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Photovoltaic Energy Systems

Program Summary Fiscal Year 1983

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Prepared for:
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A Product of the
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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.

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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[a]

Goals	Flat Plate Systems	Concentrator Systems
Module Efficiency[b]	13% - 17%	23% - 29%
Module Cost	$40 - $75/m²	$90 - $160/m²
Balance-of-System Costs		
Area-Related	$50/m²	$100/m²
Power-Related	$150/kW	$150/kW
System Life-Expectancy	30 years	30 years

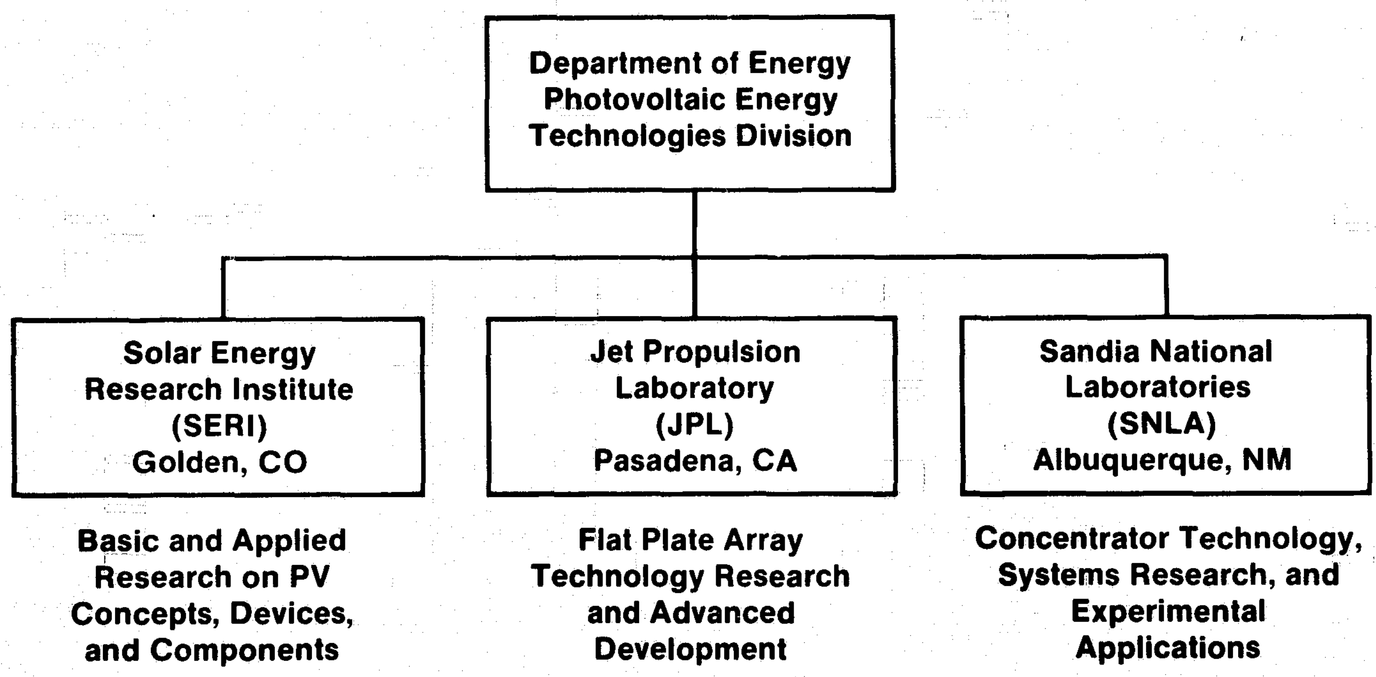
[a] 1982 dollars
[b] Measured at 28°C and AM 1.5

*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^2) with efficiencies of 8% and small cells (100 cm^2) 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^2. Two SERI contractors, RCA and Chronar, achieved this for submodules of 350 cm^2 and 127 cm^2 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 ($CuInSe_2$) solar cells for commerical 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 $CuInSe_2$ 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 $CuInSe_2$ 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 seminconductor-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^2/min by Westinghouse, exceeding the JPL contract goals of 35 cm^2/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^2. 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 quantitites, 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-verticle-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 requirments 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 $CdS/CuInSe_2$ 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 prototye 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/m² 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 (±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

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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_{sc}	short circuit current density
JPL	Jet Propulsion Laboratory
kg	kilogram
kHz	kilohertz
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	milliampere
MBE	molecular beam epitaxy
MCM	minority carrier mirror
MEPSDU	Module experimental process system development unit
MINP	metal insulator (np 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
NERES	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
Vdc	direct current voltage
V_{oc}	open circuit voltage
XPS	x-ray photoelectron spectroscopy

Index of Current Contractors

FY 1983
Contract Descriptions

Solar Energy Research Institute

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

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

Project/Area/Task: Advanced High Efficiency Concepts

Contract Funding:		Source:
FY 1979	$ 144,116	SERI
FY 1980	$ 126,604	SERI
FY 1981	$ 42,500	SERI
FY 1982	$ 41,500	SERI

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

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)

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

Project/Area/Task: Advanced High Efficiency Concepts

Contract Funding:		**Source:**
FY 1980	**$** 109,685	SERI
FY 1981	**$** -0-	SERI
FY 1982	**$** 35,000	SERI

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

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)

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

Project/Area/Task: Advanced High Efficiency Concepts

Contract Funding:		**Source:**
FY 1980	**$** 300,573	SERI
FY 1981	**$** 182,400	SERI
FY 1982	**$** 345,222	SERI
FY 1983	**$** 498,058	SERI

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^{-2}.

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

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:		Source:
FY 1978	$ 130,000	Sandia
FY 1979	$ 208,400	Sandia
FY 1980	$ 228,642	SERI
FY 1981	$ 168,900	SERI
FY 1982	$ 408,000	SERI
FY 1983	$ 100,000	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^2 plates to 2000 cm^2 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

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

Current Contract Period From: 3/1/80
To: 11/30/82

Project/Area/Task: Advanced High Efficiency Concepts

Contract Funding:		**Source:**
FY 1980	**$** 263,454	SERI
FY 1981	**$** 261,994	SERI
FY 1982	**$** 90,000	SERI

Objectives: To develop the materials technology necessary to demonstrate GaAs solar cells of 10% efficiency in polycrystalline films of less than 10 μm 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

Title: Development of High Efficiency Cascade Solar Cells

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

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

Directing Organization:
Solar Energy Research Institute

Project Engineer: L.A. Cole
Telephone: (303) 231-1841

Contract Funding:		Source:
FY 1978	$ 367,140	Sandia
FY 1979	$ 297,000	SERI
FY 1980	$ 237,809	SERI
FY 1981	$ 417,347	SERI
FY 1982	$ 56,506	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 Å /cm² 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

Contract Number: 9002-3 (2068-1)

Current Contract Period From: 11/30/79
To: 12/31/83

Project/Area/Task: Advanced High Efficiency Concepts

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

Contract Funding:		**Source:**
FY 1979	**$** 185,740	DOE
FY 1981	**$** 183,800	SERI
FY 1982	**$** 192,000	SERI
FY 1983	**$** 100,000	SERI

Objectives: To prepare polycrystalline GaAs solar cells of 10% conversion efficiency in films of less than 10 μm 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

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

Contract Number: 3033-1

Current Contract Period From: 2/18/83
To: 4/18/84

Project/Area/Task: Advanced High Efficiency Concepts

Directing Organization:
Solar Energy Research Institute

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

Contract Funding:		**Source:**
FY 1983	**$** 323,695	SERI

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

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)

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

Project/Area/Task: Advanced High Efficiency Concepts

Contract Funding:		**Source:**
FY 1980	**$** 164,260	SERI
FY 1981	**$** 155,300	SERI
FY 1981	**$** 49,000	SERI

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)

Current Contract Period From: 8/1/82
To: 6/30/84

Project/Area/Task: Advanced High Efficiency Concepts

Contract Funding:		Source:
FY 1982	$ 177,000	SERI
FY 1983	$ 264,827	SERI

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 $10^6/cm^2$ (from approximately $10^{10}/cm^2$).
- A vapour etch techniques has been discovered which further reduces surface defects down to approximately $10^4/cm^2$. Completely specular (both sides) Ge thin films have been produced.
- An annealling 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

Directing Organization:
Solar Energy Research Institute

Project Engineer: L.A. Cole
Telephone: (303) 231-1841

Contract Number: 3015-1

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

Project/Area/Task: Advanced High Efficiency Concepts

Contract Funding:		**Source:**
FY 1983	**$** 295,593	SERI

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:		Source:
FY 1979	$ 365,668	SERI
FY 1980	$ 221,273	SERI
FY 1981	$ 475,682	SERI
FY 1982	$ 86,264	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

Contract Number:

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

Project/Area/Task: Advanced Systems Research

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

Contract Funding:		**Source:**
FY 1982	$ 400,000	DOE
FY 1983	$ 510,000	DOE
FY 1984	$ 595,000	DOE

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/$CuInSe_2$ 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/$CuInSe_2$ 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.
- Lambarski, 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

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

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

Project/Area/Task: Advanced Systems Research

Contract Funding:

		Source:
FY 1981	**$** 98,222	SERI
FY 1982	**$** 32,725	SERI
FY 1983	**$** -0-	SERI

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

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:

		Source:
FY 1981	**$** 10,783	SERI
FY 1982	**$** 8,000	SERI
FY 1983	**$** -0-	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

Current Contract Period: Three Year Subcontract

Project/Area/Task: Amorphous Materials

Contract Funding: To Be Negotiated

Source:

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^2 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

Current Contract Period: Three Year Subcontract

Project/Area/Task: Amorphous Materials

Contract Funding:
To Be Negotiated

Source:

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^2; 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^2. 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^2.

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

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

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

Project/Area/Task: Amorphous Materials

Contract Funding:		Source:
FY 1979	$ 180,000	DOE
FY 1980	$ -0-	
FY 1981	$ 310,000	SERI
FY 1982	$ 240,000	SERI
FY 1983	$ 316,000	SERI

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 microrystalline 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 30Å/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 20Å/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

Contract Number: 03147

Current Contract Period From: 8/1/81
To: 10/31/84

Project/Area/Task: Amorphous Materials

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

Contract Funding:		**Source:**
FY 1981	**$** 161,500	SERI
FY 1982	**$** 180,000	SERI
FY 1983	**$** 241,500	SERI

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 intrinisic 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^2 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^2 — 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)

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

Project/Area/Task: Amorphous Materials

Contract Funding:		Source:
FY 1980	$ 280,695	SERI
FY 1981	$ 389,701	SERI
FY 1982	$ 380,000	SERI

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. (l983). "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

Contract Number: 9358-1 (2144-1)

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

Project/Area/Task: Amorphous Materials

Directing Organization:
Solar Energy Research Institute

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

Contract Funding:

		Source:
FY 1979	**$** 239,000	SERI
FY 1980	**$** 236,058	SERI
FY 1981	**$** 180,000	SERI
FY 1982	**$** 125,000	SERI
FY 1983	**$** 90,000	SERI

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 $10^{16}/cm^3$.

FY 1984 Milestones:
- Deposit high quality a-Si Ge_2: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:		Source:
FY 1980	$ 27,535	SERI
FY 1981	$ 92,000	SERI
FY 1982	$ 16,500	SERI
FY 1983	$ 141,689	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

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)

Current Contract Period From: 9/30/80
To: 9/29/83

Project/Area/Task: Amorphous Materials

Contract Funding:		Source:
FY 1980	$ 168,143	SERI
FY 1981	$ 197,674	SERI
FY 1982	$ 140,000	SERI

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^2.
- A comparison of the ESR spin density and local hydrogen binding (NMR) was made for HOMOCVD, glow discharge (SiH_4) and glow discharge (Si_2H_6) produced films.
- Low ESR spin density (less than 3×10^{16} cm^{-3}), 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 Amorhpous 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

Directing Organization:
Solar Energy Research Institute

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

Contract Number: 3117-1

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

Contract Funding:

FY	Amount	Source:
FY 1983	$ 50,000	SERI

Project/Area/Task: Amorphous Materials

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

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)

Current Contract Period From: 4/16/81
To: 4/14/84

Project/Area/Task: Amorphous Materials

Contract Funding:		**Source:**
FY 1981	**$** 15,500	SERI
FY 1982	**$** 16,290	SERI
FY 1983	**$** 25,000	SERI

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_2 and SiH_3 radicals were observed in the dc discharge with the SiH_3 as the largest observed signal.
- Identified reaction chain in gas which is responsible for large SiH_3 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^+, Ne^+ and Ar^+ with CH_4,C_2H_6, SiH_4 and Si_2H_6." *The Journal of Chemical Physics*. Vol. 79 (No. 3); pp. 1301-1311.

