, Japan; 22-26 August 1983*. Appears in: *Journal of Non-Crystalline Solids*. Vol. 59/60; pp. 449-452.
- Subbarao, K.; Singh, V.A. (1 October 1982). "Real-space Renormalization Transformations for the Free Energy of the Hubbard Hamiltonian." *Physical Review B*. Vol. 26 (No. 7); pp. 3788-3791.
- Szedon, J.R.; Krishnaswamy, S.V.; McMullin, P.G. (June 1983). *Development of Copper Sulfide/Cadmium Sulfide Thin-Film Solar Cells; Thirteenth Technical Progress Report for July 1 — September 30, 1982*. SERI/PR-8143-1-T12. Pittsburgh, PA: Westinghouse R&D Center; 25 pp.
- Thornton, J.A.; Cornog, D.G.; Anderson, W.W.; Hall, R.B.; Phillips, J.E. (1983). "Copper Sulfide/Cadmium Sulfide Heterojunction Cell Research by Sputter Deposition." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 737-742. Available from: IEEE.
- Timmons, M.L.; Bedair, S.M.; Markunas, R.J.; Hutchby, J.A. (1983). "Recent Developments for the AlGaAsSb Cell." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821. New York: IEEE Publishing Service; pp. 663-668. Available from: IEEE.
- Tomkiewicz, M.; Lyden, J.K. (1982). "Order and Disorder in Electrodeposited Polycrystalline CdSe Liquid Junction Solar Cells." *Proceedings of the Symposia on Photoelectrochemical Processes and Measurement Techniques*. Edited by W.L. Wallace, A.J. Nozik, S.K. Deb, and R.H. Wilson. Vol. 82-3. Pennington, NJ: The Electrochemical Society; pp. 423-434.
- Tsai, C.C.; Thompson, M.J.; Nemanich, R.J.; Jackson, W.B.; Stafford, B.L. (April-June 1983). "Summary Abstract: Metal-Amorphous Si Interfaces: Structural and Electrical Properties." *Proceedings of the 29th National Symposium of the American Vacuum Society; Baltimore, MD; 16-19 November 1982*. Appears in: *Journal of Vacuum Science and Technology A*. Vol. 1 (No. 2, Part I); pp. 785-786.
- Tsai, C.C.; Nemanich, R.J.; Thompson, M.J.; Stafford, B.L. (March 1983). "Metal-Induced Crystallization in Hydrogenated Amorphous Si Films." *Proceedings of the 16th International Conference on the Physics of Semiconductors; Montpellier, France; 6-10 September 1982*. Edited by M. Averous. Appears in: *Physica B+C*. Vol. 117 & 118 B+C (Part II); pp. 953-955.
- Tsaur, B-Y.; Fan, J.C.C.; Turner, G.W.; Davis, F.M.; Gale, R.P. (1983). "Efficient GaAs/Ge/Si Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1143-1148. Available from: IEEE.
- Tsuo, S.; Matson, R.; Hurd, G.; Cizek, T. (1983). "Electron Channeling and EBIC Studies of Polycrystalline Silicon Ribbons." *Polycrystalline Silicon Review Meeting; Abstracts of Presentations; Golden, CO; 27-28 June 1983*. SERI/CP-211-2025. Golden, CO: Solar Energy Research Institute; pp. 225-227.
- Tsuo, Y.S.; Hardy, R.W.; Milstein, J.B. (1983). "Grain Boundary Structure and Properties in Polycrystalline Silicon." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 616-621. Available from: IEEE.

Tsuo, Y.S.; Milstein, J.B.; Surek, T. (1982). "Grain Boundary Structures and Properties in Polycrystalline Silicon." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 155-166.

Turner, G.W.; Tsaur, B.-Y.; Fan, J.C.C.; Davis, F.M.; Gale, R.P.; Connors, M.K. (1983). "Junction Formation in GaAs Shallow-Homojunction Solar Cells by the Use of Spin-On Diffusion Sources." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1153-1156. Available from: IEEE.

van der Leeden, G.A.; Young, R.T.; Appleton, B.R.; Narayan, J. (1982). "In Situ Laser Recrystallization of CVD Silicon Films." *Materials Research Society Symposia Proceedings, Volume 4: Laser and Electron-Beam Interactions with Solids*. Edited by B.R. Appleton and G.K. Celler. New York: Elsevier-North Holland; pp. 221-226.

Vanier, P.E. (June-July 1983). "The Effect of Light Soaking on the Low Temperature Photoconductivity of Hydrogenated Amorphous Silicon." *Solar Cells*. Vol. 9 (No. 1-2); pp. 85-93.

Vanier, P.E. (15 November 1982). "Reversible Photoinduced Change in the Low Temperature Photoconductivity of Hydrogenated a-Si." *Applied Physics Letters*. Vol. 41 (No. 10); p. 986.

Vernon, S.M.; Wolfson, R.G. (1983). "Preparation of Silicon Substrates for Gallium Arsenide Solar Cells." *Photovoltaics Advanced Research and Development 5th Annual Review Meeting; Denver, CO; 19-21 May 1982*. SERI/CP-311-2011. Golden, CO: Solar Energy Research Institute; pp. 23-24.

Wager, J.F.; Geib, K.M.; Wilmsen, C.W.; Kazmerski, L.L. (July-September 1983). "Native Oxide Formation and Electrical Instabilities at the Insulator/InP Interface." *Proceedings of the 10th Annual Conference on the Physics and Chemistry of Semiconductor Interfaces; Santa Fe, NM; 25-27 January 1983*. Appears in: *Journal of Vacuum Science & Technology B*. Vol. 1 (No. 3); pp. 778-781.

Wager, J.F.; Jamjoun, O.; Kazmerski, L.L. (August 1983). "The CdS-CuInSe<sub>2</sub> Solar Cell Interface: Thermodynamic Considerations." *Solar Cells*. Vol. 9 (No. 3); pp. 159-168.

Wager, J.F.; Wilmsen, C.W.; Kazmerski, L.L. (1 April 1983). "Estimation of the Band Gap of InPO<sub>4</sub>." *Applied Physics Letters*. Vol. 42 (No. 7); p. 589.

Wagner, S. (1983). "Prospects of II-VI Based Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 685-691. Available from: IEEE.

Wallace, W. (1983). "Progress in the SERI-DOE Photoelectrochemical Cell Program." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1066-1071. Available from: IEEE.

Wallace, W.L. (1983). "Electrochemical Photovoltaic and Storage Cells Based on II-VI Polycrystalline Thin Film Materials." *Proceedings of the 1983 American Solar Energy Society Meeting: Progress in Solar Energy; Minneapolis, MN; 1-3 June 1983*. Boulder, CO: ASES; Vol. 6, pp. 107-111.

Wallace, W.L.; Nozik, A.J.; Deb, S.K.; Wilson, R.H., eds. (1982). *Photoelectrochemistry: Fundamental Processes and Measurement Techniques; Proceedings of the Symposia on Photoelectrochemical Processes and Measurement Techniques for Photoelectrochemical Solar Cells*. Vol. 82-3. Pennington, NJ: The Electrochemical Society; 723 pp.

Wanlass, M.W.; Blakeslee, A.E. (1983). "Superlattice Cascade Solar Cell." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 584-589. Available from: IEEE.

Weinberger, B.R.; Deckman, H.W.; Wronski, C.R.; Witzke, H. (1983). "AM-1 Short Circuit Currents in Small Area PIN a-Si:H<sub>x</sub> Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1316-1320. Available from: IEEE.

Wells, C.V. (October 1982). *The Challenge for Metrology in the R & D Environment*. SERI/TP-215-1758. Golden, CO: Solar Energy Research Institute; 14 pp. Presented at the 1982 Workshop and Symposium of the National Conference of Standards Laboratories; Gaithersburg, MD; 4-7 October 1982.

- Werthen, J.G.; Anthony, T.C.; Fahrenbruch, A.L.; Bube, R.H. (1983). "A 10% Efficient ITO-CdTe Heterojunction Solar Cell." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1138-1142. Available from: IEEE.
- Werthen, J.G.; Fahrenbruch, A.L.; Bube, R.H.; Zesch, J.C. (1982). "High Efficiency ITO-CdTe Heterojunction Solar Cells." *161st Meeting of the Electrochemical Society Extended Abstracts; Montreal, Canada; 9-14 May 1982*. Vol. 82-1. Pennington, NJ: ECS; p. 401 (Abstract No. 247).
- Werthen, J.G.; Haring, J.P.; Bube, R.H. (February 1983). "Correlation Between Cadmium Telluride Surface Oxidation and Metal Junctions." *Journal of Applied Physics*. Vol. 54 (No. 2); pp. 1159-1161.
- Williamson, D.L.; Deb, S.K. (May 1983). "Mossbauer Spectroscopy of Amorphous Silicon-Tin-Hydrogen Alloys." *Journal of Applied Physics*. Vol. 54 (No. 5); pp. 2588-2592.
- Williamson, D.L.; Kowalchik, M.; Rocher, A.; Gibart, P. (August 1983). "Nature of Defects in Heavily Te-Doped GaAs." *Revue de Physique Appliquée*. Vol. 18 (No. 8); pp. 475-478.
- Wolf, M. (1983). "Efficiency Improvement in Silicon Solar Cells." *Proceedings of the DOE Annual Photovoltaics Program Review; Arlington, VA; 15-16 February 1983*. CONF-830222. Pasadena, CA: Jet Propulsion Laboratory; pp. 117-131.
- Wolford, D.J.; Scott, B.A.; Reimer, J.A.; Bradley, J.A. (March 1983). "Efficient Visible Luminescence from Hydrogenated Amorphous Silicon." *Proceedings of the 16th International Conference on the Physics of Semiconductors; Montpellier, France; 6-10 September 1982*. Edited by M. Averous. Appears in: *Physica B+C*. Vol. 117 & 118 B+C (Part II); pp. 920-922.
- Wu, C-M.M.; Yang, E.S. (October 1982). "Phonon-Assisted Carrier Transport Across a Grain Boundary." *IEEE Transactions on Electron Devices*. Vol. ED-29 (No. 10); pp. 1598-1603.
- Yamashita, T.; Werthen, J.G.; Sinclair, R.; Bube, R.H. (1983). "High Resolution Lattice Imaging of the CdS/CdTe Interface." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1433-1434. Available from: IEEE.
- Yang, E.S. (1982). "Structure and Performance of Polycrystalline Thin Film Solar Cells." *Materials Research Society Symposia Proceedings, Volume 10: Thin Films and Interfaces*. Edited by P.S. Ho and K.N. Tu. New York: Elsevier-North Holland; pp. 297-309.
- Yang, E.S.; Poon, E.; Evans, H.L.; Hwang, W.; Song, J.S.; Wu, C.M. (1983). "Electronic Properties of Grain Boundaries in Polycrystalline Silicon." *Proceedings of the Society of Photo-Optical Instrumentation Engineers: Volume 385 — Laser Processing of Semiconductor Devices; Los Angeles, CA; 18-19 January 1983*. Edited by Charles C. Tang. Bellingham, WA: SPIE; pp. 59-64.
- Young, R.T.; Narayan, J.; Chang, Y.K. (1982). "Electrical and Structural Properties of Grain Boundary in Polycrystalline Si." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 111-117.
- Young, R.T.; Narayan, J.; Christie, W.H.; van der Leeden, G.A.; Levatter, J.I.; Cheng, L.J. (November 1983). "Semiconductor Processing with Excimer Lasers." *Solid State Technology*. Vol. 26 (No. 11); pp. 183-189.
- Young, R.T.; van der Leeden, G.A.; Sandstrom, R.L.; Wood, R.F.; Westbrook, R.D. (1 October 1983). "High Efficiency Silicon Solar Cells by Beam Processing." *Applied Physics Letters*. Vol. 43 (No. 7); pp. 666-668.
- Young, R.T.; van der Leeden, G.A.; Westbrook, R.D.; Sandstrom, R.L.; Levatter, J.I. (1983). "Improved Beam Processing for Terrestrial Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 May 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1468-1469. Available from: IEEE.
- Young, R.T.; van der Leeden, G.A.; Wood, R.F.; Narayan, J. (1983). "Studies of Grain Boundaries in Small-Grained Polycrystalline Silicon Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 427-430. Available from: IEEE.



