PHOTOVOLTAICS: CONTRACT LISTS FISCAL YEAR 1992

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Introduction

The U.S. Department of Energy's (DOE's) Photovoltaics Program has helped photovoltaic technologies evolve from materials and concepts in laboratories to competitive products rolling off automated assembly lines. The Program is working to expand industrial capacity while continuing basic and applied technology research and development (R&D). With continued technology development, new markets, and industry's manufacturing capabilities, photovoltaics will contribute significantly to the national energy mix.

Photovoltaics: Contract Lists, Fiscal Year 1992 is a tabulation of photovoltaics R&D contracts that were begun, continued, or completed during FY 1992 (October 1, 1991, through September 30, 1992). National laboratories or industrial, academic, and nonprofit research institutions perform the R&D activities. The document is organized first by directing organization, then by project title and individual task. Each listing provides the name of the contractor, period of performance, funding, objectives, accomplishments, and FY 1993 milestones. A bibliography and list of current contractors follows the listings.

The Photovoltaics Program is managed by the director of the Photovoltaics Division at DOE Headquarters in Washington, D.C. The division provides the central leadership necessary to ensure program activities are consistent with national energy policy and priorities. Day-to-day research activities are managed by the National Renewable Energy Laboratory in Golden, Colorado, and Sandia National Laboratories in Albuquerque, New Mexico.

For additional information on DOE's Photovoltaics Program, consult the companion piece *Photovoltaics: Program Overview, Fiscal Year 1992* (DOE/CH10093-190) and the *Photovoltaics Program Plan FY 1991-FY 1995* (DOE/CH10093-92). Copies of these documents and this contract list are available through the National Renewable Energy Laboratory, Technical Inquiry Service, 1617 Cole Boulevard, Golden, Colorado 80401-3393.

Contents

National Renewable Energy Laboratory	3
Sandia National Laboratories ..	97
U.S. Department of Energy ..	109
Index of Contractors	111

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National Renewable Energy Laboratory

Demonstrations and testing results help industry and utilities refine system designs for near-term, value-added applications and large-scale generation of electric power.

Amorphous Silicon Research

Comprehensive Research on Stability and Electronic Properties of a-Si:H and a-SiGe:H Alloys and Devices

Objectives

Enhance performance of solar cells made with narrow bandgap state-of-the-art a-SiGe:H material, stabilize performance of a-Si:H and a-SiGe:H solar cells, and enhance the performance of a-Si:H based solar cells.

Approach/Background

Prepare and evaluate a-SiGe:H samples using the electron cyclotron resonance (ECR) deposition technique. Establish through optical and electrical characterization of material and device samples whether those prepared by the ECR deposition method have different electronic properties compared to state-of-the-art glow-discharge samples, and establish whether it can be reasonably expected that these samples may perform better in solar cell structures.

Status/Accomplishments

Produced doped and undoped films of a-Si:H using reactive plasma beam epitaxy. Absorption coefficient from the constant photocurrent method at 1.2 eV saturates at a value that is one-third that for standard material after intense light soaking. Some p-i-n's have been made, but p-i interfaces are a problem.

FY 1993 Milestones

Stabilize a-SiGe:H films and devices. Analytical and numerical modeling will be used to optimize single junctions.

Major Project Reports

Annual report July 1992.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
T. McMahon
(303) 231-7039

Contractor

Iowa State University
209 Beardshear Hall
Ames, IA 50011
V. Dalai
(515) 294-1077

Contract Number

10063-7

Contract Period

3/10/91 - 5/9/94

Funding Amount (Source)

(Previous years)	\$250,317 (DOE)
(FY 1992)	\$272,822 (DOE)

Amorphous Silicon Research

Deposition of State-of-the-Art a-Si:H and Devices

Objectives

Develop and improve deposition techniques for producing high quality a-Si:H films. Fabricate stable, high efficiency solar cells based on a-Si:H. Produce samples of cells and films for in-house and external research communities.

Approach/Background

Optimize the deposition parameters for both the conventional plasma enhanced chemical vapor deposition (PECVD) and the hot-wire techniques. Demonstrate the materials improvements through the fabrication of improved solar cells.

Status/Accomplishments

Suspended operations under this task in May 1991 for safety reasons. Since then, the major accomplishments have been to prepare for a move of the equipment to a new facility (Joyce St.) and to write a detailed safety analysis review (SAR) for both NREL Building 16 and Joyce St. Set up a hot-wire system in Building 16 using "safe" silane highly diluted with he-lium. Initial films look promising.

FY 1993 Milestones

Start up the deposition systems in the Joyce St. facility, with the capability to fabricate hot-wire cells ready by January 31, 1993. Evaluated coated graphite filaments for the hot-wire technique. Evaluate the hot-wire technique for preparing

improved a-Si:H and a-SiGe:H films. Write articles for refereed journals.

Major Project Reports

Nelson, B. *Safety Analysis Review*.

Summary Date

November 1992

Directing Organization
National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
W. Luft
(303) 231-1452

Contractor
NREL
B. Nelson
(303) 940-9083

Contract Number
None

Contract Period
10/1/91 - 9/30/92

Funding Amount (Source)
(FY 1992) \$629,000 (DOE)

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Amorphous Silicon Research

Growth Mechanism and Characterization of Hydrogenated Amorphous Silicon Alloy Films

Objectives

Obtain an understanding of a-Si:H and a-SiC:H film growth mechanism leading to improved deposition processes and improved optoelectronic properties, and of the conducting oxide/p-layer/i-layer interfaces.

Major Project Reports

Gallagher, A.; et al. *Growth Mechanisms and Characterization of Hydrogenated a-Si:H Alloy films.*

Summary Date

November 1992

Approach/Background

Characterize surface structural properties by *in-situ* scanning tunneling microscopy and low-energy electron diffraction. Characterize bulk properties by standard measurements, including small-angle x-ray scattering, Raman, and secondary ion mass spectrometry.

Status/Accomplishments

Developed methods to produce exceptionally sharp probe tips for detecting nanometer-sized voids on protrusions on the film surface as it is being formed. The films developed locally uneven surfaces as the thickness increased.

FY 1993 Milestones

Determine the dependence of the characteristics of a-Si:H films on different deposition conditions for parallel-plate glow discharge.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
W. Luft
(303) 231-1452

Contractor

National Institute of Standards
and Technology
325 Broadway
Boulder, CO 80303
A. Gallagher
(303) 497-3936

Contract Number

11001-1

Contract Period

2/18/91 - 2/17/94

Funding Amount (Source)

(Previous years) \$325,000 (DOE)
(FY 1992) \$ 87,000 (DOE)

Amorphous Silicon Research

Hydrogen and Metastability in a-Si:H

Objectives

Better understand H bonding, H motion, and the role of H in metastability and optically induced degradation. Find strategies to mitigate the degradation in high quality a-Si:H materials.

Major Project Reports

None

Summary Date

November 1992

Approach/Background

Study H diffusion on samples fabricated by various techniques to help relate the diffusion to the degradation process. These studies will include the effect of optical illumination as a means of enhancing the diffusion process.

Status/Accomplishments

Discovered that light-enhanced diffusion is a result of carrier-induced increase in the rate of Si:H bond breaking. In addition, found that the bond-activation energy of hot-wire samples is less than that for glow-discharge samples, demonstrating that there is a significant difference in the way that H is incorporated into this material. This could be the reason that the hydrogen content in high-quality hot-wire samples is much less than that of glow-discharge samples.

FY 1993 Milestones

Submit two reports in the form of journal papers. Measure the depth of Si-H bonding levels in nonstandard a-Si:H and compare with standard material to see if this property can be controlled.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

W. Luft
(303) 231-1452

Contractor

NREL
H. Branz
(303) 940-9078

Contract Number

None

Contract Period

10/1/91 - 9/30/92

Funding Amount (Source)

(FY 1992) \$382,000 (DOE)

Amorphous Silicon Research

In-Situ Characterization of Growth and Interfaces in Amorphous Silicon Devices

Objectives

Apply results of *in-situ* analyses of a-Si:H surfaces and device interfaces to complement the present understanding of materials and devices.

Approach/Background

Apply the method of spectroscopic ellipsometry *in-situ* to a-Si:H-based material surfaces and device interfaces.

Status/Accomplishments

Determined the hydrogen diffusion/reaction processes at the growing surface of a-Si:H and microcrystalline layers, including the effect of surface oxides; and studied the growth of a-Si:H and a-SiC:H on a variety of transparent oxide conductors.

FY 1993 Milestones

Analyze detailed reactions in the formation of the transmitting conductive oxide/buffer/interfaces (TCO-p-i), including growth modifications by and diffusion of the boron dopant; and improved the characterization of interfaces in actual devices.

Major Project Reports

Collins, R.W.; Wronski, C.R.; An, I.; Li, Y. *In-Situ Characterization of Growth and Interfaces in a-Si:H Devices*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
B. von Roeder
(303) 231-1380

Contractor

Pennsylvania State University
248 Calder Way, Suite 300
University Park, PA 16802
R.W. Collins/C.R. Wronski
(814) 865-3059/1372

Contract Number

XG-1-10063-10

Contract Period

4/1/91 - 5/31/94

Funding Amount (Source)

(Previous years) \$100,000 (DOE)
(FY 1992) \$110,000 (DOE)

Amorphous Silicon Research

Light-Affected Shunts in a-Si:H p-i-n Cells

Objectives

Find the source of shunts which cause additional light-induced degradation in multi-junction a-Si:H solar cells; help find ways to eliminate them; and improve the understanding of the processes by which the shunts degrade in light and anneal on heating.

Major Project Reports

None

Summary Date

November 1992

Approach/Background

Obtain multijunction cells from various sources, including industries that find these shunts in their cells. Study them by various techniques including optical beam induced current (OBIC) and high resolution thermal imaging. Analyze the results to determine the position of the shunts and identify the problem layer or layers.

Status/Accomplishments

Found that areas with an OBIC defect degraded faster than nondefect areas in a shunted cell. In addition, observed visible defects during reflectance microscope imaging. However, there was no success in identifying the position of the shunts or their source. Current fluctuated in some cells, perhaps reflecting a microplasma type of punch-through behavior.

FY 1993 Milestones

Meet with industry representatives to review the work and agree on ways to solve the problem. Report in the form of at least one refereed journal article due June 1993.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

W. Luft
(303) 231-1452

Contractor

NREL
T. McMahon
(303) 231-7039

Contract Number

None

Contract Period

10/1/91 - 9/30/92

Funding Amount (Source)

(FY 1992) \$255,000 (DOE)

Amorphous Silicon Research

Microscopic Origins of Metastable Effects in a-Si:H and Deep-Defect Characterization in a-SiGe:H Alloys

Objectives

Resolve how light-induced degradation depends on material compositions, how defects in amorphous semiconductors can be measured and characterized, and how light-induced and native defects affect the electronic properties.

Major Project Reports

Cohen, J.D. *Microscopic Origins of Metastable Effects in a-Si:H and Deep Defect Characterization in a-SiGe:H Alloys.*

Summary Date

November 1992

Approach/Background

Characterize samples prepared by other laboratories by drive level capacitance spectroscopy and electron spin resonance in the as-grown and various light-soaked states, prepare selected samples in-house with specific impurities deliberately added, and suggest microscopic models for the structure of the light-induced defects.

Status/Accomplishments

Identified differences in the light induced defect spectrum for various a-Si:H-based alloys, confirmed that a-SiGe:H alloys with very low defect densities can be prepared, and determined mobility lifetime products for a variety of alloys as a function of light soaking.

FY 1993 Milestones

Participate in newly formed amorphous silicon research teams, and understand differences in the spin resonance and drive level capacitance defect spectra.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
B. von Roedern
(303) 231-1380

Contractor

State of Oregon, through the
University of Oregon
P.O. Box 3175
Eugene, OR 97403
J.D. Cohen
(503) 346-4775

Contract Number

XG-1-10063-1

Contract Period

2/1/91 - 1/31/94

Funding Amount (Source)

(Previous years)	\$106,341 (DOE)
(FY 1992)	\$107,580 (DOE)

Amorphous Silicon Research

Microcrystalline Silicon by Remote Plasma-Enhanced Chemical-Vapor Deposition

Objectives

Deposit thin films of B-compensated microcrystalline Si ($\mu\text{c-Si}$) and evaluate the transport properties by time-of-flight measurements of the majority and minority carrier mobilities.

Approach/Background

Deposited thin films of B-compensated $\mu\text{c-Si}$ by remote plasma-enhanced chemical-vapor deposition (RPECVD). These films displayed levels of photoconductivity to dark conductivity that prompted additional evaluation of their potential for use in PV technology.

Status/Accomplishments

Experienced considerable difficulty in reproducing original RPECVD results, primarily because of vacuum system cleanliness. Shifted our emphasis to deposition on B-compensated $\mu\text{c-Si}$ by reactive magnetron sputtering (RMS). Demonstrated that the dark-conductivity activation energy of B-doped/compensated $\mu\text{c-Si}$ can be varied by this approach. Currently evaluating the electrical properties of this material, using thin-film transistors to obtain electron mobilities and the grating technique for ambipolar diffusion lengths.

FY 1993 Milestones

Evaluate a-SiGe:H using RPECVD and RMS, and begin a preliminary evaluation of the optical and transport properties of Ge alloys of $\mu\text{c-Si}$. These milestones reflect a change in program direction that is in accord with NREL.

Major Project Reports

Year-end Report

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401

H. Mahan
(303) 231-1497

Contractor

North Carolina State University
Pullen Road, Box 7003
Raleigh, NC 27695-7003

G. Lucovsky
(919) 515-3468

Contract Number

XG-1-10063-2

Contract Period

2/20/91 - 2/19/94

Funding Amount (Source)

(Previous years)	\$70,000 (DOE)
(FY 1992)	\$94,000 (DOE)

Amorphous Silicon Research

Optimization of Transport and Reflecting Electrodes for Amorphous Silicon Solar Cells

Objectives

Improve transparent conducting oxide materials for use as contacts to amorphous silicon solar cells.

Approach/Background

Deposited ZnO doped with F, B, Al or Ga by atmospheric pressure chemical vapor deposition; explored lower temperature deposition for back contacts, transparency, conductivity, and texture of the films; and collaborated with industry to test active solar cells.

Status/Accomplishments

Attempted B-, Al- and Ga-doping of ZnO. Al and Ga both raised the free-electron concentration but reduced transparencies.

FY 1993 Milestones

Supply industry collaborators with 15.5-in.² (100 cm²) samples for use as solar cell substrates. To lower the ZnO contact resistance to a-Si:H, attempt both in-doping of ZnO and add a twin-capping layer of tin oxide.

Major Project Reports

Gordon, R.; et al. *Optimization of Transparent and Reflecting Electrodes for Amorphous Silicon Solar Cells.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
W. Luft
(303) 231-1452

Contractor

Harvard University
Cambridge, MA 02138
R. Gordon
(617) 495-4017

Contract Number

XH-1-11032-1

Contract Period

5/1/91 - 10/31/93

Funding Amount (Source)

(Previous years) \$130,000 (DOE)
(FY 1992) \$ 67,000 (DOE)

Amorphous Silicon Research

Recombination and Metastability in Amorphous Silicon and Silicon Germanium Alloys

Objectives

Determine how light-induced metastable defects degrade the properties of a-Si:H and a-SiGe:H in p-i-n solar cell structures.

Major Project Reports

Silver, M.; et. al. *Recombination and Metastability in Amorphous Silicon and Silicon Germanium Alloys*.

Summary Date

November 1992

Approach/Background

Measure electroluminescence (EL) efficiency, photon energy, and transient forward bias currents before and after light soaking.

Status/Accomplishments

Observed defect EL in thin commercial solar cells, but only saw main-band EL in special thick devices. A buffer layer added to the p-layer of the thin cells causes both bands to appear in the EL. This implies that defect recombination is dominant in the junctions and in unbuffered thin cells. The buffered p-i interface reduces junction recombination.

FY 1993 Milestones

Study and understand the thickness and degradation dependence of the EL to determine the mechanism and location in the cell of the degradation. Further buffer-layer studies.

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.

Golden, CO 80401-3393

W. Luft

(303) 231-1452

Contractor

University of North Carolina

Chapel Hill, NC 27599

M. Silver

(919) 962-5002

Contract Number

XG-1-10063-5

Contract Period

2/1/91-1/31/94

Funding Amount (Source)

(Previous years) \$92,000 (DOE)

(FY 1992) \$95,000 (DOE)

Amorphous Silicon Research

Research on Silicon-Carbon Alloys and Interfaces

Objectives

Identify the factors that dominate the electronic properties of the transmitting conductive oxide (TCO-p-i) interfaces and the influence of deposition conditions on the interfaces.

Approach/Background

Use *in-situ* infrared (IR) reflectance, Kelvin probe, and x-ray photoelectron spectroscopy (XPS) to study the formation of TCO-p and p-i interfaces during reactive magnetron sputter deposition of a-Si:H and a-SiC:H layers.

FY 1993 Milestones

Deposit and characterize p-doped a-SiC:H films. Use *in-situ* IR reflectance, Kelvin probe, and XPS to characterize a-SiC:H/TCO (SnO₂ and ZnO) interfaces for various dopant concentrations.

Major Project Reports

Abelson, J.R.; Maley, N. *Annual Technical Report*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
Golden, CO 80401

T. McMahon
(303) 231-7039

Contractor

Board of Trustees of the
University of Illinois
809 South Wright Street
Champaign, IL 61820

J. Abelson/N. Maley
(217) 333-7258/6861

Contract Number

XG-1-10063-6

Contract Period

2/15/91 - 4/14/94

Funding Amount (Source)

(Previous years)	\$67,000 (DOE)
(FY 1992)	\$73,852 (DOE)

Status/Accomplishments

Grew a-Si:H alloys with bandgaps between 1.8 and 2.0 eV and good electrical properties by sputtering Si in Ar+H₂+CH₄. Evaluated film properties using IR, thermal evolution, small-angle x-ray scattering, sputtered neutral mass spectroscopy, photoconductivity, dark conductivity activation energy, subgap absorption, and light soaking. Used Kelvin probe and XPS to study a-Si:H/SnO₂ and a-Si:H/ZnO interfaces. XPS studies show that SnO₂ reduction depends on the deposition temperature and H₂ partial pressure. The results suggest that it may be possible to minimize this reduction by depositing a-Si on SnO₂ and subjecting it to posthydrogenation. XPS, Kelvin probe and *in-situ* infrared reflectance studies of a-SiC:H growth are in progress.

Amorphous Silicon Research

Research on Stable High-Efficiency a-Si:H Multijunction Modules

Objectives

Demonstrate a stable, aperture-area efficiency of at least 10% for different-bandgap, multijunction modules having an aperture area of at least 140 in.² (900 cm²).

Approach/Background

Prepare, characterize, and optimize the properties of all semiconductor and nonsemiconductor materials required for a-Si:H alloy modules, and manufacture the modules.

Status/Accomplishments

Produce 0.2-in.² (1-cm²) dual-junction cells with 6.89% initial and 5.48%, 888-hours stabilized efficiency (APS measurement) and 1-ft² (929-cm²) dual-junction module with 5.86% initial efficiency (NREL measurements).

FY 1993 Milestones

Stabilize 9% efficiency cells and 8% efficiency modules.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401-3393

W. Luft
(303) 231-1452

Contractor

Advanced Photovoltaic Systems, Inc.
Princeton, NJ 08543

F. Kampas
(609) 275-5000

Contract Number

ZM-2-11091-1

Contract Period

12/1/91 - 9/30/94

Funding Amount (Source)

(Previous years) \$695,311 (DOE)
\$695,311 (APS)

Amorphous Silicon Research

Research on Stable High-Efficiency a-Si:H Multijunction Modules

Objectives

Demonstrate a stable, aperture-area efficiency of at least 12% for different-bandgap multijunction modules having an aperture area of at least 140 in.² (900 cm²).

Approach/Background

Prepare, characterize, and optimize the properties of all semiconductor and nonsemiconductor materials required for a-Si:H alloy modules, and manufacture the modules.

Major Project Reports

Catalano, A.; et al. *Research on Stable High-Efficiency a-Si:H Multijunction Modules*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
W. Luft
(303) 231-1452

Contractor

Solarex Corporation
Newton, PA 18940
R. Arya
(215) 860-0902

Contract Number

ZM-0-19033-1

Contract Period

5/1/90 - 8/15/93

Funding Amount (Source)

(Previous years) \$2,099,361 (DOE)
\$2,099,361 (Solarex)
(FY 1992) \$ 534,000 (DOE)
\$ 534,000 (Solarex)

Status/Accomplishments

Produced 0.2-in.² (1-cm²) triple-junction cells with 10.8% initial and 8.6%, 600-hours stabilized efficiency (Solarex measurement) and 1-ft² (929-cm²) triple-junction module with 9.7% initial and 7.7%, 980-hours stabilized efficiency (NREL measurements).

FY 1993 Milestones

Stabilize 13.5% efficiency cells and 11.5% efficiency modules.

Amorphous Silicon Research

Research on Stable High-Efficiency a-Si:H Multijunction Modules

Objectives

Demonstrate a stable, aperture-area efficiency of at least 12% for same-bandgap, multijunction modules having an aperture area of at least 140 in.² (900 cm²).

Major Project Reports

Guha, S.; et. al. *Research on Stable High-Efficiency a-Si:H Multijunction Modules*.

Summary Date

November 1992

Approach/Background

Prepare, characterize, and optimize the properties of all semiconductor and nonsemiconductor materials required for a-Si:H alloy modules, and manufacture the modules.

Status/Accomplishments

Produced 0.04 in.² (0.25-cm²) dual-junction cells with 10.4%, 600-hours stabilized efficiency (NREL measurement) and 1-ft² (929-cm²) dual-junction module with 9.3% initial and 8.1% stabilized efficiency (NREL measurements and estimate).

FY 1993 Milestones

Stabilize 12% efficiency cells and 10% efficiency modules.

