N76 12498

LOW COST AMOS SOLAR CELL DEVELOPMENT

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ABSTRACT

Recent developments at JPL have demonstrated that high conversion efficiencies are possible with GaAs metal-semiconductor solar cells when a particular heat treatment processing step is used to introduce an interfacial layer between the metal and the semiconductor. The new cell called AMOS (Antireflection-Coated Metal-Oxide-Semiconductor), has open-c voltages of 0.68-0.72 volts and efficiencies of 15% under terrestrial sunlight, as compared to values of 0.45-0.48 volts and 10%, respectively, for similar cells without an interfacial layer. Potentially higher efficie .es are feasible as further improvements are made in optimizing the interfacial layer effect and in increasing the blue response of the cells. These developments clearly indicate the desirability of investigating a thin film version of the AMOS solar cell which could better the economic goal of $0.50 per peak watt with an efficiency greater than 10%.

The thin film AMOS cell proposed is unique in that a thin recrystallized germanium (Ge) layer is used between a low cost metal substrate and the vapor phase epitaxially (VPE)-grown GaAs. It has already been shown that Ge films can be recrystallized to millimeter-sized crystallites by the use of scanning electron beams. Indeed, even lateral growth of single crystal Ge has been demonstrated on tungsten which was dipped and withdrawn from a melt of Ge. In the proposed program, laser beams will be primarily used to investigate recystallization. Later versions of the cell may be able to dispense with the Ge layer, as it may be possible to recrystallize GaAs to sufficient degree using techniques developed for the Ge layer. This possibility will not, however, be explored in the early phases.

The Ge layer, used as a substrate for VPE-grown GaAs, will provide a more ordered, larger-grained GaAs film. The increased ord , the use of a semiconductor with high light absorption, and the inher nt properties of the

metal-semiconductor contact, should give considerably h... ıer current and voltage outputs than have previously been obtained in polycrystalline thin-film solar cells. The availability and cost of materials are satisfactory for the amounts required and the fabrication steps envisioned for large-scale production are amendable to continuous or quasi-continuous processing.

An ancillary program for optimizing the newly added AMOS processing step, which leads to markedly higher voltage outputs, is proposed. This program will utilize electrical and chemical analysis measurements to better understand the pertinent interface (oxide-semiconductor) properties, so that the appropriate process can be added to the low-cost AMOS cell program when suitable thin films are available.

The electrical MOS-type measurements will be performed at the Pennsylvania State University on a subcontract This program will supplement an existing theoretical contract with the University (Prof. Stephen Fonash) to investigate the interfacial layer ... . The measurements, along with transient capacitance measurements at JPL, will attempt to determine surface state distribution in the band gap, surface state capture cross sections, surface state type and surface charge, modified to account for the fact that tunneling currents are flowing through the ultra-thin layers. These data will complement studies of the chemistry of the interface region using ESCA (Electron Spectroscopy for Chemical Analysis) facilities at JPL.

The parametric studies for optimum GaAs growth by vapor phase epitaxy on Ge films will be performed by Applied Materials, Inc. The company has been a supplier of exceptionally high quality single crystal GaAs, having minority carrier diffusion lengths for holes of 3-4 microns, even with doping concentrations up to 10^{17} cm^{-3}. The investigation will be focused on the nucleation characteristics of various substrates as to how they are affected by temperature and growth rate. The latter is sensitive to the ratio of the As-and Ga-bearing gases and to the concentrations in each of these gases.

As Ge and GaAs films are developed, the structural characteristics of the films will be examined by optical and scanning electron microscopy, and various x-ray techniques to characterize the grain size and of disorder, preferred orientation and dislocation density. Metal-semiconductor solar cells will be fabricated on GaAs films as they become available with particular interest in the surface preparation required, if any, and the thickness of the semitransparent metal film required for usable sheet resistances.