Young, R.T.; van der Leeden, G.A.; Wood, R.F.; Westbrook, R.D. (1983). "Update of Pulsed-Laser Processing Technology for High-Efficiency Silicon Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 748-751. Available from: IEEE.

Young, R.T.; Wood, R.F. (1982). "Laser Processing of Semiconductor Materials." *Annual Review of Materials Science*. Vol. 12; pp. 323-350.

Zhao, T-X.; Daniels, R.R.; Katnani, A.D.; Margaritondo, G.; Zunger, A. (July-September 1983). "Schottky Barrier Formation and the Initial Metal-Atom Bonding State: InP(110)-Al vs GaAs(110)-Al." *Proceedings of the 10 Annual Conference on the Physics and Chemistry of Semiconductor Interfaces; Santa Fe, NM; 25-27 January 1983*. Appears in: *Journal of Vacuum Science & Technology B*. Vol. 1 (No. 3); pp. 610-612.

Zunger, A. (15 September 1983). "Applicability of the Local-Density Theory to Interstitial Transition-Metal Impurities in Silicon." *Physical Review B*. Vol. 28 (No. 6); pp. 3628-3631.

Zunger, A. (17 June 1983). "The Origin of Schottky Barriers on the Cleavage Plane of III-V Semiconductors: Review of Some Recent Theoretical Work." *Thin Solid Films*. Vol. 104 (No. 3/4); pp. 301-316.

Zunger, A. (18 April 1983). "One-Electron Broken-Symmetry Approach to the Core-Hole Spectra of Semiconductors." *Physics Review Letters*. Vol. 50 (No. 16); pp. 1215-1218.

Zunger, A.; Lindefelt, U. (March 1983). "Electronic Structure of Substitutional 3d Transition Atom Impurities in Silicon." *Proceedings of the 16th International Conference on the Physics of Semiconductors; Montpellier, France; 6-10 September 1982*. Edited by M. Averous. Appears in: *Physica B+C*. Vol. 117 & 118 B+C (Part II); pp. 185-187.

Zunger, A.; Lindefelt, U. (15 January 1983). "Electronic Structure of Transition-Atom Impurities in Semiconductors: Substitutional 3d Impurities in Silicon." *Physical Review B*. Vol. 27 (No. 2); pp. 1191-1127.

Zunger, A., Lindefelt, U. (January 1983). "Substitutional 3d Impurities in Silicon: A Self-Regulating System." *Solid State Communications*. Vol. 45 (No. 4); pp. 343-346.

Zunger, A.; Lindefelt, U. (15 November 1982). "Theory of Substitutional and Interstitial 3d Impurities in Silicon." *Physical Review B*. Vol. 26 (No. 10); pp. 5989-5992.

Zweibel, K.; Hermann, A.M.; Mitchell, R. (1983). "Progress in Polycrystalline Thin-Film Solar Cells." *1983 Solar World Congress Extended Abstracts; Perth, Western Australia; 14-19 August 1983*. Edited by S.V. Szokolay. Victoria, Australia: International Solar Energy Society; p. 326. Available from: ISES, c/o CSIRO, Victoria, Australia.

Zweibel, K.; Hermann, A.M.; Mitchell, R. (July 1983). *Progress in Polycrystalline Thin-Film Solar Cells*. SERI/TP-211-2048, Golden, CO; Solar Energy Research Institute; 5 pp. Presented at the International Solar Energy Society — Solar World Congress; Perth, Australia; 14-19 August 1983.

# Jet Propulsion Laboratory

Alam, M.K. (August 1983). *Nucleation and Condensational Growth of Aerosols: Application to Silicon Production*. Ph.D. Dissertation, California Institute of Technology, Pasadena, CA.

Alam, M.K.; Flagan, R.C. (1983). "Aerosol Reactor for Silicon Production." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1. Pennington, NJ: ECS; pp. 338-339 (Abstract No. 212).

Allen, F.G.; Iyer, S.S.; Metzger, R.A. (1983). "Molecular Beam Epitaxial Growth of Silicon Devices." *Proceedings of the Society of Photo-Optical Instrumentation Engineers; Volume 323 — Semiconductor Growth Technology; Los Angeles, CA; 26-27 January 1982*. Edited by Esther Krikorian. Bellingham, WA: SPIE; pp. 2-12.

Allen, F.G.; Iyer, S.S.; Metzger, R.A. (July 1982). "Dopant Incorporation Studies in Silicon Molecular Beam Epitaxy (SiMBE)." *Application of Surface Science*. Vol. 11/12; pp. 517-527.

*Annual Report: Photovoltaic Module Bypass-Diode Encapsulation*. (20 June 1983). DOE/JPL/956254-1. Pasadena, CA: Jet Propulsion Laboratory; 149 pp. Work performed by General Electric, Advanced Energy Programs Department, King of Prussia, PA. Available from: NTIS.

Ast, D.G. (1983). "Structural Characterization of Solar Silicon." *High Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; pp. 39-40.

Ast, D.G.; Cunningham, B.; Strunk, H.P. (1982). "EBIC/TEM Investigation of Defects in Solar Cell Silicon." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 167-178.

Bailey, D.F. (February 1983). "Kinetics and Mechanisms of Chlorosilane Decomposition." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 51-62.

Brown, R.A. (1983). "Mathematical Modelling of High-Speed Ribbon System: A Case Study of Edge-Defined Film-Fed Growth." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; pp. 27-28.

Burger, D.R. (1983). "Determination of Contact Resistivity on Production Photovoltaic Cells." *1983 Solar World Congress Extended Abstracts; Perth, Western Australia; 14-19 August 1983*. Edited by S.V. Szokolay. Victoria, Australia: International Solar Energy Society; p. 333. Available from: ISES c/o CSIRO, Victoria, Australia.

Burger, D.R. (1983). "Development of a Contact-End-Resistance Approach to Contact-Resistivity Measurement." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1. Pennington, NJ: ECS; pp. 354-355 (Abstract No. 324).

Burger, D.R. (15 January 1983). *Development of a Large Low-Cost Double Chamber Vacuum Laminator*. DOE/JPL-1012-83. Pasadena, CA: Jet Propulsion Laboratory; 28 pp. Available from: NTIS.

Callaghan, W.T. (1983). "Flat-Plate Solar Array Progress and Plans." *1983 Solar World Congress Extended Abstracts; Perth, Western Australia; 14-19 August 1983*. Edited by S.V. Szokolay. Victoria, Australia: International Solar Energy Society; p. 345. Available from: ISES c/o CSIRO, Victoria, Australia.

Chalmers, B. (1983). "Is There a Speed Limit?" *High Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 3.

Chen, C.K.; Geis, M.W.; Tsaur, B.-Y.; Fan, J.C.C. (1983). "High Quality Silicon Films Prepared by Zone-Melting Recrystallization." *High Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; pp. 35-36.

Chen, C.P. (December 1982). "Minimum Silicon Wafer Thickness for ID Wafering". *Journal of the Electrochemical Society*. Vol. 129 (No. 12); pp. 2835-2837.

- Cheng, L.J.; Shyu, C.M. (1982). "Light Effects on Grain Boundary Properties in Silicon." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA: 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 105-110.
- Cheng, L.J.; Shyu, C.M.; Stika, K.M.; Daud, T.; Crotty, G.T. (1983). "Enhanced Diffusion of Phosphorus at Grain Boundaries." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 554-558.
- Cheng, L.J.; Shyu, C.M.; Stika, K.M.; Daud, T.; Crotty, G.T. (15 November 1983). *Characterization of Grain Boundaries in Silicon*. DOE/JPL-1012-90. Pasadena, CA: Jet Propulsion Laboratory; 44 pp.
- Ciszek, T.F. (1983). "Orientation and Morphology Effects in Rapid Silicon Sheet Solidification." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 21.
- Cockrum, R.H. (15 September 1982). *A System for Measuring Thermal Activation Energy Levels in Silicon by Thermally Stimulated Capacitance*. DOE/JPL-1012-78. Pasadena, CA: Jet Propulsion Laboratory; 40 pp. Available from: NTIS.
- Conley, W.R. (1982). *Ion-Plating of Solar Cell Arrays Encapsulation Task — LSA Project 32; Final Report for December 1, 1979-October 31, 1982*. DOE/JPL/955506-83-3. Pasadena, CA: Jet Propulsion Laboratory; 32 pp. Work performed by Illinois Tool Works, Inc., Elgin, IL. Available from: NTIS.
- Coulbert, C.D. (1 April 1983). *The Application of Encapsulation-Material Stability Data to Photovoltaic Module Life Assessment*. DOE/JPL-1012-84. Pasadena, CA: Jet Propulsion Laboratory; 52 pp. Available from: NTIS.
- Coulter, D.R.; Cuddihy, E.F.; Plueddeman, E.P. (15 November 1983). *Chemical Bonding Technology for Terrestrial Photovoltaic Modules; Status to February, 1983*. DOE/JPL-1012-91. Pasadena, CA: Jet Propulsion Laboratory; 57 pp.
- Cuddihy, E.F.; Coulbert, C.D.; Liang, R.H.; Gupta, A.; Willis, P.; Baum, B. (15 April 1983). *Applications of Ethylene Vinyl Acetate as an Encapsulation Material for Terrestrial Photovoltaic Modules*. DOE/JPL/1012-87. Pasadena, CA: Jet Propulsion Laboratory; 71 pp. Available from: NTIS.
- Culik, J.S. (1983). *Process Research on Polycrystalline-Silicon Material (PROPSM), Quarterly Report No. 10, April 1, 1983 — June 30, 1983*. DOE/JPL/955902-83/10. Pasadena, CA: Jet Propulsion Laboratory; 60 pp. Work performed by Solarex Corporation, Rockville, MD. Available from: NTIS.
- Culik, J.S. (1983). *Process Research on Polycrystalline-Silicon Material (PROPSM), Quarterly Report No. 9, for January 1 — March 31, 1983*. DOE/JPL/955902-83/9. Pasadena, CA: Jet Propulsion Laboratory; 40 pp. Work performed by Solarex Corporation, Rockville, MD. Available from: NTIS.
- Cullis, A.G. (1983). "High Speed Crystal Growth by Q-Switched Laser Melting." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 34.
- Cunningham, B.; Ast, D.G. (1982). "High Resolution Electron Microscopy of Grain Boundaries in Silicon." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA: 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 21-26.
- Cunningham, B.; Ast, D.G. (1982). "The Electrical Activity at Twin Boundaries in Silicon." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA: 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 51-56.
- Cunningham, B.; Ast, D.G. (March 1982). "Process Induced Defects in EFG Silicon Ribbons," *161st Electrochemical Society Meeting Extended Abstracts; Montreal, Canada; 9-14 May 1982*. Vol. 82-1. Pennington, NJ: ECS; p. 109 (Abstract No. 68).
- Cunningham, B.; Strunk, H.P.; Ast, D.G. (1982). "First and Second Order Twin Boundaries in Edge Defined Film Growth — Silicon Ribbons." *Applied Physics Letters*. Vol. 40 (No. 3); pp. 237-239.
- Cunningham, B.; Strunk, H.P.; Ast, D.G. (April 1982). "High Resolution Electron Microscopy of A SIGMA = 27 Boundary in Silicon." *Scripta Metallurgica*. Vol. 16 (No. 4); pp. 349-352.
- Cunningham, B.; Strunk, H.P.; Ast, D.G. (May 1982). "Electron Microscopy of WEB-Dendritic Silicon." *Journal of the Electrochemical Society*. Vol. 129 (No. 5); pp. 1089-1093.