Summary Date
October 1983

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

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

Project/Area/Task: Amorphous Materials

Contract Funding:		**Source:**
FY 1983	$ 62,000	SERI

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)

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

Project/Area/Task: Amorphous Materials

Contract Funding:		Source:
FY 1981	$ 59,000	SERI
FY 1982	$ 56,000	SERI
FY 1983	$ 25,000	SERI

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

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)

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

Project/Area/Task: Amorphous Materials

Contract Funding:

		Source:
FY 1980	$ 1,241,836	SERI
FY 1981	$ -0-	SERI
FY 1982	$ 600,000	SERI

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 DischargeDeposition Method.
- Construct p-i-n amorphous silicon solar cells to advance the state-of-the-art in small area cells ($\approx$ 1.2 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 μm have been measured under AM2 illumination.
- DLTS has been used to measure density of states of about 9×10^3 $cm^{-3}eV^{-1}$ 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

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

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

Contract Funding:

		Source:
FY 1981	$ 24,500	SERI

Project/Area/Task: Amorphous Materials

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 thisand 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

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)

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

Project/Area/Task: Amorphous Materials

Contract Funding:		**Source:**
FY 1980	**$** 99,278	SERI
FY 1981	**$** 105,303	SERI
FY 1982	$ 43,698	SERI

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_2, and SiH_3 radicals in the dc discharge with the SiH_3 as the largest observed signal.
- Identified reaction chain in gas which is responsible for large SiH_3 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^+, Ne^+, and Ar^+ with CH_4, C_2H_6, SiH_4 and Si_2H_6." *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

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:		**Source:**
FY 1979	**$** 256,747	DOE
FY 1980	**$** 336,261	SERI
FY 1981	**$** 310,001	SERI
FY 1982	**$** 248,000	SERI
FY 1983	**$** 235,000	SERI

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^2 — 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

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

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

Contract Funding:

		Source:
FY 1983	**$** 50,000	SERI

Project/Area/Task: Amorphous Materials

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

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)

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

Project/Area/Task: Amorphous Materials

Contract Funding:		**Source:**
FY 1979	$ 91,000	DOE
FY 1980	$ 176,041	SERI
FY 1981	$ 187,641	SERI
FY 1982	$ 187,048	SERI
FY 1983	$ 388,700	SERI

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 cm^2/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^+ 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:

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

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

Contract Funding:		Source:
FY 1979	$ 650,000	DOE
FY 1980	$ 800,000	DOE
FY 1981	$ 850,000	DOE
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

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:		Source:
FY 1983	$ 150,000	SERI

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

Title: New Ideas for Photovoltaic Conversion

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

Principal Investigator: Telephone:

Contract Number:

Current Contract Period: TBD

Project/Area/Task: New Ideas for Photovoltaic Conversion

Directing Organization:
Solar Energy Research Institute

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

Contract Funding:

		Source:
FY 1983	$ 725,000	SERI

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

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

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

Project/Area/Task: Performance Criteria/Test Methods

Contract Funding:		**Source:**
FY 1980	$ 24,975	SERI

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

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

Project Engineer: G. Nuss
Telephone: (303) 231-1287

Contract Number: 1289-1

Current Contract Period From: 9/30/81
To: 8/31/84

Project/Area/Task: PV Quality Assurance and Standards

Contract Funding:		**Source:**
FY 1982	$ 266,963	SERI

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

Directing Organization:
Solar Energy Research Institute

Project Engineer: P. Longrigg/G. Nuss
Telephone: (303) 231-1765/1287

Contract Number: 1073-1

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

Project/Area/Task: Performance Criteria/Test Methods

Contract Funding:		**Source:**
FY 1981	**$** 150,000	SERI

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

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

Project/Area/Task: Photoelectrochemical Cells

Contract Funding:		Source:
FY 1980	$ 134,177	SERI
FY 1981	$ 294,961	SERI
FY 1982	$ 79,960	SERI
FY 1983	$ 88,308	SERI

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).
- Garatha'a, 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

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)

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

Project/Area/Task: Photoelectrochemical Cells

Contract Funding:		**Source:**
FY 1980	$ 221,696	SERI
FY 1981	$ 187,000	SERI
FY 1982	$ 93,608	SERI
FY 1983	$ 129,483	SERI

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 $CdSe_xTe_{1-x}$ thin film photoelectrodes by co-evaporation from Cd, Se, and Te.
- Perform photoelectrochemical measurements on $CuInSe_2$ 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 $CdSe_xTe_{1-x}$ photoanodes as a function of various surface treatments and stability tests for optimization studies.
- A preliminary investigation was performed on polycrystalline thin film $CuInSe_2$ photoelectrodes.

FY 1984 Milestones:

- Electrochemical photocapacitance spectroscopy studies will be performed for $CdSe_xTe_{1-x}$ 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 $CdSe_xTe_{1-x}$ 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. "$CdSe_xTe_{1-x}$ Thin Films for Electrochemical Photovoltaic Cells." *Journal of the Electrochemical Society* (submitted for publication).

Summary Date
October 1983

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

Current Contract Period From: 4/15/80
To: 9/30/83

Project/Area/Task: Photoelectrochemical Cells

ContractFunding:		Source:
FY 1980	$ 151,737	SERI
FY 1981	$ 156,424	SERI
FY 1982	$ 25,000	SERI

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

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)

Current Contract Period From: 4/15/80
To: 7/5/84

Project/Area/Task: Photoelectrochemical Cells

Contract Funding:		**Source:**
FY 1980	**$** 219,833	SERI
FY 1981	**$** 169,648	SERI
FY 1982	**$** 85,000	SERI
FY 1983	**$** 89,623	SERI

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 $CdSe_{1-x}Te_x$ 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

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)

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

Project/Area/Task: Photoelectrochemical Cells

Contract Funding:		Source:
FY 1980	$ 128,425	SERI
FY 1981	$ 132,945	SERI
FY 1982	$ 83,012	SERI
FY 1983	$ 86,517	SERI

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

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

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

Project/Area/Task: Photoelectrochemical Cells

Contract Funding:		**Source:**
FY 1981	**$** 120,592	SERI
FY 1982	**$** 77,964	SERI
FY 1983	**$** 29,997	SERI

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_2 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)

Current Contract Period From: 10/1/80
To: 6/30/84

Project/Area/Task: Photoelectrochemical Cells

Contract Funding:

		Source:
FY 1980	$ 97,120	SERI
FY 1981	$ 61,580	SERI
FY 1982	$ 89,000	SERI
FY 1983	$ 109,318	SERI

Objectives: To construct and characterize experimental three electrode photoelectrochemical storage cells incorporating n-$CdSe_xTe_{1-x}$ 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 $CdSe_xTe_{1-x}$ electrodes.
- Evaluate the storage electrode chemistry.
- Evaluate a three electrode module.

Status/FY 1983 Accomplishments:

- $CdSe_{1-x}Te_x$ photoanodes can be prepared by electroplating yielding efficiencies up to 4.5% over 20 cm^2 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^{+4} dissolution can be suppressed yielding a stable storage system.
- Preliminary long term stability tests have been conducted for n-$CdSe_{1-x}Te_x$ 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^2 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 witn In-Situ Storage; Final Report.* 29 pp.

Summary Date
October 1983

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:

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

Contract Funding: FY 1983 $ 564,000

Source: 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 $(CdZn)S/CuInSe_2$ 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 $CuInSe_2$.
- Provide interactions with Brazil and Saudi Arabia and solar cell R&D.

Major Project Reports:

- Jamjoum, O.; Kazmerski, L.L.; Lichten, D.L.; Bachmann, K.J. (December 1982). "Low Energy Electron Loss Studies of $CuInSe_2$ 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 $CuInSe_2$." *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 1); pp. 395-398.

Summary Date
October 1983

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:

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

Contract Funding:		**Source:**
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 analyzying diagnostic device structures, especially in III-V and I-III-VI_2 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 $CuInSe_2$.
- 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.; Jamjoum, 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 $CdS/CuInSe_2$ 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.
- 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:

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

Contract Funding: FY 1983 $ 578,000

Source: 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 μm.
- 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/$CuInSe_2$, 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

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

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

Project/Area/Task: PV Devices and Measurements

Contract Funding:

		Source:
FY 1981	$ 41,500	SERI
FY 1982	$ -0-	
FY 1983	$ -0-	

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 $CuInSe_2$ 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

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

Project/Area/Task: PV Devices and Measurements

Contract Funding:		**Source:**
FY 1981	**$** 84,800	SERI
FY 1982	**$** -0-	
FY 1983	**$** -0-	

Objectives: To identify the electronic structure and electrical properties of grain boundaries in $CuInSe_2$ and InP.

Approach/Present Tasks:

- Prepare bulk polycrystalline $CuInSe_2$ 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-$CuInSe_2$ reported.

FY 1984 Milestones: None. Program completed.

Major Project Reports:

- Wagner, S. (September 1982). *Identification of Electronic Structure of Grain Boundaries in Polycrystalline $CuInSe_2$ and InP; Progress Report.*
- Wagner, S. (April 1983). *Investigations of Polycrystalline InP and $CuInSe_2$; Final Report.*

Summary Date
October 1983

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

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

Project/Area/Task: PV Devices and Measurements

Contract Funding: **Source:**

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

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 $CuInSe_2$.
- 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 $CuInSe_2$.
- 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 $CuInSe_2$ 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:

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

Project/Area/Task: Polycrystalline Silicon

Contract Funding:		**Source:**
FY 1982	$ 35,000	SERI
FY 1983	$ 35,000	SERI

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^2/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 sillicon 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)

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

Project/Area/Task: Polycrystalline Silicon

Contract Funding:		Source:
FY 1981	$ 319,960	SERI
FY 1982	$ 220,902	SERI

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^2 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

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

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

Project/Area/Task: Polycrystalline Silicon

Contract Funding:		Source:
FY 1979	**$** 232,311	DOE
FY 1980	**$** 149,970	SERI
FY 1981	**$** 119,199	SERI
FY 1982	**$** 35,000	SERI

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

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

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

Contract Funding: FY 1983 $ 50,182

Source: SERI

Project/Area/Task: Polycrystalline Silicon

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

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:		**Source:**
FY 1979	**$** 99,700	SERI
FY 1980	**$** 166,300	SERI
FY 1981	**$** 514,000	SERI
FY 1982	**$** 402,059	SERI
FY 1983	**$** 349,488	SERI

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

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:		**Source:**
FY 1983	$ 60,000	SERI

Project/Area/Task: Polycrystalline Silicon

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

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:		**Source:**
FY 1983	**$** 60,000	**SERI**

Project/Area/Task: Polycrystalline Silicon

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

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

Contract Number: 9078-1 (2076-1)

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

Project/Area/Task: Polycrystalline Silicon

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

Contract Funding:		Source:
FY 1980	$ 200,300	SERI
FY 1981	$ 250,000	SERI
FY 1982	$ 175,000	SERI
FY 1983	$ 125,000	SERI

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

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

Directing Organization:
Solar Energy Research Institute

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

Contract Number: 2009-1

Current Contract Period From: 12/1/81
To: 11/30/82

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 l/C^2 plots when an interfacial layer is present. Constant l/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

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

Contract Number: (9109-01) 2113

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

Project/Area/Task: Polycrystalline Silicon

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

Contract Funding:		Source:
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

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 ($\approx 20\ \mu m$) and high diffusion length ($\approx 50\ \mu m$) 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

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

Current Contract Period From: 12/23/82
To: 12/31/83

Contract Funding:

		Source:
FY 1982	$ $117,976	SERI

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 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

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

Current Contract Period From: 9/18/78
To: 4/14/83

Project/Area/Task: Polycrystalline Silicon

Contract Funding:		Source:
FY 1978	$ 130,000	DOE
FY 1979	$ 122,227	SERI
FY 1981	$ 199,791	SERI
FY 1982	$ 100,000	SERI

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 S; and Interpretation." *Applied Physics Letters.* Vol. 52 (No. 2); pp. 176-178.