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401-3393

W. Luft
(303) 231-1452

Contractor

United Solar Systems Corporation
Troy, MI 48064

S. Guha
(313) 362-3120

Contract Number

ZM-0-11091-2

Contract Period

1/1/91 - 2/28/94

Funding Amount (Source)

(Previous years)	\$1,521,290	(DOE)
	\$1,521,290	(USSC)
(FY 1992)	\$ 349,710	(DOE)
	\$ 349,710	(USSC)

Amorphous Silicon Research

Small-Angle X-Ray Scattering Studies of Microvoids in Amorphous-Silicon-Based Semiconductors

Objectives

Determine whether the presence of microstructure as detected by small-angle x-ray scattering (SAXS) limits the photovoltaic properties of amorphous-silicon-based semiconductors.

Major Project Reports

Williams, D.L.; Jones, S.J.; Chen, Y. *Small Angle X-Ray Scattering Studies of Microvoids in Amorphous Silicon-Based Semiconductors*.

Summary Date

November 1992

Approach/Background

Study microstructural features on a size scale from 1 to 30 μm , using the unusual technique of SAXS. Work closely with groups that can supply systematic sets of samples (a-Si:H, a-Si:H, a-SiGe:H, and a-SiC:H) and the associated optoelectronic properties.

Status/Accomplishments

Demonstrated the correlation between the microstructure of the a-Si:H as detected by SAXS and solar cell properties that cells with more microvoids in the i-layer have poorer photovoltaic performance and show more photodegradation. Extensive work is under way on a-SiGe:H alloys.

FY 1993 Milestones

Establish the role of microstructure in photovoltaic performance of a-SiGe:H and a-SiC:H alloys.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
H. Mahan
(303) 231-1497

Contractor

Colorado School of Mines
Guggenheim Hall
1500 Illinois Street
Golden, CO 80401
D. L. Williamson
(303) 273-3837

Contract Number

XG-1-10063-3

Contract Period

2/1/91 - 1/31/94

Funding Amount (Source)

(Previous years)	\$70,620 (DOE)
(FY 1992)	\$73,000 (DOE)

Amorphous Silicon Research

Stable, High Efficiency Amorphous-Silicon Solar Cells with Low Hydrogen Content

Objectives

Resolve if the reduction of hydrogen content in a-Si:H intrinsic layers can lead to higher stabilized solar cell efficiencies, resolve how the performance of cells made with narrow bandgap a-SiGe:H can be enhanced, and resolve how particular material and device parameters may enhance the stabilized cell performance.

Approach/Background

Prepare a-Si:H and SiGe:H layers with different H-contents by PECVD and photo-CVD techniques, analyze materials and devices both as prepared and as a function of light-soaking, and optimize solar cells with high stabilized efficiency.

Status/Accomplishments

Determined that low-hydrogen-content films and devices are not significantly more stable than those with normal H-content (~10 at.%); established a thermodynamic equilibrium model for light-induced defects; and established that carrier mobility may decrease upon Ge-alloying.

FY 1993 Milestones

Continue work under a new thin-film multiyear subcontract and participate in at least two amorphous silicon research teams. Develop a a-SiGe:H cell with high red response and high stabilized efficiency.

Major Project Reports

Fortmann, C.M.; Hegedus, S.S.
Stable, High-Efficiency Amorphous Silicon-Based Solar Cells with Low Hydrogen Content.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

B. von Roedern
(303) 231-1380

Contractor

University of Delaware
Institute of Energy Conversion
Newark, DE 19716-3820
S. Hegedus
(302) 831-6200

Contract Number

XG-1-10063-4

Contract Period

3/1/91 - 4/30/94

Funding Amount (Source)

(Previous years) \$367,971 (DOE)
(FY 1992) \$405,450 (DOE)

Amorphous Silicon Research

Stability, Electronic Properties, and Structure of a-Si:H and Its Alloys

Objectives

Understand how the number and nature of defects affect device performance of a-Si:H-based materials, understand which specific defects are responsible for light-induced degradation, and understand the microscopic nature of the metastable defect site.

participation in two or more amorphous-silicon research teams.

Major Project Reports

Jackson, W.B.; et al. *Research on the Stability, Electronic Properties and Structure of a-Si:H and its Alloys.*

Summary Date

November 1992

Approach/Background

Employ various spectroscopic methods to determine the density-of-states spectrum in a-Si:H and a-SiGe:H; study correlations of H-diffusion, H-content, and light-induced degradation in a-Si:H-based materials; and study a variety of transport phenomena (e.g., time-of-flight, photo-transport under high electric fields).

Status/Accomplishments

Established that under high field, electron mobility becomes strongly field-dependent; established correlations between H-diffusion and defects and the presence of free carriers; and carefully compared light-induced and current-induced degradation of p-i-n junctions.

FY 1993 Milestones

Preparation of an evaluation report that details the degradation mechanisms observed upon light-soaking or upon alloying a-Si:H with Ge; preparation of an assessment report that compares the degradation of materials and devices; and

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401-3393

B. von Roedern
(303) 231-1380

Contractor

Xerox Corporation
Palo Alto Research Center
3333 Coyote Hill Road
Palo Alto, CA 94304

R.A. Street
(415) 812-4165

Contract Number

XG-1-10063-9

Contract Period

6/1/91 - 5/31/94

Funding Amount (Source)

(Previous years)	\$200,065 (DOE)
(FY 1992)	\$214,863 (DOE)

Amorphous Silicon Research

Structural and Electronic Studies of a-Si:H Alloys

Objectives

Understand the structural and electronic transport properties of low-bandgap a-Ge:H and a-SiGe:H alloys in which the Si concentration is less than 50%.

Major Project Reports

Paul, W. *Structural and Electronic Studies of a-SiGe:H Alloys.*

Summary Date

November 1992

Approach/Background

Deposit films, characterize them, and use results to optimize deposition conditions. Explore the role of deposition conditions on the structure of the films by using various measurements.

Status/Accomplishments

Obtained the best quality a-Ge:H under deposition conditions very different from those for good a-Si:H. There is a correlation between good photo-electronic properties and minimal microstructure. We can produce stable a-SiGe:H films with mobility-lifetime almost as high as for a-Ge:H.

FY 1993 Milestones

Contract terminated.

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401-3393

W. Luft
(303) 231-1452

Contractor

Harvard University
Cambridge, MA 02138

W. Paul
(617) 495-2853

Contract Number

XX-8-18131-1

Contract Period

7/1/88 - 2/28/82

Funding Amount (Source)

(Previous years) \$245,000 (DOE)
(FY 1992) \$50,000 (DOE)

Crystalline Materials and Advanced Concepts

Arsine and Hydride Radical Generation for MOCVD Growth

Objectives

Generate *in-situ* arsine and hydride radicals from lower toxicity, solid precursor sources of arsenic.

Approach/Background

Applied techniques to the deposition of arsenic-containing semiconductors. The emphasis is on reducing the toxicity of the starting material as well as reducing the deposition temperature (due to the reactivity of the hydride radicals). These hydrogenated species are generated with microwave excited hydrogen plasmas. Good quality epitaxial GaAs films have been deposited and characterized; however, the low V-III ratios utilized resulted in high carbon concentrations (10^{18} to low $10^{20}/\text{cm}^3$).

Status/Accomplishments

Generated *in-situ* arsenic hydrides. The benefits of generating *in-situ* arsenic hydrides are increased safety and lower deposition temperature (due to higher reactivity of the hydrides). The arsenic hydrides have been used to deposit good quality GaAs films containing carbon, silicon, and oxygen contaminants. Working on AlGaAs film deposition, which will lead to GaAs/AlGaAs heterostructures. Future work includes finding ways to lower the oxygen output and increase the arsine output of the generator.

FY 1993 Milestones

None

Major Project Reports

Pihlstrom, B.G.; Sheng, T.Y.; Thompson, L.R.; Collins, C.J. *Applied Physics Letters*.

Pihlstrom, B.G.; et al. *Journal Electronics Materials*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Boulevard
Golden, CO 80401

J. Benner
(303) 231-1396

Contractor

Colorado State University
Dept. of Electrical Engineering
Fort Collins, CO 80523

G. Collins
(303) 491-8513

Contract Number

0-19142-9

Contract Period

7/90 - 7/93

Funding Amount (Source)

(Previous years)	\$205,537	(DOE)
(FY 1992)	\$ 60,000	(DOE)

Crystalline Materials and Advanced Concepts

Atomic Layer Epitaxy for High Efficiency Solar Cells

Objectives

Explore and develop a low-temperature, large-scale epitaxial process for high-efficiency solar cells based upon atomic layer epitaxy (ALE).

Approach/Background

Explore the use of photo-assisted ALE and vacuum ALE as alternative approaches for achieving usable growth rates and high throughput. ALE has the potential to be a high throughput, layer thickness control process. We have previously shown that the growth rate in atmospheric pressure, thermally driven ALE is limited by the maximum temperature attainable before homogeneous gas phase reactions dominate the process and preclude the achievement of saturated monolayer growth.

Status/Accomplishments

Experimental samples grown for C-V evaluation of the background carrier concentration have exhibited background carrier concentrations as low as $3 \times 10^{15}/\text{cm}^3$. This is two orders of magnitude lower than ever observed in materials grown by photo-assisted ALE. It may account for the much higher photoluminescence efficiency of the samples as well.

FY 1993 Milestones

Deliver two samples of AlGaAs epitaxial optical reflector solar cells. Use a new vacuum ALE reactor which uses the TMGa/TBAs ALE process.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
J. Benner
(303) 231-1396

Contractor

University of Southern California
502 Seaver Science
Los Angeles, CA 90089
D. Dapkus
(213) 740-4414

Contract Number

0-1942-6

Contract Period

7/90 - 8/93

Funding Amount (Source)

(Previous years) \$376,738 (DOE)
(FY 1992) \$ 70,000 (DOE)

Crystalline Materials and Advanced Concepts

Cl-Mo and MOCVD Crystal Growth Research

Objectives

Evaluate new reactor designs with minimal convection and high source utilization efficiency, and to characterize the growth of GaAs material using novel metalorganic precursor sources, including chlorinated alkyl sources.

Approach/Background

Develop an advanced computer program simulating organic metallic vapor phase epitaxy in practical growth situations.

Status/Accomplishments

Simulations of the system show no evidence of recirculation under typical growth conditions (2-6 L/min hydrogen flow, 1292°F [700°C] susceptor, and susceptor-inlet spacings of 0.2 to 2 in. [0.5 to 5 cm]). Simulation for the reactor in a noninverted configuration, i.e., heater above the susceptor, show that recirculation will occur with spacing in excess of 0.6 in. (1.5 cm), but not with lower values. In essence, this means that either the inverted or the more conventional configuration can be used if the spacing is sufficiently small.

FY 1993 Milestones

Develop computer prediction for the performance of a production-scale, stagnation-point reactor; establish the feasibility of growing GaAs by hot-wall epitaxy; and evaluate the silicon dopant characteristics of GaInP.

Major Project Reports

Bhimnathwala, H.; Borrego, J.M. *Solid State Electronics*.

Bhimnathwala, G.G.; Borrego, J.M. *Photoreflectance Characterization of LEC-Si GaAs and Fe-InP*.

Chinoy, P.B.; Borrego, J.M.; Ghandhi, S.K. *Solar Energy Materials and Solar Cells*.

Summary Date

November 1992

Directing Organization

National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401

J. Benner
(303) 231-1396

Contractor

Rensselaer Polytechnical Institute
6022 Engineering Center
Troy, NY 12180
S. Ghandi/J. Borrego
(518) 276-6085

Contract Number

0-19142-10

Contract Period

7/90 - 5/93

Funding Amount (Source)

(Previous years) \$251,765 (DOE)
(FY 1992) \$100,895 (DOE)

Crystalline Materials and Advanced Concepts

Crystalline Ternary Compounds

Objectives

Grow bulk crystals of CuInSe_2 (CIS) and CuGaSe_2 (CGS) and characterize the structural, electronic, and optical properties of these samples using angle resolved photoemission, Raman scattering, and photoluminescence studies. Make theoretical calculations of the band offsets between these materials and ZnSe and CdS, which are used as window layers in solar cells.

Status/Accomplishments

Produced four multicrystalline ingots of CIS and one of CGS with grain sizes ranging from 0.04 to 0.2 in. (1 to 5 mm). Using angle-resolved ultraviolet photoemission spectroscopy, studied how the electronic states of ternary alloys are made up of the electronic states of their binary end-point constituents (for the alloy $\text{Cd}_x\text{Zn}_{1-x}\text{Te}$). Theoretical first-principles, band-structure calculations yielded the band offsets between ZnSe/CIS and CdS/ CuInSe_2 as roughly 0.7 eV and 1.07 eV respectively, which agree well with the photoemission experimental results.

FY 1993 Milestones

Attempt to grow larger crystals of CIS and CGS. Characterized their structural, electronic, and optical properties to understand the solid-state phase-ordering transitions that are potential contributors to the crystal cracking problems encountered in the growth of large crystals.

Major Project Reports

Nelson, A.; et al. *Theoretical and Experimental Studies of the ZnSe/ CuInSe_2 Heterojunction Band Offset.*

Schwertfeger, R. *Crystal Growth of CuInSe_2 .*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
J. Benner
(303) 231-1396

Contractor

NREL
A. Mascarenhas
(303) 231-1368

Contract Number

None

Contract Period

10/1/91 — 10/1/92

Funding Amount (Source)

(FY 1992) \$240,560 (DOE)

Crystalline Materials and Advanced Concepts

Detailed Noncontact Electrical and Structural Characterization of PV Silicon Substrates

Objectives

Understand the chemical and electrical behavior of structural defects and impurities in PV materials.

FY 1993 Milestones

None

Major Project Reports

None

Approach/Background

Evaluate the hypothesis that extended defects may in some circumstances be electrically inactive. To evaluate this hypothesis, we studied the electrical activity of clean (as-grown) and impurity-decorated structural defects. Observed the effects on electrical activity of gettering impurities using scanning electron microscopy in the electron beam induced current mode, scanning-electron-microscope/electron-beam-induced-current, transmission electron microscopy, and other analytical techniques.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
J. Benner/B. Sopori
(303) 231-1396/1383

Contractor

North Carolina State University
Box 7214
Raleigh, NC 27695-7214
G. Rozgonyi
(919) 515-2934

Contract Number

2-110040-6

Contract Period

4/92 - 6/95

Funding Amount (Source)

(Previous years) \$96,000 (DOE)
(FY 1992) \$96,200 (DOE)

Status/Accomplishments

Recently achieved a major advancement in this technology and used it extensively in this study—the development of an effective algorithm for separating the parameters of the surface and bulk components of the minority carrier lifetimes.

Crystalline Materials and Advanced Concepts

Electronic Processes in Thin-Film PV Materials

Objectives

Grow and characterize high-quality a-Si:H and related alloys and multilayers using the glow discharge technique; characterize the roles of defects and impurities in amorphous tetrahedrally coordinated thin films by optical and magnetic resonance techniques; determine the quality of the interfaces and junctions which occur in PV devices by employing surface-sensitive optical and magnetic resonance techniques; and understand the recombination-induced metastabilities and the frozen-in departures from equilibrium in amorphous, tetrahedrally coordinated thin films.

Approach/Background

Used several techniques to accomplish these objectives. Grew samples in a state-of-the-art glow discharge deposition system and characterized them using infrared and Raman spectroscopy, electrical conductivity, electron microprobe, and photo-thermal deflection spectroscopy. Other experimental techniques include nuclear magnetic resonance (NMR), electron spin resonance (ESR), various optical spectroscopies, and double spectroscopies such as optically detected magnetic resonance.

Status/Accomplishments

Characterized a-Si_xC_{1-x}:H alloys that have been grown

using liquid organic sources mixed with silane; measured the local diffusion of hydrogen in B-doped and intrinsic a-Si:H using NMR techniques; extended the photoluminescence excitation and time-resolved photoluminescence spectra of a-Si:H to 1.1 eV; measured the photoluminescence fatigue in a-Si_xN_{1-x}:H alloys, and investigation of the temperature dependencies of both the light-induced PL decay and ESR increase in a-Si:H.

FY 1993 Milestones

Grow a-Si:H and related alloys using other less toxic sources; continue below-gap spectroscopy and a-Si:H using PLE and time-resolved PL; continue the measurements of local hydrogen diffusion in boron-doped, phosphorus-doped, and intrinsic a-Si:H using NMR techniques; investigate the optical properties of a-Si_xGe_{1-x}:H and a-Si_xN_{1-x}:H alloys; and examine the correlations between optically induced metastabilities observed in photoluminescence, ESR, and optical absorption experiments in a-Si:H and related alloys.

Major Project Reports

Taylor, P.C.; Madan, A. *Amorphous Semiconductors*.

Taylor, P.C.; Hari, P.; Street, R.A. *Dipolar measurements of Hydrogen in Amorphous Silicon*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

J. Benner
(303) 231-1396

Contractor

University of Utah
Department of Physics
University of Utah
Salt Lake, UT 84112
P.C. Taylor
(801) 581-7462

Contract Number

XM-9-18141-3

Contract Period

07/89 - 12/92

Funding Amount (Source)

(Previous years) \$570,410 (DOE)
(FY 1992) \$136,998 (DOE)

Crystalline Materials and Advanced Concepts FTIR Spectroscopy

Objectives

Provide analytical support to the Crystalline Materials Project using Fourier transform infrared (FTIR) spectroscopy at NREL's FTIR Research Center.

Approach/Background

Measure levels of dopants and impurities in crystalline silicon, specifically, carbon, oxygen, nitrogen, hydrogen, and boron. The FTIR Center enables efficient use of scarce capital equipment funds by providing FTIR spectroscopic capabilities to NREL researchers and collaborators in PV and non-PV projects.

Status/Accomplishments

Implemented quantitative analysis procedures for the silicon dopants and impurities described above, set up equipment for both room temperature and cryogenic infrared transmission measurements to support these procedures, and upgraded the FTIR microscope to enable color microphotography, automated surface scanning and mapping, and visible and infrared polarization analysis for micron-sized defects in crystalline materials.

FY 1993 Milestones

Continue the work described above; we have already contributed to a conference paper. We

have also proposed an enhancement to this project to accommodate FTIR photoluminescence measurements of crystalline materials.

Major Project Reports

Sopori, B.L.; Webb, J.D.; et al.
Characterization of Commercial Photovoltaic Silicon Substrates.

Summary Date

December 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

J. Benner
(303) 231-1396

Contractor

NREL
J. Webb
(303) 231-1203

Contract Number

None

Contract Period

10/91 - 10/92

Funding Amount (Source)

(FY 1992) \$16,000 (DOE)

Crystalline Materials and Advanced Concepts

Fundamental Studies of Defect Generation in Amorphous Silicon Alloys Grown by Remote Plasma-Enhanced CVD

Objectives

Gain a fundamental understanding of the nature of the weak bonds in the a-Si:H alloys and the degree to which their number and/or character can be modified by changes in the deposition process.

Approach/Background

Study defect generation induced by light-soaking and the complementary electrical stress biasing of films prepared by remote plasma-enhanced chemical vapor deposition (PECVD), and compare these results for defect generation and defect removal via thermal annealing with those previously reported for electronic grade glow-discharge deposited materials. This study necessitates depositing intrinsic and doped, homogeneous thin films, and, in addition forming p-i-n solar cell structures, and metal oxide/metal insulator semiconductor structures. These experiments studies will be complemented with model calculations of the possible and chemically reasonable weak bonding configurations, in an attempt to identify the ways in which the density and/or character of the weak bonds may be studied further. Techniques involve some type of structural or spectroscopic characterization; i.e., an experimental technique other than the actual defect formation processes of light-soaking and accumulation biasing.

Status/Accomplishments

Studied the photoluminescence spectra of samples of $\mu\text{c-SiB}$ prepared by remote PECVD, at 4 K and 77 K in a collaborative effort with the University of Utah. The samples displayed subbandgap absorption constants below 39 in. (100 cm), indicating a correlation with stronger photoluminescence and lower subbandgap absorption. Nonradiative quadratic recombination has been identified as the dominant relaxation mechanism for photo-induced carriers in the extended states of photovoltaic grade a-Si:H with die-gap defect state densities of the order of less than about $10^{16}/\text{cm}^3$, and for time delays up to 200 ps, the experimental data do not show any indication for trapping of photoexcited free carriers into localized bandtail states, consistent with recent time-of-flight transport measurements.

FY 1993 Milestones

Minimize weak bonds in remote PECVD films. Fabricate optimized PV structures: balance conversion efficiency and defect generation, model defect generation and annealing processes, and hold multiparticipant symposium on PV technology.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

J. Benner
(303) 231-1396

Contractor

North Carolina State University
Dept. of Physics
Raleigh, NC 27695

G. Lucovsky
(919) 515-3301

Contract Number

9-18141-2

Contract Period

7/89 - 12/92

Funding Amount (Source)

(Previous years) \$438,935 (DOE)
(FY 1992) \$105,487 (DOE)

Crystalline Materials and Advanced Concepts

Growth and Development of GaInAsP for Use in High-Efficiency Solar Cells

Objectives

Prove that the quaternary semiconductor compound GaInAsP (and hence Ge) is an ideal candidate as a top junction in monolithic cascade cells.

demonstrate GaInAsP/Ge cascade solar cells suitable for operation under concentrated (500x) sunlight.

Major Project Reports

Wanlass, M.; et al. *Solar Cells*.

Approach/Background

Developed all the necessary components for a GaInAsP/Ge cascade cell. One GaInAsP/Ge cascade cell has been grown, and initial results indicate the viability of such a device. Research for a few months will focus on improving the device.

Summary Date

October 1992

Status/Accomplishments

Made progress in developing each component of the final cascade structure. The GaInAsP cell, the Ge cells, and the GaInAsP tunnel interconnect (grown on Ge) have all been demonstrated, with the results for the GaInAsP cell previously reported. The results have been encouraging; the cascade action in the device is definitely seen, indicating that the Ge junction and the GaInAsP tunnel diode interconnect are not degraded during the growth of the GaInAsP junction.