Daud, T.; Dumas, K.A.; Schwuttke, G.H.; Smetana, P.; Kim, K.M. (1983). "Directional Solidification of Silicon in Carbon Crucibles by an Oscillating Crucible Technique." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 63-67.

*Development of Photovoltaic Array and Module Safety Requirements, Flat-Plate Solar Array Project Engineering Sciences Area — Final Report*. (June 1982). DOE/JPL-955392-1. Pasadena, CA: Jet Propulsion Laboratory; 68 pp. Work performed by Underwriters Laboratories, Inc., Melville, NY. Available from: NTIS.

*Development of Technique for AR Coating and Nickel and Copper Metalization of Solar Cells*. (1983). DOE/JPL-955986-4. Pasadena, CA: Jet Propulsion Laboratory; 35 pp. Work performed by Photowatt International, Inc., Tempe, AZ. Available from: NTIS.

Dillon, O.W.; DeAngelis, R. (1983). "Thermal Buckling of Silicon Sheet." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 29.

Dudukovic, M.P. (February 1983). "Reactor Models for CVD of Silicon." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 199-228.

Dumas, K.A.; Schwuttke, G.H.; Daud, T. (1983). "Silicon Ingot Growth by an Oscillating Crucible Technique." *Proceedings of the Society of Photo-Optical Instrumentation Engineers: Volume 407 — Photovoltaics for Solar Energy Applications II; Arlington, VA; 5-6 April 1983*. Edited by David Adler. Bellingham, WA: SPIE; pp. 121-125.

Duncan, C.S.; Seidensticker, R.G.; McHugh, J.P. (15 August 1983). *Large-Area Sheet Task Advanced Dendritic Web Growth Development, Quarterly Report for the Period January 1, 1983 to March 31, 1983*. DOE/JPL/955843-83/10. Pasadena, CA: Jet Propulsion Laboratory; 37 pp. Work performed by Westinghouse R & D Center, Pittsburgh, PA. Available from: NTIS.

Duncan, C.S.; Seidensticker, R.G.; McHugh, J.P. (22 March 1983). *Large-Area Sheet Task Advanced Dendritic Web Growth Development, Quarterly Report for the Period October 23, 1982 to December 31, 1982*. DOE/JPL/955843-83/9. Pasadena, CA: Jet Propulsion Laboratory; 31 pp. Work performed by Westinghouse R&D Center, Pittsburgh, PA. Available from: NTIS.

Duncan, C.S.; Seidensticker, R.G.; McHugh, J.P.; Schruben, J. (18 January 1983). *Large-Area Sheet Task. Advanced Dendritic Web Growth Development, Annual Report, October 23, 1981-October 22, 1982*. DOE/JPL/955843-83/8. Pasadena, CA: Jet Propulsion Laboratory; 70 pp. Work performed by Westinghouse R & D Center, Pittsburgh, PA.

Duncan, L.B.; Garcia, A., III; Cuddihy, E.F. (1983). "Empirical Testing of Structural Deflection Modeling of Large Photovoltaic Modules." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1256-1261.

Erk, H.F. (February 1983). "Chlorosilane Thermodynamic Equilibria Calculations with Applications to High Purity Silicon Preparation." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 33-50.

Fang, P.H.; Schubert, C.C.; Bei, P.; Kinnier, J.H. (15 August 1982). "Combined Microcrystal and Amorphous Silicon Cells." *Applied Physics Letters*. Vol. 41 (No. 4); pp. 365-366.

Felder, W. (February 1983). "Kinetics of Particle Growth in Silane Systems." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon — Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 89-100.

Ferber, R.R. (1983). "The DOE Photovoltaics Program." *Proceedings of the 18th Intersociety Energy Conversion Engineering Conference; Orlando, FL; 21-26 August 1983*. New York: American Institute of Chemical Engineers; Vol. 3; pp. 1266-1272.

Ferber, R.R. (1983). The DOE Photovoltaics Program: An Overview." *Solar Engineering-1983; Proceedings of the ASME Solar Energy Division Fifth Annual Conference; Orlando, FL; 18-21 April 1983*. Edited by Lawrence M. Murphy. New York: American Society of Mechanical Engineers; pp. 212-217.

Fernandez, R.; Shreter, U.; Nicolet, M.A. (1-15 May 1983). "Temperature and Diffusion Effects in Preferential Sputtering of CrSi<sub>2</sub>." *Proceedings of the 3rd International Conference on Ion Beam Modifications of Materials; Grenoble, France; 6-10 September 1982*. Appears in: *Nuclear Instruments and Methods*. Vol. 209/210 (Part I); pp. 513-519.

Finetti, M.; Pan, E. T-S.; Suni, I.; Nicolet, M.A. (1 June 1983). "Electrical Characteristics of Amorphous Iron-Tungsten Contacts on Silicon." *Applied Physics Letters*. Vol. 42 (No. 11); pp. 987-989.

Fitzgerald, T.J. (February 1983). "A Model for the Growth of Dense Silicon Particles from Silane Pyrolysis in a Fluidized Bed." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 141-158.

Flagan, R. (February 1983). "Factors Governing Particle Size in the Free Space Reactor." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 107-120.

*Flat-Plate Solar-Array Project; Experimental Process-System Development Unit for Producing Semiconductor-Grade Silicon Using the Silane-to-Silicon Process; Final Report, Phase III, April 1979-December 1981*. (1983). DOE/JPL/954334-21. Pasadena, CA: Jet Propulsion Laboratory; 354 pp. Work performed by Union Carbide Corporation, Washougal, WA. Available from: NTIS.

*Flat-Plate Solar Array Project, Progress Report 21 for the Period April 1982 to January 1983 and Proceedings of the 21st Project Integration Meeting*. (1983). DOE/JPL-1012-88. Pasadena, CA: Jet Propulsion Laboratory; 511 pp.

*Flat-Plate Solar Array Project, Progress Report 20 for the Period November 1981 to April 1982 and Proceedings of the 20th Project Integration Meeting*. (1982). DOE/JPL-1012-71. Pasadena, CA: Jet Propulsion Laboratory; 535 pp. Available from: NTIS.

*Flat-Plate Solar Array Project, Progress Report 19 for the Period July to November 1981 and Proceedings of the 19th Project Integration Meeting*. (1982). DOE/JPL-1012-67. Pasadena, CA: Jet Propulsion Laboratory; 384 pp. Available from: NTIS.

Garcia, A., III. (May 1983). *Development of Metallization Process; FSA Project, Cell and Module Formation Research Area, Quarterly Technical Progress Report for the Period Ending 31 March 1983*. DOE/JPL/956205-83/4. Pasadena, CA: Jet Propulsion Laboratory; 12 pp. Work performed by Spectrolab, Inc., Sylmar, CA. Available from: NTIS.

Garcia, A., III. (April 1983). *Development of Metallization Process, FSA Project, Cell and Module Formation Research Area, Quarterly Technical Progress Report Ending December 31, 1982*. DOE/JPL/956205-83/3. Pasadena, CA: Jet Propulsion Laboratory; Available from: NTIS.

Garcia, A., III. (February 1983). *Design, Analysis and Test Verification of Advanced Encapsulation Systems, Triannual Report for the Period Ending 30 November 1982*. DOE/JPL-955567-83/10. Pasadena, CA: Jet Propulsion Laboratory; 20 pp. Work performed by Spectrolab, Inc., Sylmar, CA. Available from: NTIS.

Garcia, A., III. (November 1982). *Design, Analysis and Test Verification of Advanced Encapsulation Systems, Triannual Report for the Period Ending 31 July 1982*. DOE/JPL-955567-82/9. Pasadena, CA: Jet Propulsion Laboratory; 39 pp. Work performed by Spectrolab, Inc., Sylmar, CA. Available from: NTIS.

Garcia, A., III. (November 1982). *Development of Metallization Process; Quarterly Technical Report for the Period Ending 30 September 1982*. DOE/JPL/956205-82/2. Pasadena, CA: Jet Propulsion Laboratory; 14 pp. Work performed by Spectrolab, Inc., Sylmar, CA. Available from: NTIS.

Garcia, A., III; Gallagher, B.D. (1983). "A Non-Noble Front Metallization Process Using Mo/Sn Screen Printed Pastes." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1. Pennington, NJ: ECS; p. 358 (Abstract No. 227).

Garcia, A., III; Kallis, J.M.; Trucker, D.C. (June 1983). *Design, Analysis and Test Verification of Advanced Encapsulation Systems, Triannual Report for the Period Ending 31 March 1983*. DOE/JPL-955567-83-11. Pasadena, CA: Jet Propulsion Laboratory; 48 pp. Work performed by Spectrolab, Inc., Sylmar, CA. Available from: NTIS.

Gleichman, R.; Ast, D.G. (July 1983). *TEM and SEM (EBIC) Investigations of Silicon Bicrystals, Quarterly Report for April 1 — June 31, 1983*. DOE/JPL/956046-83/6. Pasadena, CA: Jet Propulsion Laboratory; 12 pp. Work performed by Cornell University, Department of Materials Science and Engineering, Ithaca, NY.

Gonzalez, C.C.; Hill, G.M.; Ross, R.G., Jr. (15 December 1982). *Photovoltaic Array-Power Conditioner Interface Characteristics*. DOE/JPL-1012-79. Pasadena, CA: Jet Propulsion Laboratory; 50 pp. Available from: NTIS.