Summary Date
October 1983

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

Project/Area/Task: Polycrystalline Silicon

Directing Organization:
Solar Energy Research Institute

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

Contract Funding:		Source:
FY 1982	$ 94,585	SERI

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 ($1.5 \times 10^{20}/cm^3$) 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

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:

		Source:
FY 1979	$ 60,000	DOE
FY 1980	$ 109,400	SERI
FY 1981	$ 80,039	SERI
FY 1982	$ 60,000	SERI
FY 1983	$ 35,000	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_2 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/I-layer/ion implanted n^+/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

Current Contract Period From: 11/15/82
To: 11/14/83

Project/Area/Task: Polycrystalline Silicon

Contract Funding:

		Source:
FY 1982	**$** 147,319	SERI
FY 1983	**$** 100,000 (est.)	SERI

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

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

Project/Area/Task: Polycrystalline Silicon

Directing Organization:
Solar Energy Research Institute

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

Contract Funding:		**Source:**
FY 1982	**$** 114,010	SERI
FY 1983	**$** 125,000 (est.)	SERI

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:		Source:
FY 1982	$ 97,671	SERI
FY 1983	$ 180,000 (est.)	SERI

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

Principal Investigator: G.T. Noel
Telephone: (614) 424-7481

Contract Number: 9169-1

Current Contract Period From: 8/12/80
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:		**Source:**
FY 1980	**$** 368,061	SERI
FY 1981	**$** 314,400	SERI

Objectives: To determine the viability of high efficiency Cu_2S/CdS and $CdS/CuInSe_2$ 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 Cu_2S/CdS and $CdS/CuInSe_2$ 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 $CdS/CuInSe_2$ 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

Title: $CdS/CuInSe_2$ 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)

Current Contract Period From: 7/1/83
To: 6/30/84

Project/Area/Task: Polycrystalline Thin Films

Contract Funding:		Source:
FY 1982	$ 250,000	SERI
FY 1983	$ 250,000	SERI

Objectives: To develop high-efficiency (over 12%) $CuInSe_2/CdZnS$-based devices.

Approach/Present Tasks:
- Further optimize $CuInSe_2/CdZnS$ device to produce the highest possible efficiencies.
- Incorporate Ga atoms into $CuInSe_2$ films to raise the bandgap and open-circuit voltage.
- Investigate the possibility of developing Ionized-Cluster Beam Deposition of $CuInSe_2$.
- Investigate $CuInSe_2$ device behavior, with emphasis on O_2 heat treatment.

Status/FY 1983 Accomplishments:
- A 10.5% efficient $CuInSe_2/CdZnS$ 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^2 $CdZnS/CuInSe_2$ device.
- Assess the feasibility of incorporating Ga in $CuInSe_2$ films.
- Assess the feasibility of using ion-assisted cluster-beam deposition for $CuInSe_2$ 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: $CuInSe_2/CdS$ 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

Current Contract Period From: 5/14/82
To: 5/13/83

Project/Area/Task: Polycrystalline Thin Films

Contract Funding:		Source:
FY 1976	$ 177,500	ERDA
FY 1978	$ 177,500	DOE
FY 1979	$ 185,760	SERI
FY 1980	$ 521,023	SERI
FY 1981	$ 250,000	SERI
FY 1982	$ 250,000	SERI

Objectives: To perform research leading to the development of a large area, low cost, stable polycrystalline thin film photovoltaic solar cell based upon the $CdS/CuInSe_2$ material system.

Approach/Present Tasks:
- Lattice-match (Cd,Zn)S to $CuInSe_2$ 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) $CdZnS/CuInSe_2$ 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 $CuInSe_2$ 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, YR.; Chen, W.S.; Mickelsen, R.A.; Stewart, J.M.; Lowe, S.; Olsen, L.C.; Rothwarf, A. (May 1983). *$CuInSe_2/CdS$ Thin-Film Solar Cell Development; Final Report.* Seattle, WA: Boeing Aerospace Company.

Summary Date
October 1983

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:		Source:
FY 1979	$ 77,869	DOE
FY 1980	$ 77,581	SERI
FY 1981	$ 76,609	SERI
FY 1982	$ 80,000	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-$CuSe_{2-x}$ heterojunctions and Cu_2Se/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^2 area.

Major Project Reports:

- Cross, D.A.; Stewart, J.M; Chen, W.S. (October 1982). *CdS/Cu_2 Cell Research, Copper Selenide-Based Thin Film Solar Cells; Final Report*. Seattle, WA: Boeing Aerospace Co.; 27 pp.

Summary Date
October 1983

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

Current Contract Period From: 5/1/83
To: 6/30/84

Contract Funding: FY 1983 $ 29,000

Source: SERI

Project/Area/Task: Polycrystalline Thin Films

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

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

Current Contract Period From: 5/18/81
To: 5/31/84

Project/Area/Task: Polycrystalline Thin Films

Contract Funding:		Source:
FY 1981	$ 26,600	SERI
FY 1982	$ 14,000	SERI
FY 1983	$ 19,993	SERI

Objectives: To improve the performance of $CuInSe_2$ 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 $CuInSe_2$/(Cd,Zn)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 $CuInSe_2$/Mo interface of annealed $CuInSe_2$/CdS cells.
- Identified a barrier shift due to traps at the $CuInSe_2$/(Cd,Zn)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 $CuInSe_2$(Cd,Zn)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 $CuInSe_2$ 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

Current Contract Period From: 8/23/83
To: 10/23/84

Contract Funding: FY 1983 $ 30,000

Source: SERI

Project/Area/Task: Polycrystalline Thin Films

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 resisitivities 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_3P_2 films at the University of Delaware.
- The optimized ZnSe films shall be deposited on single crystal Zn_3P_2 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_3P_2 wafers with resistivity less than 100 ohm-cm.
- Complete characterization of heterojunction properties for sample $ZnSe/Zn_3P_2$ devices.

Major Project Reports: None. New program.

Summary Date
October 1983

Title: The Preparation and Properties of $CuInSe_2$ 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

Current Contract Period From: 4/1/82
To: 5/31/84

Contract Funding:

		Source:
FY 1982	$ 77,302	SERI
FY 1983	$ 78,000	SERI

Project/Area/Task: Polycrystalline Thin Films

Objectives: To (1) investigate various $CuInSe_2$ crystal growing techniques; (2) grow high-quality $CuInSe_2$; 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 $CuInSe_2$ for various device/research tasks.

Status/FY 1983 Accomplishments:
- High-quality $CuInSe_2$ crystal samples have been grown by the zone-leveling method.
- $CuInSe_2$ samples have been provided to both SERI in-house researchers and to subcontractors, including Princeton.

FY 1984 Milestones:
- Grow and characterize off-stoichiometric $CuInSe_2$ crystals.
- Grow $CuInS_{2y}Se_{2-2y}$ 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-$CuInSe_2$/I^-=I_2-Cu^+-HI/C." *Nature* (in press).
- Bachmann, K.J.; Fearheily, M. (March 1983). *The Preparation and Properties of $CuInSe_2$ Crystals; Annual Report*. Raleigh, NC: North Carolina State University.

Summary Date
October 1983

SERI

Title: $CuInSe_2$ 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

Current Contract Period From: 11/82
To: 2/14/85

Project/Area/Task: Polycrystalline Thin Films

Contract Funding:		**Source:**
FY 1982	125,000	SERI
FY 1983	$110,000	SERI

Objectives: To develop thin film $CuInSe_2$ devices using the close-spaced vapor transport method and to investigate various heterojunction partners to $CuInSe_2$.

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 $CuInSe_2$ 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-$CuInSe_2$.

Major Project Reports:

- Loh, C.W.; Yu, J.M.; Chu, T.L.; Chu, S.S. (November 1983). *CVD-Deposited $CuInSe_2$ Thin Film Materials Research; Annual Report.* Garland, TX: Poly Solar, Inc.

Summary Date
October 1983

SERI

Title: Optimization of p-$CuInSe_2$/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

Current Contract Period From: 5/2/82
To: 1/31/84

Project/Area/Task: Polycrystalline Thin Films

Contract Funding:

		Source:
FY 1982	**$** 135,386	SERI
FY 1983	**$** 20,000	SERI

Objectives: To fabricate and optimize the efficiency of single-crystal $CuInSe_2$/(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 $CuInSe_2$, 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/$CuInSe_2$ solar cell — 31 January 1984.

Major Project Reports:

- Becker, K.D.; Wagner, S. (1983). "Temperature-Dependent Nuclear Magnetic Resonance in $CuInVI_2$ Chalcopyrite Compounds." *Physical Review B* (in press).

Summary Date
October 1983

Title: Development of Thin Film Monolithic Cascade $ZnSiAs_2$ 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

Current Contract Period From: 8/1/82
To: 1/31/84

Contract Funding:		**Source:**
FY 1982	**$** 137,000	SERI

Project/Area/Task: Polycrystalline Thin Film

Objectives: To develop a monolithic $ZnSiAs_2/Si$ two-junction solar cell.

Approach/Present Tasks: Difficulties encountered in developing the cascade geometry required to subcontractor to direct attention to the $CdS/ZnSiAs_2$ component of the device.

Status/FY 1983 Accomplishments:

- Several $CdS/ZnSiAs_2$ 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 $ZnSiAs_2$ 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

Contract Number: 9286-1 (2097-1)

Current Contract Period From: 7/1/79
To: 3/31/85

Project/Area/Task: Polycrystalline Thin Films

Project Engineer: K. Zweibel
Telephone: (303) 231-7141

Contract Funding:		**Source:**
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

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 mA/cm^2, V_{oc} = 0.71 V, FF = 0.61, and an efficiency of 7.8% (1-cm^2 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.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.; 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 $CuInSe_2$

Contractor:
SRI International
333 Ravenwood Ave.
Menlo Park, CA 94025

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/Area/Task: Polycrystalline Thin Films

Directing Organization:
Solar Energy Research Institute

Project Engineer: R.L. Mitchell
Telephone: (303) 231-1379

Contract Funding:		Source:
FY 1981	$ 65,000	SERI

Objectives: To determine the temperature and pressure conditions under which $CuInSe_2$ 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 $CuInSe_2$ 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 $CuInSe_2$ to determine species and temperature/pressure diagrams.
- Torsion-effusion measurements on vapor phase in equilibrium with solid $CuInSe_2$ to determine vapor pressure.

Status/FY 1983 Accomplishments:

- Mass spectrometry shows major vaporization species from $CuInSe_2$ are Se_2 and In_2Se. Minor species are $InSe_2$, In, and Se with Cu_2Se 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 $CdS/CuInSe_2$ 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

Contract Number: 8104-4 (2115-1)

Current Contract Period From: 9/1/79
To: 10/31/83

Project/Area/Task: Polycrystalline Thin Films

Project Engineer: R.L. Mitchell
Telephone: (303) 231-1379

Contract Funding:		Source:
FY 1979	$ 173,309	SERI
FY 1980	$ 97,820	SERI
FY 1981	$ 243,292	SERI
FY 1982	$ 163,326	SERI

Objectives: (1) To continue the development and characterization of chemically sprayed CdS, $CuInSe_2$, and $Cd_xZn_{1-x}S$ 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-$CuInSe_2$/CdS and p-$CuInSe_2/Cd_xZn_{1-x}S$ layers formed by spray pyrolyis.
- 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 $CuInSe_2$ films with mobilities near 1 cm^2/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

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

Current Contract Period From: 4/1/79
To: 7/31/83

Project/Area/Task: Polycrystalline Thin Films

Contract Funding:		**Source:**
FY 1979	**$** 51,280	SERI
FY 1980	**$** 120,300	SERI
FY 1981	**$** -0-	SERI
FY 1982	**$** 13,343	SERI

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

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

Current Contract Period From: 2/26/79
To: 3/31/84

Project/Area/Task: Polycrystalline Thin Films

Contract Funding:		Source:
FY 1979	$ 109,013	SERI
FY 1981	$ 151,962	SERI
FY 1982	$ 40,000	SERI

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.