The standard optical, electrical and photovoltaic measurements will be made on the cells, as well as scanning electron microscopy (in the beam-induced conductivity mode) to observe grain boundary effects on current collection.

The efficiency to be expected may be estimated from the single-crystal cells already constructed. Estimating the current loss at 20% (due to the use of a somewhat thicker semitransparent metal film and a reduced minority carrier diffusion length of about one-half) and a 10% loss in voltage (due to some barrier lowering at the few grain boundaries), a long term goal of 12-14% conversion efficiency for a thin-film AMOS solar cell seems reasonable.

In summary, the research plan involves the interaction of three major groups: (1) the Research Group at JPL, (2) Pennsylvania State University, and (3) Applied Materials, Inc. JPL will select the best substrates for Ge deposition, recrystallize the Ge film by scanning laser or electron beams, characterize the Ge and GaAs films, fabricate and test metal-semiconductor solar cells on the GaAs films, and perform ESCA measurements of the AMOS interface region on single crystal GaAs. Pennsylvania State University will determine the interface electronic properties of the AMOS solar cell and correlate with theoretically determined optimum characteristics. Finally, Applied Materials, Inc., will provide the parametric studies for optimum GaAs growth by vapor phase on Ge films.

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GUIDANCE AND CONTROL RESEARCH GROUP