- Gonzalez, C.C.; Hill, G.M.; Ross, R.G., Jr. (1983). "Characterization of the Electrical Output of Flat-Plate Photovoltaic Arrays." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 384-390.
- Gonzalez, C.C. Ross, R.G., Jr. (1983). "Energy Prediction Using NOCT-Based Photovoltaic Reference Conditions." *Proceedings of the 1983 American Solar Energy Society Meeting: Progress in Solar Energy; Minneapolis, MN; 1-3 June 1983*. Boulder, CO: ASES; Volume 6; pp. 935-940.
- Grabmaier, J.G.; Foll, H. (1983). "The S-Web-Technique for High-Speed Growth of Si Sheets." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 23.
- Grimmett, E.S. (February 1983). "An Update on a Mathematical Model which Predicts the Particle Size Distribution." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 171-196.
- Helmreich, D. (1983). "Silicon Foils Grown by Interface-Controlled Crystallization." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 22.
- Ho, F.; Iles, P.A.; Curtis, H.; Baraona, C. (1983). "Recent Advances in Thin Silicon Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 156-159. Available from: IEEE.
- Hopkins, R.H. (February 1983). "Silicon Purity: Impact on Crystal Growth and Silicon Properties for Photovoltaic Applications." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 17-30.
- Hsu, G. (1983). "JPL FBR Si-Deposition Research." *Flat-Plate Solar Array Project: Progress Report 21 for the Period April 1982 to January 1983 and Proceedings of the 21st Project Integration Meeting*. DOE/JPL-1012-88. Pasadena, CA: Jet Propulsion Laboratory; pp. 233-238.
- Hsu, G.; Lutwack, R.; Rohatgi, H. (1982). "Silane Pyrolysis in a Fluidized Bed Reactor." *Third Symposium on Materials and New Processing Technologies for Photovoltaics; Montreal, Canada; May 1982*. Edited by John P. Dismukes, Earhard Sirtl, P. Rai-Choudhury, and Lee P. Hunt. Pennington, NJ: The Electrochemical Society; pp. 477-487.
- Hutchinson, J.W.; Lambropoulos, J. (1983). "The Effect of Creep on the Residual Stresses Generated During Silicon Sheet Growth." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 31.
- Hyland, S.; Dumas, K.A.; Schwuttke, G.H.; Engelbrecht, J.A.A.; Leung, D. (1983). "Characterization of Silicon Crystals Grown by the Heat Exchange Method." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1; Pennington, NJ: ECS; pp. 343-344 (Abstract No. 217).
- Hyland, S.; Iles, P.; Leung, D.; Schwuttke, G.; Engelbrecht, J.A.A. (1983). "Interaction Between Cast Silicon Properties and Solar Cell Performance." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 68-73. Available from: IEEE.
- Hyland, S.; Leung, D.; Morrison, A.; Stika, K.; Yoo, H. (June 1983). "Correlation of Solar Cell Electrical Properties with Material Characteristics of Silicon Cast by the Ubiquitous Crystallization." *Journal of the Electrochemical Society*. Vol. 130 (No. 6); pp. 1373-1376.
- Iles, P.A. (1983). "Manufacturing Trends in Space Solar Cells." *Proceedings of the 18th Intersociety Energy Conversion Engineering Conference; Orlando, FL; 21-26 August 1983*. New York: American Institute of Chemical Engineers; Vol. 3; pp. 1209-1212.
- Iles, P.A. (1982). "Current Developments in Silicon Space Cells." *Proceedings of the 17th Intersociety Energy Conversion Engineering Conference; Los Angeles, CA; 8-12 August 1982*. New York: American Institute of Aeronautics and Astronautics; Vol. 3; pp. 1624-1626.
- Jacobson, M.R. (February 1983). "Chemical Vapor Deposition of Silicon for Optical Uses." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1983*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; 265-276.

Jewett, D.N.; Bates, H.E. (1983). "Low Angle Silicon Sheet Growth: A Review of Progress, Problems and Promise." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 25.

Ji, C-R.; Sah, C-T. (June 1983). "Two-Dimensional Numerical Analysis of the Narrow Gate Effect in MOSFET." *IEEE Transactions on Electron Devices*. Vol. ED-30 (No. 6); pp. 635-647.

Kaae, J. (February 1983). "The Mechanism of the Chemical Vapor Deposition of Carbon in a Fluidized Bed of Particles." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 127-140.

Kahn, A.; Bonapace, C.R.; Duke, C.B.; Paton, A. (July-September 1983). "Structure of the Al-GaP(110) and Al-InP(110) Interfaces." *Proceedings of the 10th Annual Conference on the Physics and Chemistry of Semiconductor Interfaces; Santa Fe, NM; 25-27 January 1983*. Appears in: *Journal of Vacuum Science & Technology B*. Vol. 1 (No. 3); pp. 613-617.

Kalejs, J.P. (15 August 1983). *Stress Studies in EFG; Fourth Quarterly Progress Report, Covering the Period from April 1, 1983-June 30, 1983*. DOE/JPL/956312-83/04. Pasadena, CA: Jet Propulsion Laboratory; 50 pp. Work performed by Mobil Solar Energy Corporation, Waltham, MA. Available from: NTIS.

Kalejs, J.P. (April/May 1983). "Interface Shape Studies for Silicon Ribbon Growth by the EFG Technique; I. Transport Phenomena Modeling." *Journal of Crystal Growth*. Vol. 61 (No. 3); pp. 473-484.

Kalejs, J.P. (April/May 1983). "Interface Shape Studies for Silicon Ribbon Growth by the EFG Technique; II. Effect of Die Asymmetry." *Journal of Crystal Growth*. Vol. 61 (No. 3); pp. 485-493.

Kalejs, J.P. (15 September 1982). *Large-Area Silicon Sheet by EFG; Final Report Covering Period October 29, 1975-December 31, 1981*. DOE/JPL/954355/81-21. Pasadena, CA: Jet Propulsion Laboratory; 87 pp. Work performed by Mobil Tyco Solar Energy Corporation, Waltham, MA. Available from: NTIS.

Kalejs, J.P.; Bell, R.O. (1983). "Experimental Aspects of the Study of Stress Generating Mechanisms in Silicon Sheet Growth." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 30.

Kayihan, F. (February 1983). "Steady-State and Transient Particle Size Distribution Calculations for Fluidized Beds." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 159-170.

Koliwad, K.; Mokashi, A.R. (1983). "High Speed Growth of Silicon Crystals: FSA Project Perspective." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 2.

Kukulka, J.; Iles, P.A. (1983). "Large Area, Low Cost Space Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 146-149. Available from: IEEE.

Lathrop, J.W.; Davis, C.W.; Royal, E. (1983). "An Accelerated Stress Testing Program for Determining the Reliability Sensitivity of Silicon Solar Cells to Encapsulation and Metallization Systems." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1262-1267. Available from: IEEE.

Lau, S.S.; Liu, B-X.; Nicolet, M.A. (1-15 May 1983). "Ion Mixing and Phase Diagrams." *Proceedings of the 3rd International Conference on Ion Beam Modifications of Materials; Grenoble, France; 6-10 September 1982*. Appears in: *Nuclear Instruments and Methods*. Vol. 209/210 (Part I); pp. 97-105.

Lehmann, V.; Foll, H.; Bernewitz, L.; Grabmaier, J.G. (1983). "A High Speed Characterization Technique for Solar Silicon." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; pp. 41-42.

Leipold, M. (1983). "Crystallization of Silicon Ribbons." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 5.

Levin, H.; Escorza, M.M. (May 1983). "Gas Flow through Rotameters." *Industrial & Engineering Chemistry Fundamentals*. Vol. 22 (No. 2); pp. 163-166.

- Liang, R.H.; Oda, K.L.; Chung, S.Y.; Smith, M.V.; Gupta, A. (1 May 1983). *Handbook of Photothermal Test Data on Encapsulant Materials*. DOE/JPL-1012-86. Pasadena, CA: Jet Propulsion Laboratory; 159 pp. Available from: NTIS.
- Liebermann, H.H. (1983). "Rapidly Solidified Alloys Made by Chill Block Melt-Spinning Processes." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 16.
- Lindholm, F.A. (November 1982). "Simple Phenomenological Modeling of Transition-Region Capacitance of Forward-Biased p-n Junction Diodes and Transistor Diodes." *Journal of Applied Physics*. Vol. 53 (No. 11); pp. 7606-7608.
- Lindholm, F.A.; Chen, Y.H. (December 1982). "Current-Voltage Characteristic for Bipolar p-n Junction Devices with Drift Fields, including Correlation between Carrier Lifetimes and Shallow-Impurity Concentration." *Journal of Applied Physics*. Vol. 53 (No. 12); pp. 8863-8866.
- Lindholm, F.A.; Neugroschel, A.; Sah, C.T. (1983). "Design Principles for High Efficiency Small-Grain Polysilicon Solar Cells, with Supporting Experimental Studies." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 644-647. Available from: IEEE.
- Liu, B-X.; Johnson, W.L.; Nicolet, M.A.; Lau, S.S.; (1-15 May 1983). "Amorphous Film Formation by Ion Mixing in Binary Metal Systems." *Proceedings of the 3rd International Conference on Ion Beam Modifications of Materials; Grenoble, France; 6-10 September 1982*. Appears in: *Nuclear Instruments and Methods*. Vol. 209/210 (Part I); pp. 229-234.
- Liu, B-X.; Johnson, W.L.; Nicolet, M.A.; Lau, S.S. (1 January 1983). "Structural Difference Rule for Amorphous Alloy Formation by Ion Mixing." *Applied Physics Letters*. Vol. 42 (No. 1); pp. 45-47.
- Liu, B-X.; Nicolet, M.A.; Lau, S.S. (September 1982). "Ti-Au Metallic Glasses Formed by Ion Mixing." *Physica Status Solidi (a)*. Vol. 73 (No. 1); pp. 183-188.
- Lorenz, J.H. (February 1983). "The Silicon Challenge." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 5-16.
- Low Cost Solar Array Project Cell, and Module Formation Research Area, Process Research of Non-Cz Silicon Material, Quarterly Report Number 3 for September 1-November 30, 1982*. (1982). DOE/JPL/955909-82/8. Pasadena, CA: Jet Propulsion Laboratory; 33 pp. Work performed by Westinghouse Electric Corporation, Advanced Energy Systems Division, Pittsburgh, PA. Available from: NTIS.
- Lutwack, R. (1983). "Silicon Material Technology Status." *Proceedings of the 18th Intersociety Energy Conversion Engineering Conference; Orlando, FL; 21-26 August 1983*. New York: American Institute of Chemical Engineers; Vol. 4; pp. 1320-1324.
- McCormick, J.R. (February 1983). "The Hemlock Semiconductor Dichlorosilane-Based CVD Process." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 293-304.
- McCormick, J.R.; Plahutnik, F.; Sawyer, D.; Arvidson, A.; Goldfarb, S. (1983). "A Low-Cost Polysilicon Process Based on the Synthesis and Decomposition of Dichlorosilane." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 57-62. Available from: IEEE.
- Maeda, Y.; Yokoyama, T.; Hide, I. (1983). "Polycrystalline Silicon Sheet by the Improved Spinning Method." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; pp. 17-18.
- Maxwell, H.G.; Grimmett, C.A.; Repar, J.; Frioldand, P.O.; Amy, J.A. (15 April 1983). *FSA Field Test Report, 1980-1982*. DOE/JPL-1012-85. Pasadena, CA: Jet Propulsion Laboratory; 88 pp. Available from: NTIS.
- Mayo, W.E.; Lie, H.Y.; Chaudhuri, J. (1983). "X-Ray Topographic Methods and Application to Analysis of Microelectronic Materials." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 49.