Ma'or 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

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

Current Contract Period From: 9/29/80
To: 2/15/84

Project/Area/Task: Polycrystalline Thin Films

Contract Funding:

		Source:
FY 1981	$ 130,119	SERI
FY 1982	$ 118,616	SERI

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

Title: $CuInSe_2$ 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

Current Contract Period From: 3/31/82
To: 3/31/84

Contract Funding:		**Source:**
FY 1982	$ 333,048	SERI

Project/Area/Task: Polycrystalline Thin Films

Objectives: To develop a large-area deposition technique and a concommitant high-efficiency cell design for polycrystalline thin-film $CuInSe_2$ via: (1) the sputtering of $CuInSe_2$ 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 μm) intrinsic layer of $CuInSe_2$.

Approach/Present Tasks: The approach involved includes the optimization of sputtered $CuInSe_2$, the construction of an in-line sputtering system for a multilayered cell, and the investigation of optimal $CuInSe_2$ cell geometries.

Status/FY 1983 Accomplishments:

- A 4% cell efficiency and 33 mA/cm^2 cell current were demonstrated as proof-of-concept for the sputtering system for $CdS/CuInSe_2$ 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 $CdS/CuInSe_2$ on the in-line system.
- Study the feasibility of a p-i-n device geometry for $CuInSe_2$.

Major Project Reports:

- Thornton, J.A. (1983). "Reactive Sputtered $CuInSe_2$ 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

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

Current Contract Period From: 7/1/81
To: 6/30/84

Project/Area/Task: Polycrystalline Thin Films

Contract Funding:

		Source:
FY 1981	$ 10,354	SERI
FY 1982	$ 12,625	SERI

Objectives:
- Characterize a-Si:H charge transport and band-tail states.
- Investigate charge transport in a wide range of polycrystalline materials, including $CuInSe_2$.

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 $CuInSe_2$ polycrystalline $CuInSe_2$, 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

Title: Development of Stable High Efficiency Polycrystalline Thin Film Solar Cells Based on $CuInSe_2$

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)

Current Contract Period From: 3/16/82
To: 5/15/84

Project/Area/Task: Polycrystalline Thin Films

Contract Funding:

		Source:
FY 1982	$ 441,240	SERI
FY 1983	$ 570,000	SERI

Objectives: To develop the optimum design and deposition of $(Cd,Zn)S/CuInSe_2$ thin film photovoltaic devices which maximize cell efficiencies while maintaining high stability, and to develop polycrystalline cascade cells based on $CuInSe_2$ bottom cells.

Approach/Present Tasks:
- Develop and fabricate $(CdZn)S/CuInSe_2$ solar cell through Knudsen cell deposition and through open-boat deposition.
- Characterize the $(CdZn)S/CuInSe_2$ solar cell through illuminated IV spectral response, capacitance, laser scanning, SEM, and EBIC testing.
- Develop a CdS/CdTe tandem cell using Knudsen sources for CdTe deposition and a $CuInSe_2$ bottom cell.

Status/FY 1983 Accomplishments:
- Successfully fabricated several $CuInSe_2/CdS$ small area cells with efficiencies greater than 7%.
- Preliminary modeling studies completed.
- Stoichiometric CdTe films deposited; high resistivities produced by post-deposition anneals.

FY 1984 Milestones:
- Demonstrated controlled doping of CdTe using Knudsen cell deposition.
- Demonstrated CdS/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 $CuInSe_2$; 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

Current Contract Period From: 4/15/79
To: 5/1/84

Project/Area/Task: Polycrystalline Thin Films

Contract Funding:		**Source:**
FY 1980	**$** 54,500	SERI
FY 1981	**$** -0-	
FY 1982	**$** 26,000	SERI

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 $CuInSe_2$ thin film devices are regarded as the main object of study.

Approach/Present Tasks:
- Derive current-voltage characteristics of $CuInSe_2$ solar cells from basic device physics and postulated or measured junction properties.
- Provide theoretical guidance to experimentalists for higher $CuInSe_2$ solar cell efficiencies.

Status/FY 1983 Accomplishments:
- Predicted open-circuit voltage increase in $CuInSe_2$ devices when the material's resistivity is decreased.
- Developed sophisticated computer model for the $CdZnS/CuInSe_2$ 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 $CuInSe_2$ devices.
- A summary report will suggest strategies for improving $CuInSe_2$ devices.

Major Project Reports:

- Boer, K.W. (June 15, 1983). *Polycrystalline Semiconductor Heterojunction Modeling ($CdS/CuInSe_2$); 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:		Source:
FY 1979	$ 425,164	SERI
FY 1980	$ 248,210	SERI
FY 1981	$ 363,394	SERI
FY 1982	$ 224,963	SERI
FY 1983	$ 150,716	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^2.
- 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

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

Current Contract Period From: 9/1/83
To: 10/31/84

Contract Funding:

		Source:
FY 1983	$ 47,000	SERI

Project/Area/Task: Polycrystalline Thin Films

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

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. Szedon
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:		Source:
FY 1977	$ 170,500	ERDA
FY 1978	$ 170,500	DOE
FY 1979	$ 285,251	SERI
FY 1980	$ 201,849	SERI
FY 1981	$ 144,612	SERI

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_2S 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_2S solar cells. The aging time for a 50% degradation in J_{sc} of treated cells was 260 hrs as compared to 35 hrs for untreated cells.

FY 1984 Milestones:

- Complete Final Report.

Major Project Reports:

- Szdeon, 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:

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

Project/Area/Task: Solid State Research

Contract Funding:		Source:
FY 1983	$ 830,000	DOE

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 photoconductivity.
- a-Si p-i-n junctions fabricated using the following configuration: stainless steel/p^+/i/n^+/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 $cm^2s^{-1}v^{-1}$ unlike 1000 $cm^2s^{-1}v^{-1}$ 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:

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

Project/Area/Task: Solid State Research

Contract Funding:

		Source:
FY 1982	\$ 496,000	DOE
FY 1983	\$ 453,000	DOE

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 $CuInSe_2$ 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 $CuInSe_2$ 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

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:

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

Contract Funding: | **Source:**
FY 1983 $ 275,000 | DOE

Project/Area/Task: Solid State Research

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 Cu_3Si.
- 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 -Cu." *Journal of Applied Physics* (submitted for publication).
- Olsen, J.M. (1983). "Silicon Electrorefining and the Transport Properties of Cu_3Si." "*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

Objectives: To formulate a self-consistent, quantum-mechanical model for the electronic structures of semiconductors. 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, $CuGaS_2$, $CuInS_2$, $CuAlSe_2$, $CuGaSe_2$, and $CuInSe_2$ 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) $CuInSe_2$ mixed basis bands, (3) the impurity set of programs, to run on CYBER 205 and reproduce results of CDC 7600 — April 1984.
- Theroetical 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 $CuInSe_2$-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_2 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:

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

Contract Funding:

		Source:
FY 1982	\$ 265,000	DOE
FY 1983	\$ 450,000	DOE

Project/Area/Task: Solid State Research

Objectives: Fabricate and characterize promising thin film solar cell materials and devices.

Approach/Present Tasks:
- Study of thin film growth of $CuInSe_2$ 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 $CuInSe_2$ films.
- Fabricated and characterized $CuInSe_2$/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 $CuInSe_2$ (Report) — December 1983.
- Conclude the studies on CdTe deposition by hotwall evaporation process.
- Quantitatively establish the role of two layers of $CuInSe_2$ in CdS/$CuInSe_2$ 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/$CuInSe_2$ 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/$CuInSe_2$ 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:

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

Project/Area/Task: Solid State Research

Contract Funding:

		Source:
FY 1983	**$** 442,000	DOE
FY 1983	**$** 474,000	DOE

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 $GaAs_{1-x}P_x$/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

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

Current Contract Period:

Contract Funding:

		Source:
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

Title: Photovoltaic Array/Power Conditioner Interface Requirements Study

Contractor:
In-House

Directing Organization:
Jet Propulsion Laboratory

Principal Investigator: C. Gonzalez
Telephone: (213) 577-9115

Contract Number: Not applicable

Current Contract Period From: 05/81
To: 06/83

Project/Area/Task: Flat-Plate Solar Array Project; Engineering Sciences Area

Project Engineer: R. Ross
Telephone: (213) 577-9111

Contract Funding:		**Source:**
FY 1981	**$** 35,000	DOE
FY 1982	**$** 144,000	DOE
FY 1983	**$** 20,000	DOE

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

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

Current Contract Period From: FY 1981
To: FY 1983

Project/Area/Task: Flat-Plate Solar Array Project; Engineering Sciences Area

Contract Funding:		Source:
FY 1981	$ 50,000	DOE
FY 1982	$ 200,000	DOE
FY 1983	$ 50,000	DOE

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

Principal Investigator: G. Royal
Telephone: (202) 626-7524

Contract Number: 955893

Current Contract Period From: 11/80
To: 12/81

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:		Source:
FY 1981	$ 391,288	DOE
FY 1982	$ (5,137)	DOE
FY 1983	$ 10,000	DOE

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

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

Current Contract Period From: 12/77
To: 10/84

Project/Area/Task: Flat-Plate Solar Array Project; Engineering Sciences Area

Contract Funding:

		Source:
FY 1978	$ 123,649	DOE
FY 1979	$ 110,534	DOE
FY 1980	$ 81,308	DOE
FY 1981	$ 105,134	DOE
FY 1982	$ 119,905	DOE
FY 1983	$ 180,334	DOE

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

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:		Source:
FY 1982	$ 77,974	DOE
FY 1983	$ 156,848	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

Current Contract Period From: 05/79
To: 03/83

Project/Area/Task: Flat-Plate Solar Array Project; Engineering Sciences Area

Contract Funding:		Source:
FY 1979	$ 65,730	DOE
FY 1980	$ 54,100	DOE
FY 1981	$ 111,689	DOE
FY 1982	$ 80,000	DOE
FY 1983	$ -0-	DOE

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

Title: Investigation of Photovoltaic Module and Array Materials

Contractor:
Underwriters Laboratories, Inc.
333 Pfingsteen 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

Current Contract Period From: 11/82
To: 10/83

Contract Funding:		**Source:**
FY 1983	**$** 53,051	DOE

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

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

Current Contract Period From: 08/80
To: 09/83

Project/Area/Task: Flat-Plate Solar Array Project; Engineering Sciences Area

Contract Funding:		**Source:**
FY 1980	$ 57,400	DOE
FY 1981	$ -0-	DOE
FY 1982	$ 147,000	DOE
FY 1983	$ 100,000	DOE

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

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

Current Contract Period From: FY 1982
To: on-going

Project/Area/Task: Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area

Contract Funding:		**Source:**
FY 1982	**$** 679,000	DOE
FY 1983	**$** 645,000	DOE

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

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

Current Contract Period From: FY 1982
To: on-going

Project/Area/Task: Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area

Contract Funding:		Source:
FY 1982	**$** 282,000	DOE
FY 1983	**$** 303,000	DOE

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

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

Current Contract Period From: FY 1983
To: on-going

Project/Area/Task: Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area

Contract Funding:

		Source:
FY 1982	$ 249,000	DOE
FY 1983	$ 257,000	DOE

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

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

Current Contract Period From:
To: on-going

Project/Area/Task: Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area

Contract Funding:

		Source:
FY 1982	$ 362,000	DOE
FY 1983	$ 291,000	DOE

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

Contract Number: Not applicable

Current Contract Period From: FY 1982
To: on-going

Project/Area/Task: Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area

Project Engineer: L. Runkle
Telephone: (213) 577-921;

Contract Funding:		**Source:**
FY 1982	**$** 315,000	DOE
FY 1983	**$** 280,000	DOE

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

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

Current Contract Period From: 09/82
To: 07/83

Contract Funding:		**Source:**
FY 1982	**$** 41,388	DOE
FY 1983	**$** -0-	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

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:

Contract Number: 956336

Current Contract Period From: 11/82
To: 07/83

Project/Area/Task: Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area

Project Engineer: M. Smokler
Telephone: (213) 577-9237

Contract Funding:		**Source:**
FY 1983	$ 45,667	DOE

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

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

Current Contract Period From: 01/83
To: 01/84

Contract Funding:

		Source:
FY 1983	**$** 64,045	DOE

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

Current Contract Period From: 09/82
To: 09/83

Contract Funding:		**Source:**
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

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

Current Contract Period From: 09/82
To: 01/84

Contract Funding:

		Source:
FY 1982	$ 83,302	DOE
FY 1983	$ -0-	DOE

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 m[illegible] (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

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

Current Contract Period From: 09/82
To: 07/83

Contract Funding:		**Source:**
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

