N76 12485

GLASS-Si HETEROJUNCTION SOLAR CELLS

The objective of this program is the development of a low temperature, low-cost process to combine a wide band gap top surface material with silicon to form a heterojunction solar cell. The top material, in addition to forming a junction, provides an optically transparent window, low resistance contact, and an optical match for low reflectivity. The requirements for an overall low-cost array require, in addition to a low-cost process, a low cost substrate material such as polycrystalline silicon.

Progress during this six month period is best indicated by the achievement of an increase in efficiency on polycrystal silicon from an initial 2% to over 7% (as measured both at INNOTECH and NASA-Lewis facilities). The cells were produced in the 2 cm by 2 cm and 1 cm by 1cm size, with top-side grid metallization. The polycrystalline silicon has crystal grains varying from 5μm to 5mm. The junction is an n+/n heterojunction between an SnO_2-based glass and the polycrystalline silicon. Voltages of up to 475mV were measured under open circuit conditions.

For single crystal substrates, efficiencies very close to 10% were measured. These cells had the same structure as the polycrystalline cells described above. Open-circuit voltages as high as 529mV were measured.

Short-circuit current density for single crystal approaches $30mA/cm^2$ for the polycrystalline units; the short-circuit is about 90% of the short-current measured for the single crystal units. We believe this demonstrates the potential of solar cells using polycrystalline materials to achieve 90% of the efficiency of a non-textured single-crystal solar cell.

The cells are n+-type SnO_2 based glass on an n-type silicon forming an n+/n junction. Theoretical investigation of the current generation model and barrier layer model is underway. The built-in voltage and the resulting open-circuit voltage is process dependent.

Work on p+/n heterojunction using In_2O_3-based glass resulted in cells of 3% efficiency on polycrystalline material and 4% efficiency on single crystal material. Values of 337 mV were achieved for open-circuit voltage. This low voltage is the main limit for high efficiencies.

Work on other glass/silicon systems did not show appreciable promise. Cells with fine grain polycrystalline material had lower photocurrent than the polycrystalline material reported on above.

As the number of grain boundaries increases, further losses in current must be tolerated. The experiments were limited and information as to V_{OC} reduction due to reduction of effective lifetime with fine grain sizes could not be determined.

Initial work on spray coating of glass on silicon substrates showed very promising results. We believe this method can lead to a vacuum-free process.

The contract work for the next year will be focused towards achieving 10% efficiency on polycrystalline materials and 14% efficiency on single crystal cells. Further understanding of the n^+/n glass-Si heterojunction will be a prime effort. We are excited about this technology as representing a potentially lower cost, viable alternate to diffusion.

GLASS-SI HETEROJUNCTION SOLAR CELLS

NSF GRANT AER74-17631

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
SYRACUSE UNIVERSITY
SYRACUSE, NEW YORK

INNOTECH CORPORATION
NORWALK, CONNECTICUT

PERIOD OF GRANT: 1 AUG. 1974 - 31 JULY 1975

FUNDING FOR 1 AUG. 1974 - 31 JULY 1975: $313,900

PRINCIPAL INVESTIGATOR:

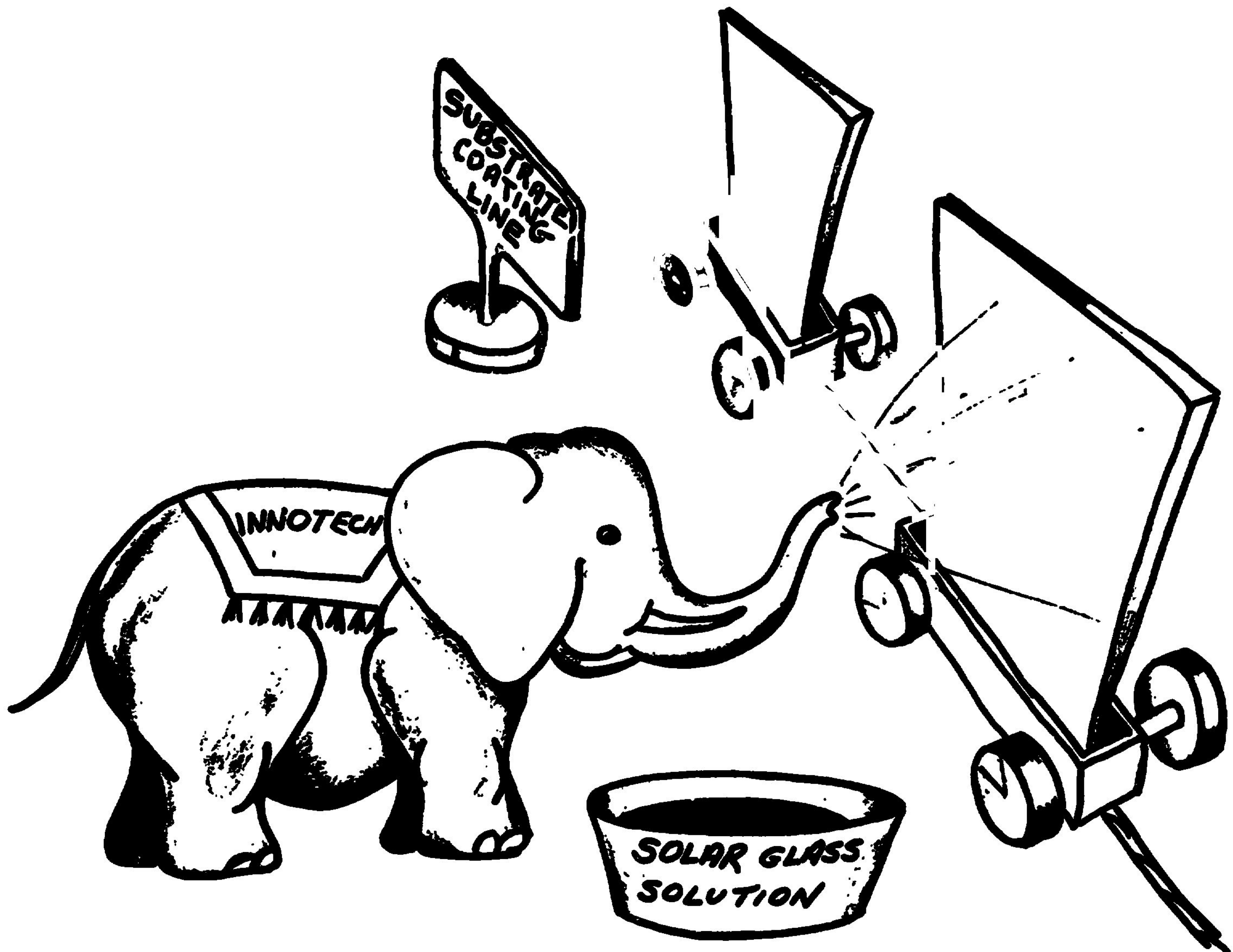
R.L. ANDERSON
SYRACUSE UNIVERSITY

OVERALL OBJECTIVES OF PROJECT

THE PURPOSE OF THIS PROJECT IS TO INVESTIGATE THE FEASIBILITY OF FABRICATING LOW-COST SOLAR CELLS SUITABLE FOR TERRESTRIAL APPLICATION. THESE CELLS CONSIST OF GLASS-SILICON HETEROJUNCTIONS. SPECIFIC GOALS INCLUDE THE PREPARATION AND CHARACTERIZATION OF GLASS-MONOCRYSTALLINE Si AND GLASS-POLYCRYSTALLINE Si HETEROJUNCTIONS, AND MODELING THESE DEVICES.