- Mokashi, A.R. (September 1982). *Price Estimates for the Production of Wafers from Silicon Ingots*. DOE/JPL-1012-74. Pasadena, CA: Jet Propulsion Laboratory; 23 pp.
- Mon, G.R.; Ross, R.G., Jr. (1983). "Design Solutions for the Solar Cell Interconnect Fatigue Fracture Problem." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1268-1276. Available from: IEEE.
- Moody, J. (1983). "Overview of Bulk Silicon Single Crystal Growth." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 4.
- Morrison, A.D. (1983). "Sheet Silicon Cell/Module Technology." *Proceedings of the 18th Intersociety Energy Conversion Engineering Conference; Orlando, FL; 21-26 August 1983*. New York: American Institute of Chemical Engineers; Vol. 4; pp. 1325-1330.
- Mui, J.Y.P. (15 April 1983). *Investigation of the Hydrochlorination of SiCl<sub>4</sub> — Final Report, Covering the Period July 9, 1981–April 8, 1983*. DOE/JPL-956061-7. Pasadena, CA: Jet Propulsion Laboratory; 101 pp. Work performed by Solarelectronics, Inc., Bellingham, MA.
- Mui, J.Y.P. (18 January 1983). *Flat-Plate Solar Array Project, Advanced-Materials Research Task Quarterly Report: Investigation of the Hydrochlorination of SiCl<sub>4</sub>, Covering the Period October 9, 1982 to January 8, 1983*. DOE/JPL/956061-6. Pasadena, CA: Jet Propulsion Laboratory; 43 pp. Available from: NTIS.
- Mui, J.Y.P. (15 October 1982). *Investigation of the Hydrochlorination of SiCl<sub>4</sub> — Fifth Quarterly Report, July 9–October 8, 1982*. DOE/JPL-956061-5. Pasadena, CA: Jet Propulsion Laboratory; 27 pp. Work performed by Solarelectronics, Inc., Bellingham, MA. Available from: NTIS.
- Natesh, R.; Stringfellow, G.B.; Virkar, A.V.; Dunn, J.; Guyer, T. (February 1983). *Analysis of Defect Structure in Silicon, Characterization of Semix Material; Final Report*. DOE/JPL/955676-4. Pasadena, CA: Jet Propulsion Laboratory; 137 pp. Work performed by Materials Research, Inc., Centerville, UT. Available from: NTIS.
- Neugroschel, A.; Lindholm, F.A. (15 January 1983). "Evidence for Low Density and Mobility of Minority Carriers in Highly Doped Si and Interpretation." *Applied Physics Letters*. Vol. 42 (No. 2); pp. 176-178.
- Neugroschel, A.; Pao, S.C.; Lindholm, F.A. (May 1982). "A Method for Determining Energy Gap Narrowing in Highly Doped Semiconductors." *IEEE Transactions on Electron Devices*. Vol. ED-29 (No. 5); pp. 894-902.
- Nowlan, M.J. (July 1983). *Final Technical Report for: Hermetic Edge Sealing of Photovoltaic Modules*. DOE/JPL/956352-2. Pasadena, CA: Jet Propulsion Laboratory; 29 pp. Work performed by Spire Corporation, Bedford, MA. Available from: NTIS.
- Nowlan, M.J. (February 1983). *Hermetic Edge Sealing of Photovoltaic Modules; Quarterly Technical Report*. DOE/JPL/956352-1. Pasadena, CA: Jet Propulsion Laboratory; 20 pp. Work performed by Spire Corporation, Bedford, MA. Available from: NTIS.
- Olson, M. (February 1983). "Kinetics of Silicon Electrodeposition." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 279-292.
- Oth, D.H.; Ross, R.G., Jr. (1983). "Assessing Photovoltaic Module Degradation and Lifetime from Long Term Environmental Tests." *Environmental Technology — A Key to Product Acceptability; Proceedings of the 29th Institute of Environmental Sciences Annual Technical Meeting; Los Angeles, CA; 19-21 April 1983*. Mt. Prospect, IL: IES; pp. 121-126.
- Paine, R.M.; Nicolet, M.A. (1-15 May 1983). "Shifts of Dilute Pt Impurities in Amorphous Si by Ion Irradiation." *Proceedings of the 3rd International Conference on Ion Beam Modifications of Material; Grenoble, France; 6-10 September 1982*. Appears in: *Nuclear Instruments and Methods*. Vol. 209/210 (Part I); pp. 173-177.
- Parker, J.; Gallagher, B. (1983). "Application of Thermoanalysis to Thick Film Materials Development." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983*. Vol. 83-1. Pennington, NJ: ECS; pp. 352-353 (Abstract No. 223).
- Pettit, D. (February 1983). "Coherent Detection of Scattered Light from Submicron Particles." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 121-124.

- Pettit, D. (February 1983). "Submicron Particle Size Measurement." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 101-106.
- Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. (February 1983). DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; 314 pp.
- Process Research on Non-Cz Silicon Material, Quarterly Report No. 5, March 1, 1983 to May 31, 1983*. (1983). DOE/JPL/955909-83/10. Pasadena, CA: Jet Propulsion Laboratory; 33 pp. Work performed by Westinghouse Electric Corporation, Advanced Energy Systems Division, Pittsburgh, PA. Available from: NTIS.
- Process Research on Non-Cz Silicon Material, Quarterly Report No. 4 for the Period December 1, 1982-February 28, 1983*. (1983). DOE/JPL/955909-83/9. Pasadena, CA: Jet Propulsion Laboratory; 29 pp. Work performed by Westinghouse Electric Corporation, Advanced Energy Systems Division, Pittsburgh, PA. Available from: NTIS.
- Process Research on Non-Cz Silicon Material, Quarterly Report No. 3, September 1, 1982 to November 30, 1982*. (1983). DOE/JPL/955909-82/8. Pasadena, CA: Jet Propulsion Laboratory; 37 pp. Work performed by Westinghouse Electric Corporation, Advanced Energy Systems Division, Pittsburgh, PA. Available from: NTIS.
- Rao, C.V.H.; Cretella, M.C. (1983). "Defects in High Speed Growth of EFG Silicon Ribbon." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; pp. 43-44.
- Ravi, K. (1983). "Overview of Characterization Approaches for High Speed Crystal Growth." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 6.
- Ravishankar, P.S.; Younhouse, L.B. (1983). "Segregation of Impurities in Directional Solidification of Silicon." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; pp. 51.
- Regnault, W.; Yoo, K.C.; Johnson, S. (1983). "Effects of Non-Equilibrium Solidification on the Material Properties of Brick Silicon for Photovoltaics." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; pp. 52.
- Reif, R. (February 1983). "Chemical Vapor Deposition of Epitaxial Silicon." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 253-264.
- Ring, M.A. (February 1983). "Kinetics and Mechanisms of the Silane Decomposition." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 63-74.
- Rohatgi, A.; Davis, J.R.; Hopkins, R.H.; Rai-Choudhury, P. (1983). "Impurities in Polycrystalline Silicon Solar Cells." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 411-416. Available from: IEEE.
- Rosemeir, R.G. (1983). "Real Time X-Ray Diffraction: Applications to Materials Characterization." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; pp. 46-47.
- Sachs, E.M. (1983). "Edge Stabilized Ribbon: Stress Dislocation Density and Electronic Performance." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 24.
- Sanjurjo, A. (February 1983). "Production of Silicon by the Reduction of Silicon Tetrafluoride with Sodium." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 305-316.
- Sarma, K.R. (February 1983). "Mechanisms in Plasma Enhanced Deposition of Silicon." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 241-252.

Schmid, F.; Khattak, C.P. (December 1982). *Silicon Ingot Casting-Heat Exchanger Method (HEM) Multi-Wire Slicing-Fixed Abrasive Slicing Technique (FAST); Phase III-Phase IV; Final Report*. DOE/JPL/954373-81/19. Pasadena, CA: Jet Propulsion Laboratory; 200 pp. Work performed by Crystal Systems, Inc., Salem, MA. Available from: NTIS.

Schwuttke, G. H. (1983). "Crystal Defect Problems." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 327-332. Available from: IEEE.

Schwuttke, G.H. (1983). "Electrical and Structural Characterization of Web-Dendrite." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 45.

Scott, B.A. (February 1983). "The Deposition of Low Defect Density Amorphous Semiconductors by Homogeneous Chemical Vapor Deposition." *Proceedings of the Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 229-240.

Scott, D.M.; Nicolet, M.A. (1-15 May 1983). "The Effects of Implanted Oxygen on Pd<sub>2</sub>Si Formation." *Proceedings of the 3rd International Conference on Ion Beam Modification of Material; Grenoble, France; 6-10 September 1982*. Appears in: *Nuclear Instruments and Methods*. Vol. 209/210 (Part I); pp. 297-301.

Seidensticker, R.G.; Schruben, J.S. (1983). "Control of Thermal Stress in Dendritic Web Growth." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; pp. 32.

Sekerka, R.F. (1983). "Non-Equilibrium Processes in Crystal Growth." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983*. 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 9.

Shepard, N.F., Jr. (1983). "The Design and Development of a Rectangular, Shingle-Type Photovoltaic Module." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 828-833.

Shimada, K. (15 February 1983). *Photovoltaic Research and Development in Japan*. DOE/JPL-1012-80. Pasadena, CA: Jet Propulsion Laboratory; 40 pp. Available from: NTIS.

Shimada, K.; Costogno, E.N. (1983). "Photovoltaics Program, Technical Development and Applications in the U.S.A." *1983 Solar World Congress Extended Abstracts; Perth, Western Australia; 14-19 August 1983*. Edited by S.V. Szokolay. Victoria, Australia: International Solar Energy Society; p. 327. Available from: ISES c/o CSIRO, Victoria, Australia.

Shreter, U.; Fernandez, R.; Nicolet, M.A. (1 August 1983). "Temperature-Dependent Ion Mixing and Diffusion During Sputtering of Thin Films of CrSi<sub>2</sub> on Silicon." *Applied Physics Letters*. Vol. 43 (No. 3); pp. 247-249.

Shyu, C.M.; Cheng, L.J. (1982). "Electronic States Associated with Grain Boundaries in Silicon." *Materials Research Society Symposia Proceedings, Volume 5: Grain Boundaries in Semiconductors; Boston, MA; 16-19 November 1981*. Edited by H.J. Leamy, G.E. Pike, and C.H. Seager. New York: Elsevier-North Holland; pp. 131-136.

Spitzer, M.B. (June 1983). *Evaluation of the Ion Implantation Process for Production of Solar Cells from Silicon Sheet Materials, Quarterly Technical Report No. 2 for April 1-July 1, 1983*. DOE/JPL/956381-83/2. Pasadena, CA: Jet Propulsion Laboratory; 15 pp. Work performed by Spire Corporation, Bedford, MA.

Spitzer, M.B. (April 1983). *Evaluation of the Ion-Implantation Process for Production of Solar Cells from Silicon Sheet Materials, Quarterly Report No. 1 for Period Covering 1 January-1 April 1983*. DOE/JPL/956381-1. Pasadena, CA: Jet Propulsion Laboratory; 13 pp. Work performed by Spire Corporation, Bedford, MA. Available from: NTIS.

Steinwandel, J. (February 1983). "Homogeneous Gas-Phase Condensation of Silicon by Shock Wave Induced Decomposition of SiH<sub>4</sub>." *Proceedings of Flat-Plate Solar-Array Workshop on the Science of Silicon-Material Preparation; Phoenix, AZ; 23-25 August 1982*. DOE/JPL-1012-81. Pasadena, CA: Jet Propulsion Laboratory; pp. 79-88.

*Stress Studies in EFG, Third Quarterly Progress Report for January 1-March 31, 1983*. (15 April 1983). DOE/JPL/956312-83/03. Pasadena, CA: Jet Propulsion Laboratory; 40 pp. Work performed by Mobil Solar Energy Corporation, Waltham, MA. Available from: NTIS.

*Stress Studies in EFG, Second Quarterly Progress Report for the Period October 1-December 31, 1982.* (15 February 1983). DOE/JPL/956312-83/02. Pasadena, CA: Jet Propulsion Laboratory; 18 pp. Work performed by Mobil Solar Energy Corporation, Waltham, MA. Available from: NTIS.