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

Current Contract Period From: 09/82
To: 09/83

Project/Area/Task: Flat-Plate Solar Array Project; Module Performance and Failure Analysis Area

Contract Funding:		Source:
FY 1982	$ 16,516	DOE
FY 1983	$ -0-	DOE

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

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

Current Contract Period From: 12/82
To: 04/84

Contract Funding:		**Source:**
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

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

Current Contract Period From: 10/82
To: 12/84

Contract Funding:

		Source:
FY 1982	$ 408,000	DOE
FY 1983	$ 404,000	DOE

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Advanced Materials Research Task

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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

JPL

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

Current Contract Period From: 10/81
To: 09/83

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Component Research Area; Advanced Materials Research Task

Contract Funding:		Source:
FY 1982	$ 175,000	DOE
FY 1983	$ 178,000	DOE

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

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

Current Contract Period From: 03/77
To: 06/81

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Advanced Materials Research Task

Contract Funding:		**Source:**
FY 1976	**$** 208,393	DOE
FY 1977	**$** 427,408	DOE
FY 1978	**$** 499,832	DOE
FY 1979	**$** 273,854	DOE
FY 1980	**$** 687,345	DOE
FY 1981	**$** 364,139	DOE

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 954373-81/19. 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

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Advanced Materials Research Task

Directing Organization:
Jet Propulsion Laboratory

Project Engineer: R. Lutwack
Telephone: (213) 354-7648

Contract Funding:		**Source:**
FY 1983	**$** 50,000	DOE

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

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

Current Contract Period From: 10/79
To: 12/83

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Advanced Materials Research Task

Contract Funding:		**Source:**
FY 1980	**$** 727,000	DOE
FY 1981	**$** 783,000	DOE
FY 1982	**$** 510,450	DOE
FY 1983	**$** -0-	DOE

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

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

Current Contract Period From: 09/80
To: 05/82

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Advanced Materials Research Task

Contract Funding:		Source:
FY 1980	$ 153,440	DOE
FY 1981	$ 508,479	DOE
FY 1982	$ 132,634	DOE
FY 1983	$ -0-	DOE

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 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

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

Current Contract Period From: 10/75
To: 03/82

Project/Area/Task: Photovoltaic Components Research Area; Advanced Materials Research Task

Contract Funding:		**Source:**
FY 1978	**$** 777,010	DOE
FY 1979	**$** 965,996	DOE
FY 1980	**$** 659,042	DOE
FY 1981	**$** 659,042	DOE
FY 1982	**$** 129,451	DOE
FY 1983	**$** -0-	

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 ± 2 mil and to demonstrate maximum conversion efficiency for large area cell (50 cm^2) 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

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

Current Contract Period From: 07/82
To: 07/84

Contract Funding:

		Source:
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

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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

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

Current Contract Period From: 09/81
To: 10/83

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Advanced Materials Research Task

Contract Funding:		**Source:**
FY 1981	**$** 30,000	DOE
FY 1982	**$** 16,474	DOE
FY 1983	**$** -0-	DOE

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 distributer 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

Title: Investigation of Hydrochlorination of $SiCl_4$ 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:		**Source:**
FY 1981	**$** 35,000	DOE
FY 1982	**$** 165,790	DOE
FY 1983	**$** (17,885)	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.

MajorProject Reports:

- Mui, J.Y.P. (April 1983). *Investigation of the Hydrochlorination of $SiCl_4$ — 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 $SiCl_4$, 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 $SiCl_4$ — 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

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

Current Contract Period From: 10/75
To: 12/84

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Advanced Materials Research Task

Contract Funding:		Source:
FY 1978	**$** 851,621	DOE
FY 1979	**$** 1,236,000	DOE
FY 1980	**$** 4,354,000	DOE
FY 1981	**$** 5,402,000	DOE
FY 1982	**$** 555,000	DOE
FY 1983	**$** 430,000	DOE

Objectives: Contract objective is to conduct a program to establish the practicality of a process for high-volume, low-cost productin 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 Wahougal 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

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:		Source:
FY 1981	$ 16,489	DOE
FY 1982	$ 33,750	DOE
FY 1983	$ 46,000	DOE

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

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:
FY 1983	**$** 88,513	DOE

Current Contract Period From: 06/83
To: 07/84

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

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

Current Contract Period From: 10/80
To: 03/84

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Advanced Materials Research Task

Contract Funding:

		Source:
FY 1981	**$** 927,266	DOE
FY 1982	**$** 729,721	DOE
FY 1983	**$** 499,986	DOE

Objectives: 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

Title: Device Characterization Research

Contractor:
In-House

Directing Organization:
Jet Propulsion Laboratory

Principal Investigator:

Telephone:

Contract Number:

Current Contract Period From: 1982
To: on-going

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Device and Measurements Research Task

Project Engineer: T. Daud
Telephone: (213) 354-5782

Contract Funding:		**Source:**
FY 1982	**$** 200,000	DOE
FY 1983	**$** 75,000	DOE

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

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

Current Contract Period From: 05/78
To: 12/82

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Device and Measurements Research Task

Contract Funding:

		Source:
FY 1978	$ 223,920	DOE
FY 1979	$ 113,000	DOE
FY 1980	$ 302,572	DOE
FY 1981	$ 250,049	DOE
FY 1982	$ 112,429	DOE
FY 1983	$ 36,158	DOE

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

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

Project Engineer: T. Daud
Telephone: (213) 354-5782

Contract Number: 956369

Current Contract Period From: 10/82
To: 10/83

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, $p^+ - p^+/n$, have shown improved V_{oc}, 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

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

Contract Number: 956046

Current Contract Period From: 06/81
To: 05/82

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Device and Measurements Research Task

Project Engineer: L. Cheng
Telephone: (213) 354-3068

Contract Funding:		Source:
FY 1981	$ 20,000	DOE
FY 1982	$ 21,210	DOE
FY 1983	$ 42,043	DOE

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

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

Current Contract Period From: 06/80
To: 05/83

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Device and Measurements Research Task

Contract Funding:		**Source:**
FY 1980	**$** 80,000	DOE
FY 1981	**$** -0-	DOE
FY 1982	**$** 59,700	DOE
FY 1983	**$** 550	DOE

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^2, 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, disclocations, 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

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

Current Contract Period From: 04/83
To: 03/84

Contract Funding:		**Source:**
FY 1983	**$** 38,350	DOE

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

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

Current Contract Period From: 07/82
To: 08/84

Contract Funding:

		Source:
FY 1982	$ 69,853	DOE
FY 1983	$ -0-	DOE

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 μm (18% efficiency) to 40 μm (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

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:		**Source:**
FY 1982	**$** 28,834	JPL
FY 1983	**$** 59,311	DOE

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

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

Directing Organization:
Jet Propulsion Laboratory

Project Engineer: T. Daud
Telephone: (213) 354-5782

Contract Number: 956525

Current Contract Period From: 06/83
To: 05/84

Contract Funding:

		Source:
FY 1983	$ 55,000	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 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

JPL

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

Current Contract Period From: 09/82
To: 11/83

Contract Funding:

		Source:
FY 1982	$ 80,000	DOE
FY 1983	$ -0-	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 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 μm-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

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

Directing Organization:
Jet Propulsion Laboratory

Project Engineer: L. Cheng
Telephone: (213) 354-3068

Contract Number: 956613

Current Contract Period From: 09/83
To: 08/84

Contract Funding:

		Source:
FY 1983	$ 68,000	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

Title: Investigation of Silicon Surface Passivation by SiN_x 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

Directing Organization:
Jet Propulsion Laboratory

Project Engineer: R. Stirn
Telephone: (213) 577-9230

Contract Number: 956614

Current Contract Period From: 08/83
To: 08/84

Contract Funding:

		Source:
FY 1983	**$** 86,995	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_x 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_x films from transmission and reflectance data.

FY 1984 Milestones:
- SiN_x 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

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.

Current Contract Period From: FY 1977
To: on-going

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Environmental Isolation Research Task

Contract Funding:		Source:
FY 1982	$ 250,000	DOE
FY 1983	$ 150,000	DOE

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

Current Contract Period From: 12/79
To: 10/82

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Environmental Isolation Research Task

Contract Funding:		Source:
FY 1980	$ 120,000	DOE
FY 1981	$ 100,000	DOE
FY 1982	$ -0-	DOE
FY 1983	$ -0-	DOE

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

Current Contract Period From: 01/83
To: 09/85

Contract Funding:		**Source:**
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

Principal Investigator: D. Kaelble
Telephone: (904) 498-4545

Contract Number: 954739

Current Contract Period From: 03/77
To: 12/83

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Environmental Isolation Research Task

Directing Organization:
Jet Propulsion Laboratory

Project Engineer: D. Coulter
Telephone: (213) 354-3638

Contract Funding:		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

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

Current Contract Period From: 11/79
To: 12/83

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Environmental Isolation Research Task

Contract Funding:		**Source:**
FY 1980	$ 358,000	DOE
FY 1981	$ 300,000	DOE
FY 1982	$ 207,584	DOE
FY 1983	$ 94,558	DOE

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 replate 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 pottants. 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

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

Project Engineer: D. Fitzgerald
Telephone: (213) 577-9097

Contract Number: 956381

Current Contract Period From: 12/82
To: 09/83

Contract Funding: | **Source:**

FY 1983	**$** 103,377	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

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

Current Contract Period From: 05/76
To: 08/84

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Environmental Isolation Research Task

Contract Funding:		Source:
FY 1978	$ 190,000	DOE
FY 1979	$ 100,000	DOE
FY 1980	$ 121,666	DOE
FY 1981	$ 160,000	DOE
FY 1982	$ 112,153	DOE
FY 1983	$ 302,037	DOE

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

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

Current Contract Period From: 03/83
To: 01/84

Contract Funding: FY 1983 $ 12,915 **Source:** 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_2 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

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: O. Vogl
Telephone: (413) 545-0433

Directing Organization:
Jet Propulsion Laboratory

Project Engineer: A. Gupta
Telephone: (213) 354-5783

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

Contract Funding:

		Source:
FY 1979	$ 15,000	DOE
FY 1980	$ 32,000	DOE
FY 1981	$ 38,000	DOE
FY 1982	$ 100,000	DOE
FY 1983	$ -0-	DOE

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

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

Directing Organization:
Jet Propulsion Laboratory

Project Engineer: R. Liang
Telephone: (213) 354-6314

Contract Number: 956590

Current Contract Period From: 06/83
To: 09/83

Contract Funding:		**Source:**
FY 1983	**$** 7,500	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

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:		Source:
FY 1980	$ 55,000	DOE
FY 1981	$ 52,085	DOE
FY 1982	$ 108,100	DOE
FY 1983	$ 20,750	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

Current Contract Period From: FY 1981
To: FY 1984

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

Contract Funding:		Source:
FY 1982	$ 75,000	DOE
FY 1983	$ 34,000	DOE

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:

Contract Number: Not applicable

Current Conctract Period From: FY 1982
To: FY 1983

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

Project Engineer: D. Burger
Telephone: (213) 577-9374

Contract Funding:		Source:
FY 1982	**$** 35,000	DOE
FY 1983	**$** 64,000	DOE

Objectives: Large area (greater than 1-1/2 ft × 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

Current Contract Period From: 10/82
To: 09/83

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

Contract Funding:

		Source:
FY 1982	$ 20,000	DOE
FY 1983	$ 92,000	DOE

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

Title: Semix Material Processing

Contractor:
In-House

Directing Organization:
Jet Propulsion Laboratory

Principal Investigator:
Telephone:

Contract Number: Not applicable

Current Contract Period From: FY 1981
To: FY 1984

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

Project Engineer: P. Alexander
Telephone: (213) 577-9324

Contract Funding:		Source:
FY 1982	$ 70,000	DOE
FY 1983	$ 28,000	DOE

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

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

Current Contract Period From: 03/79
To: 10/84

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

Contract Funding:		Source:
FY 1979	$ 135,000	DOE
FY 1980	$ -0-	DOE
FY 1981	$ 75,000	DOE
FY 1982	$ 68,000	DOE
FY 1983	$ 27,000	DOE

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

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

Current Contract Period From: 05/80
To: 01/83

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

Contract Funding:

		Source:
FY 1980	**$** 113,716	DOE
FY 1981	**$** 20,000	DOE
FY 1982	**$** 69,260	DOE
FY 1983	**$** -0-	DOE

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

Current Contract Period From: 07/82
To: 07/84

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

Contract Funding:

		Source:
FY 1982	$ 60,000	Caltech
FY 1982	$ 10,000	In-House
FY 1983	$ 65,000	DOE

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 $CrSi_2$." *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_2Si 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 Amorhpous 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 $CrSi_2$ on Silicon." *Applied Physics Letters*. Vol. 43, (No. 3); pp. 247-249.