JET PROPULSION LABORATORY

PROPOSED START DATE : SEPTEMBER 1, 1975

$ 225,250

PRINCIPAL INVESTIGATOR : RICHARD J. STIRN

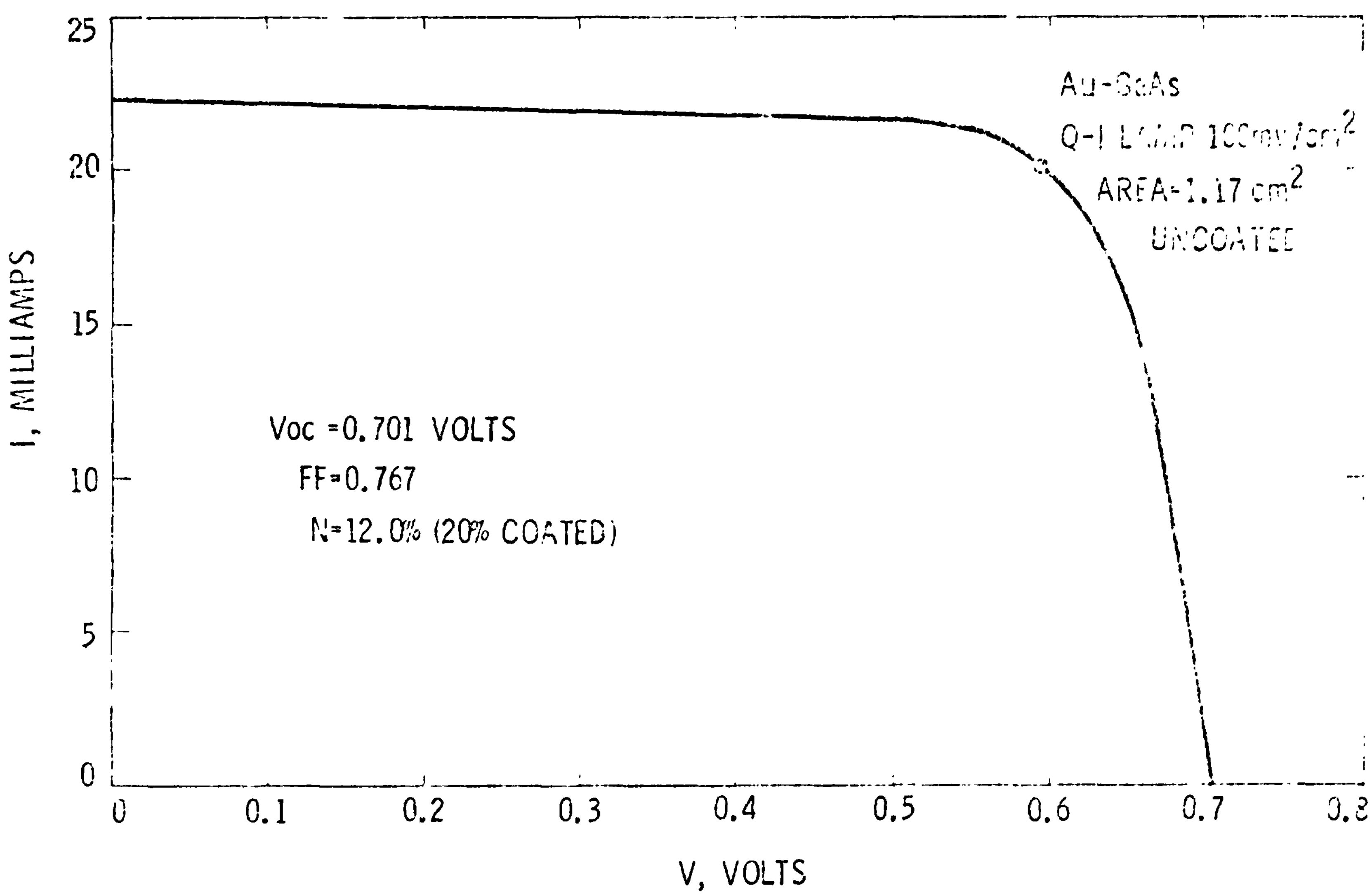
PRESENTED AT : NATIONAL SOLAR PHOTOVOLTAIC PROGRAM REVIEW MEETING, UCLA

JULY 22-25, 1975

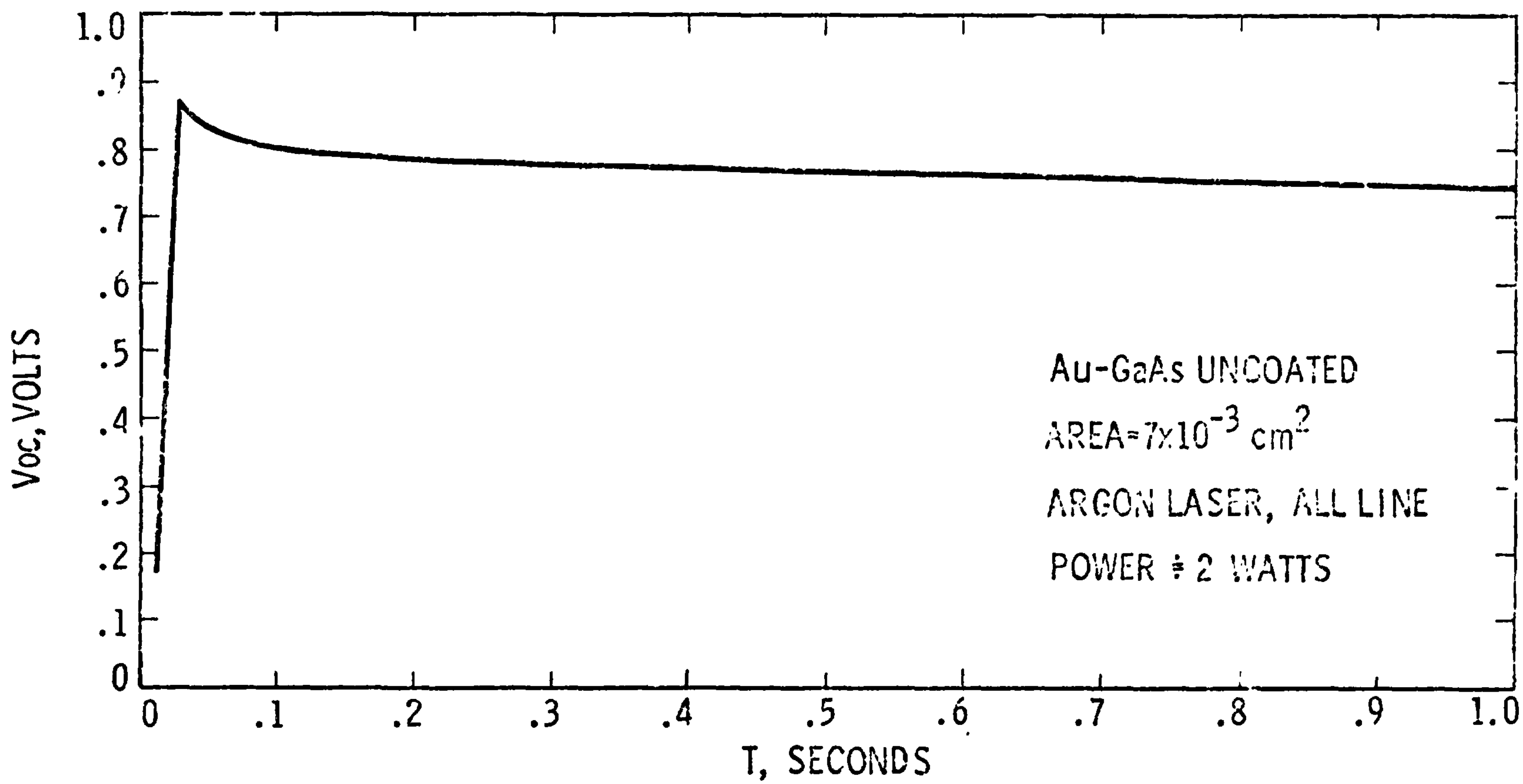
OBJECTIVE

- DEMONSTRATE THE FEASIBILITY OF A LOW-COST THIN-FILM GALLIUM ARSENIDE SOLAR CELL
  - RECRYSTALLIZE Ge FILMS ON LOW COST SUBSTATES
  - OPTIMIZE GaAs VPE-GROWTH ON Ge FILMS
  - FABRICATE AMOS SOLAR CELLS ON GaAs/Ge FILMS
  - INVESTIGATE INTERFACE PHYSICS AND CHEMISTRY