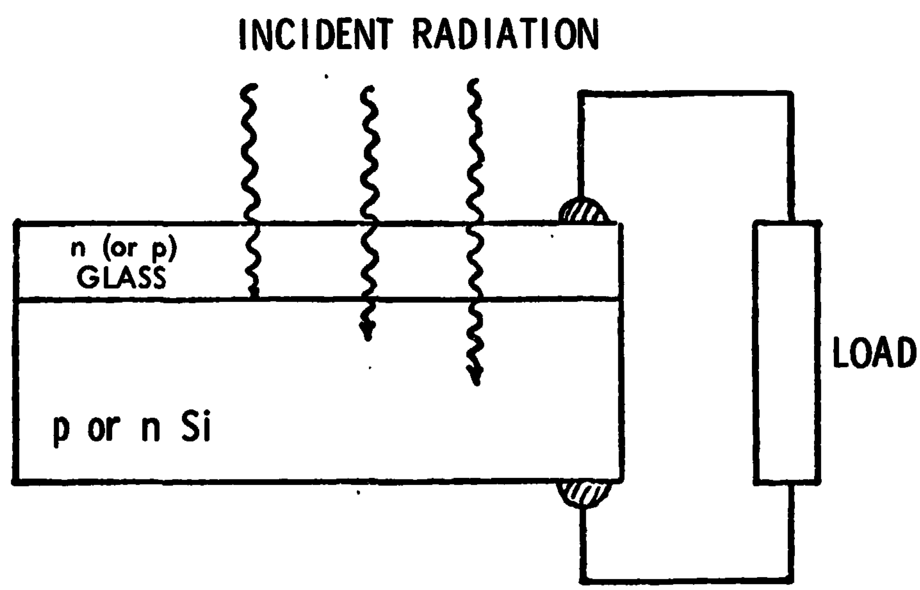
PLANNED ACTIVITY LAST 6 MONTHS

- DEVELOP PRELIMINARY THEORY OF HETEROJUNCTION SOLAR CELLS
- INCREASE OPEN CIRCUIT VOLTAGE ON EXISTING AND NEW GLASS/SILICON MATERIAL SYSTEMS
- PRODUCE LARGE SIZE CELLS ON VARIOUS SUBSTRATES
- DEVELOP PROCESSING TECHNIQUES
- INCREASE FILL FACTOR