Sullivan, T.; Ast, D.G. (May 1983). *EBIC Investigation of Hydrogenation of Crystal Defects in EFG Solar Silicon Ribbons, Quarterly Report, January 1-March 31, 1983.* DOE/JPL/956046-83/5. Pasadena, CA: Jet Propulsion Laboratory; 91 pp. Work performed by Cornell University, Department of Materials Science and Engineering, Ithaca, NY.

*Summary of Flat-Plate Solar Array Project Documentation; Abstracts of Published Documents, 1975 to June 1982.* (15 September 1982). DOE/JPL-1012-76. Pasadena, CA: Jet Propulsion Laboratory; 395 pp. Available from: NTIS.

Tarneja, K.S.; Campbell, R.B.; Alexander, P. (1983). "Investigation of Liquid Dopants for High Efficiency Solar Cell Production Using Dendritic Web Material." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983.* Vol. 83-1. Pennington, NJ: ECS; p. 798 (Abstract No. 529)

Trenchard, S.E.; Royal, E.; Anderson, R.T. (1983). "Development of a Photovoltaic Module Qualification Test Based on Combined-Environment Accelerated Stress Data." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 1030-1035. Available from: IEEE.

Trivedi, R.; Somboonsuk, K. (1983). "The Effect of Growth Rate on Interface Morphology." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983.* 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 14.

Vasquez, R.P.; Lewis, B.F.; Grunthaner, F.J. (July-September 1983). "Cleaning Chemistry of GaAs(100) and InSb(100) Substrates for Molecular Beam Epitaxy." *Proceedings of the 10th Annual Conference on the Physics and Chemistry of Semiconductor Interfaces; Santa Fe, NM; 25-27 January 1983.* Appears in: *Journal of Vacuum Science & Technology B.* Vol. 1 (No. 3); pp. 791-794.

Vaudin, M.D.; Cunningham, B.; Ast, D.G. (February 1983). "The Structure of Second Order and Third Order Twin Boundaries in Silicon." *Scripta Metallurgica.* Vol. 17 (No. 2); pp. 191-198.

Wargo, M.J. (1983). "Maximization of Growth Rates During Czochralski Pulling." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983.* 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 50.

White, C.W. (1983). "Nonequilibrium Crystal Growth During Laser Annealing of Silicon." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983.* 5101-234. Pasadena, CA: Jet Propulsion Laboratory; p. 37.

Wilcox, W. (1983). "Use of the Burton-Prim-Slichter Equation at High Growth Rates." *High-Speed Growth and Characterization of Crystals for Solar Cells Research Forum; General Information Agenda, Authors Abstracts; Port St. Lucie, FL; 25-27 July 1983.* 5101-234. Pasadena, CA: Jet Propulsion Laboratory; pp. 11-12.

Willis, P.B.; Baum, B. (July 1982). *Investigation of Test Methods, Material Properties, and Processes for Solar Cell Encapsulants.* DOE/JPL/954527-82/23. Pasadena, CA: Jet Propulsion Laboratory; 138 pp. Work performed by Springborn Laboratories, Inc., Enfield, CT. Available from: NTIS.

Wohlgemuth, J.H. (1982). *A Module Experimental Process System Development Unit (MEPSDU).* DOE/JPL/955902-82/7. Pasadena, CA: Jet Propulsion Laboratory; 140 pp. Work performed by Solarex Corporation, Rockville, MD. Available from: NTIS.

Wohlgemuth, J.H.; Culik, J.S.; Alexander, P. (1983). "Mechanisms Limiting Performance in Polycrystalline Silicon Solar Cells." *163rd Electrochemical Society Meeting Extended Abstracts; San Francisco, CA; 8-13 May 1983.* Vol. 83-1. Pennington, NJ: ECS; pp. 346-347 (Abstract No. 219).

Wolf, M. (1983). "Bill Cherry: Example of a Career Devoted to Solar Energy." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 1-5. Available from: IEEE.

Wolf, M. (1983). "How Will We Get to 20% (AM1) Efficient Si Solar Cells?" *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 355-360. Available from: IEEE.

Wolf, M. (1982). "New Silicon Cell Design Concepts for Greater Than 20 Percent AM1 Efficiency." *Space Photovoltaic Research and Technology 1982: High Efficiency, Radiation Damage, and Blanket Technology*; Cleveland, OH; 20-22 April 1982. NASA CP 2256. Cleveland, OH: NASA Scientific and Technical Information Office; pp. 5-12.

Wolf, M. (30 April 1982). *Analysis and Evaluation in the Production Process and Equipment Area of the Low-Cost Solar Array Project; Final Report*. DOE/JPL/956034-81/1. Pasadena, CA: Jet Propulsion Laboratory; 61 pp. Work performed by University of Pennsylvania, The Moore School of Electrical Engineering, Philadelphia, PA. Available from: NTIS.

Zhao, T-X.; Daniels, R.R.; Katnani, A.D.; Maragaritondo, G.; Zunger, A. (July-September 1983). "Schottky Barrier Formation and the Initial Metal-Atom Bonding State: InP(110)-Al vs GaAs(110)-Al." *Proceedings of the 10th Annual Conference on the Physics and Chemistry of Semiconductor Interfaces*; Santa Fe, NM; 25-27 January 1983. Appears in: *Journal of Vacuum Science & Technology B*. Vol. 1 (No. 3); pp. 791-794.

# Sandia National Laboratories

*Automated Installation Methods for Photovoltaic Arrays.* (November 1982). SAND 81-7192. Albuquerque, NM: Sandia National Laboratories; 232 pp. Work performed by Burt Hill Kosar Rittelmann Associates, Research and Solar Applications Division, Butler, PA. Available from: NTIS.

Boes, E.C. (1983). "Photovoltaic Concentrator Progress." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp 702-712. Available from: IEEE.

Bonk, G.J.; Jones, G.J.; Thomas, M.G. (August 1983). *The Effects of Future Energy Scenarios on Photovoltaic Energy Value.* SAND83-1283. Albuquerque, NM: Sandia National Laboratories; 96 pp. Work performed by General Electric Company, Electric Utility Systems Engineering Department, Schenectady, NY and Sandia National Laboratories. Available from: NTIS.

Broadbent, S.; et al. (December 1982). *Second Generation Photovoltaic Concentrator Array Design.* SAND82-7133. Albuquerque, NM: Sandia National Laboratories; 293 pp. Work performed by Martin Marietta Corporation, Denver, CO. Available from: NTIS.

Burgess, E.L., ed. (March 1983). *A Bibliography of Reports by the Sandia Photovoltaic Projects.* SAND81-0135 Revision 2. Albuquerque, NM: Sandia National Laboratories; 64 pp. Available from: NTIS.

Burgess, E.L.; Biringer, K.L. (1983). "Design and Installation Experiences from Nine Intermediate-Sized Photovoltaic Systems: A Critical Analysis." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 1189-1197. Available from: IEEE.

Burgess, E.L.; Post, H.N.; Key, T.S. (1982). "Subsystem Engineering and Development of Grid-Connected Photovoltaic Systems." *Fourth EC Photovoltaic Solar Energy Conference; Proceedings of the International Conference; Stresa, Italy, 10-14 May 1982.* Edited by W.H. Bloss and G. Grassi. Boston, MA: D. Reidel Publishing Company; pp. 238-247.

Carmichael, D.C.; Alexander, G.; Noel, G.T.; Scurlock, L.D.; Huss, W.R.; Stickford, G.H. (August 1983). *Development of a Building Block Design for Modular Photovoltaic Concentrator Array Fields.* SAND82-7069. Albuquerque, NM: Sandia National Laboratories; 211 pp. Work performed by Battelle Columbus Laboratories, Columbus, OH. Available from: NTIS.

Carmichael, D.C.; Alexander, G.; Noel, G.T.; Smith, R.W.; Huss, W.R. (November 1982). *Development of a Standard Modular Design for Low-Cost Flat-Panel Photovoltaic Array Fields.* SAND81-7183. Albuquerque, NM: Sandia National Laboratories; 179 pp. Work performed by Battelle Columbus Laboratories, Columbus, OH. Available from: NTIS.

Chu, D.; Key, T.; Fitzer, J. (1983). "Utility Interface Issues for Grid-Connected Photovoltaic Systems." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 391-395. Available from: IEEE.

Cluff, C.B.; Call, R.L. (December 1982). *Hybrid Azimuth-Tracking Intermediate Photovoltaic Concentrator System.* SAND 82-7158. Albuquerque, NM: Sandia National Laboratories; 39 pp. Work performed by University of Arizona, Tucson, AZ. Available from: NTIS.

*Concentrator Receiver Encapsulant Evaluation.* (February 1983). SAND82-7146. Albuquerque, NM: Sandia National Laboratories; 26 pp. Work performed by Applied Solar Energy Corporation, City of Industry, CA. Available from: NTIS.

*Design and Development of Low Cost Photovoltaic Concentrator Modules.* (November 1983). SAND83-7022. Albuquerque, NM: Sandia National Laboratories; 46 pp. Work performed by Applied Solar Energy Corporation, City of Industry, CA. Available from: NTIS.

*Design and Fabrication of a Low-Cost Two-Axis Solar Tracking Structure for Photovoltaic Concentrator Arrays.* (May 1983). SAND82-7150. Albuquerque, NM: Sandia National Laboratories; 325 pp. Work performed by Martin Marietta Aerospace, Denver, CO. Available from: NTIS.

Dudley, V. E.; Workhoven, R. M. (1982). *Variation of Collector Efficiency and Receiver Thermal Loss as a Function of Solar Irradiance.* SAND82-0163C. Albuquerque, NM: Sandia National Laboratories; 13 pp.