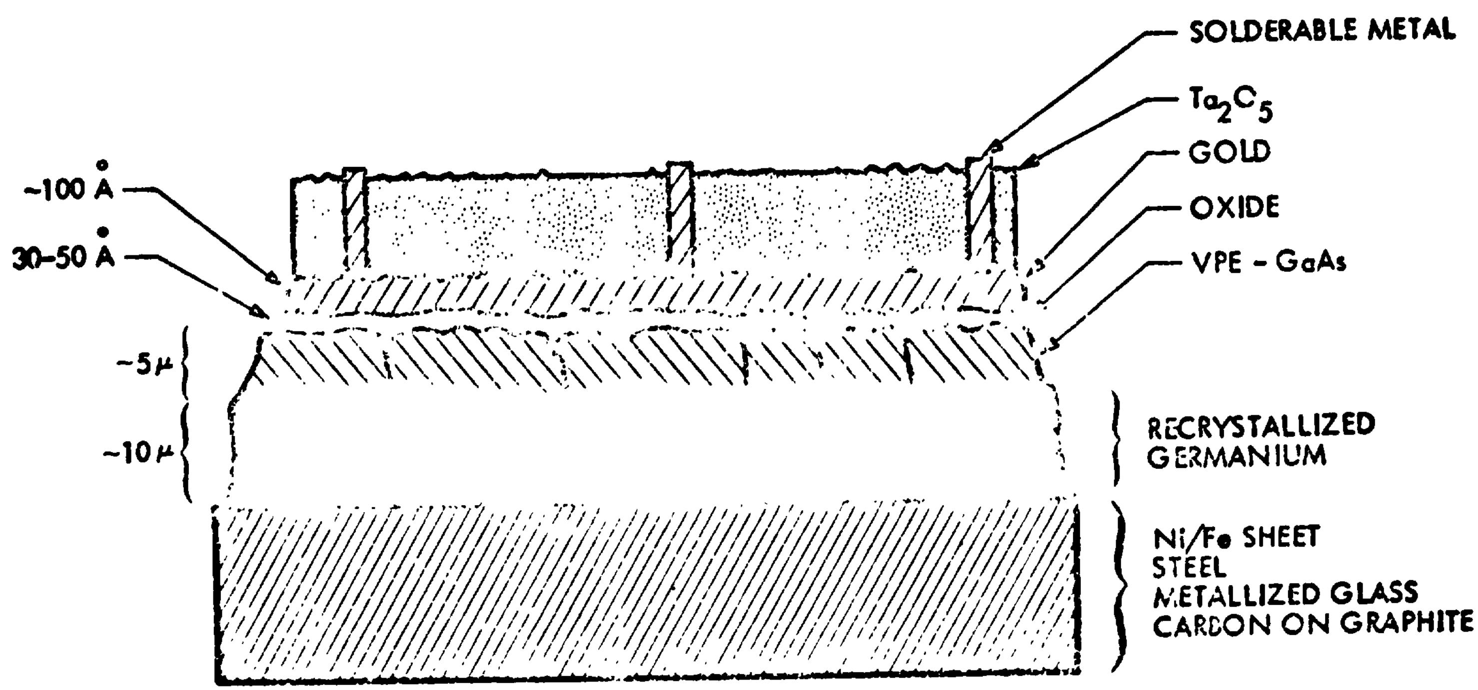
LIGHT I-V CURVE FOR AMOS CELL



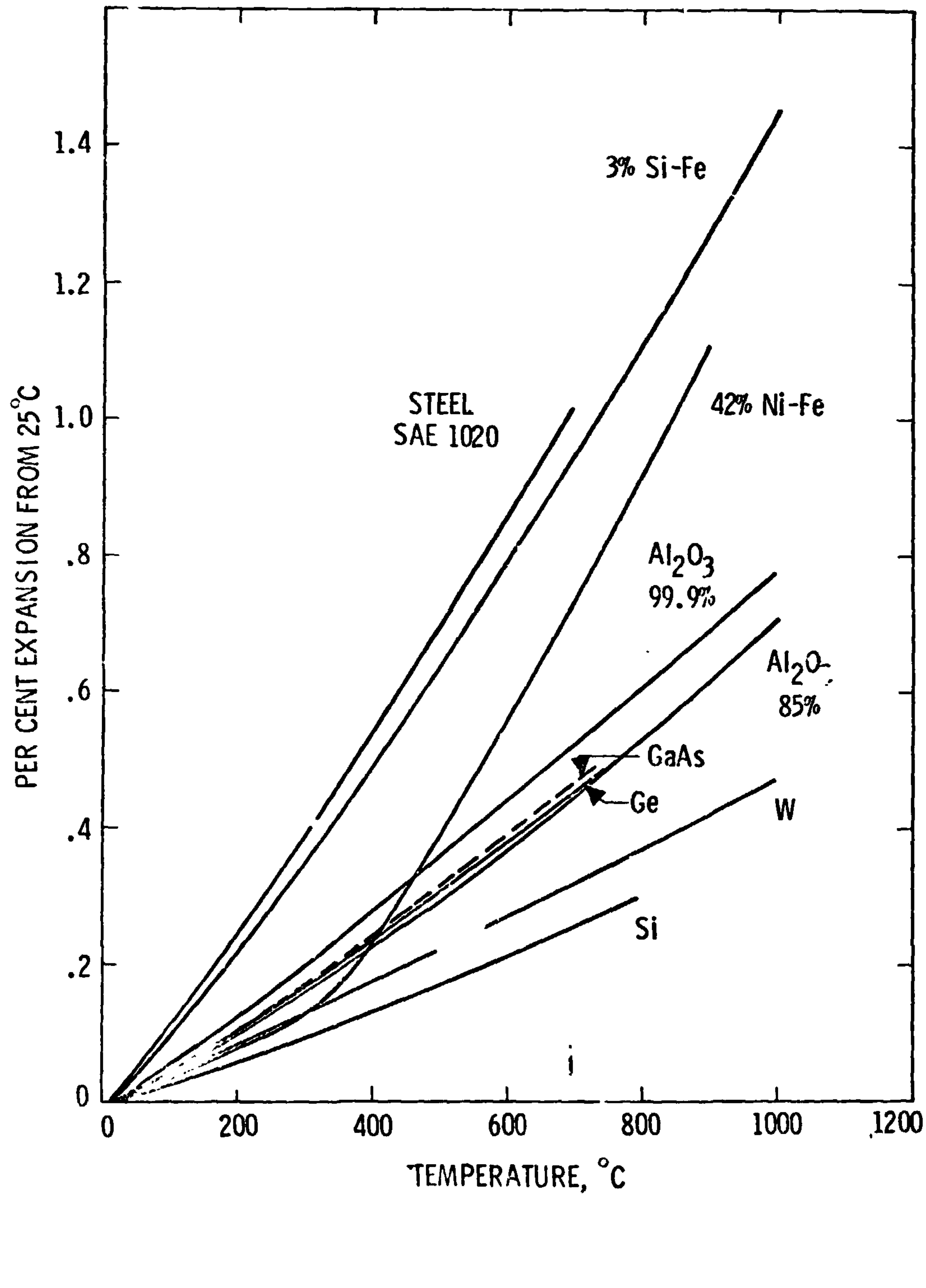
OPEN C[illegible] V[illegible] CELL [illegible] VERY HIGH LIGHT [illegible]