LOW COST SOLAR CELL PROCESSING LINE

PROJECT CONCEPTS



SCHEMATIC DIAGRAM OF GLASS-Si HETEROJUNCTION CELL

ADVANTAGES OF CELL

1. OPTICALLY TRANSPARENT WINDOW
2. LOW SERIES RESISTANCE
3. LOW REFLECTIVITY
4. LOW COST

BEST CELL RESULTS

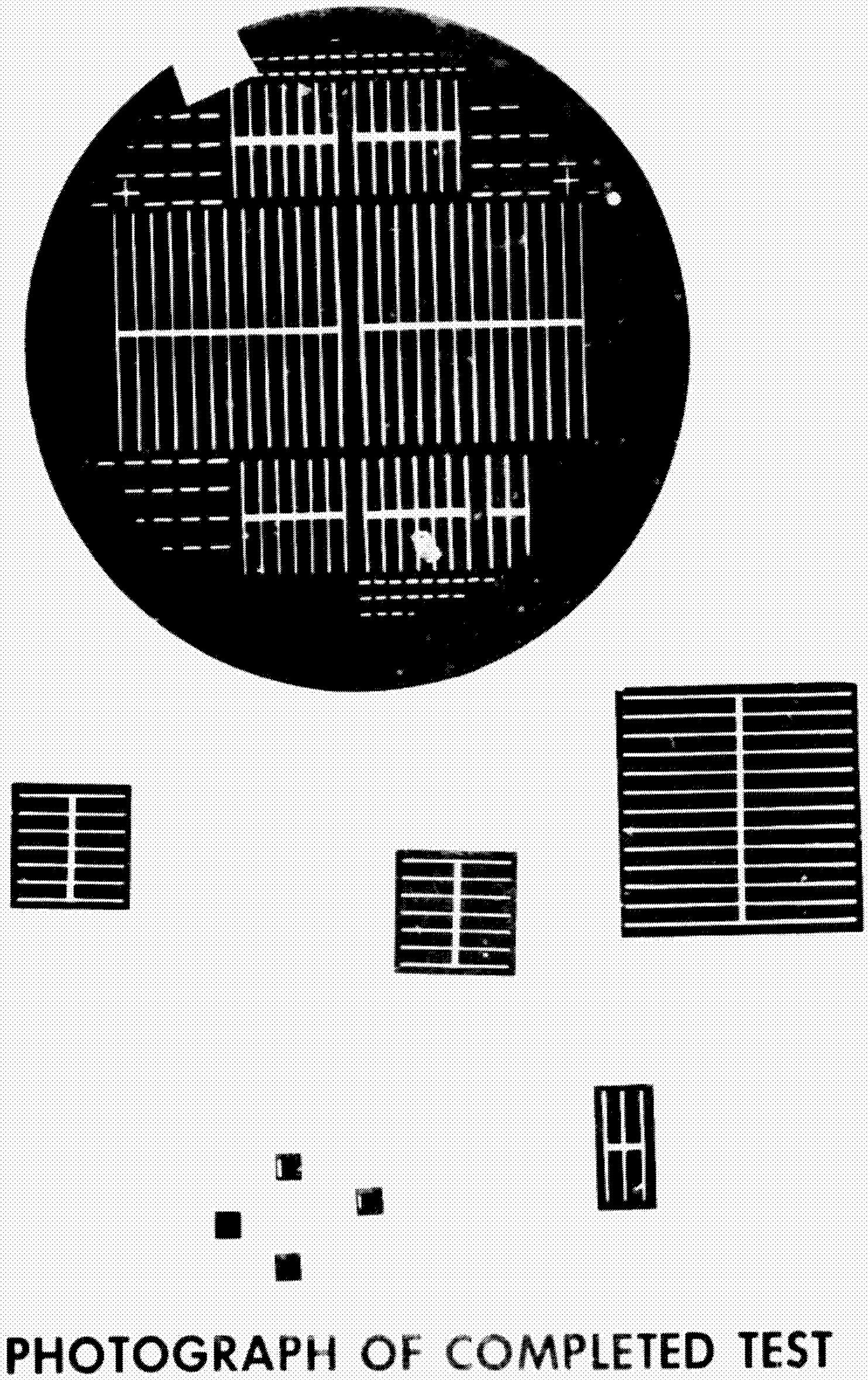
Evap. n^{+} — SnO_2 / n – Si CELL

@AM 1 100 mW/cm^2

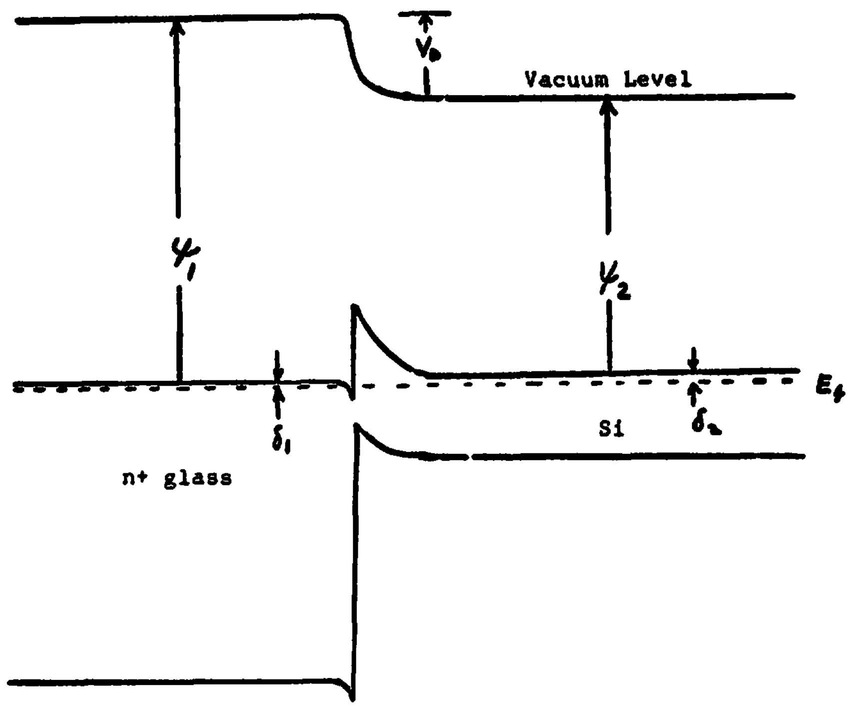
AREA	Voc	Isc	FF	Eff.	Location
	mV	mA	%	%	
4cm²	468	106	56	6.94	NASA
Polycrystal	466	109	55	7.0	INNOTECH
4cm²	523	117	[illegible]	9.41	NASA
Single Crystal	516	122	58	9.1	INNOTECH
1cm²	463	26	60	7.18	NASA
Polycrystal	470	32	53	8.0	INNOTECH
1cm²	521	29.4	64	9.54	NASA
Single Crystal	524	36	53	10.1	INNOTECH