FY 1993 Milestones

Develop the necessary technology to grow 1.55 eV band gap GaInAsP layers that are lattice-matched to GaAs, demonstrate high-efficiency GaInAsP single-junction solar cells and

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
J. Benner
(303) 231-1396

Contractor

Research Triangle Institute
P.O. Box 12194
Research Triangle Park, NC 27709
P.R. Sharps/M. Timmons
(919) 541-6515

Contract Number

0-19142-4

Contract Period

6/90 - 8/93

Funding Amount (Source)

(Previous years) \$242,494 (DOE)
(FY 1992) \$ 44,000 (DOE)

Crystalline Materials and Advanced Concepts High-Efficiency Thin-Film Solar Cells

Objectives

Investigate thin-film GaAs/GaInP cells using the CLEFT technique and determine the process to enable overgrowth of GaAs films using organometallic chemistry.

Major Project Reports

None

Summary Date

November 1992

Approach/Background

Establish fundamental understanding and background data needed for development of viable cost-effective terrestrial application of GaAs/GaInP in the mid-1990s.

Status/Accomplishments

Fabricated and measured GaInP cells from GaInP/GaAs structures. Efficiencies reached 14% on both GaInP-window and GaInP-emitter structures, being limited by cell current. Work on the GaInP/GaAs interface is ongoing. GaAs growth using diethylgalliumchloride chemistry was demonstrated with good morphologies and growth rates up to 10 $\mu\text{m}/\text{h}$.

FY 1993 Milestones

Demonstrate lateral overgrowth of AlGaAs using DEAC, deliver GaAs DH structure using DEAC-grown AlGaAs cladding (GaAs grown with either TMGa or DEGC). Achieve 26% efficiency GaAs cell with back-surface reflector, achieve efficiency in tandem solar cell, and demonstrate cost-effective substrate reuse technology.

Directing Organization

National Renewable Energy

Laboratory

1617 Cole Blvd.

Golden, CO 80401

J. Benner

(303) 231-1396

Contractor

Kopin Corporation

695 Myles Standish Blvd.

Taunton, MA 02780

R. Gale

(617) 824-6696

Contract Number

0-19142-4

Contract Period

6/90 -- 8/93

Funding Amount (Source)

(Previous years) \$684,511 (DOE)

(FY 1992) \$ 87,000 (DOE)

Crystalline Materials and Advanced Concepts

I-D and Control Lifetime Reducing Defects in Polycrystalline Silicon PV Material

Objectives

Identify the dominant lifetime-limiting defects and carry out studies on thermal treatments that improve the post-growth quality where the enhancement process can be applied to improve solar cell performance.

Major Project Reports

None

Summary Date

November 1992

Approach/Background

Use various analytical techniques including deep level transient spectroscopy, electron beam induced current, surface photovoltage, electron paramagnetic resonance, Fourier transform infrared spectroscopy, and transmission electron microscopes to characterize commercial PV silicon. The data obtained from analyses will be used to develop a systematic database of impurities, defects, and minority carrier lifetimes in various as-grown solar cell silicon materials.

FY 1993 Milestones

Identify lifetime-reducing defects in PV silicon and characterize six samples supplied by NREL in terms of the concentrations of the dominant defects/impurities that control the minority carrier lifetime.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
J. Benner
(303) 231-1396

Contractor

University of California
Department of Electrical Engineering
Berkeley, CA 94720
E. Weber
(510) 642-9164

Contract Number

2-11004-3

Contract Period

7/92 - 5/93

Funding Amount (Source)

(Previous years) \$141,546 (DOE)
(FY 1992) \$141,456 (DOE)

Crystalline Materials and Advanced Concepts

III-V Materials and Devices

Objectives

Assist industry in developing low-cost, high-efficiency concentrator-based solar cells.

Approach/Background

The GaInP/GaAs tandem cell, invented and developed at NREL, is now being developed commercially by several U.S. manufacturers for space power applications. This manufacturing operation will soon be in a position to spin off a concentrator terrestrial capability with a capacity of 100 MW/yr. Our approach is to continue the concentrator development work in cooperation with industry, focusing on problems for which we are technically and strategically positioned to address.

FY 1993 Milestones

Develop a concentrator GaInP/GaAs tandem cell with an efficiency of greater than 30%.

Major Project Reports

Olson, J.M.; et al. *GaInP₂/GaAs Tandem Cells for Space Applications*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
J. Benner
(303) 231-1396

Contractor

NREL
J.M. Olson
(303) 231-1121

Contract Number

None

Contract Period

10/91 - 10/92

Funding Amount (Source)

(FY 1992) \$950,000 (DOE)

Status/Accomplishments

Redesigned, rebuilt, and restarted the two metal organic chemical vapor deposition reactors critical to synthesis of the GaInP/GaAs tandem cell and related materials and devices to comply with new stricter safety standard. These reactors are presently being calibrated and tuned for maximum tandem cell efficiency.

Crystalline Materials and Advanced Concepts

An Inverted AlGaAs/GaAs Patterned-Ge Tunnel-Junction Cascade Concentrator Solar Cell

Objectives

Develop an inverted-growth technique and the related technology for monolithic cascade AlGaAs/GaAs solar cells using a tunnel junction for concentrator devices, based on a lattice-matched AlGaAs/GaAs material system.

Approach/Background

Use a metal interconnect between monolithic AlGaAs/GaAs cells as part of post-growth processing, and a cover glass produced by ENTECH to reduce obscuration losses. Alternatively, grow the AlGaAs top cell at high temperatures, and then grow a GaAs interconnect and bottom cell at lower temperatures. The cascade structure is then removed from the parent substrate, Ge in this case, for front-side illumination.

Status/Accomplishments

Developed a rapid multi-wafer process for etching Ge to produce thin AlGaAs/GaAs films that can be used to develop a current-matched AlGaAs/GaAs/Si (three-junction) cell.

Also developed the "cycled" organometallic vapor phase epitaxy (OMVPE) growth technique that gave enhanced conductance of GaAs tunnel junctions. Demonstrated an inverted-grown, thin-film, GaAs solar cell with a 17.9% active-

area efficiency. Subsequent cells are reported at 20.3% efficiency (active-area). These inverted-grown cells were eutectic-metal-bonded onto silicon.

Obtained a thin-film, inverted-grown $\text{Al}_{0.34}\text{Ga}_{0.66}\text{As}/\text{GaAs}$ cascade cell reported as 19.9% efficient at 1-sun and 21% efficient at 7-suns. This development demonstrates the proof-of-concept for this approach.

FY 1993 Milestones

None

Major Project Reports

Venkatasubramanian, R.; Timmons, R.L.; Colpitts, T.S.; Hutchby, J.A. *An Inverted-Growth Approach to Development of an IR-Transparent, High-Efficiency, AlGaAs/GaAs Cascade Solar Cell.*

Venkatasubramanian, R.; et al. *High Quality Eutectic-Metal-Bonded GaAs-AlGaAs Thin Films on Si Substrates.*

Venkatasubramanian, R.; Timmons, R.L.; Colpitts, T.S.; Asher, S. *Properties and Use of "Cycled" OMVPE GaAs:Zn, GaAs:Si, and GaAs:Se Layers for High-Conductance GaAs Tunnel Junctions.*

Venkatasubramanian, R.; Timmons, R.L.; Colpitts, T.S. *Selective Plasma Etching of Ge Substrates for Thin Freestanding GaAs-AlGaAs Heterostructures.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

T.S. Basso
(303) 231-7035

Contractor

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

M.L. Timmons
(919) 541-5920

Contract Number

XM-0-18-10-1

Contract Period

1/1/90 - 8/30/92

Funding Amount (Source)

(Previous years) \$205,000 (NREL)

Crystalline Materials and Advanced Concepts

Ion and Photon Assisted Growth and Doping of II-VI Compounds

Objectives

Investigate the influence of laser radiation on the incorporation of p- and n-type dopants (photon-assisted doping or PAD), on the growth and structural and photoelectronic properties of II-VI semiconductor materials, particularly CdTe. Continue and complete the study of ion-assisted doping of CdTe.

Approach/Background

Investigate PAD, for high yield doping and good diffusion length (L_d). Although we could not reproduce the PAD results of Schetzina et al., most researchers agree that illumination during deposition increases both doping and crystalline quality. We returned to ion-assisted doping (IAD) to find ways to increase L_d while maintaining the doping level. These include lowering the ion energy to reduce damage, using coincident low-energy electron irradiation, and increasing the Cd/Te flux ratio slightly to increase dopant incorporation. Characterization methods include measurements of resistivity, carrier density (by $1/C^2$ vs V) and analysis of In-Schottky barriers on the films. Secondary ion mass spectroscopy, x-ray diffraction rocking curves, and photoluminescence measurements were also made.

Status/Accomplishments

Despite good doping control with IAD, the unacceptable small L_d values previously observed

suggested that the method had limited usefulness. However, the use of lower ion energies (10 to 20 eV), electron irradiation during growth, and small excess Cd fluxes has enabled us to dope CdTe up to $p \approx 1 \times 10^{17}/\text{cm}^3$, while maintaining a respectable L_d of $\approx 0.35 \mu\text{m}$. The results emphasize the importance of microstoichiometry control in the deposition and doping of II-VI compounds. Significant increases in L_d at lower ion energies and with electron flux during growth and the reports of successful IAD-doping with N for CdTe and ZnSe promise higher doping levels, better L_d values, and the application of these methods to polycrystalline material in the future.

FY 1993 Milestones

Explore transport properties of various photovoltaic junctions involving CdTe using our capabilities for IAD deposition of p-CdTe; explore the use of N radicals as a dopant for p-CdTe; explore further the use of nonionized Cd_3As_2 as dopant source; and extend polycrystalline thin films. Investigate single-crystal and polycrystalline ZnTe films, grown by close-space vapor transport, for low-resistance ohmic contacts to p-CdTe as an active component in tandem cells.

Major Project Reports

Bube, R.H. *Photon and Ion-Assisted Doping and Growth of II-VI Compound Thin Films*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
J. Benner
(303) 231-1396

Contractor

Stanford University
Materials Science and Engineering
Stanford, CA 94305
R. Bube
(415) 497-2534

Contract Number

XM-9-18141-4

Contract Period

7/89 - 12/92

Funding Amount (Source)

(Previous years)	\$566,968 (DOE)
(FY 1992)	\$136,998 (DOE)

Crystalline Materials and Advanced Concepts Materials Characterization

Objectives

Provide and maintain a research and support program in the characterization of crystalline photovoltaic materials and devices, with particular emphasis on the development and use of high-resolution analytical electron microscopy. Of special interest is the characterization of structural defects, compositional inhomogeneities and crystalline properties. The intent of the program is to provide, on an interactive and cooperative basis, a comprehensive evaluation of the microstructural and micro-electrical properties that limit the performance of photovoltaic devices.

Approach/Background

Use electron microscopy techniques such as transmission electron microscopy (TEM), high resolution electron microscopy, scanning electron microscopy in its various modes, electron beam induced current, cathodoluminescence, secondary electron, and electron channeling to investigate the chemical, compositional, structural, electrical and luminescent properties of photovoltaic materials and devices. The task maintains an active program in measurement-technique development so that special methods can be rapidly made available to the PV community. The emphasis of this program is on high-resolution electron microscopy to study the nature, origin, and generation mechanisms of defects, and their effects on device performance. Special attention is directed

toward the investigation of defects at interfaces. The results obtained by the above-mentioned characterization techniques are correlated with the growth parameters and with the cell characteristics.

Status/Accomplishments

Examined more than 1000 PV samples and provided chemical, structural, topographic, luminescent and defect properties to NREL in-house researchers and our subcontractors. Furthermore, we developed and implemented a light element x-ray detection system to be used on our TEM to analyze oxygen and carbon. We have initiated many collaborations with the Si industry, one of which is resulting in a cooperative research and development agreement.

FY 1993 Milestones

Provide advanced characterization of crystalline Si, thin-film Si and III-V materials and devices, and develop, test and implement a high resolution image analysis system to study structural and chemical defects.

Major Project Reports

Jones, K.M.; Al-Jassim, M.M.; Sopori, B.L. *TEM Investigation of Hydrogen-Implanted Polycrystalline Si.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

J. Benner
(303) 231-1396

Contractor

NREL
M. Al-Jassim
(303) 231-1042

Contract Number

None

Contract Period

10/91 - 10/92

Funding Amount (Source)

(FY 1992) \$338,455 (DOE)

Crystalline Materials and Advanced Concepts

New III-V Cell Design Approaches for Very High-Efficiency Cells

Objectives

Realize cost-effective solar cells with efficiencies exceeding 30%, and examine new design approaches for achieving very high conversion efficiencies.

Approach/Background

Explore new thin-film approaches specifically designed for III-V semiconductors, explore design approaches for achieving high conversion efficiencies without requiring extremely high-quality material; and increase our basic understanding of the physics of III-V cell devices and explore the potential of unconventional cell designs.

Status/Accomplishments

Measure the doping-dependent absorption coefficient, the temperature-dependent lifetime, and tests for the presence of Auger recombination. Plans are to examine the lifetimes in thin-film double heterostructures with the substrate removed. This information will give us a detailed understanding of radiative recombination and photon recycling. Work to further characterize our molecular beam epitaxy films also continues, and techniques to fabricate thin-film cells are being developed. New designs for AlGaAs cells are being explored.

FY 1993 Milestones

Fabricate and test p-i-n $\text{Al}_x\text{Ga}_{1-x}\text{As}$ solar cells, apply test structure to separate surface and bulk recombination losses in GaAs and $\text{Al}_x\text{Ga}_{1-x}\text{As}$ solar cells. Deliver solar cells or materials at least 0.2-in.^2 (1-cm^2) area.

Major Project Reports

Lush, G.B.; et al. *A Study of Minority Carrier Lifetime Versus Doping in N-Type GaAs Grown by Metal-organic Chemical Vapor Deposition.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401

J. Benner
(303) 231-1371

Contractor

Purdue University
School of Electrical Engineering
West Lafayette, IN 47907

M. Lundstrom/M. Melloch
(317) 494-3515

Contract Number

0-190142-1

Contract Period

8/90 - 9/93

Funding Amount (Source)

(Previous years) \$448,740 (DOE)
(FY 1992) \$ 50,000 (DOE)

Crystalline Materials and Advanced Concepts

New Approaches for High Efficiency Solar Cells

Objectives

Address current problems that are hindering progress toward achieving high-efficiency cascade solar cells.

Approach/Background

Construct new atomic layer epitaxy (ALE) reactor (production type) that can handle three, 2-in. (5-cm) wafers and grow high quality GaAs and AlGaAs. The ALE approach is used to achieve carbon doping up to $10^{20}/\text{cm}^3$ resulting from the cracking of the TMGa precursors.

uniformly deposited tunnel junction using C as p⁺-dopant, and a GaAs or p-GaAs/n(SLS) bottom cell. Optimize the p-GaAs/n(SLS) bottom cell structure.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401

J. Benner
(303) 231-1396

Contractor

North Carolina State University
Box 7214

Raleigh, NC 27695-7214

S. Bedair
(919) 515-5204

Contract Number

9-18141-1

Contract Period

7/89 - 12/92

Funding Amount (Source)

(Previous years)	\$547,234 (DOE)
(FY 1992)	\$149,232 (DOE)

Status/Accomplishments

Used ALE to grow device-quality GaAs and AlGaAs in a newly designed reactor. Carbon as a p-type dopant can be effectively used for high-level doping using the ALE approach. Device quality GaAs and $\text{Al}_x\text{Ga}_{1-x}\text{As}$ films were grown with p-type background carbon doping in the ranges 10^{15} to $10^{20}/\text{cm}^3$.

FY 1993 Milestones

Grow, in the liquid-phase chemical vapor deposition system, monolithic AlGaAs/GaAs cascade structures using GaAs patterned tunnel junction. Repeat the structure in 3.1, with InGaAs tunnel junction, p-GaAs/n(SLS) (strained layer superlattice) bottom cell and $\text{In}_{0.5}\text{Ga}_{0.5}\text{P}$ top cell. Grow, in ALE/FME (flow modulated epitaxy) system, a cascade cell with a GaInP top cell, a GaAs

Crystalline Materials and Advanced Concepts New Growth Techniques and Operating Regimes for Ultra-High-Efficiency Solar Cells

Objectives

Establish a technology to produce very-high-efficiency solar cells for terrestrial photovoltaic applications, using either multijunction or single-junction concepts.

Approach/Background

Growth of GaAs and/or GaInP₂ materials on Si substrates by the metalorganic chemical vapor deposition technique. Efforts have been devoted to reducing the defect density in GaAs-on-Si layers by substrate patterning, and developing a technology for producing Bragg-reflector structures for improved-efficiency solar cells having a reduced base thickness. In the past our achievements of a GaAs-on-Si terrestrial solar cell were 20% at 200 suns.

Status/Accomplishments

Improve the efficiency of GaAs solar cells as well as reducing the defect level of GaAs-on-Si "substrates." High-efficiency cell studies included the development of GaInP₂ monolithic tandems, continued optimization of Bragg reflector structures, and combination of Bragg-reflector and concentrator concepts into GaAs-on-Si solar cells. GaAs-on-Si material improvements will be accomplished by continued study of substrate patterning and

two-dimensional-nucleation techniques based on the use of atomic-layer epitaxy.

FY 1993 Milestones

Nucleation site reduction and silicon surface patterning using holographic lithography; development of the technology needed to mimic the optimum dimensions and oxide coverage of the holographically defined patterned silicon substrates for a low-cost, lower control approach.

Major Project Reports

S.M. Vernon; et al. *Growth and Characterization of Uniform AlGaAs Bragg Reflectors by LP-MOCVD.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

J. Benner
(303) 231-1396

Contractor

Spire Corporation
1 Patriots Park
Bedford, MA 01730
S. Vernon
(617) 275-6000

Contract Number

0-19142-7

Contract Period

8/90 - 10/93

Funding Amount (Source)

(Previous years) \$538,535 (DOE)
(FY 1992) \$ 63,000 (DOE)

Crystalline Materials and Advanced Concepts

Non-H₂Se, Ultrathin CIS Devices

Objectives

Develop techniques for producing efficient, large-area CuInSe₂-based PV modules in a manner consistent with the demands of a manufacturing process, namely with good control, high material utilization and with safety. A particular objective is the demonstration of a 50-W CIS module.

Approach/Background

Use an all-vacuum approach for material deposition. The CIS is produced by selenization of appropriate precursors without use of toxic H₂Se, but with elemental Se instead.

FY 1993 Milestones

Produce a 12% 0.2-in.² (1-cm²) device, a 7-W, 1-ft² (929 cm²) module, and scale-up of CIS deposition to 5 ft² (4645 cm²).

Major Project Reports

Delahoy, A.E.; Kiss, Z.
Non-H₂Se, Ultrathin CIS Devices.

Summary Date

November 1992

Status/Accomplishments

Made progress in the area of precursor formation, window layers, cells, patterning, and modules. Device efficiency has reached 9%–10% (active area) using an interim chemical bath deposited CdS window layer. Wider gap window layers are being developed, and working submodules up to 1 ft² (929 cm²) are being produced. Three methods of patterning have been successfully employed: mechanical, chemical, and laser.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd
Golden, CO 80401
H.S. Ullal
(303) 231-1486

Contractor

Energy Photovoltaics, Inc.
P.O. Box 7456
Princeton, NJ 08543-7456
A.E. Delahoy
(609) 452-1155

Contract Number

XG-2-12051-1

Contract Period

3/10/92 – 2/9/95

Funding Amount (Source)

(FY 1992) \$419,000 (DOE)

Crystalline Materials and Advanced Concepts

Novel Ways of Depositing ZnTe Films by a Solution Growth Technique

Objectives

Develop novel processes for deposition of semiconductor window/contact layers for thin-film polycrystalline solar cells; specifically a method of depositing continuous, thin (<500Å), semitransparent ZnTe films having the required electronic properties for CdTe solar cells.

Approach/Background

Investigate solution growth and electrochemical techniques for ZnTe deposition, and characterize structural, optical, and electrical properties using x-ray diffraction and total reflection and transmission measurements.

Fabricated superstrate CdS/CdTe/ZnTe cells, comparing device properties to devices using Au or Cu/ITO as the CdTe contact. Investigated different deposition processes for ZnSe onto Mo/glass and CuInSe₂/Mo/glass substrates, including solution growth, electrodeposition, and, galvanic deposition. Also investigated deposition of CdS and CdTe films by the galvanic technique to determine its applicability to other II-VI compounds and to demonstrate the feasibility of an all-galvanically deposited device.

Status/Accomplishments

Investigated three deposition processes for ZnTe—galvanic (electrochemical) deposition from an aqueous bath, surface exchange with CdTe where Cd is

replaced by Zn from an aqueous bath to form a ZnTe layer, and solution growth. The galvanic technique was the only one resulting in ZnTe (including ZnTe:Cu-doped) films being formed successfully and reproducibly. The formation of ZnSe and CdSe films using this galvanic method was attempted, providing encouraging results for the formation of CdSe films on SnO₂/glass substrates. Electrochemical deposition processes for ZnSe film formation on CuInSe₂/Mo/glass substrates proved problematic. Preliminary results indicate that the deposition methods investigated are potentially feasible.

FY 1993 Milestones

None

Major Project Reports

Mondal, M.; Birkmire, R.W.; McCandless, B.E., *A New Method for Forming ZnTe Contacts For CdTe Cells*.

Mondal, M.; Birkmire, R.W.; and McCandless, B.E. *Electrodeposition of Thin ZnTe Films As a Contact For CdTe Solar Cells*.

Birkmire, R.W.; McCandless, B.E.; Yokimcus, T.A.; and, Mondal, M. *Electrodeposition of Thin ZnTe Films As a Contact: Novel Ways of Depositing ZnTe Films By a Solution Growth Technique*.

Summary Date

November 1992

Directing Organization

National Renewable Energy

Laboratory

1617 Cole Blvd.

Golden, CO 80401

T.S. Basso

(303) 231-7035

Contractor

University of Delaware

Institute of Energy Conversion

Newark, Delaware, 19716-3820

R.W. Birkmire

(303) 451-6200

Contract Number

XM-0-18110-2

Contract Period

1/1/90 – 1/1/92

Funding Amount (Source)

(Previous years) \$200,000 (NREL)

Crystalline Materials and Advanced Concepts

Optimization of Gettering Processes for PV Silicon

Objectives

Develop and optimize gettering processes whose application prior to solar cell fabrication and during fabrication will enhance the quality of low-cost photovoltaic silicon, improve the reproducibility of the material, and reduce cost by allowing use of lower-quality feed material.