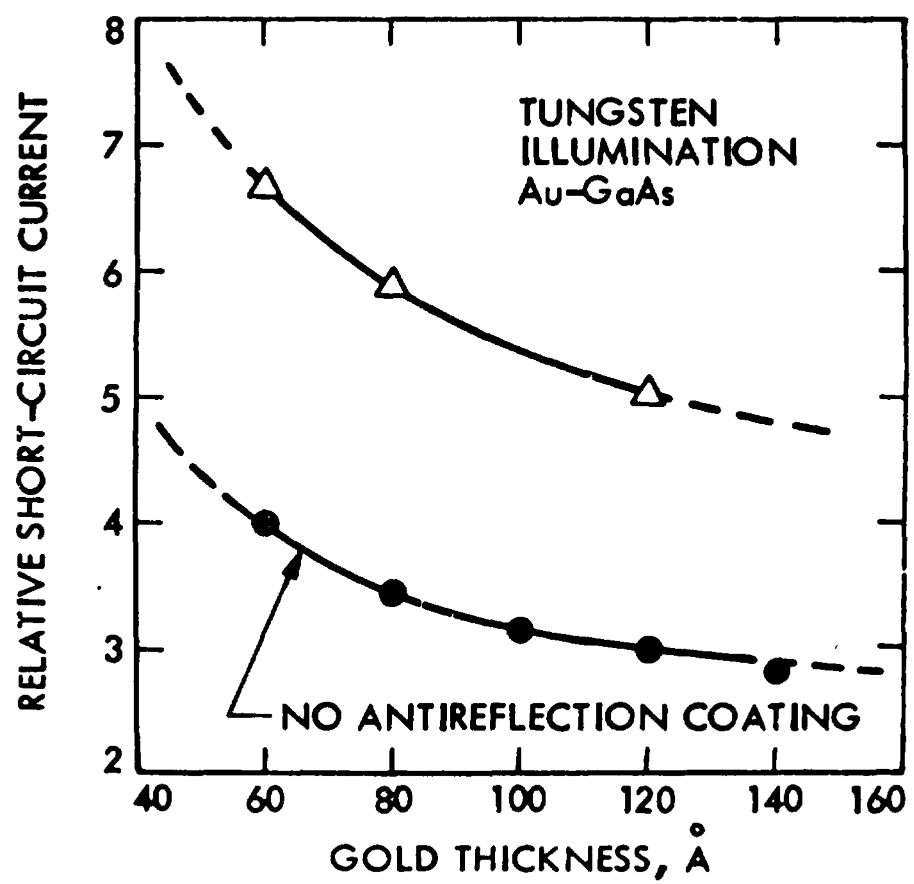
THIN-FILM AMOS SOLAR CELL - FIRST GENERATION (NOT TO SCALE)