CRYSTAL SIZE: 5 m – 5mm

PHOTOGRAPH OF
n – TYPE POLYCRYSTALLINE WAFER



PHOTOGRAPH OF COMPLETED TEST WAFER AND SOLAR CELLS



$$V_D = \psi_1 - \psi_2 + -\delta_2 + \delta_1$$

SIMPLIFIED ENERGY BAND DIAGRAM AND BARRIER VOLTAGE EQUATION FOR N+/N HETEROJUNCTION NEGLECTING SURFACE STATES AND SiO_2 BARRIER LAYER

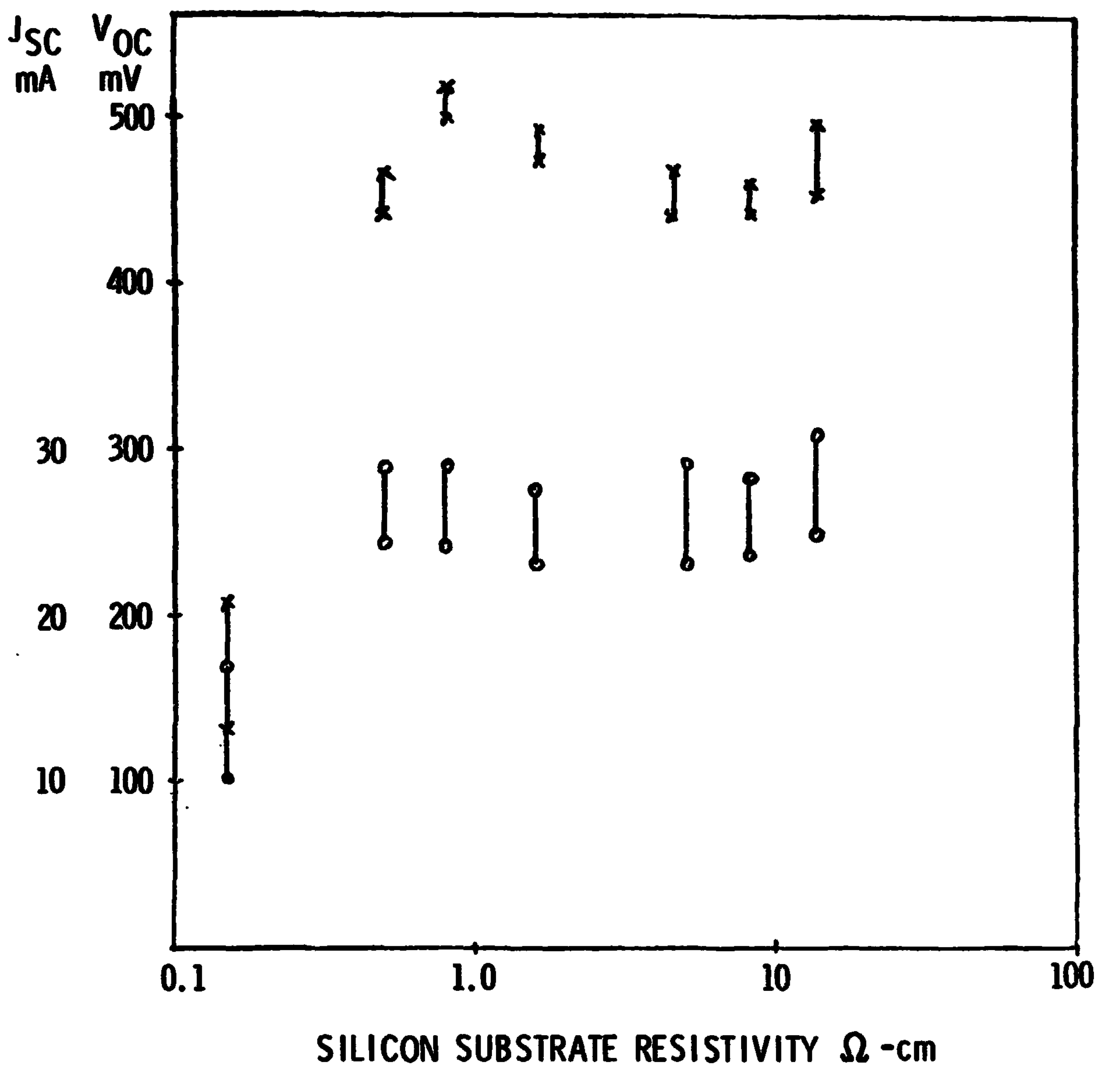
DEVELOPMENT OF AN ECONOMICAL SILICON SOLAR CELL