Approach/Background

Establish an experimental base that allows a better understanding of the interaction of impurities with defects and will lead to the development of a comprehensive gettering model. The model will take into account the impurity defect interaction, the role of heat treatments (temperature, time, and atmosphere), and gettering sources. Contamination-control experiments will be conducted to investigate the basic behaviors and gettering properties of various heavy metals in monocrystalline and photovoltaic polycrystalline silicon.

Status/Accomplishments

Study the redissolution of heavy metals, optimize POCl_3 gettering, and study of Cl gettering.

FY 1993 Milestones

Study of Al gettering; study of backside damage gettering, fluorine/hydrogen plasma, engineering and optimization of oxygen concentration; and study of crystallographic defect annealing.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
J. Benner
(303) 231-1396

Contractor

University of South Florida
College of Engineering
Tampa, FL 33620
L. Jastrzebski
(813) 974-5136

Contract Number

2-11004-5

Contract Period

4/92 - 6/95

Funding Amount (Source)

(Previous years) \$141,744 (DOE)
(FY 1992) \$141,744 (DOE)

Crystalline Materials and Advanced Concepts

Optoelectronic Spectroscopy

Objectives

Perform spectroscopic investigations on spontaneously ordered GaInP₂ to determine the effects of this phenomenon on the electronic band structure, and shed light on the physical nature of this process as exhibited during epitaxial growth. Explore the possibility of using lateral superlattice architectures generated by spinodal decomposition so as to yield ultra-high minority carrier lifetime devices.

Major Project Reports

Mascarenhas, A.; et al. *Experimental Evidence for a Spontaneously Generated Effective-Mass Superlattice.*

Horner, G.; et al. *Photoluminescence Excitation Spectroscopy Studies in Spontaneously Ordered GaInP₂.*

Alonso, R.; et al. *Piezomodulation Spectroscopy Studies in Spontaneously Ordered GaInP₂.*

Summary Date

November 1992

Status/Accomplishments

Used low-temperature polarized photoluminescence, polarized photoluminescence excitation spectroscopy, and polarized piezomodulation spectroscopy experiments to show that spontaneous ordering in GaInP₂ does not result in ordered domains distributed in a matrix of the disordered alloy but rather in a distribution of domains whose order parameter obeys a distribution function. Discovered that lateral superlattices generated by spinodal decomposition are actually effective-mass superlattices as contrasted to Esaki-Tsu bandgap modulation superlattices.

FY 1993 Milestones

Use resonance Raman measurements to elucidate the crystal-field splitting caused by spontaneous ordering in GaInP₂. Perform similar measurements on lateral superlattices. Publish three publications in refereed journals.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

J. Benner
(303) 231-1396

Contractor

NREL
A. Mascarenhas
(303) 231-1368

Contract Number

None

Contract Period (Source)

10/1/91 - 10/1/92

Funding Amount

(FY 1992) \$114,840 (DOE)

Crystalline Materials and Advanced Concepts

Photoluminescence Studies of GaInP₂

Objectives

Identify the optical process in ordered and disordered GaInP with the ultimate goal of understanding the details of the microstructure of ordered GaInP, how specific configurations result from conditions of growth, and how these configurations determine the optical and electronic properties of the material.

Approach/Background

Analyzed samples of GaInP supplied by NREL using microwave-modulated photoluminescence to give insight into possible kinds of processes which influence emission from ordered small bandgap samples. The anomalous temperature dependence of photoluminescence characteristics reported in GaInP were investigated by measuring the band gap and photoluminescence characteristics in the range from 2 K to 300 K. Photoluminescence- and selective-excitation spectroscopy were applied to compare the optical properties and degree of ordering between samples of GaInP grown by means of organic metallic vapor-phase epitaxy and molecular beam epitaxy.

Status/Accomplishments

The research collaboration between NREL and University of Utah has added significantly to the body of knowledge about GaInP and its tendency to order spontaneously into the CuPt structure. Because the ordering phenomena has a profound effect on the band structure of

material, analysis of the optical properties using techniques developed by the subcontractor is the most sensitive probe of the changes occurring in the GaInP.

FY 1993 Milestones

Have at least one paper accepted for publication in technical journals, a gauge of the successful performance of this research.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
J. Benner
(303) 231-1396

Contractor

University of Utah
Physics Dept/201 JFB
Salt Lake City, UT 84112
M. DeLong
(801) 581-7462

Contract Number

2-12121-1

Contract Period

4/92 - 3/93

Funding Amount (Source)

(Previous years)	\$40,000 (DOE)
(FY 1992)	\$40,000 (DOE)

Crystalline Materials and Advanced Concepts

Self-Interstitials Injected by Phosphorus Diffusion in Crystalline Silicon

Objectives

Assist in the development of new processing and characterization techniques to improve the quality of commercial silicon substrates to produce 16% to 18% commercial solar cells.

Approach/Background

Study several parameters involved in phosphorus in-diffusion: phosphorus spin-on glass vendor and concentration, and spin-on conditions. Two means of measuring the diffusion profile were investigated: spreading resistance profiling and electrochemical etch profiling.

Status/Accomplishments

Obtained a stable array of misfit screw dislocations via the wafer bonding technique. The wafer bonding technique can be used to study the electrical properties of the silicon/oxide interface. The oxides produced by wafer bonding may either be a continuous film or be an array of oxide precipitates distributed in a defined patterns and size range. The electrical activity of both types will be examined before and after self-interstitial injection.

FY 1993 Milestones

Complete measurement of implanted boron layer. Complete study of thinning and electron beam induced epitaxy (EBIC) or Si wafers before and after phosphorus diffusion.

Generation of oxidation-induced stacking fault and transmission electron microscopy characterization data. Complete EBIC measurements of commercially available buried oxide layer, before and after hydrogen passivation. Initiate wafer bonding for formation of broken-up oxide and thinning. Complete self-interstitial injection experiments for different Cz materials.

Major Project Reports

Gosele, U.; et al. *Final Report for Solar Energy Research Institute*, 1992.

Taylor, W.J.; Gosele, U.; Tan, W.Y. *Journal of Applied Physics*, 1992.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

J. Benner/B. Sopori
(303) 231-1396/1383

Contractor

Duke University
School of Engineering
Durham, NC 27705
U. Gosele
(919) 660-5322

Contract Number

2-11004-1

Contract Period

4/92 - 6/95

Funding Amount (Source)

(Previous years) \$141,758 (DOE)
(FY 1992) \$141,758 (DOE)

Crystalline Materials and Advanced Concepts

Solid State Theory

Objectives

Provide the solid state physics foundation for better selection of photovoltaic materials and optimization of their properties through use of state-of-the-art theoretical modelling.

Approach/Background

Apply our understanding of thermodynamic phase-equilibria near the surface of III-V alloys to achieve bandgap engineering of these PV materials during growth; and investigate the potential of the newly discovered "porous silicon wires" to PV by analyzing the mechanism of enhanced light emission. This second area replaces the task on "theory of interfacial GaAs/ZnSe bonding."

Status/Accomplishments

Discovered that the spontaneous ordering of $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ alloys occurs at the sample surface during growth, rather than in the bulk. This was accomplished by performing a set of total energy calculations on various GaInP surface structures and applying to the resulting energies a statistical mechanics treatment, thereby obtaining temperature composition surface phase diagrams. Ordering resulted from the reconstruction of the alloy surface. This means we could control the degree of ordering by manipulating the surface structure during growth, e.g., by light, doping, or by "poisoning" reconstructions. We also found how the optical properties of the alloy depend on the degree of order attained at the

surface. This means we could control the materials properties during growth. We have further studied surface segregation in both GaAs (001) and $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ (001) as a function of coverage and reconstruction, thus shedding light on the surface morphology. A novel "truncated crystal model" showed that quantum confinement in clean porous silicon could not explain the observed enhanced light emission. Instead, coverage of porous Si by hydrogen and oxygen appear to be the decisive factor.

FY 1993 Milestones

Assess research requirements to establish theoretical techniques for studying mesoscopic systems and apply them to complex PV semiconductors.

Major Project Reports

Osorio, R.; Bernard, J.; Froyen, S.; Zunger, A. *Ordering Thermodynamics of Surface and Subsurface Layers in GaInP Alloy.*

Froyen, S.; Osorio, R.; Zunger, A. *Surface Energetics and Ordering in GaInP.*

Osorio, R.; Bernard, J.; Froyen, S.; Zunger, A. *Thermodynamics of Surface-Induced Ordering in GaInP Alloy.*

Dandrea, R.; Duke, Zunger, A. *Interfacial Atomic Structure and Band Offsets at Semiconductor Heterojunctions.*

Zhang, S.B.; Zunger, A. *Truncated Crystal Approach to Porous Si.*

Summary Date

December 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

J. Benner
(303) 231-1396

Contractor

NREL

A. Zunger
(303) 231-1172

Contract Number

None

Contract Period

10/91 - 10/92

Funding Amount (Source)

(FY 1992) \$518,750 (DOE)

Crystalline Materials and Advanced Concepts

Surface and Interface Analysis

Objectives

Maintain and provide state-of-the-art chemical, compositional and microelectrical characterization of crystalline photovoltaic materials/devices in support of in-house researchers and industry. Understand surface and interface electronic properties of crystalline semiconductor materials as a function of chemistry and structure as determined by growth/process parameters. Determine how these surface/interface properties influence device performance and stability.

Approach/Background

Use surface analysis techniques, including scanning Auger microscopy, x-ray photoelectron spectroscopy, ultraviolet photoelectron spectroscopy, secondary ion mass spectrometry, electron energy loss spectroscopy and scanning tunneling microscopy to support the investigation of the chemical and compositional properties and electronic structure of crystalline photovoltaic materials and devices. These techniques are applied to crystalline Si, microcrystalline Si, porous Si films, binary and ternary III-Vs and H_2S gas/plasma passivated surfaces of crystalline III-V materials.

Status/Accomplishments

Coordinated activities in silicon material/device development and process development with subcontractors (Siemens, Solarex, Mobil) by providing advanced measurement and

characterization support. Similar support was provided in III-V material/device development for Kopin and Spire. We also developed and implemented a sulfurization process for surface passivation of III-V semiconductors to improve device performance.

FY 1993 Milestones

Provide advanced characterization of crystalline Si, microcrystalline Si, porous Si and III-V materials/devices/processes for subcontractor support. Determine the effects of plasma processing on contact/junction stability and performance.

Major Project Reports

Nelson, A.J. *Soft X-Ray Photoemission Characterization of the H_2S Exposed Surface of p-InP.*

Summary Date

December 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd
Golden, CO 80401

J. Benner
(303) 231-1396

Contractor

NREL
A.J. Nelson
(303) 231-7128

Contract Number

None

Contract Period

10/91 - 10/92

Funding Amount

(FY 1992) \$335,450 (DOE)

Crystalline Materials and Advanced Concepts Semiconductor Device Process Development and Industry Support

Objectives

Develop low-cost silicon solar cell fabrication processes that can improve cell performance. Develop and standardize material and cell characterization techniques that can be used by the silicon industry as characterization and quality assurance tools; and analyze the material, processes, and devices of PV silicon manufacturers and provide them with feedback and suggestions for improvements.

Approach/Background

Work closely with the PV silicon industry to identify applications of new technologies in the areas of cell processing that can lower the cell cost and/or improve the cell performance; identify the areas of material characterization in which NREL can support industry; and develop joint long-term research projects in which NREL can complement industry research.

Status/Accomplishments

Established a Silicon Industry Support Task under which PV silicon material from industry is analyzed to determine the impurities and defects in the material and establish the performance-limiting mechanisms in the material. We have worked with Solarex, Crystal Systems, Mobil Solar, Siemens Solar, and AstroPower. A large-area, high-speed defect mapping system was developed that determines the distribution of dislocations and grain boundaries

in a wafer. This technique has been used to characterize materials from solar cell industry and to determine the locations of high thermal stress in the ingots from casting. We have demonstrated that optical processing can be applied to commercial solar cells to improve the contacts. We have demonstrated that back-side hydrogenation followed by optical processing can be applied to finished cells with a significant improvement in the efficiency (about a 20% increase).

FY 1993 Milestones

Complete a computer-controlled optical processing furnace to process commercial silicon wafers/cells; develop cooperative research and development agreements with three industry partners to carry out materials research for improved substrate quality; and develop a commercially compatible method for hydrogenation of solar cells.

Major Project Reports

None

Summary Date

February 1993

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

J. Benner
(303) 231-1396

Contractor

NREL
B.L. Soporì
(303) 231-1383

Contract Number

None

Contract Period

10/1/91 - 9/30/92

Funding Amount (Source)

(FY 1992) \$800,000 (DOE)

Module and System Performance and Engineering 1-kW Photovoltaic System

Objectives

Design and install a 1-kW PV array at the NREL PV Outdoor Test Facility in Golden, Colorado. This array will provide technical validation for the Solar Cells, Inc. (SCI) thin-film CdTe modules prior to installation of 20-kW array for the EMT-3 part of the PVUSA program.

Major Project Reports

None

Summary Date

November 1992

Approach/Background

The support structure for the 1-kW array is based on a low-cost design SCI has worked with in the past. Eight 2 × 12-ft (60 × 360-cm) panels each containing three modules will be installed on the support structure to evaluate the performance of the 2 × 4-ft (60 × 120-cm) thin-film CdTe modules. This configuration will then be used in the PVUSA project.

Status/Accomplishments

Signed the subcontract on August 24, 1992. The support structure was installed at the NREL test site in Golden, and is ready to receive the PV panels when they are ready.

FY 1993 Milestones

Complete the rest of the subcontracted work, including the installation of the PV panels and delivery of ten spare modules for testing.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

L. Mrig
(303) 231-7178

Contractor

Solar Cells, Inc.
2650 North Reynolds Road
Toledo, OH 43615

J.F. Nolan
(419) 435-3377

Contract Number

A1-2-12262-1

Contract Period

8/24/92 - 12/31/92

Funding Amount (Source)

(FY 1992) \$15,676 (DOE)

Module and Systems Performance and Engineering 1.8-kWp PV System of Dual-Junction Amorphous Silicon PV Modules

Objectives

Install and evaluate performance of 96 UPM-880 modules from United Solar Systems Corp., which use a dual-junction amorphous silicon alloy.

Approach/Background

Design the PV array including inverter, junction boxes, and data acquisition system and provide hardware for installation at NREL field test location in Golden.

Status/Accomplishments

Designed system and supplied major components.

FY 1993 Milestones

Supply balance of hardware by mid-November; install array and start up by end of November.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
L. Mrig
(303) 231-7178

Contractor

United Solar Systems Corp.
1100 W. Maple Road
Troy, MI 48064
L. Slominski
(619) 625-2080

Contract Number

AG-2-12074-1

Contract Period

8/31/92 - 8/31/93

Funding Amount (Source)

(FY 1992) \$20,846 (DOE)

Module and System Performance and Engineering

Amorphous Silicon Utility/Industry Photovoltaic Power Project

Objectives

Develop amorphous silicon photovoltaic modules with a 6.3% average stabilized total-area efficiency, certify that these modules pass NREL's interim qualification tests and procedures for terrestrial photovoltaic thin-film flat-plate modules, and deploy these modules in a 20-kW_p (ac) system.

Approach/Background

Develop amorphous silicon modules with dimensions of approximately 1.1 × 1.2 ft (33 × 37 cm) in Phase 1. Stabilized efficiency is defined as the efficiency measured under standard test conditions after the module has been exposed for 600 hours to approximately 1000 W/m² of nominally white light with the module at 122°F (50°C) and under a fixed resistive load. During Phase 1, Utility Power Group (UPG) will certify that these modules have passed NREL's interim qualification tests and procedures for terrestrial photovoltaic thin-film flat-plate modules. Phase 2 is negotiated to design and install a 20-kW_p (ac) system in the service territory of the Los Angeles Department of Water and Power.

Status/Accomplishments

Began subcontract on October 20, 1992.

FY 1993 Milestones

By October 1993, UPG should demonstrate four amorphous silicon modules with a 6.3% average stabilized total-area efficiency and certify that these modules have passed NREL's interim qualification tests and procedures for terrestrial photovoltaic thin-film flat-plate modules.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

B. Stafford
(303) 231-7126

Contractor

Utility Power Group
9410 DeSoto Avenue, Unit G
Chatsworth, CA 91311

G. Duran
(818) 700-1995

Contract Number

A1-8-1106-05-103106

Contract Period

10/20/92 – 10/19/93

Funding Amount (Source)

(FY 1992) \$100,000 (DOE)

Module and Systems Performance and Engineering

Amorphous Silicon Utility/Industry Photovoltaic Power Project

Objectives

Develop triple-junction amorphous silicon photovoltaic modules with a 7% average stabilized total-area efficiency, certify that these modules pass NREL's interim qualification tests and procedures for terrestrial photovoltaic thin-film flat-plate modules, and deploy these modules in a 10-kW_p (ac) system.

Approach/Background

Develop triple-junction amorphous silicon photovoltaic modules with dimensions of approximately 1.1 × 4.2 ft (34 × 126 cm). Stabilized efficiency is defined as the efficiency measured under standard test conditions after the module has been exposed for 600 hours to approximately 1000 W/m² of nominally white light with the module at 122°F (50°C) and under a fixed resistive load. During Phase 1, Energy Conversion Devices (ECD) will certify that these modules have passed NREL's interim qualification tests and procedures for terrestrial photovoltaic thin-film flat-plate modules. Phase 2 is negotiated to design and install a 10-kW_p (ac) system on the Auburn Hills Campus of Oakland Community College in Oakland, Michigan.

Status/Accomplishments

ECD has delivered two modules representative of their latest progress. ECD reports an 8.0% average initial total-area efficiency.

FY 1993 Milestones

By July 1993, ECD should demonstrate four triple-junction amorphous silicon photovoltaic modules with a 7% average stabilized total-area efficiency and certify that these modules have passed NREL's interim qualification tests and procedures for terrestrial photovoltaic thin-film flat-plate modules.

Major Project Reports

None

Summary Date

November 1992.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
B. Stafford
(303) 231-7126

Contractor

Energy Conversion Devices, Inc.
West Maple Road
Troy, MI 48064
M. Izu
(313) 280-1900

Contract Number

A1-2-11061-1

Contract Period

7/21/92 – 5/21/94

Funding Amount (Source)

(FY 1992) \$150,000 (DOE)

Module and Systems Performance and Engineering

Amorphous Silicon Utility/Industry Photovoltaic Power Project

Objectives

Demonstrate dual-junction amorphous silicon photovoltaic modules with 22-W average stabilized maximum power output, certify that these modules have passed NREL's interim qualification tests and procedures for terrestrial photovoltaic thin-film flat-plate modules, and deploy these modules in a 15-kW_p (ac) system.

Approach/Background

Deliver dual-junction amorphous silicon photovoltaic modules with dimensions of approximately 1.2 × 4.2 ft (35 × 125 cm) in Phase 1. Stabilized power output is defined as the power output measured under standard test conditions after the module has been exposed for 600 hours to approximately 1000 W/m² of nominally white light with the module at 122°F (50°C) and under a fixed resistive load. During Phase 1, Integrated Power Corporation will certify that these modules have passed NREL's interim qualification tests and procedures for terrestrial photovoltaic thin-film flat-plate modules and deliver engineering drawings for a 15-kW_p (ac) system using these modules. Phase 2 is negotiated to install a 15-kW_p (ac) system on the roof of a New York Transit Authority bus maintenance building in Maspeth, New York. The system will be in the service territory of the New York Power Authority.

Status/Accomplishments

Began contract on October 23, 1992.

FY 1993 Milestones

If Phase 1 is successful, Phase 2 is negotiated for system deployment during the summer of 1993.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
B. Stafford
(303) 231-7126

Contractor

Integrated Power Corporation
7524 Standish Place
Rockville, MD 20855
D. Panjco
(301) 294-9133

Contract Number

A1-2-11061-3

Contract Period

10/23/92 - 12/23/93

Funding Amount (Source)

(FY 1992) \$481,343 (DOE)

Module and Systems Performance and Engineering Management and Administration of IEC TC-82, Solar Photovoltaic Energy Systems

Objectives

Develop international PV standards that will protect the interests of U.S. photovoltaic industry in a world marketplace.

Approach/Background

Serve as the secretary of the International Electrotechnical Commission Technical Committee 82, Solar Photovoltaic Energy System. The secretary has the final responsibility for all technical input.

Status/Accomplishments

Publish three international PV standards. Reaffirm three Institute of Electrical and Electronics Engineers PV standards.

FY 1993 Milestones

Publish six international PV standards.

Major Project Reports

Paper presented at NREL 11th PV AR&D Review Meeting.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401

L. Mrig
(303) 231-7178

Contractor

Solar Energy Industries Association
777 North Capitol St., N.E.

Suite 805
Washington, DC 20002-4226

R. Klein
(717) 346-1364

Contract Number

HI-2-12006-9

Contract Period

4/06/92 - 3/19/93

Funding Amount (Source)

(Previous years)	\$80,000 (DOE)
(FY 1992)	\$43,000 (DOE)

Module and Systems Performance and Engineering

Cell and Module Standardized Characterization Performance Measurements

Objectives

Support the photovoltaic community by providing standardized cell and module PV performance measurements; efficiency verification of contract deliverables; current versus voltage (I-V) measurements under varying temperature, spectral irradiance and total irradiance; transfer of information on PV measurement equipment and systems that are appropriate for the end user; I-V measurement procedures; and uncertainty analysis.

Approach/Background

Provide calibrated reference cells and standardized I-V measurements of single and multi-junction cells and modules.

Status/Accomplishments

Completed two new outdoor I-V systems for PV module and cell performance measurements in support of internal research and that of PV manufacturers. Performed 1381 cell I-V calibrations, and standardized measurements on more than 1100 modules.