- Dudley, Workhoven, R.M. (November 1982). *Performance Testing of the Solar Kinetics T-700A Solar Collector*. (November 1982). SAND81-0984. Albuquerque, NM: Sandia National Laboratories; 96 pp. Available from: NTIS.
- Edenburn, M.W.; Gerwin, H.J.; Chiang, C.J. (1983). "Test Data Analysis and Results for Concentrating Photovoltaic Modules." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 669-674. Available from: IEEE.
- Franklin, H.A. (April 1983). *Integrated Structure Designs for Photovoltaic Arrays*. SAND81-7191. Albuquerque, NM: Sandia National Laboratories; 256 pp. Work performed by Bechtel Group, Inc., Research and Engineering Operation, San Francisco, CA. Available from: NTIS.
- Gerwin, H.J. (1982). "Photovoltaic Concentrator Module Characterization." *Fourth EC Photovoltaic Solar Energy Conference; Proceedings of the International Conference; Stresa, Italy; 10-14 May 1982*. Edited by W.H. Bloss and G. Grassi. Boston, MA: D. Reidel Publishing Company; pp. 222-226.
- Gerwin, H.J.; Rogers, C.B.; Beavis, L.C. (1983). "Sandia Concentrator Array Testing Experiences." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference -- 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1252-1255. Available from: IEEE.
- Ginley, D.S.; Baughman, R.J.; Butler, M.A. (October 1983). "BP — Stabilized n-Si and n-GaAs Photoanodes." *Journal of the Electrochemical Society*. Vol. 130 (No. 10); pp. 1999-2002.
- Hill, M.J. (January 1983). *A Capacitive Load and Data Acquisition System for Photovoltaic Array Testing*. SAND82-2547. Albuquerque, NM: Sandia National Laboratories; 26 pp. Available from: NTIS.
- Hodge, R.C. (1982). *Design and Development of a High-Concentration Photovoltaic Concentrator*. SAND81-7007. Albuquerque, NM: Sandia National Laboratories; 112 pp. Work performed by General Electric Company, Advanced Energy Programs Department, Philadelphia, PA. Available from: NTIS.
- Hodge, R.C. (December 1982). *Design and Development of a Laminated Fresnel Lens for Point Focus PV Systems — Phase II*. SAND82-7127. Albuquerque, NM: Sandia National Laboratories; 70 pp. Work performed by General Electric Company, Advanced Energy Programs Department, King of Prussia, PA. Available from: NTIS.
- Holmes, J.T. (1982). *High Temperature Materials Experience at the Central Receiver Test Facility*. SAND82-0263C. Albuquerque, NM: Sandia National Laboratories; 14 pp. Available from: NTIS.
- Intermediate Photovoltaic System Application Experiment Operational Performance Report for BDM Office Building, Albuquerque, NM for November 1982–March 1983*. (August 1983). SAND81-7082. Albuquerque, NM: Sandia National Laboratories; 131 pp. Work performed by Boeing Computer Services, Co., Seattle, WA. Available from: NTIS.
- Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 16 for Beverly High School, Beverly MA for December 1982*. (February 1983). SAND81-7088/16. Albuquerque, NM: Sandia National Laboratories; 30 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.
- Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 15 for Beverly High School, Beverly, MA for November 1982*. (February 1983). SAND81-7088/15. Albuquerque, NM: Sandia National Laboratories; 32 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.
- Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 14 for Beverly High School, Beverly MA for October 1982*. (February 1983). SAND81-7088/14. Albuquerque, NM: Sandia National Laboratories; 131 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.
- Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 13 for Beverly High School, Beverly, Massachusetts for September 1982*. (January 1983). SAND81-7088/13. Albuquerque, NM: Sandia National Laboratories; 31 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.
- Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 12 for Beverly High School, Beverly, MA for August 1982*. (January 1983). SAND81-7088/12. Albuquerque, NM: Sandia National Laboratories; 29 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 11 for Beverly High School, Beverly, MA for July 1982. (January 1983). SAND81-7088/11. Albuquerque, NM: Sandia National Laboratories; 33 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 10 for Beverly High School, Beverly, MA for June 1982. (January 1983). SAND81-7088/10. Albuquerque, NM: Sandia National Laboratories; 37 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for CDC Light Manufacturing Bldg., San Bernardino, California for December 1982. (March 1983). SAND81-7089/10. Albuquerque, NM: Sandia National Laboratories; 27 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 9 for CDC Light Manufacturing Bldg., San Bernardino, California for November 1982. (March 1983). SAND81-7089/9. Albuquerque, NM: Sandia National Laboratories; 28 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 8 for CDC Light Manufacturing Bldg., San Bernardino, California for October 1982. (March 1983). SAND81-7089/8. Albuquerque, NM: Sandia National Laboratories; 27 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for CDC Light Manufacturing Bldg., San Bernardino, California for September 1982. (March 1983). SAND81-7089/7. Albuquerque, NM: Sandia National Laboratories; 28 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for CDC Light Manufacturing Bldg., San Bernardino, California for July 1982. (November 1982). SAND81-7089/5. Albuquerque, NM: Sandia National Laboratories; 24 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 4 for CDC Light Manufacturing Bldg., San Bernardino, CA. (October 1982). SAND81-7089/4. Albuquerque, NM: Sandia National Laboratories; 23 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 2 for Dallas-Fort Worth Regional Airport, TX for August 1982. (December 1982). SAND81-7083/2. Albuquerque, NM: Sandia National Laboratories; 28 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for Dallas-Fort Worth Regional Airport, Texas for July 1982. (November 1982). SAND81-7083/1. Albuquerque, NM: Sandia National Laboratories; 27 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 9 for G.N. Wilcox Memorial Hospital, Kauai, HI for January 1983. (June 1983). SAND81-7080/9. Albuquerque, NM: Sandia National Laboratories; 38 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 8 for G.N. Wilcox Memorial Hospital, Kauai, HI for December 1982. (March 1983). SAND81-7080/8. Albuquerque, NM: Sandia National Laboratories; 31 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 7 for G.N. Wilcox Memorial Hospital, Kauai, HI for November 1982. (January 1983). SAND81-7080/7. Albuquerque, NM: Sandia National Laboratories; 28 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*



*Intermediate Photovoltaic System Application Experiment Operational Performance Report for G.N. Wilcox Memorial Hospital, Kauai, Hawaii for October 1982.* (January 1983). SAND81-7080/6. Albuquerque, NM: Sandia National Laboratories; 28 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 5 for G.N. Wilcox Memorial Hospital, Kauai, HI for September 1982.* (January 1983). SAND81-7080/5. Albuquerque, NM: Sandia National Laboratories; 28 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for G.N. Wilcox Memorial Hospital, Kauai, Hawaii for June, July, and August 1982.* (December 1982). SAND81-7080/4. Albuquerque, NM: Sandia National Laboratories; 74 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 3 for G.N. Wilcox Memorial Hospital, Kauai, HI.* (September 1982). SAND81-7080/3. Albuquerque, NM: Sandia National Laboratories; 30 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for G. N. Wilcox Memorial Hospital, Kauai, HI.* (October 1982). SAND81-7080/2. Albuquerque, NM: Sandia National Laboratories; 51 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 20 for Lovington Square Shopping Center, Lovington, NM for February-March 1983.* (August 1983). SAND81-7085/20. Albuquerque, NM: Sandia National Laboratories; 50 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 19 for Lovington Square Shopping Center, Lovington, NM for January 1983.* (June 1983). SAND81-7085/19. Albuquerque, NM: Sandia National Laboratories; 30 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 18 for Lovington Square Shopping Center, Lovington, NM for December 1982.* (March 1983). SAND81-7085/18. Albuquerque, NM: Sandia National Laboratories; 32 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 17 for Lovington Square Shopping Center, Lovington, NM for November 1982.* (January 1983). SAND81-7085/17. Albuquerque, NM: Sandia National Laboratories; 27 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for Lovington Square Shopping Center, Lovington, New Mexico for October 1982.* (January 1983). SAND81-7085/16. Albuquerque, NM: Sandia National Laboratories; 26 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for Lovington Square Shopping Center, Lovington, New Mexico for September 1982.* (January 1983). SAND81-7085/15. Albuquerque, NM: Sandia National Laboratories; 26 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for Lovington Square Shopping Center, Lovington, New Mexico for July and August 1982.* (December 1982). SAND81-7085/14. Albuquerque, NM: Sandia National Laboratories; 48 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for Mississippi County Community College, Blytheville, AR, for April 1982.* (January 1983). SAND81-7091/2. Albuquerque, NM: Sandia National Laboratories; 29 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 20 for Newman Power Station, El Paso, TX for February-March 1983.* (August 1983). SAND81-7086/20. Albuquerque, NM: Sandia National Laboratories; 45 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 19 for Newman Power Station, El Paso, TX for January 1983. (June 1983). SAND81-7086/19. Albuquerque, NM: Sandia National Laboratories; 26 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 18 for Newman Power Station, El Paso, TX for December 1982. (March 1983). SAND81-7086/18. Albuquerque, NM: Sandia National Laboratories; 28 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 17 for Newman Power Station, El Paso, TX for November 1982. (January 1983). SAND81-7086/17. Albuquerque, NM: Sandia National Laboratories; 23 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 16 for Newman Power Station, El Paso, TX for October 1982. (January 1983). SAND81-7086/16. Albuquerque, NM: Sandia National Laboratories; 24 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 15 for Newman Power Station, El Paso, TX for September 1982. (January 1983). SAND81-7086/15. Albuquerque, NM: Sandia National Laboratories; 30 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for Newman Power Station, El Paso, Texas for July and August 1982. (January 1983). SAND81-7086/14. Albuquerque, NM: Sandia National Laboratories; 47 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 10 for Oklahoma Center for Science and Arts, Oklahoma City, OK for February-March 1983. (August 1983). SAND81-7087/10. Albuquerque, NM: Sandia National Laboratories; 57 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 9 for Oklahoma Center for Science and Arts, Oklahoma City, OK for January 1983. (June 1983). SAND81-7087/9. Albuquerque, NM: Sandia National Laboratories; 52 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for Oklahoma Center for Science and Arts, Oklahoma City, Oklahoma for December 1982. (March 1983). SAND81-7087/8. Albuquerque, NM: Sandia National Laboratories; 28 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 7 for Oklahoma Center for Science and Arts, Oklahoma City, OK for November 1982. (January 1983). SAND81-7087/7. Albuquerque, NM: Sandia National Laboratories; 25 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for Oklahoma Center for Science and Arts for October 1982. (December 1982). SAND81-7087/6. Albuquerque, NM: Sandia National Laboratories; 30 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for Oklahoma Center for Science and Arts for September 1982. (January 1983). SAND81-7087/5. Albuquerque, NM: Sandia National Laboratories; 30 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 4 for Oklahoma Center for Science and Arts, Oklahoma City, OK. (November 1982). SAND81-7087/4. Albuquerque, NM: Sandia National Laboratories; 70 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.*

*Intermediate Photovoltaic System Application Experiment Operational Performance Report for Oklahoma Center for Science and Arts.* (October 1982). SAND81-7087/3. Albuquerque, NM: Sandia National Laboratories; 45 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 2 for Sky Harbor Airport Project, Phoenix, AZ for January-March 1983.* (August 1983). SAND81-7081/2. Albuquerque, NM: Sandia National Laboratories; 86 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

*Intermediate Photovoltaic System Application Experiment Operational Performance Report; Volume 1 for Sky Harbor Airport Project, Phoenix, AZ for June-December 1982.* (August 1983). SAND81-7081/1. Albuquerque, NM: Sandia National Laboratories; 227 pp. Work performed by Boeing Computer Services Co., Seattle, WA. Available from: NTIS.

Jackson, J.L. (1982). "Photovoltaic Retrofit Feasibility in the United States." *Fourth EC Photovoltaic Solar Energy Conference; Proceedings of the International Conference, Stresa, Italy; 10-14 May 1982.* Edited by W.H. Bloss and G. Grassi. Boston, MA: D. Reidel Publishing Company; pp. 101-105.

Jones, G., ed. (March 1983). *Fourth Photovoltaic Systems Definition and Applications Projects Integration Meeting; Albuquerque, NM; 12-14 April 1983.* SAND83-0603. Albuquerque, NM: Sandia National Laboratories; 271 pp. Available from: NTIS.

Jones, G.J. (1983). "The Value of Tracking for Flat-Panel Photovoltaic Collectors." *Proceedings of the 1983 American Solar Energy Society Meeting: Progress in Solar Energy; Minneapolis, MN; 1-3 June 1983.* Boulder, CO: ASES; pp. 953-958.

Jones, G.J. (April 1983). *Energy Production Trade-Offs in Photovoltaic System Design.* SAND82-2239. Albuquerque, NM: Sandia National Laboratories; 10 pp. Available from: NTIS.

Jones, G.J. (1982). *Photovoltaic System Design in Grid-Connected Applications.* SAND82-0923C. Albuquerque, NM: Sandia National Laboratories; 4 pp. Available from: NTIS.

Jones, G.J.; Biringer, K.L. (1983). "Residential Photovoltaic Systems: Results and Issues." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 253-256. Available from: IEEE.

Jones, G.J.; Bonk, G.J. (1983). "Future Contingencies and Photovoltaic System Worth." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 955-960. Available from: IEEE.