Summary Date
October 1983

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

Current Contract Period From: 05/81
To: 10/82

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

Contract Funding:

		Source:
FY 1981	**$** 79,000	JPL
FY 1982	**$** 45,859	JPL
FY 1983	**$** -0-	JPL

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 Metalizatioin 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

Current Contract Period From: 11/80
To: 12/83

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

Contract Funding:		Source:
FY 1981	$ 689,000	DOE
FY 1982	$ 192,154	DOE
FY 1983	$ -0-	DOE

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 resisitivity/thickness experiments — May 1983.
- Completed mini-cell experiments (400 cells on 100 cm^2 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

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

Current Contract Period From: 07/82
To: 12/82

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

Contract Funding:		**Source:**
FY 1982	**$** 29,025	DOE
FY 1983	**$** -0-	DOE

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_3N_4 (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

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

Current Contract Period From: 04/82
To: 11/83

Contract Funding:

		Source:
FY 1982	$ 202,709	DOE
FY 1983	$ -0-	DOE

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

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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

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

Current Contract Period From: 01/80
To: 02/82

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

Contract Funding:

Contract Funding:		Source:
FY 1980	**$** 865,000	DOE
FY 1981	**$** 600,000	DOE
FY 1982	**$** 320,000	DOE

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

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

Current Contract Period From: 11/82
To: 06/83

Contract Funding:

		Source:
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

Title: Analyses and Evaluation of Module Experimental Process System Development Unit Processes

Contractor:
The Trustees of the University of Pennsylvania
3451 Walnut Street, I6
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

Current Contract Period From: 05/81
To: 05/82

Project/Area/Task: Flat-Plate Solar Array Project; Photovoltaic Components Research Area; Process Research Task

Contract Funding:

		Source:
FY 1981	**$** 59,691	DOE
FY 1982	**$** -0-	DOE
FY 1983	**$** -0-	DOE

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:		Source:
FY 1981	$ 830,000	DOE
FY 1982	$ 538,886	DOE
FY 1983	$ -0-	DOE

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_2 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

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

Current Contract Period From: 09/83
To: 09/84

Contract Funding:

		Source:
FY 1983	**$** 203,421	DOE

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

Title: Project Analysis and Integration

Contractor:
In-House

Directing Organization:
Jet Propulsion Laboratory

Principal Investigator:
Telephone:

Contract Number: Not applicable

Current Contract Period From: 01/75
To: 12/88

Project/Area/Task: Flat-Plate Solar Array Project; Project Analysis and Integration Area

Project Engineer: P. Henry
Telephone: (213) 577-9414

Contract Funding:		**Source:**
FY 1982	**$** 591,000	DOE
FY 1983	**$** 520,000	DOE

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 $0.60/W$_p$. 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:		**Source:**
FY 1980	**$** 715,266	SNLA
FY 1981	**$** 836,446	SNLA
FY 1982	**$** 668,346	SNLA
FY 1983	**$** 210,000	SNLA
FY 1984	**$** -0-	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:		Source:
FY 1981	$ 983,400	SNLA
FY 1982	$ 56,000	SNLA
FY 1983	$ 56,010	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

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 identifed 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:

Current Contract Period From: 10/1/82
To: 09/30/83

Contract Funding: | **Source:**

FY 1983	**$** 83,000	DOE/PV

Project/Area/Task: Array Subsystem Development

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

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: FY 1983 $ 241,500

Source: DOE/PV

Current Contract Period From: 10/13/82
To: 02/5/84

Project/Area/Task: Array Subsystem Development

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

Current Contract Period From: 03/8/82
To: 07/15/83

Contract Funding:		Source:
FY 1982	$ 491,700	DOE/PV
FY 1983	$ -0-	DOE/PV

Project/Area/Task: Array Subsystem Development

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 thre 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 (≈ 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

Current Contract Period From: 02/15/82
To: 05/15/84

Project/Area/Task: Array Subsystem Development

Contract Funding:		**Source:**
FY 1982	**$** 297,500	DOE/PV
FY 1983	**$** 128,000	DOE/PV

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

Current Contract Period From: 08/15/82
To: 08/14/83

Contract Funding:

		Source:
FY 1982	$ 195,800	DOE/PV
FY 1983	$ -0-	

Project/Area/Task: Array Subsystem Development

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

Current Contract Period From: 03/19/82
To: 07/15/83

Contract Funding:

		Source:
FY 1982	**$** 467,600	DOE/PV
FY 1983	**$** 30,200	DOE/PV

Project/Area/Task: Array Subsystem Development

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

Current Contract Period From: 03/30/83
To: 12/30/83

Contract Funding:

		Source:
FY 1983	$ 411,700	DOE/PV

Project/Area/Task: Array Subsystem Development

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 (≈ 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

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

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

Directing Organization:
Sandia National Laboratories

Project Engineer: M. Rios, Jr.
Telephone: (505) 844-7812

Contract Number: 46-5791

Current Contract Period From: 10/82
To: 12/83

Project/Area/Task: Concentrator Arrays

Contract Funding:		Source:
FY 1981	**$** 349,000	DOE/PV
FY 1982	**$** 143,000	DOE/PV
FY 1983	**$** 6,000	DOE/PV
FY 1984	**$** 1,940	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 Laborratories 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^2 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

Directing Organization:
Sandia National Laboratories

Project Engineer: C. Chiang
Telephone: (505) 846-3254

Contract Number: 62-7219

Current Contract Period From: 05/11/81
To: 02/29/84

Contract Funding:

		Source:
FY 1981	**$** 391,000	DOE/PV

Project/Area/Task: Concentrator Arrays

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

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:		Source:
FY 1982	$ 252,890	DOE/PV
FY 1983	$ 246,932	DOE/PV

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

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:		Source:
FY 1981	$ 497,000	DOE/PV
FY 1982	$ 78,000	DOE/PV

Objectives: To design and develop a PV concentrator array for intermediate load applications. The array includes a tracking stucture, 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

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

Directing Organization:
Sandia National Laboratories

Project Engineer: M. Rios, Jr.
Telephone: (505) 844-7812

Contract Number: 67-7220

Current Contract Period From: 04/81
To: 10/82

Project/Area/Task: Concentrator Arrays

Contract Funding:

		Source:
FY 1981	**$** 344,000	DOE/PV
FY 1982	**$** 49,000	DOE/PV
FY 1983	**$** 4,600	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^2 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

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

Current Contract Period From: 08/09/82
To: 09/30/83

Project/Area/Task: Concentrator Arrays

Contract Funding:		Source:
FY 1982	$ 445,000	DOE/PV
FY 1983	$ 22,000	DOE/PV

Objectives: To fabricate a full array for evalution 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

Directing Organization:
Sandia National Laboratories

Project Engineer: M. Edenburn
Telephone: (505) 844-4003

Contract Number: 37-2358

Current Contract Period From: 11/18/82
To: 11/30/83

Contract Funding: FY 1983 $ 460,000

Source: DOE

Project/Area/Task: Concentrator Arrays

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

Directing Organization:
Sandia National Laboratories

Project Engineer: A. Maish
Telephone: (505) 844-8771

Contract Number: 61-5994

Current Contract Period From: 10/15/81
To: 01/15/83

Project/Area/Task: Concentrator Arrays

Contract Funding:

		Source:
FY 1981	$ 183,000	DOE/PV
FY 1982	$ 69,000	DOE/PV

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

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

Current Contract Period From: 09/83
To: 09/86

Contract Funding:

FY 1983	$ 50,000	**Source:** DOE/PV

Project/Area/Task: Concentrator Arrays

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:

Current Contract Period From:
To:

Contract Funding: FY 1983 $ 610,000

Source: DOE

Project/Area/Task: Concentrator Cell Research

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 reliabily 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:

Current Contract Period From:
To:

Contract Funding:		**Source:**
FY 1983	$ 432,000	DOE

Project/Area/Task: Concentrator Cell Research

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 obcuration 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:

Current Contract Period From:
To:

Contract Funding:

		Source:
FY 1983	**$** 200,000	DOE/PV

Project/Area/Task: Concentrator Cell Research

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

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

Current Contract Period From: 06/82
To: 11/83

Contract Funding:		**Source:**
FY 1982	$ 200,000	DOE

Project/Area/Task: Concentrator Cell Research

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 peripherial buss area have been fabricated. Cells of 0.15 Ω-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

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

Current Contract Period From:
To:

Contract Funding:		**Source:**
FY 1983	$ 235,000	DOE

Project/Area/Task: Concentrator Cell Research

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_2 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

Current Contract Period From: 08/83
To: 08/84

Contract Funding:		**Source:**
FY 1983	**$** 75,000	DOE/PV

Project/Area/Task: Concentrator Cell Research

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

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

Current Contract Period From: 06/1/82
To: 03/31/83

Contract Funding:

		Source:
FY 1982	**$** 80,000	DOE/PV

Project/Area/Task: Concentrator Cell Research

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 Ω-cm cells. For .15 Ω-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

Current Contract Period From:
To:

Contract Funding:		**Source:**
FY 1983	**$** 35,000	DOE

Project/Area/Task: Concentrator Cell Research

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

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

Current Contract Period From: 10/15/81
To: 05/15/83

Contract Funding:

		Source:
FY 1981	$ 250,000	DOE/PV
FY 1982	$ 70,000	DOE/PV

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

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

Current Contract Period From: 06/83
To: 06/84

Contract Funding:

		Source:
FY 1983	**$** 63,500	DOE/PV
FY 1984	**$** 168,500	DOE/PV

Project/Area/Task: Concentrator Cell Research

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

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

Current Contract Period From: 04/82
To: 04/83

Project/Area/Task: Concentrator Cell Research

Contract Funding:

		Source:
FY 1982	$ 252,000	DOE/PV

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_2 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

Current Contract Period From: 02/1/81
To: 12/15/82

Contract Funding:		**Source:**
FY 1981	**$** 349,000	DOE/PV

Project/Area/Task: Concentrator Cell Research

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

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

Current Contract Period From: 10/82
To: 10/83

Contract Funding:		**Source:**
FY 1982	**$** 200,000	DOE/PV

Project/Area/Task: Concentrator Cell Research

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^+nn^+ 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

Directing Organization:
Sandia National Laboratories

Project Engineer: D. E. Arvizu
Telephone: (505) 846-0387

Contract Number: 52-5675

Current Contract Period From: 04/83
To: 04/84

Contract Funding: FY 1983 $ 75,000

Source: DOE/PV

Project/Area/Task: Concentrator Cell Research

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

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

Directing Organization:
Sandia National Laboratories

Project Engineer: D. E. Arvizu
Telephone: (505) 846-0387

Contract Number: 73-6299

Current Contract Period From: 01/82
To: 01/83

Project/Area/Task: Concentrator Cell Research

Contract Funding:		Source:
FY 1982	$ 50,000	DOE/PV
FY 1983	$ 24,744	DOE/PV

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

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

Current Contract Period From: 08/83
To: 08/84

Project/Area/Task: Concentrator Cell Research

Contract Funding:		**Source:**
FY 1983	**$** 16,000	DOE/PV
FY 1984	**$** 84,000	DOE/PV

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

Current Contract Period From: 10/1/81
To: 09/31/82

Project/Area/Task: Concentrator Cell Research

Contract Funding:		Source:
FY 1981	$ 30,000	DOE/PV
FY 1983	$ 30,000	DOE/PV
FY 1983	$ -0-	

Objectives: To investigate amphorous 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_2O_2. 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

Current Contract Period From: 09/83
To: 09/84

Project/Area/Task: Concentrator Cell Research

Contract Funding:		**Source:**
FY 1983	**$** 15,700	DOE/PV
FY 1984	**$** 159,300	DOE/PV

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

Current Contract Period From: 11/15/81
To: 05/1/83

Contract Funding:

		Source:
FY 1982	**$** 302,000	DOE/PV
FY 1983	**$** -0-	

Project/Area/Task: Concentrator Cell Research

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 μm) 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

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

Current Contract Period From: 12/3/80
To: 06/82

Project/Area/Task: Concentrator Cell Research

Contract Funding:		**Source:**
FY 1981	**$** 175,000	DOE/PV
FY 1982	**$** 29,000	DOE/PV
FY 1983	**$** -0-	

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

Current Contract Period From: 01/15/81
To: 12/10/82

Project/Area/Task: Concentrator Cell Research

Contract Funding:		Source:
FY 1981	$ 81,000	DOE/PV
FY 1982	$ 23,000	DOE/PV
FY 1983	$ -0-	

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

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 silicons look very promising as high-conductivity assembly-to-heat exchanger bonds. Fatigue and tin migratice 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

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

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

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: FY 1983 $ 300,000

Source: DOE/PV

Current Contract Period From:
To: 06/83

Project/Area/Task: Concentrator Module Research

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

Current Contract Period From: 12/01/83
To: 03/01/85

Contract Funding:		**Source:**
FY 1983	**$** 100,000	DOE/PV

Project/Area/Task: Concentrator Module Research

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 paramters, make the lens masters, and start the molding trials by the end of FY 1984.