FY 1993 Milestones

Continue to support the standardized PV performance characterization needs of the DOE program and the PV community. Maintain our state-of-the-art capability by replacing, repairing, and enhancing obsolete equipment. Use the outdoor I-V systems for evaluating rating methods and standardized performance measurements on cells and modules.

Major Project Reports

Nann, S.; Emery, K. *New Proposals for Energy Rating of Photovoltaic Devices.*

Nann, S.; Emery, K. *A Numerical Analysis of PV-Rating Methods.*

Molenbroek, E.; Waddington, E.W.; Emery, K. *Hot Spot Susceptibility and Testing of PV Modules.*

Osterwald, C.R.; *ASTM Photovoltaic Standards Development Status.*

Emery, K.A. *Efficiency Measurements on Thin-Film PV Cells and Modules.*

Kazmerski, L.; Emery, K. *Photovoltaic Technologies: From Atoms to Arrays.*

Emery, K.; Beck, E.; Field, H.; Rummel, S. *PV Performance Measurements at NREL.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

R. DeBlasio
(303) 231-1286

Contractor

NREL
K. Emery
(303) 231-1032

Contract Number

None

Contract Period

10/1/91 - 9/30/92

Funding Amount (Source)

(FY 1992) \$584,900 (DOE)

Module and Systems Performance and Engineering

National Electric Code – Article 690 (PV Systems) Support

Objectives

Increase participation of the U.S. photovoltaic industry in developing the National Electric Code (NEC) Article 690: Solar Photovoltaic Systems, and related standards.

Approach/Background

Assist in building PV industry consensus on developing NEC Article 690 and supporting standards and codes by bringing together representatives from the PV industry biannually.

Status/Accomplishments

Began contract on October 1, 1992.

FY 1993 Milestones

Hold two meetings on NEC Article 690 and potential revisions; produce a report on commercial testing laboratories' capabilities.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
L. Mrig
(303) 231-7178

Contractor

Solar Energy Industries Association
777 North Capitol St., N.E.
Suite 805
Washington, DC 20002-4226
R. Sellers
(202) 408-0660

Contract Number

HI2-12006-27

Contract Period

10/1/92 – 9/30/93

Funding Amount (Source)

(FY 1992) \$23,200 (DOE)

Module and Systems Performance and Engineering Photovoltaic Solar Radiation Research

Objectives

Provide measurements, instrumentation, calibrations and measurement techniques enhancing scientific understanding of solar radiation incident upon photovoltaic devices under engineering test, performance evaluation, and operational conditions.

Approach/Background

Use carefully characterized commercially available broadband and spectral measuring instrumentation with highest accuracy radiometric reference standards to calibrate instrumentation. Develop, discuss, and exchange information on instrumentation, models, radiative transfer and atmospheric physics with recognized experts in the field and PV performance-testing engineers. Provide measurements or measurements instrumentation as requested.

Status/Accomplishments

Evaluated two new commercial systems for PV solar data collection and evaluation by electric utilities in cooperation with the Electric Power Research Institute. Calibrated, provided instrumentation, and collected one year of solar radiation data for PV applications at two locations, in cooperation with Public Service of Colorado. Designed and tested a system for measuring devices for plane-of-array radiation measurements for PV module test applications. Measured spectral distribution of various solar simulators used to calibrate and rate PV-device

performance and to accelerate weathering of PV materials.

FY 1993 Milestones

Develop a reference irradiance and meteorological measurement station and provide common radiometric and weather data to the facility. Validate a method for measuring spectral variation in pulsed simulator lamps on a time scale from a millisecond to a month. Document difference between historical data and the newer NREL National Solar Radiation Data Base when applied to the PV systems.

Major Project Reports

Hulstrom, R.; Riordan, C.; Cannon, R.; Stoffel, T. *Annual Progress Report, Photovoltaic Solar Radiation Research Task, October 1991–September 1992.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

R. DeBlasio
(303) 231-1286

Contractor

NREL
D.R. Meyers
(303) 231-1490

Contract Number

None

Contract Period

10/1/91 – 9/30/92

Funding Amount (Source)

(FY 1992) \$498,800 (DOE)

Module and Systems Performance and Engineering

PV Module and System Performance

Objectives

Monitor and evaluate the performance of PV modules and systems under outdoor field conditions as well as accelerated test conditions in the laboratory.

Approach/Background

Installed and monitored PV modules and systems with NREL subcontractors and through commercial procurements at NREL's PV Outdoor Test Facility. Tested modules for reliability using test procedures outlined in NREL's "Internal Qualification Test Procedure for Terrestrial Thin-Film Flat-Plate Modules."

Status/Accomplishments

Awarded the contracts for two PV systems: a 1.8-kW_p amorphous silicon system from United Solar Systems Corporation and a 1-kW CdTe PV system from Solar Cells, Inc. Obtained and tested modules from various PV manufacturers; and analyzed and reported the results.

FY 1993 Milestones

Monitor and evaluate the performance of two PV system contracts, and obtain two additional PV systems along with modules from various manufacturers.

Major Project Reports

Mrig, L. *Proceedings of the Photovoltaic Performance and Reliability Workshop.*

Mrig, L.; Waddington, S.; Rummel, S.; Caiyem, Y. *11th NREL PV AR&D Review Meeting.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401

R. DeBlasio
(303) 231-1286

Contractor

NREL

L. Mrig
(303) 231-7178

Contract Number

None

Contract Period

10/1/91 - 9/30/92

Funding Amount (Source)

(FY 1992) \$934,305 (DOE)

Module Systems and Performance and Engineering

PV Module Reliability Research

Objectives

Identify new or improved low-cost encapsulation materials, materials processing procedures, design or fabrication methods, and compatible materials interfaces that offer greater promise for a module life expectancy of 30 years.

Approach/Background

Focus on contemporary thin-film and crystalline silicon flat-plate PV module technologies, conduct experimental work, interpret the results, establish test methods and protocols, identify mechanisms of degradation in both present and future PV modules, and seek solutions to module reliability and materials durability problems.

Status/Accomplishments

Identified additional ethylene vinyl acetate (EVA) degradation mechanisms, established an accelerated life testing protocol, acquired and used high-performance liquid chromatograph and fluorescence analysis equipment, identified potential ultraviolet (UV)-absorber-stabilizer combinations, and measured efficiency losses from yellowed EVA. The purpose is to improve EVA by accelerated testing of the UV-stabilizer-absorber combinations in EVA, and to continue to work closely with industry.

FY 1993 Milestones

Establish an accelerated testing protocol and an initial ranking of candidate stabilizers

in modified EVA and an initial ranking of several candidate polymers to replace EVA. Complete a research paper for journal submission on EVA degradation. Identify probable environmentally-induced degradation mechanisms at SnO_2CdS interfaces.

Major Project Report

Pern, F.J.; Czanderna, A.W. *EVA Degradation Mechanisms Simulating those in PV Modules.*

Pern, F.J.; Czanderna, A.W.; Emery, K.A.; Dhere, R.G. *Weathering Degradation of EVA Encapsulant and the Effect of its Yellowing on Solar Cell Efficiency.*

Pern, F.J. *Polymer Encapsulants Characterized by Fluorescence Analysis Before and After Degradation.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

R. DeBlasio
(303) 231-1286

Contractor

NREL
A.W. Czanderna
(303) 231-1240

Contract Number

None

Contract Period

10/1/89 - Open

Funding Amount (Source)

(Previous years)	\$630,000	(DOE)
(FY 1992)	\$578,915	(DOE)

Polycrystalline Thin Films

Advanced Processing Technology for High-Efficiency, Thin-Film CuInSe₂ Solar Cells

Objectives

Improve the performance of CuInSe₂ solar cells through experimental work on materials and devices, and working with computer models, identify, the mechanisms which limit cell performance.

Major Project Reports

None

Summary Date

November 1992

Approach/Background

Prepare CuInSe₂ layers without the use of HSe₂ gas, characterize materials and devices, and optimize the performance of diagnostic solar cells.

Status/Accomplishments

Prepared and characterized high-quality CuInSe₂ layers and identified and, to some extent, mitigated problems relating to film adhesion.

FY 1993 Milestones

Prepare state-of-the-art CuInSe₂ solar cells and add a research task on CdTe solar cells. World-record efficiency CdTe solar cells have been fabricated at the University of South Florida. NREL is negotiating with USF to support work to evaluate how the present deposition processes used in the laboratory can be altered to be compatible with low-cost mass production techniques.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
B.G. von Roedern
(303) 231-1380

Contractor

University of South Florida
4202 East Fowler Avenue
Tampa, FL 33620
D. Morel
(813) 974-2508

Contract Number

XG-2-11036-1

Contract Period

3/1/92 - 2/28/95

Funding Amount (Source)

(FY 1992) \$134,793 (DOE)

Polycrystalline Thin Films

Characterization of Polycrystalline Thin Films

Objectives

Assist industry to develop CdTe and CIS commercial products by responding to pressing issues, filling critical experimental niches that industry cannot address, and supporting a base of technical knowledge that can be a backdrop for continued progress.

Approach/Background

Respond to ongoing industry request for sample analysis, develop new and improved methods of analysis, and design specific experiments to investigate questions critical to industrial success.

Status/Accomplishments

Using time-resolved photoluminescence (TRPL), studied state-of-the-art CdTe material made by close-spaced sublimation and supplied by University of South Florida (USF). TRPL is a new technique developed in our lab that allows us to measure for the first time very short, minority-carrier lifetimes such as those exhibited by CdTe. Even the best CdTe made by USF was nonuniform in terms of lifetime, although the material was somewhat improved by process adjustments at USF. Studied new CIS made by International Solar Electric Technology using an advanced, proprietary method of depositing Cu/In metals. Our analysis of the morphology and electronics allowed them to improve their low-cost films.

FY 1993 Milestones

Continue to analyze industrial samples on demand. Develop or improve existing measurement tools; specifically, modifying the TRPL equipment to measure CIS lifetimes.

Major Project Reports

Bode, M.; Al-Jassim, M.; Jones, K.; Hasoon, F. *Microcharacterization of Polycrystalline Semiconductor Thin Films for Photovoltaic Applications*.

Jones, K., et al. *The Morphology and Microstructure of Polycrystalline CdTe Thin Films for Solar Cells Applications*.

Al-Jassim, M.; Bode, M.; Abou-Elfotouh, F. *The Morphology, Microstructure, and Electrical Properties of CuInSe₂ and CdTe Thin-Film Solar Cells*.

Nelson, A. *The Morphology, Microstructure, and Electrical Properties of CuInSe₂ and CdTe Thin-Film Solar Cells*.

Niles, D. *CdZnTe Alloys Grown on CdTe: A Photoemission and RHEED Study*.

Key, B. *Minority-Carrier Lifetime of Compound Semiconductors in Polycrystalline CdTe*.

Niles, D.; Hochst, H. *Manifestation of Electric Dipole Selection Rules in Angle Resolved Photoemission Spectra from Zinc Blend Semiconductors*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

K. Zweifel
(303) 231-7141

Contractor

NREL
M. Al-Jassim
(303) 231-1042

Contract Number

None

Contract Period

10/91 - 10/92

Funding Amount (Source)

(FY 1992) \$801,560 (DOE)

Polycrystalline Thin Films

Development and Application of a Computer Model for CdTe and CuInSe₂ Solar Cells

Objectives

Develop accurate and user-friendly computer models for CdTe and CuInSe₂ solar cells.

Approach/Background

Using the ADEPT model, refine inputs and device physics to reflect actual CdTe and CuInSe₂ cells.

Status/Accomplishments

Released the model in August 1992.

FY 1993 Milestones

Released a user-friendly model.

Major Project Reports

Gray, J.L.; Schwartz, R.J.
Development of a Computer for Polycrystalline Thin-Film CuInSe₂ and CdTe Solar Cells.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

B.G. von Roeder
(303) 231-1380

Contractor

Purdue Research Foundation
1021 Hovde Hall, Room 301
West Lafayette, IN 47907

R. Schwartz/J. Gray
(317) 494-3539/3478

Contract Number

XG-2-11036-2

Contract Period

3/1/92 - 2/28/95

Funding Amount (Source)

(FY 1992) \$79,971 (DOE)

Polycrystalline Thin Films

Development of High-Efficiency, Thin-Film CdTe Solar Cells

Objectives

Improve thin-film CdTe solar cell efficiencies to about 14% through fundamental understanding of defects and loss mechanisms.

Approach/Background

Prepare and characterize materials and devices using metal organic chemical vapor deposition growth techniques and conduct detailed analyses of "treatments," such as annealing after CdTe exposure or rapid thermal processing, to better understand their effects on solar cell performance.

Major Project Reports

Rohatg, A.; Sudharsanan, R.; Ringel, S. *High-Efficiency Cadmium and Zinc-Telluride Based Thin-Film Solar Cells*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

B.G. von Roedern
(303) 231-1380

Contractor

Georgia Institute of Technology
Office of Contract Administration
Atlanta, GA 30332-0420

A. Rohatgi
(404) 894-7692

Contract Number

XG-2-11036-3

Contract Period

2/1/92 - 1/31/95

Funding Amount (Source)

(FY 1992) \$140,000 (DOE)

Status/Accomplishments

Achieved state-of-the-art CdS layers by solution growth and fabricated state-of-the-art solar cells.

FY 1993 Milestones

Achieve high solar cell efficiency (~13%) in best-device configuration, continue the investigation of treatments and the identification of the most crucial factors limiting cell performance.

Polycrystalline Thin Films

Development of Large-Area Monolithically Integrated Silicon-Film Photovoltaic Modules

Objectives

Develop AstroPower's Silicon-Film Product III into low-cost, stable solar cells for large-scale terrestrial power applications.

Approach/Background

Product III consists of a thin, polycrystalline layer of silicon on a durable, insulating ceramic substrate. The insulating ceramic allows solar-cell elements to be isolated electrically and monolithically interconnected. Low cost and high efficiency modules can thus be formed from large-area, ceramic-based submodules.

Status/Accomplishments

Developed a device process that enables the thin silicon layers to be formed into solar cells and monolithically interconnected. Device performance has been limited by low minority carrier diffusion lengths. Recent success identifying and controlling contamination sources has led to diffusion-length improvements and the development of a successful gettering process.

FY 1993 Milestones

Fabricate prototype arrays with improved material. Short term optimizations of device processing are expected to generate monolithic arrays over 8% efficient. End-of-FY 1993 goals are for 78 in.² (500-cm²) devices over 11% efficient.

Major Project Reports

Rand, J.A., et al. *Development of Large-Area Monolithically Integrated Silicon-Film Photovoltaic Modules.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

H.S. Ullal
(303) 231-1486

Contractor

AstroPower, Inc.
Solar Park
Newark, DE 19716-2000

J.A. Rand
(303) 366-0400

Contract Number

ZR-1-11064-1

Contract Period

5/1/91 - 2/28/94

Funding Amount (Source)

(Previous years)	\$485,000 (DOE)
	\$106,000 (AstroPower)
(FY 1992)	\$412,000 (DOE)
	\$103,000 (AstroPower)

Polycrystalline Thin Films

Fabrication of Stable, Large-Area, Thin-Film CdTe Photovoltaic Modules

Objectives

Develop and demonstrate fabrication methods consistent with high throughput manufacturing of thin-film CdTe solar cells and modules.

Approach/Background

Accomplish semiconductor deposition by condensing vapors of the elements at pressures less than atmospheric. The vapors are generally produced by sublimation of compounds, but experimental work with elemental sources is also in progress.

Status/Accomplishments

Designed, constructed, and operated equipment for deposition of 2 × 4-ft (60 × 120-cm) CdS and CdTe films. Produced interconnected modules with power output greater than 45 W on a total area of 7.75 ft² (7200 cm²). Semiconductor deposition time is less than 60 s.

FY 1993 Milestones

Develop a 0.16-in² (1-cm²) efficiency active area of 12%, 3.1 × 3.1-in. (8 × 8-cm) sub-module efficiency (aperture area) of 10%, and 2 × 4-ft (60 × 120-cm) module efficiency (total area) of 8% (58 W).

Major Project Reports

Nolan, J.F.; Meyers, P.V.
Fabrication of Stable, Large Area, Thin-Film CdTe Photovoltaic Modules.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401

H.S. Ullal
(303) 231-1486

Contractor

Solar Cells, Inc.
2650 North Reynolds Road
Toledo, OH 43615

P.V. Meyers
(419) 534-2794

Contract Number

ZR-1-11059-1

Contract Period

5/1/91 -- 6/30/94

Funding Amount (Source)

(Previous years)	\$398,000 (DOE)
	\$170,000 (Solar Cells)
(FY 1992)	\$275,000 (DOE)
	\$117,000 (Solar Cells)

Polycrystalline Thin Films

Innovative Sputtering Techniques for CIE and CdTe Submodules Fabrication

Objectives

Develop commercially viable, large-area-deposition techniques for polycrystalline thin-film CIS and CdTe PV manufacturing, and using monolithic integration and large-area-deposition techniques to fabricate 1-ft² (929-cm²) modules.

Approach/Background

Scale up initial work at Martin Marietta on dual rotating cylindrical magnetron (C-Mag) sputtering of CIS modules up to 1-ft² (929-cm²) area; scale up initial work at Martin Marietta on electrodeposition to cell and minimodule size; utilize expertise at International Solar Electric Technology (ISET) for selenization and device fabrication; and improve our laser scribing techniques with capability of 4 × 8-ft. (1.2 × 2.4-m) substrates for monolithically integrated modules.

Status/Accomplishments

Demonstrated the following:

- Highly adherent, pinhole-free Mo back contact on soda-lime glass
- C-Mag fabrication of CIS solar cells
- 8.4% efficiency (AM 1.5, total area, at NREL) for CIS made by C-Mag
- 8.4% efficiency (AM 1.5, total area, at NREL) for CIS made by C-Mag sputtered films with H₂Se selenization at ISET

- 7.5% efficiency (AM 1.5, active area at NREL) for CIS made by C-Mag sputtered films with Se vapor selenization at NREL
- 6.3% efficiency (AM 1.5, total area at NREL) for CdTe made by electrodeposition (all fabrication conducted at Martin Marietta)
- 1-ft² (929-cm²) laser scribed Mo back contact
- minimodule fabrication.

FY 1993 Milestones

Fabricate 2 × 2-in. (5 × 5-cm) monolithically integrated CIS and CdTe devices; fabricate 6 × 6-in. (15 × 15-cm) monolithically integrated CIS and CdTe devices; fabricate 12 × 12-in. (30.5 × 30.5-cm) monolithically integrated device (either CIS or CdTe); identify further areas of investigation to scale to 1 × 4-ft (3 × 1.2-m) area; and complete final report.

Major Project Reports

Armstrong, J.M.; Misra, M.
Innovative Sputtering Techniques for CIS and CdTe Submodule Fabrication.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
H.S. Ullal
(303) 231-1486

Contractor

Martin Marietta Corp.
P.O. Box 179
Denver, CO 80201
J.M. Armstrong
(303) 971-9399

Contract Number

XG-1-11070-1

Contract Period

9/1/91 - 11/30/93

Funding Amount (Source)

(FY 1992) \$395,000 (DOE)

Polycrystalline Thin Films

Investigation of Polycrystalline Thin-Film CuInSe₂ Solar Cells Based on ZnSe Windows

Objectives

Improve CuInSe₂-based solar cell performance by developing and testing Zn-based window layers.

Approach/Background

Prepare and characterize solar cells with various Zn-based window layers. The CuInSe₂ absorbers will be supplied by other collaborating groups.

Status/Accomplishments

Established the deposition capabilities of ZnSe and ZnO, and fabricated complete solar cell structures.

FY 1993 Milestones

Achieve a 12% efficient CuInSe₂ solar cell with Zn-based window.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy

Laboratory

1617 Cole Blvd.

Golden, CO 80401

B.G. von Roeder

(303) 231-1380

Contractor

Washington State University

Office of Grant and Research

Development

Pullman, WA 99164-3140

L. Olsen

(509) 375-9221

Contract Number

XG-2-11036-6

Contract Period

2/15/92 - 2/14/95

Funding Amount (Source)

(FY 1992) \$95,000 (DOE)

Polycrystalline Thin Films

Module Optimization and Device Efficiency Improvement for Stable, Low-Cost, Large-Area CdTe Photovoltaic Module Production

Objectives

Develop large-area, CdTe, photovoltaics using low cost, scalable processes.

Approach/Background

Further optimized the window-layer material, improved the module design and encapsulation, and optimized and developed the process further.

Status/Accomplishments

Obtained small-device efficiencies of up to 12.7%; a large-area module (1 ft² [929 cm²]) with over 8% aperture area efficiency and 9.5% to 9.9% active-area efficiency; and a large-area module (4 ft² [3716 cm²]) with over 21.3-W output.

FY 1993 Milestones

Improve large-area modules (4 ft² [3716 cm²]) to 32-W output.

Major Project Reports

Albright, S.P.; Ackerman, B.; Chamberlin, R.R.; Jordan, J.F. *Module Optimization and Device Efficiency Improvement for Stable Low-Cost, Large-Area, Cadmium Telluride-Based Photovoltaic Modules Production.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401

H.S. Ullal
(303) 231-1486

Contractor

Photon Energy, Inc.
9650A Railroad Drive
El Paso, TX 79924

S.P. Albright
(915) 751-9948

Contract Number

ZN-0-19019-1

Contract Period

6/18/90 - 8/17/93

Funding Amount (Source)

(Previous years) \$660,000 (DOE)

\$266,000 (Photon Energy)

(FY 1992) \$300,000 (Photon Energy)

Polycrystalline Thin Films

Novel Thin-Film CuInSe₂ Fabrication

Objectives

Explore the formation of CuInSe₂ by rapid thermal annealing (RTP) methods using various precursor layers and substrates.

Approach/Background

Prepare CuInSe₂ layers from different precursors, which are characterized and evaluated by fabricating solar cell devices.

Status/Accomplishments

Identified methods to mitigate delamination of films produced by RTP, working solar cells, and identified unexpected compositional changes of the precursor films and the films prepared by RTP.

FY 1993 Milestones

Prepare a solar cell with 8% efficiency by RTP.