GRANT No. GI-43091

18 MONTHS, INITIATED 1JUNE 1974

$114,100

PRINCIPAL INVESTIGATOR:
JOSEPH LINDMAYER
SOLAREX CORPORATION



RESISTIVITY OF WAFER vs OPEN-CIRCUIT VOLTAGE AND SHORT-CIRCUIT CURRENT

BEST CELL RESULTS

SPRAY $n^+ - SnO_2$ / n-Si CELL

@AM 1 100 mW/cm^2

AREA	Voc	Isc	FF	Eff.	Location
	mV	mA	%	%	
4cm² Polycrystal	4[illegible]	80.5	43	3.49	NASA
	405	83	44	3.7	INNOTECH
4cm² Single Crystal	514	100.5	48	6.15	NASA
	486	105	46	5.9	INNOTECH
1cm² Polycrystal	425	19	56	4.49	NASA
	436	23	52	5.2	INNOTECH
1cm² Single Crystal	468	25.5	54	6.39	NASA
	477	32	45	6.9	INNOTECH

BEST CELL RESULTS

Evap. $n^+ - In_2O_3 / p$ -Si CELL

@AM 1 100 mW/cm²

AREA	Voc	Isc	FF	Eff.	Location
	mV	mA	%	%	
4cm²	337	96	38	3.32	NASA
Polycrystal	332	100	33	2.8	INNOTECH
4cm²	317	95	54	4.09	NASA
Single Crystal	315	100	53	4.4	INNOTECH
1cm²	359	23.1	56	4.61	NASA
Polycrystal	340	2.9	51	5.0	INNOTECH
1cm²	343	24 9	57	4.9	NASA
Single Crystal	322	30	50	5.0	INNOTECH

CRYSTAL SIZE: 5μm – 5mm

PHOTOGRAPH OF p-TYPE POLYCRYSTALLINE WAFER

OTHER SILICON SUBSTRATES

- EPI POLYCRYSTALLINE (PROF. CHU-SMU)
  POOR INNOTECH RUN FOR V_{OC}
  PHOTOCURRENT - 20mA/cm^2 - ABOUT 2/3 OF SINGLE CRYSTAL IN RUN