Major Project Reports: None.

Summary Date
December 1983

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

Current Contract Period From: 03/3/81
To: 04/30/83

Project/Area/Task: Concentrator Module Research

Contract Funding:		**Source:**
FY 1981	$ 390,840	DOE/PV
FY 1982	$ 35,684	DOE/PV

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

Current Contract Period From: 02/11/81
To: 11/30/82

Contract Funding:		**Source:**
FY 1981	$ 270,000	DOE

Project/Area/Task: Concentrator Module Research

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 Encapsulent 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

Current Contract Period From: 03/12/82
To: 09/30/82

Contract Funding:		**Source:**
FY 1982	$ 33,000	DOE

Project/Area/Task: Concentrator Module Research

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

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

Current Contract Period From: 08/6/81
To: 11/30/83

Contract Funding:

		Source:
FY 1981	$ 145,000	DOE
FY 1983	$ 49,348	DOE

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°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

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:		Source:
FY 1981	$ 20,000	DOE

Project/Area/Task: Concentrator Module Research

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

Directing Organization:
Sandia National Laboratories

Project Engineer: M. Rios, Jr.
Telephone: (505) 844-7812

Contract Number: 37-7490

Current Contract Period From: 12/82
To: 04/84

Contract Funding:		**Source:**
FY 1983	$ 97,231	DOE/PV
FY 1984	$ 51,937	DOE/PV

Project/Area/Task: Concentrator Module Research

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 Ω-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 Ω-cm to 1.5 Ω-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 Ω-cm to 1.5 Ω-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 Ω-cm. The cells will be tested and a report will be issued.

Major Project Reports: None.

Summary Date
December 1983

Title: Third-Generation Module Development

Contractor:
Entech, Inc.
P.O. Box 612246
DFW Airport
Dallas, TX 75261

Directing Organization:
Sandia National Laboratories

Principal Investigator: M. J. O'Neill
Telephone: (214) 272-0515 ext. 3830

Project Engineer: M. Rios, Jr.
Telephone: (505) 884-7812

Contract Number: 52-1485

Current Contract Period From: 03/10/83
To: 09/84

Contract Funding:

		Source:
FY 1983	$ 43,510	DOE/PV
FY 1984	$ 255,759	DOE/PV

Project/Area/Task: Concentrator Module Research

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 inear 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:		Source:
FY 1981	$ 236,800	DOE
FY 1982	$ 50,072	DOE

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, const' ıction 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^2 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:		**Source:**
FY 1982	**$** 197,626	DOE/PV
FY 1983	**$** 49,403	DOE/PV
FY 1984	**$** 46,963	DOE/PV

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:		Source:
FY 1979	$ 213,900	DOE/PV
FY 1980	$ -0-	DOE/PV
FY 1981	$ -0-	DOE/PV
FY 1982	$ 50,328	DOE/PV

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

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

Directing Organization:
Sandia National Laboratories

Project Engineer: C. R. Stillwell
Telephone: (505) 844-2130

Contract Number: 62-9975

Current Contract Period From: 10/20/81
To: 07/15/82

Contract Funding:		**Source:**
FY 1981	**$** 172,376	DOE/PV

Project/Area/Task: Concentrator Module Research

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

Current Contract Period From: 04/01/83
To: 06/01/84

Contract Funding:		**Source:**
FY 1983	**$** 314,926	DOE/PV

Project/Area/Task: Concentrator Module Research

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

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

Current Contract Period From: 09/01/82
To: 03/01/83

Contract Funding:		**Source:**
FY 1982	$ 7,000	DOE/PV

Project/Area/Task: Concentrator Module Research

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

Principal Investigator: L. W. James
Telephone: (303) 484-5296

Contract Number: 47-3871

Current Contract Period From: 07/01/83
To: 08/01/83

Directing Organization:
Sandia National Laboratories

Project Engineer: C. B. Stillwell
Telephone: (505) 844-2170

Contract Funding:		Source:
FY 1983	$ 2,700	DOE/PV

Project/Area/Task: Concentrator Module Research

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

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

Current Contract Period From: 07/12/82
To: 12/31/82

Contract Funding:		**Source:**
FY 1982	**$** 27,750	DOE/PV

Project/Area/Task: Concentrator Module Research

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:		**Source:**
FY 1979	**$** 348,000	DOE
FY 1980	**$** -0-	DOE
FY 1981	**$** 61,000	DOE
FY 1982	**$** 17,000	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^2 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

Title: Baseline Module Improvement

Contractor:
Martin Marietta
Aerospace Division
P.O. Box 179
Denver, CO 80201
Principal Investigator: L. Marshall
Telephone: (303) 977-0139

Directing Organization:
Sandia National Laboratories

Project Engineer: M. Edenburn
Telephone: (505) 844-4003

Contract Number: 52-1484

Current Contract Period From: 02/24/83
To: 11/24/83

Contract Funding: FY 1983 $ 70,000

Source: DOE/PV

Project/Area/Task: Concentrator Module Research

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

Directing Organization:
Sandia National Laboratories

Project Engineer: L. Beavis
Telephone: (505) 844-2231

Contract Number: 68-0490

Current Contract Period From: 08/11/81
To: 12/30/82

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_2 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_2O_3-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

Current Contract Period From: 12/81
To: 06/83

Contract Funding:		**Source:**
FY 1982	**$** 110,000	DOE/PV

Project/Area/Task: Concentrator Module Research

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 compuer 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:

Current Contract Period From: 11/01/82
To: 02/01/84

Contract Funding: FY 1983 $ 244,275

Source: DOE/PV

Project/Area/Task: Concentrator Module Research

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

Directing Organization:
Sandia National Laboratories

Project Engineer: T. D. Harrison
Telephone: (505) 844-6394

Contract Number: 16-0895

Current Contract Period From: 10/1/81
To: 09/30/84

Project/Area/Task: Intermediate PV System Experiments

Contract Funding:		Source:
FY 1982	$ 22,100	SNLA
FY 1983	$ 23,000	SNLA

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 intermdiate PV sites, 30 September 1984.

Major Project Reports: None.

Summary Date
December 1983

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

Current Contract Period From: 02/24/82
To: 01/31/84

Contract Funding:

		Source:
FY 1982	**$** 49,500	DOE/PV
FY 1983	**$** 8,400	DOE/PV

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

Directing Organization:
Sandia National Laboratories

Project Engineer: C. B. Stillwell
Telephone: (505) 844-2130

Contract Number: 47-5883

Current Contract Period From:
To:

Contract Funding:		**Source:**
FY 1983	**$** 160,000	DOE/PV

Project/Area/Task: Concentrator Module Research

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

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

Directing Organization:
Sandia National Laboratories

Project Engineer: C. B. Stillwell
Telephone: (505) 844-2130

Contract Number: 74-1349

Current Contract Period From: 04/28/81
To: 10/28/82

Project/Area/Task: Concentrator Module Research

Contract Funding:

		Source:
FY 1981	$ 189,204	DOE/PV
FY 1982	$ -0-	
FY 1983	$ -0-	

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^2 in volume runs. The films are to be bonded to a superstrate to from 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 evaluted. 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

Current Contract Period From: 03/1/83
To: 06/1/84

Contract Funding:		**Source:**
FY 1983	**$** 164,200	DOE

Project/Area/Task: Concentrator Module Research

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

Title: High Efficiency, Low Cost, Passively-Cooled PV Concentrator Module Development

Contractor:
Varian Associates
611 Hansen Way
Palo Alto, Ca 94303

Principal Investigator: N. Kaminar
Telephone:(415) 424-5090

Contract Number:74-2999

Current Contract Period From: 05/1/81
To: 02/1/83

Project/Area/Task: Concentrator Module Research

Directing Organization:
Sandia National Laboratories

Project Engineer: D. E. Arvizu
Telephone:(505) 846-0387

Contract Funding:

		Source:
FY 1981	$ 320,000	DOE
FY 1982	74,000	DOE/PV

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% ± 0.3% conversion efficiency for the module at NOCT (i.e., 28°C ambient and 880 W/m^2 DNI) with a peak efficiency (i.e., 28°C cell temperature and 800 W/m^2 DNI) of 17.2% ± 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:

Current Contract Period From: 10/1/82
To: 09/30/83

Contract Funding: FY 1983 $ 420,000

Source: DOE/PV

Project/Area/Task: PV Systems Experiment Project

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

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:

Current Contract Period From: 10/81
To: 09/83

Project/Area/Task: Power Conditioning and Control

Contract Funding:		**Source:**
FY 1982	**$** 200,000	DOE/PV
FY 1983	**$** 200,000	DOE/PV
FY 1984	**$** 200,000	DOE/PV

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

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:

Current Contract Period From: 12/81
To: 09/84

Project/Area/Task: Power Conditioning and Control

Contract Funding:		Source:
FY 1982	$ 239,000	DOE/PV
FY 1983	$ 557,000	DOE/PV
FY 1984	$ 450,000	DOE/PV

Objectives: Characterize photovoltaic power conditioners with respect to performance, safety, reliability, maintenance, and survival under various operationg 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

Current Contract Period From: 11/83
To: 11/84

Contract Funding:

FY	$	Source:
FY 1982	$ 200,000	DOE/PV

Project/Area/Task: Power Conditioning and Control

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 deisgn.

Status/FY 1983 Accomplishments: None. New Program.

FY 1984 Milestones: Publish final report.

Major Project Reports: None.