Major Project Reports

Gabor, A.; Hermann, A. *Novel Thin Film CuInSe₂ Fabrication*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

B.G. von Roeder
(303) 231-1380

Contractor

University of Colorado
Office of Contracts and Grants
206 Armory, Campus Box 19
Boulder, CO 80309-2661

A. Hermann
(303) 492-2661

Contract Number

XC-0-10012-1

Contract Period

3/1/90 - 10/31/93

Funding Amount (Source)

(Previous years)	\$35,046 (DOE)
(FY 1992)	\$20,000 (DOE)

Polycrystalline Thin Films

Novel Two-Stage Selenization Methods for Fabrication of Thin-Film CIS Cells and Polycrystalline Thin-Film Submodules

Objectives

Apply a novel, proprietary, low-cost, nonvacuum, innovative process for the deposition of CIS films to develop a complete sequence of submodule fabrication using CIS films deposited either by the two-stage selenization or by the nonvacuum process.

Approach/Background

Deposit CIS films by the proprietary process in which stoichiometry and uniformity of CIS films is controlled and the material utilization is very high.

Status/Accomplishments

Fabricated a small-area cell with an efficiency 10.3% on CIS film deposited by the nonvacuum process, and fabricated a submodule (1 ft² [929 cm²]) with power output of 4 W/ft² (43 W/m²).

FY 1993 Milestones

Fabricate solar cells with efficiencies approaching 12% on CIS films deposited by the novel nonvacuum process; fabricate submodules (1 ft² [929 cm²]) with power output of 6–7 W/ft² (70 W/m²).

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
H.S. Ullal
(303) 231-1486

Contractor

International Solar Electric
Technology, Inc.
8635 Aviation Blvd.
Inglewood, CA 90301
B.M. Sasol
(310) 216-4427

Contract Number

YI-2-12069-1

Contract Period

3/1/92 – 4/30/94

Funding Amount (Source)

(FY 1992) \$495,000 (DOE)

Polycrystalline Thin Films

Polycrystalline Thin-Film CdTe Solar Cells Fabricated by Electrodeposition

Objectives

Develop necessary techniques to grow CdS and CdTe layers by dip coating and electrodeposition methods and develop ancillary treatments such as rapid thermal processing and photoelectrochemical stimulation.

Major Project Reports

None

Summary Date

November 1992

Approach/Background

Deposit and characterize thin-film layers and devices, develop better understanding of the effects of deposition treatments on material and device properties; and optimize the resulting solar cell structures.

Status/Accomplishments

Established solution-growth techniques for CdTe and CdS and prepared initial working diagnostic solar cells.

FY 1993 Milestones

Establish whether ZnTe can be deposited by solution growth methods, and fabricate a state-of-the-art 0.16 in² (1 cm²) solar cell.

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401

B.G. von Roeder
(303) 231-1380

Contractor

Colorado School of Mines
1500 Illinois Street
Golden, CO 80401

J.U. Trefny
(303) 273-3833

Contract Number

XG-2-11036-4

Contract Period

3/20/92 - 5/19/95

Funding Amount (Source)

(FY 1992) \$142,000 (DOE)
\$ 9,547 (GSM)

Polycrystalline Thin Films

Polycrystalline Thin-Film CuInSe₂ and CdTe Photovoltaic Solar Cells

Objectives

Improve efficiency of CuInSe₂ and CdTe solar cells.

Approach/Background

Prepare CuInSe₂ solar cells without use of H₂Se gas and investigate doping and minimum thickness requirements for CdTe solar cells.

Status/Accomplishments

Made two new deposition systems operational, and established a chemical bath deposition process for CdS films.

FY 1993 Milestones

Prepare devices with 10% to 12% efficiency.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401

B.G. von Roeder
(303) 231-1380

Contractor

University of Central Florida
Finance and Accounting
P.O. Box 25000
Orlando, FL 32816

N. Dhere
(407) 783-0300

Contract Number

XG-2-11036-5

Contract Period

4/15/92 - 4/14/95

Funding Amount (Source)

(FY 1992) \$89,976 (DOE)

Polycrystalline Thin Films

Polycrystalline Thin-Film Materials and Devices

Objectives

Obtain the necessary understanding of the materials processing, properties, and performance of polycrystalline thin-film solar cells needed to produce efficient, reliable, and low-cost flat-plate PV systems.

Approach/Background

Characterize and optimize CdTe and CuInSe₂ materials and devices; investigate in parallel the effects of different deposition techniques on preparing nominally similar solar cell materials; and evaluate innovative materials or device structures for polycrystalline thin-film solar cells.

Status/Accomplishments

Achieved state-of-the-art CuInSe₂ solar cells using three different selenization techniques; achieved state-of-the-art CdTe solar cells and established some tentative models for such cells which include interdiffusion of the CdS/CdTe interface and the possibility of doping the CdTe (e.g., with Cu); investigated long term variations in CdTe solar cell performance, and correlated such changes with contacts or treatments; and established collaborations with other research groups and with industry.

FY 1993 Milestones

Continue this work under a new multiyear thin-film subcontract; and develop better criteria

to predict cell performance from material data or processing conditions.

Major Project Reports

Baron, B.N.; et al. *Polycrystalline Thin Film Materials and Devices*.

Summary Date

November 1992

Directing Organization

National Renewable Energy

Laboratory
1617 Cole Blvd.
Golden, CO 80401

B.G. von Roedern
(303) 231-1380

Contractor

University of Delaware
Institute of Energy Conversion
Newark, DE 19716

R.W. Birkmire/J.E. Phillips
(302) 831-6218/6244

Contract Number

XN-0-10023-1

Contract Period

1/16/90 - 3/15/93

Funding Amount (Source)

(Previous years) \$626,440 (DOE)
(FY 1992) \$653,164 (DOE)

Polycrystalline Thin Films

Polycrystalline Thin Films (CdTe)

Objectives

Assist industry in developing CdTe commercial products by responding to pressing issues, filling critical experimental niches that industry cannot address, and supporting a base of technical knowledge that can be a backdrop for continued progress.

Approach/Background

Develop manufacturable closed-spaced sublimation (CSS) CdTe cells based on industrial-grade soda-lime glass substrates, and conduct studies on sputtered CdTe cell and contacts. We are in the process of scaling up our CdTe- and CdS-deposition processes to larger sizes to study area-related issues.

film blistering (stress), as we have developed techniques for making stress-free films.

FY 1993 Milestones

Fabricate a 12% CdTe cell by CSS on soda lime glass; design and construct a CSS CdTe apparatus for 15.5-ft² (100 cm²) substrates, and achieve 10% by sputtering.

Major Project Reports

Ramanathan, K.; et al. *Status of CdS/CdTe Solar Cell Research at NREL.*

Gessert, T.A.; Coutts, T. *Grid Metallization and Antireflection Coating Optimization for Concentrator and On-Sun Photovoltaic Solar Cells.*

Summary Date

November 1992

Status/Accomplishments

Fabricated a 11.3% efficient CdS/CdTe cell by CSS. As part of this effort, developed an in-house capability to make thin CdS by a solution-growth method. We are collaborating with Golden Photon and Solar Cells Inc. to test this deposition technique with their CdTe material. If successful, they may adopt solution growth as their mainstream manufacturing option for CdS. We are studying commercial tin oxide-coated glass in order to facilitate industry's choice of whether to buy this ready made or to make it themselves on-site. Our studies of losses in tin-oxide/glass have been shared with industry. In sputtering, we have examined issues that limit reproducibility and that cause

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401

K. Zweibel
(303) 231-7141

Contractor

NREL

T. Coutts
(303) 231-1261

Contract Number

None

Contract Period

10/91 - 10/92

Funding Amount (Source)

(FY 1992) \$646,671 (DOE)

Polycrystalline Thin Films

Polycrystalline Thin Films CIS Task

Objectives

Assist industry in developing CuInSe₂ (CIS) commercial products by responding to pressing issues, filling critical experimental niches that industry cannot address, and supporting a base of technical knowledge that can be a backdrop for continued progress.

Approach/Background

Perform research and development on CIS using a variety of deposition techniques: selenization with hydrogen selenide, selenium, and rapid thermal annealing; and vacuum evaporation. We make state-of-the-art window layers with solution grown CdS and ZnO. Our materials studies are correlated with device performance in order to verify our technical insights.

Status/Accomplishments

Developed a selenization process that produced near-10% CIS cells. Shared this technique with industry at Energy Photovoltaics, Solarex, Martin Marietta, and International Solar Electric Technology. Began work on a simplified method of CIS deposition to find a more durable chemical path to make effective cells. Initiated work on an alternative heterojunction partner, making near-10% cells with several novel interlayers.

FY 1993 Milestones

Produce 10% efficient CIS cell using a selenization process, and fabricate a 12%-efficient ZnO/CdS/CIS cell.

Major Project Reports

Tuttle, J.R.; et al. *Novel Processing and Device Structures in Thin-Film CuInSe₂-based Solar Cells*.

Albin, D.; et. al. *Fundamental Thermodynamics and Experiments in Fabricating High Efficiency CuInSe₂ Solar Cells by Selenization without the Use of H₂Se*.

Cahen, D.; Noufi, R. *Free Energies and Enthalpies of Possible GaAs Phase and Surface Reactions for Preparation of CuInSe₂*.

Albin, D.; et al. *The Effects of Microstructure and Strain in In/Cu/Mo/glass Precursors on CdS/CuInSe₂ Photovoltaic Device Fabrication by Selenization*.

Tuttle, J.; Contreras, M.; Albin, D.; Noufi, R. *Physical Chemical, and Structural Modifications to Thin Film CuInSe₂-based Photovoltaic Devices*.

Noufi, R.; et al. *Optical Bandgap and Lattice Constant of Cd_xZn_{1-x}Se_yS_{1-y} Thin Film Alloys for Heterojunction PV Cells*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401

K. Zweibel
(303) 231-7141

Contractor

NREL
R. Noufi
(303) 231-7310

Contract Number

None

Contract Period

10/91 - 10/92

Funding Amount (Source)

(FY 1992) \$1,124,000 (DOE)

Polycrystalline Thin Films

Research on High Efficiency, Large-Area CuInSe₂ Thin-film Modules

Objectives

Demonstrate large-area, stable 12.5% aperture-area efficiency CuInSe₂ modules using processes that can be transferred to manufacturers.

Approach/Background

The module design consists of 53 cells monolithically interconnected in series, fabricated on a 4.46 ft² (4141 cm²) glass substrate. The nominal aperture area is 4.2 ft² (3895 cm²). Since module performance is strongly dependent upon the spatial uniformity of cells and interconnects, the initial emphasis has been on the development of techniques to use for module diagnostics. Results of these diagnostics are then used to guide the ongoing improvement in module performance.

Status/Accomplishments

Achieved output power greater than 40 W on several unencapsulated CIS submodules. The best submodule performance was 40.8 W or an aperture-area efficiency of 10.5%. An encapsulated module power of 37.7 W with an aperture-area efficiency of 9.7% was demonstrated and verified at NREL. Contract milestones (M3 and M4) were delivered to NREL.

FY 1993 Milestones

Continue efforts to increase understanding of the mechanisms that control CIS module

performance, defining improvements in those mechanisms, and defining improvements in module design and processing leading to CIS module aperture efficiencies of 12.5%.

Major Project Reports

Gay, R. et al. *Progress in Large Area CuInSe Module Performance and Reliability*.

Mitchell, K. *Research on High-Efficiency, Large-Area CuInSe₂-Based Thin-film Modules, Phase 1: Annual Technical Progress Report for the Period May 1, 1991 to April 30, 1992*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401

H.S. Ullal
(303) 231-1486

Contractor

Siemens Solar Industries
4750 Adohr Lane
Camarillo, CA 93011

R. Gay
(805) 388-6507

Contract Number

ZN-1-19019-5

Contract Period

5/1/91 - 6/30/94

Funding Amount (Source)

(Previous years) \$700,000 (DOE)
\$575,000 (Siemens Solar)
(FY 1992) \$367,000 (DOE)
\$353,000 (Siemens Solar)

Polycrystalline Thin Films

Research on Polycrystalline Thin Film CuInSe₂ Solar Cells

Objectives

Fabricate high-efficiency thin-film CuInGaInSe₂ solar cells.

Approach/Background

Fabricate ZnO/CdZnS/CuGaInSe₂ thin-film solar cells by elemental co-evaporation of the CIGS film, aqueous deposition of thin (<0.05 μ m) CdZnS films, and reactive sputtering of ZnO:Al. Study various combinations of gallium and zinc alloy compositions.

Major Project Reports

Stanbery, B.J.; Chen, W.S.; Devaney, W.E.; Stewart, J.W. *Research on Polycrystalline Thin-Film CuGaInSe₂ Solar Cells.*

Summary Date

November 1992

Status/Accomplishments

Delivered a ZnO/Cd_{1-x}Zn_yS/CuIn_{1-x}Ga_xSe₂ thin-film solar cell with y=0.20 and x=0.26 to NREL and measured at 13.7% total area efficiency. This is the best reported total area efficiency for a thin film solar cell and exceeds our key technical milestone for Phase 2 of this contract.

FY 1993 Milestones

Procure and install a new dual rotating cathode sputtering source that will be used to investigate low-cost, higher rate processes for the deposition of device-quality ZnO. New process parameters for CIGS deposition will be studied in an effort to improve overall cell performance.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
H.S. Ullal
(303) 231-1486

Contractor

Boeing Defense and Space Group
P.O. Box 3999
Seattle, WA 98124-2499
B. Stanbery
(206) 657-6964

Contract Number

ZM-1-19019-6

Contract Period

5/91 - 5/94

Funding Amount (Source)

(Previous years) \$150,000 (DOE)
(FY 1992) \$214,000 (DOE)

Polycrystalline Thin Films

Research on Polycrystalline Thin-Film Submodules Based on CuInSe_2

Objectives

Develop process and technologies required for low-cost, high-performance CIS modules.

Approach/Background

Developed and scaled up an elemental deposition and compound formation (EDCF) for CIS preparation, which does not use H_2Se gas.

Status/Accomplishments

Demonstrated 10.2% efficient solar cell on EDCF-prepared CIS material; developed laser scribing for Mo rear contact; developed mechanical scribing for CIS-CdS and ZnO scribing; scaled up all processes and scribing to 8×8 in. (20×20 cm); building large area CIS machine for 12×12 -in (30.5×30.5 -cm) substrates.

FY 1993 Milestones

Demonstrate 12% efficient CIS submodule (area 12×12 in. [30.5×30.5 cm]).

Major Project Reports

Catalano, A. *Research on Polycrystalline Thin Film Submodule Based on CuInSe_2 Materials.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
H.S. Ullal
(303) 231-1486

Contractor

Solarex Corporation
Thin Film Division
826 Newtown-Yardley Road
Newtown, PA 18948
R.R. Arya
(215) 860-0902

Contract Number

ZN-1-19019-4

Contract Period

11/8/90 - 12/31/93

Funding Amount (Source)

(Previous years)	\$6,000,000 (DOE)
	\$ 257,000 (Solarex)
(FY 1992)	\$ 596,000 (DOE)
	\$ 255,000 (Solarex)

Polycrystalline Thin Films

Role of Polycrystallinity in CdTe and CuInSe₂

Objectives

Provide a standardized characterization and analysis of losses for polycrystalline thin-film solar cells; identify the role of polycrystallinity on the performance of such cells; and provide specialized measurements on partial or completed solar cell structures.

Approach/Background

Characterize and analyze less than ideal qualities in many of the recent record-setting polycrystalline thin-film solar cells; identify the factors that cause time-dependent increases in V_{oc} and fill factor upon illumination of such cells; and provide standardized parameters for solar cells for comparison with current device models.

Status/Accomplishments

Published numerous reports and publications analyzing the performance of recent polycrystalline thin-film solar cells; established close collaborations and provided input for the research of most U.S. groups working with CdTe and CuInSe₂; and established a data base for time dependent phenomena in such solar cells.

FY 1993 Milestones

Continue the standardized solar cell analyses for other research institutions and for industry; and develop improved two-dimensional solar cell model for polycrystalline thin-film solar cells.

Major Project Reports

Sites, J.R. *Role of Polycrystallinity in CdTe and CuInSe₂ Photovoltaic Cells.*

Summary Date

November 1992

Directing Organization

National Renewable Energy

Laboratory

1617 Cole Blvd.

Golden, CO 80401

B.G. von Roedern

(303) 231-1380

Contractor

Colorado State University

Office of Sponsored Programs

University Services Center

Fort Collins, CO 80523

J.R. Sites

(303) 491-6206

Contract Number

XC-0-10046-1

Contract Period

4/1/90 – 5/31/93

Funding Amount (Source)

(Previous years) \$80,000 (DOE)

(FY 1992) \$80,000 (DOE)

Polycrystalline Thin Films

Thin Film CdTe Photovoltaic Cells

Objectives

Improve the performance of CdTe thin-film solar cells by optimizing laser-drive physical-vapor deposition (LDPVD) and magnetron-sputtering deposition processes.

Major Project Reports

Compaan, A. Bohn, R. *Thin-Film Cadmium Telluride Photovoltaic Cells.*

Summary Date

November 1992

Approach/Background

Correlate the quality of CdTe films prepared by LDPVD with optical emission data from the deposition "plume," and establish a variety of material characterization measurements. Establish in-house capability to fabricate solar cells. Cells are routinely fabricated and optimized for improved performance. Focus work on improved contact layers (e.g., ZnTe) for CdTe cells.

Status/Accomplishments

Achieved >10% cell efficiencies for both deposition processes; achieved >10% cell efficiency for a cell where all semiconductor layers were sputter-deposited; and established close collaborations with Solar Cells, Inc., and performed back-up characterizations for them.

FY 1993 Milestones

Achieve even higher cell efficiencies by sputter deposition of all layers for CdTe solar cells; and continue work on improving contacts for CdTe solar cells.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401
B.G. von Roedern
(303) 231-1380

Contractor

The University of Toledo
Grants Accounting
2801 West Bancroft Street
Toledo, OH 43606
A. Compaan
(419) 537-4787

Contract Number

ZN-1-19019-3

Contract Period

7/23/90 - 1/1/94

Funding Amount (Source)

(Previous years) \$385,000 (DOE)
\$222,322 (U of T)

PV Analysis and Applications Development

Building-Integrated Photovoltaics

Objectives

Analyze the point of view of the design community concerning building-integrated PV products for office/commercial and industrial applications. During the study, remember that the success of a product in the building market depends on acceptance by building owners, managers, regulators, designers, tenants and users, as well as on issues of economics.

Approach/Background

Passive solar design has never become common among the building community. It has implied fairly rigid design limitations regarding orientation, sloping roof elements and sun spaces, and it has exacted penalties in lifestyle for the occupants (having to operate insulating shades or pumps, the inability to put rugs or furniture on a thermal collector floor slab, etc). PV building introduces a new language to architecture. For the first time a building's skin will do more than keep out the weather and modulate heat and light transmission. It will produce energy (and therefore revenue) instead of losing energy. As an active element of the building, it will be dynamically linked to other systems in ways we cannot fully anticipate.

Status/Accomplishments

The inherent flexibility of PVs compared with other types of solar collectors (wiring is inherently easier to run than plumbing), combined with a potentially low material cost,

raises the possibility that PV can be used as a building material first, and as a PV device second. Further study of the costs and benefits of PV-integrated building skins and products is warranted. If the economics permit, PVs can be used in any number of building component configurations and without an overriding demand for optimal orientation.

FY 1993 Milestones

Further detailed study of the construction cost implications combined with new data on PV and balance of systems costs will indicate whether and when PV products will become competitive in the construction market.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

R. Taylor
(303) 231-1332

Contractor

Kiss Cathcart Anders Architects, P.C.
New York, NY

G. Kiss
(212) 513-1711

Contract Number

ET-2-12278-1

Contract Period

8/4/92 - 12/31/92

Funding Amount (Source)

(FY 1992) \$9,900 (DOE)

PV Analysis and Applications Development

Evaluation of DSM Incentive Opportunities for Photovoltaics

Objectives

Evaluate existing residential, commercial, and industrial demand-side management (DSM) programs with regard to incentive levels and utility-avoided costs; analyze the interactions between incentive programs, avoided costs, and regulatory influences; describe the role photovoltaic (PV) could play in residential and commercial DSM programs; and evaluate the technical feasibility of PV-assisted operation as a load reduction strategy equivalent to one commonly used by U.S. utilities in their direct load control (DLC) programs.

Approach/Background

Developed a data base of electric utility DSM incentive programs offered to all customer sectors, analyzed, using a multivariate approach, the data collected to estimate an empirical relationship between rebate levels offered by utility DSM programs and electricity (kW) savings; identified the end-uses that are the most attractive targets for PV-DSM applications; and designed a test program for PV-DSM with a structure consistent with the structure of existing DLC incentive programs in the service territory of Delmarva Power.

Status/Accomplishments

Although it has been recognized that the utility market is the most promising for solar technologies, the present cost of

PV power as a generation option is too expensive to stimulate much interest by either electric utilities or state regulatory authorities. PV system costs are currently in the range of 25¢ to 50¢/kWh compared to current peak power costs of between 8¢ to 13¢/kWh. For PV to play an important role in the utility sector at its present price, the best possibility is to penetrate the DSM markets, functioning as a load management device. The availability and extent of tax benefits, such as exemptions and credits for investment in solar technologies, is a crucial factor in determining the competitive position of PV technology in DSM market. Perhaps even more critical is the creation of an environment which would allow solar technologies to be routinely evaluated as a DSM option in integrated resource planning and DSM plans.

FY 1993 Milestones

Complete testing in cooperation with Delmarva Power to determine technical feasibility of both water heater and air conditioning PV-DLC programs. Testing will continue at the University of Delaware's Solar One House in Newark.

Major Project Reports

Byrne, J.; Wang, Y-D., Nigro, R.; Kumar, T. *Public Utility Fornightly*.

Byrne, J.; Nigro, R. *Applying Photovoltaics as a Demand-Side Tool*.