Jones, G.J.; Thomas, M.J. (August/September 1983). "Grid Connected PV Systems: Are They Worth It?" *Photovoltaics International.* Vol. 1 (No. 3); pp. 26-29.

Key, T.S. (1983). *Evaluation of Grid-Connected Inverter Power Systems: The Utility Interface.* SAND83-1492C. Albuquerque, NM: Sandia National Laboratories; 8 pp. Presented at the IEEE Industrial Applications Society Annual Meeting; Mexico City, Mexico; October 1983. Available from: NTIS.

Key, T.S.; Klein, J.W. (1983). "Residential Photovoltaic Power Conditioning Technology for Grid-Corrected Applications." *The Conference Record of the Sixteenth IEEE Photovoltaics Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 1456-1458. Available from: IEEE

Kingston, K. (November 1982). *Advanced Concentrator Cell Mount Analysis: Final Report.* SAND82-7119. Albuquerque, NM: Sandia National Laboratories; 184 pp. Work performed by Motorola, Government Electronics Division, Scottsdale, AZ. Available from: NTIS.

Kirsch, P.A. (December 1982). *Development and Fabrication of Solar Collector SMC Reflector Assemblies.* SAND82-7109. Albuquerque, NM: Sandia National Laboratories; 39 pp. Work performed by The Budd Company, Technical Center, Fort Washington, PA. Available from: NTIS.

Klein, J.W.; Key, T.S. (1983). "Intermediate Power Conditioners: Where Are We Now?" *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 1454-1455. Available from: IEEE.

Kull, J.; Maraschin, R.; Rafinejad, D.; Spencer, R.; Sutton, G. (August 1983). *Linear Fresnel Lens Photovoltaic Concentrator Program.* SAND83-7020. Albuquerque, NM: Sandia National Laboratories; 140 pp. Work performed by Acurex Corporation, Mountain View, CA. Available from: NTIS.

Larson, D.L. (March 1983). *Coolidge Solar Irrigation Project — FY 1982 Monthly Technical Reports*. SAND82-7155. Albuquerque, NM: Sandia National Laboratories; 104 pp. Work performed by University of Arizona, Soils, Waters, and Engineering Department, Tucson, AZ. Available from: NTIS.

McDanal, A.J.; O'Neill, M.J.; Waller, R.A. (1983). "Performance Analysis of a Third-Generation Linear Fresnel Lens Passively Cooled Photovoltaic Collector." *Proceedings of the 1983 American Solar Energy Society Meeting: Progress in Solar Energy; Minneapolis, MN; 1-3 June 1983*. Boulder, CO: ASES; Volume 6; pp. 495-500.

McDanal, A.J.; O'Neill, M.J.; Waller, R.A. (1982). "Development of a Passively Cooled Linear Fresnel Lens Photovoltaic Concentrator Module." *Proceedings of the 1982 Annual Meeting of the American Solar Energy Society: Progress in Solar Energy — The Renewable Challenge*. Edited by Barbara H. Glenn and William A. Kolar. New York: ASES Publishing Office; pp. 281-286.

Maish, A.B. (1983). "Design and Economics of a Photovoltaic Concentrator Array for Off-Grid Applications." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982*. 82CH1821-8. New York: IEEE Publishing Service; pp. 1362-1367. Available from: IEEE.

Marshall, L.S. (August 1983). *Cell-Substrate Bonding System Design and Development*. SAND83-7021. Albuquerque, NM: Sandia National Laboratories; 99 pp. Work performed by Martin Marietta Corporation, Solar Energy Systems, Denver, CO. Available from: NTIS.

Morris, V.L. (November 1982). *Environmental Degradation of Solar Optical Materials: Volume 1. Literature Survey*. SAND82-7068/1. Albuquerque, NM: Sandia National Laboratories; 126 pp. Work performed by McDonnell Douglas Astronautics Company, Huntington Beach, CA.

Muller, T.; Maraschin, R. (November 1982). *Novel Approaches for Low-Cost Photovoltaic Concentrators; Final Report for the Period January 1978 through July 1980*. SAND82-7125. Albuquerque, NM: Sandia National Laboratories; 162 pp. Work performed by Acurex Corporation, Mountain View, CA. Available from: NTIS.

Naff, G.J. (March 1983). *Photovoltaic Array Field Optimization and Modularity Study*. SAND81-7193. Albuquerque, NM: Sandia National Laboratories; 328 pp. Work performed by Hughes Aircraft Company, Los Angeles, CA. Available from: NTIS.

Palmer, R.S.; Penasa, D.A.; Thomas, M.G. (April 1983). *Detailed Cost Estimate of Reference Residential Photovoltaic Designs*. SAND83-0504. Albuquerque, NM: Sandia National Laboratories; 37 pp. Available from: NTIS.

Pesse, R.L.; Barnum, J.R.; Vulliet, W.V.; van Lin, V.A.J.; Wrobel, T.F. (1982). *Silicon-Solar-Cell Damage from Electrical Overstress*. SAND82-7072C. Albuquerque, NM: Sandia Laboratories; 45 pp. Work performed by Mission Research Corporation, Albuquerque, NM and San Diego, CA.

Picraux, S.T.; Biefeld, R.M.; Dawson, L.R.; Osbourn, G.C.; Chu, W.K. (July-September 1983). "Summary Abstract: Structural Studies of InGaAs/GaAs and GaAsP/GaP Strained-Layer Superlattices by Ion Channeling." *Proceedings of the 10th Annual Conference on the Physics and Chemistry of Semiconductor Interfaces, Santa Fe, NM; 25-27 January 1983*. Appears in: *Journal of Vacuum Science & Technology B*. Vol. 1 (No. 3); p. 687.

Post, H.N.; Burgess, E.L. (1983). *New Designs and Installations of Photovoltaic-Array Fields with Low Balance-of-System Costs*. SAND83-0155C. Albuquerque, NM: Sandia National Laboratories; 18 pp. Available from: NTIS.

Post, H.N.; Carmichael, D.C.; Castle, J.A. (1982). "Low Cost Modular Designs for Photovoltaic Array Fields." *Fourth EC Photovoltaic Solar Energy Conference; Proceedings of the International Conference; Stresa, Italy; 10-14 May 1982*. Edited by W.H. Bloss and G. Grassi. Boston, MA: D. Reidel Publishing Company. pp. 275-279.

Ronney, K.; Aerni, E. (February 1983). *500-Watt Commercialized Concentrator System*. SAND82-7154. Albuquerque, NM: Sandia National Laboratories; 75 pp. Work performed by Soectrolab, Sylmar, CA. Available from: NTIS.

Stember, L.H.; Huss, W.R. (January 1983). *User's Guide to SOLREL: A Simulation of Reliability and Availability of Photovoltaic Systems*. SAND82-7152. Albuquerque, NM: Sandia National Laboratories; 100 pp. Work performed by Battelle Columbus Laboratories, Columbus, OH. Available from: NTIS.

Stember, L.H.; Huss, W.R.; Bridgman, M.S. (November 1982). *Reliability-Economics Analysis Models for Photovoltaic Power Systems*. SAND82-7126. Albuquerque, NM: Sandia National Laboratories; 2 vols. Work performed by Battelle Columbus Laboratories, Columbus, OH. Available from: NTIS.

*20-Kilowatt El Paso Photovoltaic System; Phase III. Initial Operation. January 27, 1981, through April 23, 1982. (May 1982)*. DOE/ET/17093-T7. Washington, DC: U.S. Department of Energy; 72 pp. Work performed by New Mexico State University, New Mexico Solar Energy Research Institute, Las Cruces, NM and El Paso Electric Company, El Paso, TX. Available from: NTIS.

Wabrek, R.; Whitaker, C.; Hastings, R.; Schaefer, J. (1983). "Comparison of Predicted and Measured Energy Production for Eight Residential Photovoltaic Prototypes." *Proceedings of the 1983 American Solar Energy Society Meeting: Progress in Solar Energy; Minneapolis, MN; 1-3 June 1983*. Boulder, CO: ASES; pp. 959-964.

Wasynesuk, O. (1982). *Dynamic Behavior of a Class of Photovoltaic Converters*. SAND82-7075C. Albuquerque, NM: Sandia National Laboratories; 30 pp. Available from: NTIS.

Wiley, J.D.; Perepezko, J.H.; Nordman, J.E. (April 1983). *Annealing Studies of Amorphous Alloys*. SAND82-7156. Albuquerque, NM: Sandia National Laboratories; 30 pp. Work performed by The University of Wisconsin, Madison, WI. Available from: NTIS.



# NASA Lewis Research Center

Brainard, W. (1983). "The Worldwide Market for Photovoltaics in the Rural Sector." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 1308-1313. Available from: IEEE.

Cull, R.C.; Eltimsahy, A.H. (1983). "Investigation of Energy Management Strategies for Photovoltaic Systems — An Analysis Technique." *The Conference Record of the Sixteenth IEEE Photovoltaic Specialists Conference — 1982; San Diego, CA; 27-30 September 1982.* 82CH1821-8. New York: IEEE Publishing Service; pp. 270-275. Available from: IEEE.

Rosenblum, L. (1983). "Status of Flat-Plate Photovoltaic Systems for Applications in Developing Countries." *Solar Energy*. Vol. 31 (No. 4); pp. 381-392.

# Brookhaven National Laboratory

Moskowitz, P.D.; Coveney, E.A.; Rabinowitz, S.; Barancik, J.I. (September 1983). "Rooftop Photovoltaic Arrays: Electric Shock and Fire Health Hazards." *Solar Cells*. Vol. 9 (No. 4); pp. 327-336.

# Oak Ridge National Laboratory

Kaplan, S.I. (1982). "Startup Experience with a Concentrating Photovoltaic Power System." *AIAA 20th Aerospace Sciences Meeting; Orlando, FL; 11-14 January 1982.* Paper No. AIAA-82-0068. New York: American Institute of Aeronautics and Astronautics. Available from: AIAA.

Kaplan, S.I. (December 1982). *Evaluation of Mississippi County Community College and Northwest Mississippi Junior College Solar-Power Systems.* ORNL/TM-8396. Oak Ridge, TN: Oak Ridge National Laboratory; 40 pp.

Smith, H.V. (1982). "The Mississippi County Community College Large-Scale Demonstration Project — A Success Story." *Fourth EC Photovoltaic Solar Energy Conference; Proceedings of the International Conference; Stresa, Italy; 10-14 May 1982.* Edited by W.H. Bloss and G. Grassi. Boston, MA: D. Reidel Publishing Company; pp. 94-96.

# DOE Albuquerque Operations Office

*Airport Solar Photovoltaic Concentrator. Phase III.* DOE/ET/20624-T4. Washington, D.C.: U.S. Department of Energy; 22 pp. Work performed by Arizona Public Service Company, Phoenix, AZ.

Russell, M.C. (January 1983). *Photovoltaic-System Evaluation at the Northeast Residential Experiment Station; November 1980 — May 1982; Final Report.* DOE/ET/20279-219. Washington, D.C.: U.S. Department of Energy; 163 pp. Work performed by Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, MA.

*20-Kilowatt El Paso Photovoltaic System; Phase III, Initial Operation, January 27, 1981, through April 23, 1982. (May 1982).* DOE/ET/17093-T7. Washington, D.C.: U.S. Department of Energy; 72 pp. Work performed by New Mexico State University, New Mexico Solar Energy Research Institute, Las Cruces, NM and El Paso Electric Company, El Paso, TX.