Summary Date
December 1983

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

Current Contract Period From: 11/82
To: 08/83

Contract Funding:

		Source:
FY 1982	$ 129,228	DOE/PV
FY 1983	$ 107,000	DOE/PV

Project/Area/Task: Power Conditioning and Control

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
Albuqueruqe, 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

Current Contract Period From: 10/14/80
To: 11/30/82

Contract Funding:		**Source:**
FY 1982	$ -0-	DOE/PV

Project/Area/Task: Power Conditioning and Control

Objectives: To obtain and charcterize 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

Directing Organization:
Sandia National Laboratories

Principal Investigator: N. S. Andersson
Telephone: (203) 846-1633

Project Engineer: D. Chu
Telephone: (505) 846-2457

Contract Number: 52-1419

Current Contract Period From: 08/15/83
To: 08/15/84

Contract Funding:		Source:
FY 1983	$ 205,000	DOE/PV

Project/Area/Task: Power Conditioning and Control

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 — ≥ 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

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

Current Contract Period From: 04/5/83
To: 03/31/84

Contract Funding:

		Source:
FY 1983	$ 294,400	DOE/PV

Project/Area/Task: Power Conditioning and Control

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

Current Contract Period From: 08/12/82
To: 11/12/83

Contract Funding:		Source:
FY 1982	$ 492,000	DOE/PV

Project/Area/Task: Power Conditioning and Control

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

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

Project Engineer: T. S. Key
Telephone: (505) 844-3043

Contract Number: 68-4728

Current Contract Period From: 11/81
To: 10/83

Contract Funding:		**Source:**
FY 1982	$ 400,000	DOE/PV
FY 1983	$ 260,000	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

Current Contract Period From: 07/1/81
To: 11/30/83

Project/Area/Task: Power Conditioning and Control

Contract Funding:

		Source:
FY 1981	**$** 162,200	DOE/PV
FY 1982	**$** 14,500	DOE/PV
FY 1983	**$** 112,000	DOE/PV

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:

Directing Organization:
Sandia National Laboratories

Project Engineer: D. Chu
Telephone: (505) 846-2457

Contract Number: 37-3011

Current Contract Period From: 05/3/83
To: 03/31/84

Contract Funding: FY 1983 $ 191,760

Source: DOE/PV

Project/Area/Task: Power Conditioning and Control

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

Current Contract Period From: 10/15/82
To: 01/15/84

Project/Area/Task: Residential PV Systems

Contract Funding:

		Source:
FY 1980	$ 100,000	MIT/LL
FY 1981	$ 185,284	MIT/LL
FY 1982	$ 75,000	SNLA

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 colleciton 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 quadraplex 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

Contract Number:

Current Contract Period From: 10/1/82
To: 09/30/83

Project/Area/Task: Systems Research

Project Engineer:

Telephone:

Contract Funding:		**Source:**
FY 1982	**$** 650,000	SNLA

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

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

Current Contract Period From: 01/1/82
To: 12/31/82

Contract Funding:

		Source:
FY 1982	**$** 19,600	DOE

Project/Area/Task: Systems Research

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

Current Contract Period From: 05/27/82
To: 05/31/83

Contract Funding:		**Source:**
FY 1982	**$** 143,100	DOE/PV

Project/Area/Task: Systems Research

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

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

Current Contract Period From: 03/22/82
To: 03/31/83

Contract Funding: **Source:**

FY 1982 **$** 200,000 DOE/PV

Project/Area/Task: Systems Research

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

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

Current Contract Period From: 11/9/81
To: 11/9/82

Project/Area/Task: Systems Research

Contract Funding:		Source:
FY 1982	$ 395,400	DOE/PV
FY 1983	$ 53,000	DOE/PV

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

Current Contract Period From: 04/1/81
To: 09/30/82

Contract Funding:

		Source:
FY 1983	**$** 401,600	DOE/PV
FY 1982	**$** 72,000	DOE/PV

Project/Area/Task: Systems Research

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

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

Directing Organization:
Sandia National Laboratories

Project Engineer: M. G. Thomas
Telephone: (505) 844-6111

Contract Number: 50-8426

Current Contract Period From: 09/2/82
To: 05/1/83

Project/Area/Task: Systems Research

Contract Funding:		**Source:**
FY 1982	**$** 163,700	DOE/PV

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

Current Contract Period From: 06/11/81
To: 12/31/82

Contract Funding: **FY** 1982 **$** 383,000

Source: DOE/PV

Project/Area/Task: Systems Research

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

Current Contract Period From: 10/28/82
To: 05/2/83

Contract Funding:

		Source:
FY 1983	**$** 100,000	DOE/PV

Project/Area/Task: Systems Research

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

Current Contract Period From: 11/4/82
To: 06/30/83

Project/Area/Task: Systems Research

Contract Funding:		**Source:**
FY 1983	**$** 150,000	DOE/PV

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

Principal Investigator: K. Weber
Telephone: (303) 231-7067

Contract Number: 37-5047

Current Contract Period From: 10/11/82
To: 01/31/83

Project/Area/Task: Systems Research

Directing Organization:
Sandia National Laboratories

Project Engineer: G. J. Jones
Telephone: (505) 844-2433

Contract Funding:		**Source:**
FY 1983	**$** 50,000	DOE/PV

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 evaluted 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

Current Contract Period From: 01/12/83
To: 09/30/83

Contract Funding:

		Source:
FY 1983	$ 70,000	DOE/PV

Project/Area/Task: Systems Research

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

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

Project Engineer: J. Stevens
Telephone: (505) 846-2457

Contract Number: 50-5811

Current Contract Period From: 15/15/82
To: 01/15/84

Contract Funding: FY 1982 $ 79,748

Source: DOE/PV

Project/Area/Task: Systems Research

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

Title: Task 9 — Technology Evaluation

Contractor:
In-House

Directing Organization:
Sandia National Laboratories

Principal Investigator: H. Gerwin
Telephone: (505) 844-0112

Contract Number:

Current Contract Period From:
To:

Project Engineer:

Telephone:

Contract Funding:

		Source:
FY 1983	**$** 500,000	DOE/PV

Project/Area/Task: Technology Evaluation

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

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

Current Contract Period From: 06/1/81
To: 12/31/82

Project/Area/Task: Utility Interface

Contract Funding:		**Source:**
FY 1982	**$** 301,200	DOE/PV
FY 1983	**$** 148,769	DOE/PV

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

Current Contract Period From: 11/10/82
To: 9/10/83

Contract Funding:

		Source:
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

Current Contract Period From: 11/80
To: 7/83

Project/Area/Task: Stand-Alone Applications/System Development

Contract Funding:

		Source:
FY 1980	**$** 457,900	DOE
FY 1981	**$** -0-	DOE
FY 1982	**$** -0-	DOE
FY 1983	**$** -0-	DOE

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: Utirik 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:		**Source:**
FY 1982	$ -0-	DOE
FY 1983	$ 170,634	DOE

Cost Sharing: $100,000, Republic of the Marshall Islands

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 Marshal 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

Current Contract Period From: 01/19/82
To: 11/19/83

Project/Area/Task: Stand-Alone Applications

Contract Funding:

		Source:
FY 1982	**$** 92,999	DOE
FY 1983	**$** -0-	DOE

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, Maldive 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

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

Current Contract Period From: 8/29/83
To: 8/29/85

Project/Area/Task: Stand-Alone Applications

Contract Funding:		**Source:**
FY 1982	**$** -0-	DOE
FY 1983	**$** 500,000	DOE

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

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

Current Contract Period From: 1/26/83
To: 1/31/84

Project/Area/Task: Stand-Alone Applications/System Development

Contract Funding:

		Source:
FY 1982	**$** -0-	DOE
FY 1983	**$** 341,413	DOE

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:

Current Contract Period From:
To:

Project/Area/Task: PV Health and Safety

Contract Funding:		Source:
FY 1980	$ 200,000	DOE/Solar
FY 1981	$ 225,000	DOE/Solar
FY 1982	$ 120,000	DOE/Solar
FY 1983	$ 250,000	DOE/Solar

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

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:

Current Contract Period From:
To:

Contract Funding: **Source:**

FY 1984	**$** 95,000	DOE

Project/Area/Task: Photovoltaic Technology Assessment

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

Current Contract Period From:
To:

Project/Area/Task:

Contract Funding:		**Source:**
FY 1983	**$** 78,000	DOE
FY 1984	**$** 35,000	DOE

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 ot 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

Current Contract Period From:
To:

Project/Area/Task:

Contract Funding:

		Source:
FY 1983	$ 78,000	DOE
FY 1984	$ 75,000	DOE

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 (≈ 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

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:		**Source:**
FY 1979-1980	**$** 1,368,927	DOE
FY 1981	**$** 422,315	DOE
FY 1982	**$** 45,104	DOE
FY 1983	**$** -0-	

Cost Sharing: $412,000

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, ≈ 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

Current Contract Period From: 03/19/80
To: 06/30/84

Project/Area/Task: Array Design and Evaluation

Contract Funding:		Source:
FY 1980	**$** 3,088,176	DOE
FY 1981	**$** 3,412,877	DOE
FY 1982	**$** 274,965	DOE
FY 1983	**$** -0-	

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

Current Contract Period From: 09/28/79
To: 09/30/83

Project/Area/Task: Array Design and Evaluation

Contract Funding:		**Source:**
FY 1979-1980	**$** 1,111,421	DOE
FY 1981	**$** 550,219	DOE
FY 1982	**$** -0-	
FY 1983	**$** 49,971	DOE

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

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:		**Source:**
FY 1979-1980	\$ 784,552	DOE
FY 1981	\$ 345,572	DOE
FY 1982	\$ 339,409	DOE
FY 1983	\$ -0-	

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 prepration.

Summary Date
December 1983

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

Current Contract Period From: 09/30/79
To: 08/31/83

Project/Area/Task: Array Design and Evaluation

Contract Funding:		Source:
FY 1979-1980	$ 2,663,358	DOE
FY 1981	$ 220,738	DOE
FY 1982	$ 186,571	DOE
FY 1983	$ -0-	

Cost Sharing: $51,000

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

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:		Source:
FY 1979-1980	$ 470,870	DOE
FY 1981	$ 233,082	DOE
FY 1982	$ -0-	
FY 1983	$ -0-	

Cost Sharing: $5,000

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

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:

		Source:
FY 1979-1980	**$** 2,516,912	DOE
FY 1981	**$** $-0-	
FY 1982	**$** 434,661	DOE
FY 1983	**$** -0-	

Cost Sharing: $327,0000

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

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

Current Contract Period From: 09/28/79
To: 11/30/83

Project/Area/Task: Array Design and Evaluation

Contract Funding:		**Source:**
FY 1979-1980	**$** 2,747,288	DOE
FY 1981	**$** 376,266	DOE
FY 1982	**$** 22,875	DOE
FY 1983	**$** -0-	
Cost Sharing:	**$**131,000	

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 negotations to continue system data and insolation data collection.

Status/FY 1983 Accomplishments: Establish steady-state operation. Ground fault trips related to oversenstive GFIs rather than array problems.

FY 1984 Milestones: None.

Major Project Reports: None.

Summary Date
December 1983

Title: NE Residential Experiment Station

Contractor:
MIT Energy Laboratoary
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

Current Contract Period From: 06/30/84
To: 09/30/84

Contract Funding:

		Source:
FY 1983	**$** 384,000	DOE

Project/Area/Task: Residential Project

Objectives: Continued operation of existing facility and implementation of retrofit evaluation experimenation.

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

Contract Funding:		Source:
FY 1982	$ 802,497	DOE
FY 1983	$ 950,000	DOE

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

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

Current Contract Period From: 09/30/82
To: 09/30/84

Project/Area/Task: Residential Project

Contract Funding:

		Source:
FY 1982	**$** 2,000,000	DOE
FY 1983	**$** -0-	

Cost Sharing: **$**1,842,896

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 approachs.

Major Project Reports: Annual reports and topicals on milestones; annual experimental plans.

Summary Date
December 1983

DOE Oak Ridge Operations Office

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

Current Contract Period From: 8/80
To: 6/85

Contract Funding:		**Source:**
FY 1981-1986	**$** 23,680,000	DOE

Project/Area/Task:

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.

Statue/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

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

Project Engineer: N. Lingle
Telephone: (615) 576-5580

Contract Number: DE-AC05-810R20846

Current Contract Period From: 7/81
To: 7/86

Contract Funding:		**Source:**
FY 1981-1986	$ 343,302	DOE

Project/Area/Task:

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 Sequndo Boulevard
El Sequndo, 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

Current Contract Period From: 1/16/81
To: 9/30/83

Project/Area/Task: Utility Applications

Contract Funding:		**Source:**
FY 1981	$ 550,000	DOE
FY 1982	$ 450,000	DOE
FY 1983	$ 100,000	DOE

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 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

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

Current Contract Period From: 8/22/83
To: 9/1/86

Project/Area/Task: Photovoltaic Powerplant

Contract Funding:		**Source:**
FY 1982	**$** 6,800,000	DOE
FY 1983	**$** 6,800,000	DOE

Cost Sharing: FY 1982 $3,200,000 (SMUD); $2,000,000 (CEC), FY 1983 $3,600,000 (SMUD)

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

Principal Investigator: G. Storti
Telephone: (301) 948-4680

Contract Number: DE-FC01-80ET 23197

Current Contract Period From: 6/19/80
To: 9/30/83

Project/Area/Task: Advanced Materials Research

Directing Organization:
Department of Energy
Division of Photovoltaic Energy Technology

Project Engineer: M. Prince
Telephone: (202) 252-1725

Contract Funding:		**Source:**
FY 1980	$ 1,669,000	DOE
FY 1981	$ 900,000	DOE
FY 1982	$ 840,000	DOE
FY 1983	$ 400,000	DOE

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^2 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^2 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

Project/Area/Task: Photoelectrochemical

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:		Source:
FY 1979	$ 12,500,000	DOE

Cost Sharing: $5,300,000 (TI)

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.

Statue/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 $MoTe_2$ 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.

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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/$CuInSe_2$ 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 $ZnSiAs_2$ 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 $CuInSe_2$ 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.

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