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
R. Taylor
(303) 231-1332

Contractor

University of Delaware
Center for Energy and
Urban Policy Research
Newark, DE 19716
J. Byrne
(302) 831-8405

Contract Number

2-11248-1

Contract Period

10/15/91 - 3/31/94

Funding Amount (Source)

(Previous years)	\$96,948 (DOE)
(FY 1992)	\$27,202 (DOE)

PV Analysis and Applications Development

Evaluation of Roof-Integrated PV Module Designs and Systems

Objectives

Evaluate the present state-of-the-art of roof integrated PV modules, identify the pros and cons of roof-integrated thin film and crystalline silicon PV modules, provide recommendations for further development of roof-integrated concepts including building changes and modules changes (if any) required to facilitate implementation of roof-integrated concepts, and outline a research plan for proof-of-concept implementation.

FY 1993 Milestones

Completed report.

Major Project Reports

None

Summary Date

November 1992

Approach/Background

A literature review of past work in PV and low-temperature solar-thermal collectors, telephone discussion with manufacturers of residential skylights and commercial architectural glass, and site visits provided the information needed for a report identifying the pros and cons of roof-integrated thin film and crystalline silicon PV modules.

Status/Accomplishments

Performed a technology assessment of present state-of-the-art work in PV and low-temperature solar-thermal collectors. Evaluated the information gathered and provided a detailed list of the pros and cons of roof-integrating PV modules. Outlined a research and development program based on information and insights developed. Delivered a report with said information May 1992.

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401-3393

R. Taylor
(303) 231-1332

Contractor

Florida Solar Energy Center
300 State Road 401
Cape Canaveral, FL 32902

K. Collier
(407) 783-0300 x185

Contract Number

2-12002-1

Contract Period

11/91 - 5/92

Funding Amount (Source)

(Previous years)	\$49,999 (DOE)
(FY 1992)	\$49,999 (DOE)

PV Analysis and Applications Development

Long-Term Environmental Effects on Roof-Mounted Photovoltaic Modules

Objectives

Characterize the effects of long term exposure to sunlight on fielded photovoltaic (PV) modules. Of particular interest in this effort are the combined effects of high solar flux and high module operating temperatures on module performance.

Approach/Background

Prepared a report summarizing the various photovoltaic roof mount designs in use at Southwest Regional Experiment Station (SWRES). Compiled a report that presented all of the historical performance data collected from four photovoltaic arrays at the SWRES. The criteria used for selection of the four arrays were, to the extent possible, that they should represent different PV technologies, that all should be encapsulated with EVA, and that preference should be given to arrays with the longest continuous set of recorded performance data. Instrument 12 modules from each of the selected arrays. Instrumentation provides a resistive load so that each module is operated near its peak power point. In addition, current-voltage (I-V) curves can be automatically taken of all instrumented modules every week for the duration of the contract. Initially, the I-V curves were used to derive normalization coefficients.

Status/Accomplishments

Completed required reports.

FY 1993 Milestones

Prepare module performance evaluation reports quarterly over a period of two years to document changes in performance parameters produced by exposure to ambient conditions. Modules will be removed from their arrays and sent to NREL for analysis to correlate observed performance changes with ranges in module encapsulant composition.

Major Project Reports

Rosenthal, A. *The Effects of Photovoltaic Module Mounting on Operating Temperature.*

Rosenthal, A. *Photovoltaic Trends—Module Historical Data.*

Rosenthal, A. *Module Performance Report.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401-3393

R. Taylor
(303) 231-1332

Contractor

Southwest Technology Development
Institute

Box 30001
Las Cruces, NM 88003

A.L. Rosenthal
(505) 646-1846

Contract Number

2-120014-1

Contract Period

2/92 – 1/94

Funding Amount (Source)

(Previous years)	\$50,000 (DOE)
(FY 1992)	\$50,000 (DOE)

PV Analysis and Applications Development

Risk-Adjusted IRP Procedures: Reflecting the True Costs of Conventional and Solar Options

Objectives

Suggest analytic tools that will improve the quality of decisions made by electric utilities in the Integrated Resource Planning (IRP) Process.

Approach/Background

Utilities use standard capital budgeting techniques, which have changed little since their introduction 40 years ago. That era was marked by a regulatory environment that reflected a strong monopoly with low price elasticities of demand coupled with a rather limited menu of fossil-based generating options whose cost and risk properties were quite similar. In contrast, today's environment is marked by weakened monopoly, a diverse range of resource options, and a diverse range of institutional and business options that includes independent power producers. The revenue requirements method can no longer work in the 1950's mode. Public Utility Commissions should require utilities to use state-of-the-art techniques to evaluate resource alternatives.

Status/Accomplishments

There are three principal cost areas that affect generation costs: flexibility and reversibility, overhead utilization, and option values. These cost considerations suggest that if all costs were measured and included, IRP should favor capacity that is

flexible and reversible and can be installed with short lead-times over "lumpy" central station capacity. These objectives serve to reduce cost by matching supply with demand continually—costs are not minimized when even the cheapest kWh units are produced unnecessarily, or the cheapest capacity is idle.

FY 1993 Milestones

Through reports recommend that public utility commissions require utilities to reflect differences in financial risk exhibited by alternative capacity choices. Convince regulators they need to rely less on fuel price forecasts and more on developing diversified portfolios of generating assets that can perform well under a variety of economic conditions.

Major Project Reports

None

Summary Date

November 1992

Directing Organization
National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
R. Taylor
(303) 231-1332

Contractor
University of Massachusetts
Lowell, MA
S. Awerbuch
(603) 891-1342

Contract Number
CK-2-1202-1

Contract Period
1/15/92 – 12/31/92

Funding Amount (Source)
(FY 1992) \$105,000 (DOE)

PV Analysis and Applications Development Project

Solar Resource, Utility Load Matching Assessment

Objectives

Apply the techniques demonstrated in New York to a broad cross section of utilities located in various regions of the United States.

Approach/Background

Send participating utilities a preliminary evaluation of PV's potential for contributing to meeting their load requirements, which will better inform them about how to pursue an interest in PV development.

FY 1993 Milestones

May include deployment of solar resource measuring equipment, high value systems, and/or demonstration systems.

Major Project Reports

None

Summary Date

November 1992

Status/Accomplishments

Gave presentation at NREL including a thorough review of the work conducted for the New York Power Authority and plans for this project. Performed selected satellite/ground truth correlations for the years 1987 and/or 1988. For utilities with large service territories covering many climatic zones, provided an indication of areas of high and low resource potential. Performed PV output versus utility load correlations for the utility loads provided by NREL. The criteria used to quantify the load matching included PV effective-load-carrying capability, PV energy versus load distributions, and minimum buffer storage requirements.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
R. Taylor
(303) 231-1332

Contractor

Atmospheric Sciences Research
Center
State University of New York
at Albany
Buffalo, NY 14260
R. Perez
(716) 636-3121

Contract Number

1-11168-1

Contract Period

9/91 - 3/93

Funding Amount (Source)

(Previous years)	\$106,301	(DOE)
(FY 1992)	\$106,301	(DOE)

Photovoltaic Manufacturing Technology

a-Si Photovoltaic Manufacturing Technology—Phase 2A

Objectives

Perform manufacturing research and development which will reduce module production costs, increase average module performance, and increase the production capacity existing in Utility Power Group and Advanced Photovoltaic Systems, Inc.

Approach/Background

Research encapsulation of a-Si:H modules (preferring designs that do not require a second glass layer), and automate module termination. The effort will be addressed in three, one-year phases. Success of this program will result in increasing the module manufacturing yield by 35% and decreasing direct cost by about 25%.

Status/Accomplishments

Completed POWERGLASS® module qualification testing for candidate encapsulation materials; completed yield analysis for Eureka® modules; and completed design of full-scale enhanced Eureka® modules.

FY 1993 Milestones

Complete POWERGLASS module qualification testing of candidate encapsulation materials; complete fabrication of full-scale enhanced Eureka® module; automate the final quality control steps in the Eureka® encapsulation line; complete program for automation of glass transport processes on Eureka® manufacturing line by 25%; complete design of automated POWERGLASS encapsulation and termination stations; and demonstrate a compound Eureka® module manufacturing cost-reduction of 8%.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

R.L. Mitchell
(303) 231-1379

Contractor

Utility Power Group
9410 DeSoto Avenue, Unit G
Chatsworth, CA 91311

G. Duran
(818) 700-1995

Contract Number

ZM-1-11040-6

Contract Period

4/20/92 – 7/19/95

Funding Amount (Source)

(FY 1992) \$1,612,800 (DOE)
\$23,204 (UPG)

Photovoltaic Manufacturing Technology

Continuous Roll-to-Roll Amorphous Silicon Photovoltaic Manufacturing Technology

Objectives

Perform manufacturing research and development that will help Energy Conversion Devices, Inc. (ECD) advance roll-to-roll, high-volume, low-cost photovoltaic manufacturing technologies, reduce its 4-ft² (3716-cm²) a-Si alloy module production costs, increase stabilized module performance, and expand the commercial capacity utilizing ECD technology.

Approach/Background

Produce 1 × 4-ft (30 × 122-cm) PV modules with 11% stable efficiency, reducing their manufacturing costs through utilization of ECD's high-deposition-rate microwave technology to enhance the production throughput and by reducing material and labor costs. The effort will be addressed in three, one-year phases. Success in this program will allow ECD to work toward building a 100-MW/yr roll-to-roll, automated a-Si PV module manufacturing facility.

Status/Accomplishments

Completed initial improvements to Si-Ge alloy deposition systems; demonstrated stable 7.5% efficient ≥4-ft² (3716-cm²) a-Si alloy modules; and completed incorporation of linear applicator microwave plasma source for multipurpose deposition.

FY 1993 Milestones

Demonstrate a 15% gain in J_{sc} , demonstrate 40% quantum efficiency @ 800 nm for the Si-Ge alloy, demonstrate an 8% stable efficiency ≥4ft² (3716 cm²) a-Si alloy module, and demonstrate a stable 6% efficiency microwave CVD a-Si alloy device.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
R.L. Mitchell
(303) 231-1379

Contractor

Energy Conversion Devices, Inc.
1675 West Maple Road
Troy, MI 48064
M. Izu
(313) 280-1900

Contract Number

ZM-1-11040-7

Contract Period

4/8/92 - 4/7/95

Funding Amount (Source)

(FY 1992) \$1,499,999 (DOE)
\$1,760,869 (ECD)

Photovoltaic Manufacturing Technology

Large-Area, Triple-Junction, a-Si Alloy Production Scale-Up Project

Objectives

Perform manufacturing R&D which will help Solarex's PV manufacturing technologies, reduce its a-Si:H module production costs, increase module performance, and expand the Solarex commercial production capacity.

Approach/Background

Improve the deposition and quality of the transparent front contact; optimize the laser-patterning process; scale up the semiconductor-deposition process; improve the back-contact deposition; and scale up and improve the encapsulation and testing of its modules. The effort will be addressed in three, one-year phases. Successful implementation of this program will result in Solarex producing $\geq 6\text{-ft}^2$ (5574-cm^2), 10% stabilized efficiency, 75-W a-Si:H modules with a total overall module yield of $\geq 75\%$.

Status/Accomplishments

Completed design of a $\geq 6\text{ ft}^2$ (5574 cm^2) PECVD a-Si:H based deposition system; complete the light soaking test of a-Si:H modules; demonstrated new laser scribing system will pass wet hi-pot test; and completed frit dispenser fabrication.

FY 1993 Milestones

Complete design and setup of environmental test equipment, initialize operation of PECVD a-Si:H based deposition system, demonstrate $\geq 6\text{ ft}^2$ (5574 cm^2) state-of-the-art, encapsulated, a-Si:H-based modules, complete the design and testing of the auto test and cure system, and demonstrate $\pm 5\%$ uniformity on $\geq 6\text{ ft}^2$ (5574 cm^2) a-Si:H deposition system.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
R.L. Mitchell
(303) 231-1379

Contractor

Solarex Corporation
1335 Piccard Drive
Rockville, MD 20850
R.S. Oswald
(301) 698-4200

Contract Number

ZM-1-11040-2

Contract Period

3/18/92 - 3/17/95

Funding Amount (Source)

(FY 1992) \$1,680,296 (DOE)
(FY 1992) \$1,680,296 (Solarex)

Photovoltaic Manufacturing Technology

Photovoltaic Cz-Si Manufacturing Technology Improvements

Objectives

Perform manufacturing R&D which will advance PV manufacturing technologies, reduce module production costs, increase module performance, and expand commercial production capacities.

Approach/Background

Improve the quality of silicon ingots made by the Czochralski method (Cz-Si), increase the materials use efficiency for crystalline silicon (c-Si) wafer sawing, investigate improvements in device processing, investigate the introduction of automation to a significant portion of the c-Si module manufacturing lines, and reduce the amount of hazardous waste generated. The effort will be addressed in three, one-year phases. Successful implementation of this program will result in decreasing Siemens Solar Industries' c-Si module cost by more than half and a doubling of its U.S. manufacturing capability.

Status/Accomplishments

Demonstrated c-Si modules fabricated by improved methods and using wire-sawn c-Si wafers.

FY 1993 Milestones

Demonstrate a 10% increase in Cz-Si grower productivity, demonstrate a 10% reduction in the c-Si cell processing costs, demonstrate a 10% reduction in the module fabrication costs for

the c-Si modules, complete the evaluation of thin c-Si wafer wire saw performance, and demonstrate c-Si modules representing a 15% (\$/W) manufacturing cost reduction.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
R.L. Mitchell
(303) 231-1379

Contractor

Siemens Solar Industries
4650 Adohr Lane
P.O. Box 6032
Camarillo, CA 93011

T. Jester
(805) 388-6505

Contract Number

ZM-1-11040-1

Contract Period

3/13/92 - 3/12/95

Funding Amount (Source)

(FY 1992) \$1,662,228 (DOE)
\$1,825,452 (Siemens)

Photovoltaic Manufacturing Technology

PVMaT Cost Analysis Methodology

Objectives

Investigate manufacturing costs for different PV technologies, analyze these costs, and prepare resulting information for utilization by the PVMaT project.

Approach/Background

Use knowledge about the PV industry in general and, more specifically, expertise in analyzing the manufacturing costs of photovoltaic manufacturing technologies to assist in developing data for comparing module manufacturing costs of differing PV technologies.

Status/Accomplishments

Designed PV cost-analysis methodology to facilitate the comparison of costs for the different PV manufacturing processes expected to be supported by PVMaT; completed a report on characterization parameters detailing quantitative specifications for the expected module manufacturing costs for each of the process-specific technologies to be considered for PVMaT Phase 2A support; and summarized the advantages and disadvantages of the processes.

FY 1993 Milestones

None

Major Project Reports

Whisnant, R.A. *Cost Analysis Methodology Photovoltaic Manufacturing Technology Project.*

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory

1617 Cole Blvd.
Golden, CO 80401-3393

G.D. Mooney
(303) 231-7074

Contractor

Center for Semiconductor Research
Research Triangle Institute
Research Triangle Park, NC 27709

R.A. Whisnant
(919) 541-5825

Contract Number

XR-1-11039-1

Contract Period

3/11/91 - 2/28/93

Funding Amount (Source)

(Previous years) \$49,533 (DOE)

Photovoltaic Manufacturing Technology

PVMaT Improvements for ENTECH's Concentrator Module

Objectives

Perform manufacturing R&D that will help ENTECH advance PV manufacturing technologies, reduce the module production costs, increase module performance, and expand ENTECH's commercial production capacities.

Approach/Background

Automate a significant portion of ENTECH's manufacturing line, aid key ENTECH vendors in improving the vendors' technologies, scale up the ENTECH manufacturing line to accommodate large volume production, and address environmental, safety, and health issues throughout all of the associated manufacturing processes. The effort will be addressed in two, one-year phases. Successful implementation of this program will result in a concentrator-module manufacturing plant with the capability of producing PV modules at a rate of 10 MW/yr.

Status/Accomplishments

Developed laboratory prototype work stations for PV cell assemblies and PV receivers, delivered four representative samples of advanced cells from a vendor, and developed improved prismatic lens covers and rolled Fresnel lens capability.

FY 1993 Milestones

Develop a representative linear Fresnel lens concentrator module, complete key process definition and prototype parts production, demonstrate prototype components manufactured from PV cell assembly and PV receiver assembly stations, complete design of automated stations for PV cell and PV receiver assemblies, deliver one representative linear Fresnel lens concentrator module, and complete automation and operation of the PV cell assembly and PV receiver line.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
R.L. Mitchell
(303) 231-1379

Contractor

ENTECH, Incorporated
1015 Royal Lane
DFW Airport, TX 75261
M.J. O'Neill
(214) 456-0900

Contract Number

ZM-1-11040-4

Contract Period

2/17/92 - 5/16/94

Funding Amount (Source)

(FY 1992) \$1,914,310 (DOE)
\$ 59,205 (ENTECH)

Photovoltaic Manufacturing Technology

Silicon-Film Photovoltaic Manufacturing Technology

Objectives

Perform manufacturing research and development that will advance PV manufacturing technologies, reduce polycrystalline silicon-film module production costs, increase module performance, and expand AstroPower's commercial production capacities.

Approach/Background

Enhance AstroPower's silicon-film wafer production capabilities, optimize solar-cell processing, and improve the polycrystalline silicon-film module assembly portion of the manufacturing line. The effort will be addressed in three, one-year phases. Successful implementation of this program will result in an upgrade to AstroPower's facility that will allow them to reach a production rate of 19 MW/yr of 13.2 ft² (1.22-m²) polycrystalline silicon PV modules with an output of 170 W_p each by the mid-1990s.

Status/Accomplishments

Demonstrated 8.8% efficient 3.9 × 3.9-in. (10 × 10-cm) silicon-film solar cell, and fabricated the first 5.8 × 17.6-in. (5 × 45-cm) silicon-film solar cell.

FY 1993 Milestones

Demonstrate 75% wafer product yield at 400 kW/yr; produce four 39 W, 4 solar-cell, 675-cm² silicon-film submodules; demonstrate an 11.5% efficient 15 × 45-cm silicon-film solar cell; and deliver a 135-W silicon-film module.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

R.L. Mitchell
(303) 231-1379

Contractor

AstroPower, Inc.
30 Lovett Avenue
Newark, DE 19711

W.R. Bottenberg
(302) 366-0400

Contract Number

ZM-1-11040-5

Contract Period

1/15/92 - 2/14/95

Funding Amount (Source)

(FY 1992) \$1,599,914 (DOE)

\$ 668,634 (AstroPower)

Photovoltaic Manufacturing Technology

Solar Industry Outreach Development— PVMaT Support

Objectives

Provide support for the PVMaT program coordination structure.

Major Project Reports

None

Summary Date

November 1992

Approach/Background

Provide input for the coordination of the program direction; provide industry perspective on PVMaT goals; develop informational material for use by DOE, NREL, Sandia National Laboratory, and the PVMaT Program; and provide studies on technology barriers for PV in achieving commercialization and U.S. PV industry needs and market-pull strategies.

Status/Accomplishments

Complete report on PV market identification and document on industry manufacturing needs.

FY 1993 Milestones

Complete a report on institutional barriers analysis to U.S. PV industry achieving commercialization, on two market-pull strategies previously identified, on industry needs related to manufacturing, and a final report.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
R.L. Mitchell
(303) 231-1379

Contractor

Solar Energy Industries Association
777 North Capitol St., N.E., Suite 805
Washington, DC 20002-4226
R. Sellers
(202) 408-0660

Contract Number

HI-2-12006-33

Contract Period

10/29/92 – 10/28/93

Funding Amount (Source)

(Previous years)	\$73,803 (DOE)
(FY 1992)	\$73,129 (DOE)

Photovoltaic Manufacturing Technology

Technology Baseline for PVMaT

Objectives

Provide input to the PV costing methodology developed by the Research Triangle Institute (RTI) under a PVMaT subcontract and establish a baseline for the status of the U.S. PV industry by reviewing and summarizing the PVMaT Phase 1 final reports and the PVMaT Phase 2A statements of work.

Major Project Reports

None

Summary Date

November 1992

Approach/Background

Conduct research on costing methodology inputs on a-Si PV manufacturing. Baseline data will include data resulting from the RTI costing methodology, as well as data summarized from the PVMaT Phase 1 final reports and the Phase 2A statements of work. The results of the a-Si manufacturing costing methodology will also be incorporated into the establishment of the industry baseline. This baseline will serve as a tool for use by PVMaT teams for monitoring current and future PVMaT subcontracts.

Status/Accomplishments

Completed costing methodology for a-Si PV module manufacturing and summary of PVMaT Phase 1 research.

FY 1993 Milestones

Complete a summary of PVMaT Phase 2A statements of work.

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

G.D. Mooney
(303) 231-7074

Contractor

Sherring Energy Associates
1 Trumbull Ct.
Princeton, NJ 08540
C. Sherring
(609) 951-0744

Contract Number

ET-2-12235-1

Contract Period

6/25/92 - 12/31/92

Funding Amount (Source)

(FY 1992) \$53,342 (DOE)

Photovoltaic Manufacturing Technology

Thin, Edge-Defined Film-Fed Growth (EFG) Octagons

Objectives

Perform manufacturing R&D that will advance PV manufacturing technologies, reduce EFG-grown Si-wafer and module production costs, and expand Mobil Solar's commercial production capacities.

Approach/Background

Reduce the cost of solar cell processing through a 50% reduction in EFG Si-wafer thickness; increase the throughput of the laser cutting of the wafers; increase the mechanical strength and thus yield of the wafers; and evaluate integrated computer-aided manufacturing control programs for the Mobil Solar crystal-growth manufacturing line to enhance productivity. It will be addressed in three, 1-yr phases. Successful implementation of this program will allow Mobil Solar to produce 200- μm -thick octagonal Si tubes with a thickness variation of $\pm 50\text{ }\mu\text{m}$ and laser wafer cutting capabilities resulting in the processing of 12 wafers per minute.

Status/Accomplishments

Completed the investigation of die/susceptor design to improve thickness uniformity on 300- μm -thick octagons, of outside after-heater to control stress in 300- μm -thick octagons, and of coil design to improve thickness uniformity; completed hot-zone design to minimize ambient effects while maintaining

productivity and yield and developed a 3-D magnetic model.