LINEAR COEFFICIENTS OF EXPANSION



DEPENDENCE OF SHORT-CIRCUIT CURRENT IN A GaAs MS SOLAR CELL ON METAL THICKNESS



MATERIAL AVAILABILITY
(METRIC TONS)

MATERIAL	ANNUAL REQUIREMENT[a]	PRESENT ANNUAL PRODUCTION[b] (DEMAND LIMITED)	IDENTIFIED WORLD RESOURCES[b]
Ga	92.5	not given	1.3×10^5
As	89.5	5×10^4	1.6×10^7
Ge	168	~100 (1971)	~8×10^4
Au	1.9	—	—

[a] ASSUMES 500 MW/YR OR 5×10^6 M^2 @ 10% EFFICIENCY, 80% UTILIZATION, THICKNESS OF GaAs AND Ge LAYERS TO BE 5 UM, 100 Å THICK Au LAYER WITH 10% GRID COVERAGE

[b] U.S. MINERAL RESOURCES, U.S. GEOLOGICAL SURVEY PROF. PAPER 820, 1973

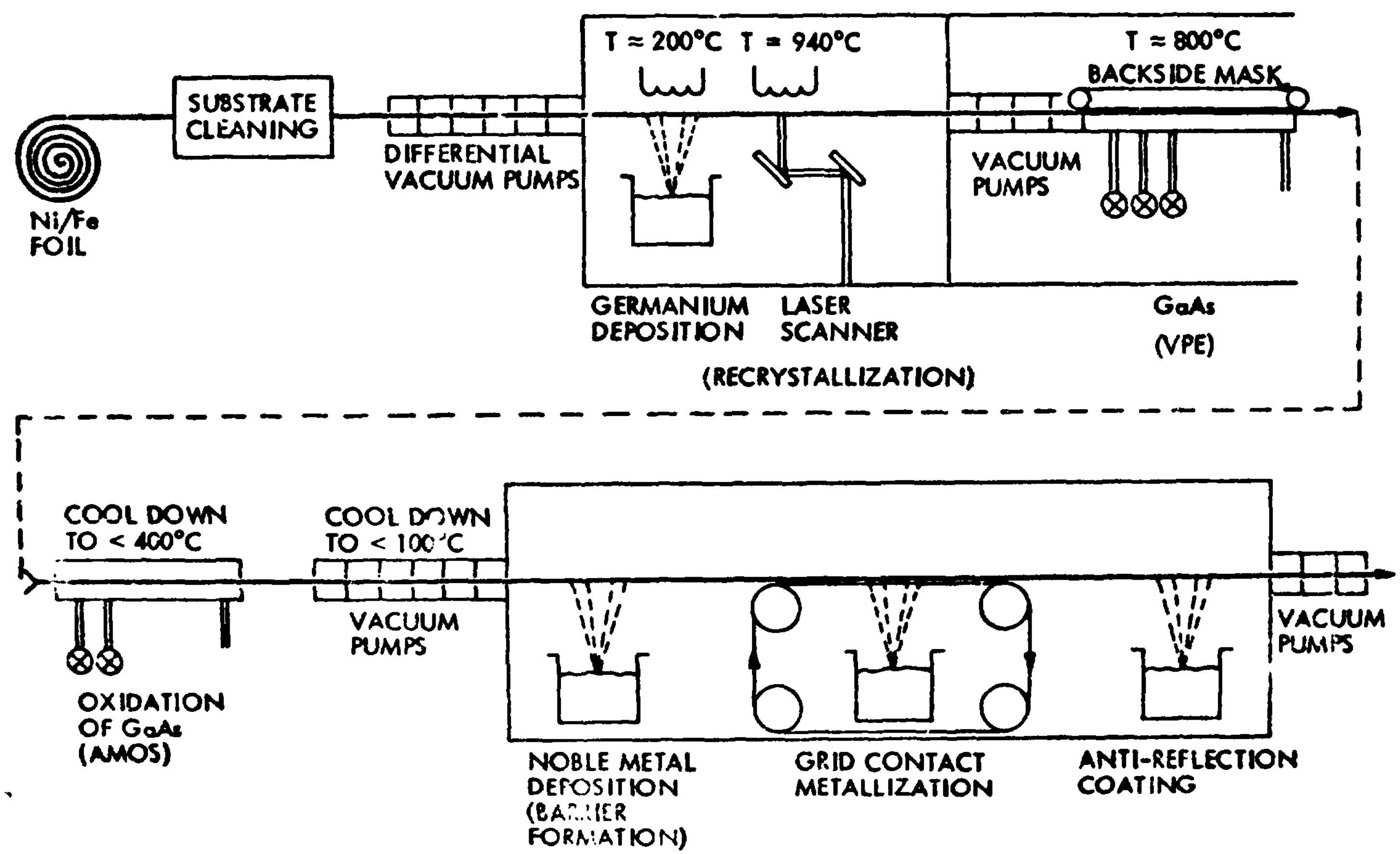
MATERIAL COSTS

MATERIAL	UNIT COST[a]	COST ($1/peak-watt)[b]	
Ga (HIGH PURITY)	60¢/gm	0.111	
As (" ")	15¢/gm	0.027	
Ge (" ")	25¢/gm	0.083	
			$0.221 (SEMICONDUCTORS)
Au	$175/oz	0.0250	
Fe/Ni (4 mil)	$7.30/$m^2$	0.0730	
			$0.319 TOTAL WITH Fe/Ni SUBSTRATE
Si-STEEL (12 mil)	2.40/m^2	0.0240	

[a] PRESENT DAY SMALL-LOT PRICES

[b] ASSUMES 10% EFFICIENCY, THICKNESS OF GaAs AND Ge LAYERS TO BE 5 UM, 100 Å THICK Au FILM WITH 10% GRID COVERAGE AND 80% UTILIZATION, OF SEMICONDUCTORS AND GOLD.

CONCEPTUAL DIAGRAM OF A POSSIBLE THIN FILM AMOS PRODUCTION LINE



PLANNED ACTIVIES

- SELECT SEVERAL CANDIDATE LOW COST SUBSTRATES
- FABRICATE TWO-DIMENSIONAL LASER SCANNING APPARATAS FOR RECRYSTALLIZATION STUDIES ON GERMANIUM FILMS
- DETERMINE OPTIMUM GaAs GROWTH PARAMETERS ON SINGLE CRYSTAL AND RECRYSTALLIZED GERMANIUM SUBSTRATES
- PERFORM CHEMICAL ANALYSIS OF INTERFACE REGION WITH ESCA SPECTROSCOPY ON SINGLE CRYSTAL AMOS SAMPLES TO INVESTIGATE ALTERNATE PROCESSING STEPS
- LET CONTRACT TO CONDUCT CAPACITANCE-CONDUCTANCE MEASUREMENTS ON SINGLE CRYSTAL AMOS SOLAR CELLS