- EPI POLYCRYSTALLINE ON SILICON (EPI REACTOR)
  PHOTOCURRENT - 15 mA/cm^2 - ABOUT 1/2 OF SINGLE CRYSTAL IN RUN

- VACUUM DEPOSITED POLYCRYSTALLINE ON GLASS AND METAL (PROF. FANG - BC)
  SHORTED THROUGH TO SUBSTRATE

- RIBBON

  N+ In_2O_3/P Si - GOOD AS SINGLE CRYSTAL - FIRST GROUP
  N+ In_2O_3/P Si - HIGH LEAKAGE - SECOND GROUP
  N+ SnO_2/N Si - POOR V_{OC} I_{SC} AND FF

OTHER GLASSES

- V_2O_5
- $.5V_2O_5 . .5P_2O_5$
- $.85V_2O_5 . .15P_2O_5$
- CABAL GLASSES
- $2Sb_2O_3 . SnO_2$
- TiO_2
- Cd_2SnO_4 (G. HAACKE - AMERICAN CYANAMID)

HETEROFACE CELLS

$N^+In_2O_3/N^+Si/PSi$

- EFFICIENCY 10%
- LOW PRIORITY PROGRAM

SUMMARY OF KEY RESULTS

- 7% EFFICIENCY USING POLYCRYSTALLINE MATERIAL WITH 1 CM^2 AND 4 CM^2 SOLAR CELLS
- 10% EFFICIENCY USING SINGLE CRYSTAL
- BEST RESULTS ON N^+/N JUNCTIONS WITH SnO_2 BASED GLASS
- GOOD REPRODUCIBILITY
- SPRAYED GLASS HETEROJUNCTION SHOWS PROMISING INITIAL RESULTS FOR A VACUUM-FREE PROCESS

MAJOR PROBLEMS

TECHNICAL

- UNDERSTANDING EFFECT OF SURFACE STATES AND SiO_2 BARRIER ON V_{OC} AND V_D
- EFFECT OF VARIOUS PROCESSING PARAMETER ON V_{OC} AND V_D
- INCREASE OF V_{OC}
- SUPPLY OF POLYCRYSTALLINE MATERIAL

COST

- FUNDS EXHAUSTED - NEED CONTINUING SUPPORT EFFECTIVE 1 AUGUST

PLANNED ACTIVITY FOR NEXT 12 MONTHS

- DEVELOP BETTER THEORETICAL UNDERSTANDING OF THE GLASS/Si INTERFACE TO ACHIEVE HIGHER V_{OC}

- INCREASE EFFICIENCY
  - HIGHER V_{OC}
  - HIGHER I_{SC}
    - TEXTURE ON SINGLE CRYSTAL
  - HIGHER FILL FACTOR
    - BETTER CONTACT
    - LOWER SHEET RESISTANCE
    - IMPROVE GRID STRUCTURE

- PRODUCE LARGER (> 4 cm^2) POLYCRYSTALLINE AND SINGLE CRYSTAL CELLS

- DEVELOP VACUUM FREE PROCESSING
  - SPRAY GLASS AND OTHERS
  - METALLIZATIONS

- INVESTIGATE OTHER GLASSES

- IMPROVE TEST SETUP - CORRELATE TO ERDA APPROVED TEST LOCATIONS

PLANNED RENEWAL REQUESTS

MAJOR GOAL - 12 MONTHS

- 10% EFFICIENCY ON POLYCRYSTALLINE SILICON
- 14% EFFICIENCY ON SINGLE CRYSTAL SILICON
- HIGH REPRODUCIBILITY
- BETTER JUNCTION UNDERSTANDING
- VACUUM FREE PROCESSING

DATES

1 AUGUST 1975 TO 31 JULY 1975

ESTIMATED COSTS

$449,000 (INNOTECH AND MIT)