FY 1993 Milestones

Complete an investigation of new graphite material and coatings to improve thickness uniformity; an investigation of main coil position to control stress and thickness uniformity; an evaluation of laser cutting facilities for 300- μm -thick octagons under pilot line conditions; test of laser cutting for 250- μm -thick octagons under pilot line cutting conditions; and residual stress measurement, wafer-edge characterization, and flatness specification.

Major Project Reports

None

Summary Date

November 1992

Directing Organization

National Renewable Energy
Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
R.L. Mitchell
(303) 231-1379

Contractor

Mobil Solar Energy Corporation
4 Suburban Park Drive
Billerica, MA 01821-3980
J. Kalejs
(508) 667-5900

Contract Number

ZM-1-11040-3

Contract Period

4/8/92 - 4/7/95

Funding Amount (Source)

(FY 1992) \$1,734,554 (DOE)
\$1,419,181 (Mobil Solar)

Sandia National Laboratories

The PV Program works to stimulate strong, growing markets so that industry will increase investments in new manufacturing capacity and prepare for large-scale applications.

Photovoltaic Cell Research and Development

Numerical Modeling of Solar Cells

Objectives

Improve our fundamental understanding of silicon and gallium arsenide solar cells.

Approach/Background

Develop advanced numerical models for one-, two-, and three-dimensional analysis of the internal operation of solar cells.

Status/Accomplishments

Developed ADEPT, a computer code capable of running on personal computers, is being refined for public release.

FY 1993 Milestones

Release one-dimensional version of ADEPT to the public. Add transient analysis to ADEPT. Release two-dimensional version of ADEPT to the public.

Major Project Reports

None

Summary Date

December 1992

Directing Organization

Sandia National Laboratories
Department 6213
Albuquerque, NM 87185-5800
P.A. Basore
(505) 844-3761

Contractor

Purdue Research Foundation
Purdue University
West Lafayette, IN 47907
J.L. Gray/R.J. Schwartz
(317) 494-3478/3536

Contract Number

AB-1520

Contract Period

5/5/92 - 7/31/95

Funding Amount (Source)

(Previous years) \$340,688 (DOE)
(FY 1992) \$75,000 (DOE)

Photovoltaic Cell Research and Development

Silicon Cell Research and Development

Objectives

Improve the efficiency of silicon solar cells in both 1-sun and concentrator applications.

Approach/Background

Fabricate and analyze silicon solar cells produced using passivated structures, plated buried-contact structures, and measure fundamental parameters of silicon.

Status/Accomplishments

Transferred passivated-emitter technology successfully to Applied Solar Energy Corporation for use in the Concentrator Initiative. Demonstrated a cell efficiency of more than 20% for a 1.9-in² (12-cm²) buried-contact cell with grooves formed inexpensively using a mechanical saw.

FY 1993 Milestones

Deliver at least four silicon cells of each of the following types for evaluation at Sandia: double-sided buried-contact cells, high-performance cells, 200-sun concentrator cells, and polycrystalline cells. Prepare final report describing processes developed and their manufacturing potential.

Major Project Reports

Green, M.A. *Concentrator Silicon Cell Research*.

Summary Date

December 1992

Directing Organization

Sandia National Laboratories
Department 6213
Albuquerque, NM 87185-5800
Paul A. Basore
(505) 844-3761

Contractor

University of New South Wales
P.O. Box 1
Kensington, NSW 2033, AUSTRALIA
Martin A. Green
61-2-697-4018

Contract Number

96-0231

Contract Period

3/19/92 - 3/31/93

Funding Amount

(Previous years) \$300,372 (DOE)
(FY 1992) \$300,372 (DOE)

Photovoltaic Cell Research and Development

University Center of Excellence in Photovoltaics

Objectives

Provide a supply of graduates trained in the fabrication of silicon solar cells to stimulate industrial development of this technology.

Approach/Background

Operate a world-class silicon cell fabrication facility available to faculty or students from other U.S. universities. Also perform leading research in silicon solar cell design, fabrication, and characterization.

Status/Accomplishments

Officially recognized by DOE on July 23, 1992, as the first University Center of Excellence in Photovoltaics Research and Education. Demonstrated a small-area cell on multicrystalline silicon with a world-record efficiency of over 17%.

FY 1993 Milestones

Demonstrate and document 18%-efficient cell. Prepare brochure for prospective university participants. Enroll at least one other university participant.

Major Project Reports

Rohatghi, Al; Smith, A.W.; Salami, J. *Modeling and Fabrication of High-Efficiency Silicon Solar Cells*.

Summary Date

December 1992

Directing Organization

Sandia National Laboratories
Department 6213
Albuquerque, NM 87185-5800
J.M. Gee
(505) 844-7812

Contractor

Georgia Tech Research Corporation
Georgia Institute of Technology
Atlanta, GA 30332
A. Rohatgi
(404) 894-7692

Contract Number

AA-1638

Contract Period

6/11/92 - 5/31/95

Funding Amount (Source)

(Previous years) \$1,315,672 (DOE)
(FY 1992) \$ 236,000 (DOE)

Photovoltaic Collector Development

Back-Contacted Cell Development

Objectives

Develop back-contacted concentrator cells for use at 100–300 suns.

Major Project Reports

None

Summary Date

December 1992

Approach/Background

Equip and bring on-line a dedicated solar cell processing facility that can fabricate SunPower's baseline back-contacted cell. Transfer the Stanford-developed technology to SunPower's cell pilot line (CPL). Achieve high efficiency (25%) at 200 suns concentration.

Status/Accomplishments

Brought new CPL facility on line. By eliminating gaseous dopants and most solvents, the CPL qualified for an occupancy rating comparable to that for commercial buildings rather than the expensive and hazardous rating normally given to semiconductor plants. SunPower established a baseline cell process and transferred 100% of the processing to the CPL. SunPower achieved a cell efficiency of 25% at 100 suns, 24% at 200 suns.

FY 1993 Milestones

Optimize the back-contact cell and the process sequence for manufacturability (low cost and high yield). Demonstrate optimized cell through production run of 500 cells.

Directing Organization

Sandia National Laboratories
Department 6213
Albuquerque, NM 87185-5800

A.B. Maish
(505) 844-8771

Contractor

SunPower Corporation
435 Indio Way
Suite 100
Sunnyvale, CA 94086

R. Swanson
(408) 991-0900

Contract Number

54-2129D

Contract Period

10/90 – 6/94

Funding Amount (Source)

(Previous years) \$1,535,000 (DOE)
\$ 612,000 (SunPower)
(FY 1992) \$ 342,000 (DOE)

Photovoltaic Collector Development

High-Concentration Cell Development

Objectives

Transfer the passivated-emitter (PESC) cell technology developed at the University of New South Wales to Applied Solar Energy Corporation's production line, improve yield and reduce cost, and achieve 22% efficiency between 150 and 300 suns for non-prismatically covered cells.

Major Project Reports

Applied Solar Energy Corporation. *Development of Concentrator Cells: Phase I Report.*

Summary Date

December 1992

Approach/Background

Investigate 3-, 4-, and 5-mask processes, variations in grid line widths and pitches, and send samples to Sandia for evaluation.

Status/Accomplishments

Overcame series resistance and blue response problems with help from Sandia. Achieved 21.4% at 150 suns, maintaining 21% out to 250 suns on cells designed for use with prismatic covers but tested without covers. Transferred image reversal process from Sandia which improved microgroove definition, reducing reflection losses. Developed optimized grid design for use without prismatic cover.

FY 1993 Milestones

Implement new front metal design and use image reversal process on grid line definition to reduce width blooming and improve cell currents.

Directing Organization

Sandia National Laboratories
Department 6213
Albuquerque, NM 87185-5800
A.B. Maish
(505) 844-8771

Contractor

Applied Solar Energy Corporation
P.O. Box 1212
City of Industry, CA 91749
H. Yoo
(818) 968-6581

Contract Number

54-2129B

Contract Period

10/90 - 5/94

Funding Amount (Source)

(Previous years) \$1,026,665 (DOE)
\$ 342,222 (ASEC)
(FY 1992) \$ 231,000 (DOE)

Photovoltaic Collector Development

High-Concentration Collector Development

Objectives

Develop a reliable, commercially viable high-concentration collector and tracking array.

Approach/Background

Fabricate iterations of prototype modules for testing according to Sandia's PV-concentrator evaluation procedures. Develop production fabrication and testing processes, and develop a new, low-cost tracking array drive. Prepare quality assurance/quality control manual.

Status/Accomplishments

Delivered cell assemblies and back plane sections incorporating the improved features of Alpha Solarco's new module design to Sandia for evaluation. Numerous parts delivered to Sandia for testing show Alpha Solarco is currently able to make good cell solder bonds, and it has made great progress improving the consistency of its secondary optical element adhesive bonds. Alpha Solarco has tested an improved lens/housing seal and will use it in two electrically active modules to be delivered to Sandia shortly.

FY 1993 Milestones

Deliver prototype modules for evaluation. Retrofit Pahrump test array. Automate cell testing, interconnection process, and module testing, and establish module product line.

Major Project Reports

None

Summary Date

December 1992

Directing Organization

Sandia National Laboratories
Department 6213
Albuquerque, NM 87185-5800

A.B. Maish
(505) 844-8771

Contractor

Alpha Solarco
11534 Gondola Drive
Cincinnati, OH 45241

E. Schmidt
(513) 771-1690

Contract Number

40-8941D

Contract Period

9/90 - 6/94

Funding Amount (Source)

(Previous Year) \$1,237,668 (DOE)

\$1,142,463 (Alpha

Solarco)

(FY 1992) \$ 239,924 (DOE)

Photovoltaic Collector Development

High-Concentration Collector Development

Objectives

Develop a reliable, commercially viable low-concentration collector and tracking array.

Major Project Reports

None

Summary Date

December 1992

Approach/Background

Fabricate iterations of cell assemblies and prototype modules for testing according to Sandia's PV concentrator evaluation procedures. Develop tracking array for evaluation.

Status/Accomplishments

Delivered numerous cell assemblies for evaluation. Fabricated and evaluated two iterations of modules at Sandia. A third generation is nearing completion. Developed and installed a 2-kW tracking array at Solar Kinetics for evaluation.

FY 1993 Milestones

Complete third-generation module and finalize cell assembly fabrication process. Complete array testing and develop production cost estimates.

Directing Organization

Sandia National Laboratories
Department 6213
Albuquerque, NM 87185-5800
A.B. Maish
(505) 844-8771

Contractor

Solar Kinetics, Inc.
10635 King William Drive
Dallas, TX 75220

A. Konnerth
(214) 556-2376

Contract Number

40-8941B

Contract Period

10/90 - 1/95

Funding Amount (Source)

(Previous years) \$2,287,545 (DOE)
\$ 315,579 (SKI)
(FY 1992) \$ 251,000 (DOE)

Photovoltaic Collector Development Project

Low-Concentration Cell Development

Objectives

Develop low-cost, low-concentration (16-sun) buried-contact cells for use in ENTECH's linear-focus collector.

Major Project Reports

None

Summary Date

December 1992

Approach/Background

Transfer UNSW buried-contact technology to Czochralski and multicrystalline material. Develop low-cost processing techniques to achieve 20% efficiencies when tested with prismatic covers.

Status/Accomplishments

Brought high-efficiency laboratory on-line after shutting down the Solarex Aerospace unit. Transferred the UNSW buried-contact technology to Solarex. Developed a potentially low-cost saw-cut method for grooving cells to replace laser grooving. Produced a 15.4% efficient cell (Sandia measurement) at 1-sun or planar float zone (FZ); a 16.8% efficient cell 1-sun on textured FZ; and an 11.8% efficient cell 1-sun on multicrystalline FZ.

FY 1993 Milestones

Deliver >18% cells (covered) on Cz cells made at Solarex. Demonstrate ability to use buried-contact cells in ENTECH cell assemblies.

Directing Organization

Sandia National Laboratories
Department 6213
Albuquerque, NM 87185-5800

Alexander B. Maish
(505) 844-8771

Contractor

Solarex Corp.
630 Solarex Court
Frederick, MD 21701

John Wohlgemuth
(301) 698-4375

Contract Number

54-2191C

Contract Period

10/90 - 5/94

Funding Amount

(Previous years) \$1081,000 (DOE)
\$553,000 (Solarex)
(FY 1992) \$243,000 (DOE)

Photovoltaic Collector Development

Low-Concentration Cell Development

Objectives

Pursue a simplified approach to the UNSW passivated-emitter cell for high-concentration applications that will extract most of the major performance benefits of the design while keeping the number of processing steps to a minimum.

Major Project Reports

None

Summary Date

December 1992

Approach/Background

Develop cells that take advantage of Spectrolab's current cell production line and processes to develop a simple, low-cost, high-concentration cell. Spectrolab plans to study parts of the problem independently and then combine all processes to demonstrate final cell processing.

Status/Accomplishments

Conducted research on several parameters including emitter passivation and oxide thickness; with Sandia's assistance, solved cell shunting and surface texturing problems, and developed a new optimized grid design. Spectrolab is currently working to put all elements together. Spectrolab has so far delivered over 200 concentrator cells; the best peak at 18.3% at 100 suns and maintain 18.2% at 200 suns.

FY 1993 Milestones

Complete development of 1- and 3-mask designs and deliver 1000 cells as final delivery. Complete final report.

Directing Organization

Sandia National Laboratories
Department 6213
Albuquerque, NM 87185-5800

A.B. Maish
(505) 844-8771

Contractor

Spectrolab, Inc.
12500 Gladstone Ave.
Sylmar, CA 91342-5373

D. Krut
(818) 898-2827

Contract Number

54-2191A

Contract Period

10/90 - 1/93

Funding Amount (Source)

(Previous years) \$258,000 (DOE)
\$ 86,000 (Spectrolab)
(FY 1992) \$ 99,000 (DOE)

Photovoltaic Collector Development

Low-Concentration Collector Development

Objectives

Make iterative improvements in ENTECH's 21X low-concentration line-focus collector to improve performance, manufacturability, and cost.

Major Project Reports

None

Summary Date

December 1992

Approach/Background

Redesign the module around 3M's new single-piece, 1-m-wide Lensfilm linear Fresnel lens material, which reduces production handling. Increase module length and improve the heat spreader to lower cell operating temperature. Develop an automated receiver assembly capability.

Status/Accomplishments

Developed and fabricated two new Lensfilm designs. As part of the complementary PVMaT DOE program, fabricated lenses using 3M's new in-line lamination process, which eliminates having ENTECH bond solvent to a superstrate. Designed a new associated prismatic cover. Using PVMaT funding, 3M manufactured a 10,000-cover roll, eliminating the individual part molding process by ENTECH. Redesigned ENTECH's heat spreader to enable cells to operate 20°C cooler with low winds. Began work on an automated receiver assembly capability.

FY 1993 Milestones

Deliver at least three modules for evaluation and complete contract final report.

Directing Organization

Sandia National Laboratories
Department 6213
Albuquerque, NM 87185-5800

A.B. Maish
(505) 844-8771

Contractor

ENTECH, Incorporated
P.O. Box 612246
DFW Airport, TX 75261

M. O'Neill
(214) 456-0900

Contract Number

40-8941A

Contract Period

10/90 - 2/93

Funding Amount (Source)

(Previous years) \$887,438 (DOE)
\$73,494 (ENTECH)
(FY 1992) \$259,000 (DOE)

Photovoltaic Collector Development Project

Low-Concentration Collector Development

Objectives

Develop a reliable, commercially viable low-concentration collector and tracking array.

Major Project Reports

None

Summary Date

December 1992

Approach/Background

Fabricate iterations of phototype modules for testing according to Sandia PV concentrator evaluation procedures. Develop an automated receiver assembly process and a low-cost tracking array for evaluation. Prepare a quality assurance/quality control (QA/QC) manual.

Status/Accomplishments

Demonstrated 79% efficient extruded linear Fresnel lens. Fabricated three active and one mechanical module, which were evaluated at Sandia. Currently making improvements to modules, developing an automated receiver assembly station, and fabricating a demonstration array.

FY 1993 Milestones

Complete automated receiver assembly station. Deliver 1-ft (30-cm) sections, six modules, and three populated arrays (containing 30 modules) for evaluation. Prepare QA/QC document.

Directing Organization

Sandia National Laboratories
Department 6213
Albuquerque, NM 87185-5800
A.B. Maish
(505) 844-8771

Contractor

Solar Energy Applications Corporation
305 N. Mathilda Ave.
Sunnyvale, CA 94086
N. Kaminar
(408) 720-1804

Contract Number

40-8941C

Contract Period

10/90 - 10/94

Funding Amount (Source)

(Previous years) \$1,549,496 (DOE)
\$ 290,532 (SEAC)
(FY 1992) \$ 145,000 (DOE)

U.S. Department of Energy

The mission of the Photovoltaics Program is to help U.S. industry develop photovoltaic technology for large-scale generation of economically competitive electric power in the United States, thus making PV a significant part of our national energy mix.

Health and Safety/Solar Energy Conversion

Health, Environmental, and Safety Effects of Photovoltaics

Objectives

Identify and examine potential environmental and health-and-safety barriers, and control strategies for existing and new photovoltaic material, process, and application options.

Approach/Background

In collaboration with DOE Headquarters, other national laboratories, other federal organizations, and industry, identify and evaluate environmental and health-and-safety problems of continuing or new interest to the photovoltaic community.

Status/Accomplishments

Conceptualized and assisted in the preparation of the Safety Analysis Report for National Renewable Energy Laboratory; conducted accident investigations at Institute of Energy Conversion and Pacific Gas and Electric; cosponsored workshop on recycling of cadmium and selenium from photovoltaic modules and wastes; coordinated toxicology studies on copper indium diselenide (CIS) with the National Toxicology Program and the Fraunhofer Institute for Solid State Technology, Munich, Germany.

FY 1993 Milestones

Maintain information center on environmental, health, and safety issues; prepare safety manual for SUNRAYCE 93; prepare risk assessment for CIS module production and use; evaluate air pollution control

systems for metal fumes and dusts from photovoltaic manufacturing options; coordinate toxicology studies being conducted by the National Institute of Environmental Health Sciences/Fraunhofer Institute for Solid State Technology; and, on request, conduct accident investigations and prepare other topical reports.

Major Project Report

Crandall, R.S.; Nelson, P.P.; Moskowitz, P.D.; Fthenakis, V.M. *Safety Analysis Report for the Use of Hazardous Production Materials in Photovoltaic Applications at the National Renewable Energy Laboratory.*

Jacobson, L.; Moskowitz, P.D.; Garrett, J.O.; and Tyler, R. *Accident Investigation of the Electrical Shock Incident at the PG&E PVUSA Site, Davis, California.*

Summary Date

November 1992

Directing Organization

U.S. Department of Energy
PV Division, CE-131
1000 Independence Ave. SW
Washington, DC 20585
A.D. Bulawka
(202) 586-5633

Contractor

Brookhaven National Laboratory
Upton, NY 11973
P.D. Moskowitz
(516) 282-2017

Contract Numbers

EB-22-01, AS-034-ASD

Contract Period

10/1/92 - Open

Funding Amount (Source)

(Previous years) \$3,045,000 (DOE)
(FY 1992) \$ 350,000 (DOE)

Index of Contractors

Advanced Photovoltaic Systems, Inc.	15
Alpha Solarco	103
Applied Solar Energy Corporation	102
AstroPower, Inc.	64, 93
Atmospheric Sciences Research Center	86
Board of Trustees of the University of Illinois	14
Boeing Defense and Space Group	77
Brookhaven National Laboratory	110
Center for Semiconductor Research	91
Colorado School of Mines	18, 71
Colorado State University	22, 79
Duke University	45
Energy Conversion Devices, Inc.	52, 88
Energy Photovoltaics, Inc.	40
ENTECH, Incorporated	92, 107
Florida Solar Energy Center	83
Georgia Institute of Technology	63
Georgia Tech Research Corporation	100
Harvard University	12, 21
Integrated Power Corporation	53
International Solar Electric Technology, Inc.	70
Iowa State University	4
Kiss Cathcart Anders Architects, P.C.	81
Kopin Corporation	31
Martin Marietta Corporation	66
Mobil Solar Energy Corporation	96
National Institute of Standards and Technology	6
National Renewable Energy Laboratory	5, 7, 9, 25, 28, 33, 36, 43, 46-48, 55, 57-59, 61, 74, 75
North Carolina State University	11, 26, 29, 38
Pennsylvania State University	8
Photon Energy, Inc.	68
Purdue Research Foundation	62, 98
Purdue University	37
Rensselaer Polytechnical Institute	24
Research Triangle Institute	30, 34

The PV Program offers the resources of government laboratories and universities to assist industry's applied research and development activities.

Sherring Energy Associates	95
Siemens Solar Industries	76, 90
Solar Cells, Inc.	49, 65
Solar Energy Applications Corporation	108
Solar Energy Industries Association	54, 56, 94
Solar Kinetics, Inc.	104
Solarex Corporation	16, 78, 89, 105
Southwest Technology Development Institute	84
Spectrolab, Inc.	106
Spire Corporation	39
Stanford University	35
State of Oregon	10
SunPower Corporation	101
United Solar Systems Corporation	17, 50
University of California	32
University of Central Florida	72
University of Colorado	69
University of Delaware	19, 41, 73, 82
University of Massachusetts	85
University of New South Wales	99
University of North Carolina	13
University of South Florida	42, 60
University of Southern California	23
University of Toledo	80
University of Utah	27, 44
Utility Power Group	51, 87
Washington State University	67
Xerox Corporation	20

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KEY CONTACTS

U.S. Department of Energy

James E. Rannels
Photovoltaics Technology Division
Director, CE-131
1000 Independence Avenue, SW
Washington, DC 20585
(202) 586-1720
FAX (202) 586-5127

National Renewable Energy Laboratory

Thomas Surek
Photovoltaics Program Manager
Photovoltaics Division
1617 Cole Boulevard
Golden, CO 80401-3393
(303) 231-1371
FAX (303) 231-1030

Sandia National Laboratories

David Hasti
Photovoltaic Projects Manager
Division 6223
Albuquerque, NM 87185-5800
(505) 844-8161
FAX (505) 844-6541

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Golden, CO 80401-3393

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