NREL/TP-410-5812 • UC Category: 270 • DE93018218

NREL Photovoltaic Subcontract Reports: Abstracts and Document Control Information

1 August 1992 – 31 July 1993

Photovoltaic Energy Program
L. Pohle, Coordinator

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
Operated by Midwest Research Institute
for the U.S. Department of Energy
under Contract No. DE-AC02-83CH10093

Prepared under Task No. PV310101

September 1993

NOTICE

Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Microfiche A01
Printed Copy A04

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PREFACE

This report contains document control information and abstracts for the National Renewable Energy Laboratory (NREL) subcontracted photovoltaic (PV) program publications. It also lists source information on additional publications that describe U.S. Department of Energy (DOE) PV research activities. It is not totally exhaustive, so it lists NREL contacts for requesting further information on the DOE and NREL PV programs. This report covers the period from August 1, 1992, through July 31, 1993. This report is published periodically, with the previous one covering the period from August 1, 1991, through July 31, 1992.

The purpose of continuing this type of publication is to help keep people abreast of specific PV interests, while maintaining a balance on the costs to the PV program. The information in this report is organized under PV technology areas:

- Amorphous Silicon Research
- Polycrystalline Thin Films (including copper indium diselenide, cadmium telluride, and thin-film silicon)
- Crystalline Materials and Advanced Concepts (including silicon, gallium arsenide, and other group III-V materials)
- PV Manufacturing Technology Development (which may include manufacturing information for various types of PV materials)

The referenced documents are mostly available from the National Technical Information Service (NTIS), and an NTIS order form is enclosed. In addition to these sections are listings of a more general nature. These additional listings identify their source.

The NREL Photovoltaics Program is sponsored by the U.S. Department of Energy under contract No. DE-AC02-83CH10093. NREL is operated by Midwest Research Institute for the U.S. Department of Energy.

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7. Author(s) S. Guha	8. Performing Organization Rept. No.
9. Performing Organization Name and Address United Solar Systems Corporation Troy, Michigan	10. Project/Task/Work Unit No. PV241101 11. Contract (C) or Grant (G) No. (C) ZM-1-19033-2 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393	13. Type of Report & Period Covered Technical Report 1 January 1992 - 28 February 1993 14.

15. Supplementary Notes
NREL technical monitor: W. Luft

16. Abstract (Limit: 200 words)

This report describes the progress made during Phase II of the R&D program to obtain high-efficiency amorphous alloy multijunction PV modules. The highlight of the work includes: (1) demonstration of world-record small-area efficiency of 11.2% after one-sun light-soaking at 50°C for 600 h using a dual band gap, double-junction structure; and (2) demonstration of initial module efficiency of 10.6% over 0.09-m^2 (1-ft^2) area using the same double-junction approach. In addition, fundamental studies on material properties and cell performance showed an interesting correlation between microstructure in the material and cell efficiency both in the initial and light-degraded conditions.

17. Document Analysis
a. Descriptors
high-efficiency ; amorphous silicon ; multijunction ; modules ; photovoltaics ; solar cells ; PV

b. Identifiers/Open-Ended Terms

c. UC Categories
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18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	19. No. of Pages 72 20. Price A04

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-411-5457	2. NTIS Accession No. DE93010021	3. Recipient's Accession No.
4. Title and Subtitle Structural and Electronic Studies of a-SiGe:H Alloys			5. Publication Date April 1993 6.
7. Author(s) W. Paul			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Harvard University Cambridge, Massachusetts 02138			10. Project/Task/Work Unit No. PV341101 11. Contract (C) or Grant (G) No. (C) XX-8-18131-1 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 January 1991 - 28 February 1993 14.

15. Supplementary Notes
NREL technical monitor: B. Stafford

16. Abstract (Limit: 200 words)
This report describes work to produce alloys of a-$Si_{1-x}Ge_x$:H of improved photoelectronic quality by plasma-enhanced chemical vapor deposition (PECVD). The goal was to discover optimum preparation conditions for the end-component, a-Ge:H, to establish whether modification of the usual practice of starting from a-Si:H preparation conditions was advisable. Such modification, found to be necessary, gave films of a-Ge:H with efficiency-mobility-lifetime products ($\eta\mu\tau$) 10^2 to 10^3 higher than were earlier available, in homogeneous environmentally stable material. Both a-Ge:H and a-$Si_{1-x}Ge_x$:H of large x were studied in detail. Alloy material was shown to have $\eta\mu\tau$ 10^2 larger than found earlier. However, just as the $\eta\mu\tau$ of a-Si:H decreases when Ge is added, so also the $\eta\mu\tau$ of these alloys decreases with Si addition. By contrast, the ambipolar diffusion lengths, L_o, which are governed by the hole mobility, vary by only a factor of two over the whole alloy series. Using the experimental finding of a small valence band offset between a-Si:H and a-Ge:H, compositional fluctuations on a 10-nm scale are suggested to explain the behavior of $\eta\mu\tau$ and L_o. The implications for eventual improvement of the alloys are profound, but require direct experimental tests of the postulated compositional fluctuations.

17. Document Analysis
a. Descriptors
electronic ; amorphous silicon ; alloys ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
271

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	64 20. Price A04

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-411-5456	2. NTIS Accession No. DE93010009	3. Recipient's Accession No.

4. Title and Subtitle

Optimization of Transparent and Reflecting Electrodes for Amorphous Silicon Solar Cells

5. Publication Date
April 1993

6.

7. Author(s)

R. G. Gordon

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Harvard University
Department of Chemistry
Cambridge, Massachusetts 02138

10. Project/Task/Work Unit No.
PV341101

11. Contract (C) or Grant (G) No.

(C) XH-1-11032-1

(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered

Technical Report
1 May 1991 - 30 April 1992

14.

15. Supplementary Notes
NREL technical monitor: B. Stafford

16. Abstract (Limit: 200 words)

This report describes work to improve the performance of solar cells by improving the electrical and optical properties of their TCO layers. Boron-doped zinc-oxide films were deposited by atmospheric pressure chemical vapor deposition in a laminar-flow reactor from diethyl zinc, tert-butanol, and diborane in the temperature range between 300°C and 420°C. When the deposition temperature was above 320°C, both doped and undoped films have highly oriented crystallites with their c-axes perpendicular to the substrate plane. Films deposited from 0.07% diethyl zinc and 2.4% tert-butanol have electron densities between 3.5 x 10^{20} cm^{-3} and 5.5 x 10^{20} cm^{-3}, conductivities between 250 Ω^{-1} cm^{-1} and 2500 Ω^{-1} cm^{-1} and mobilities between 2.5 cm^2/V-s and 35.0 cm^2/V-s, depending on dopant concentration, film thickness, and deposition temperature. Optical measurements show that the maximum infrared reflectance of the doped films is close to 90%, compared to about 20% for undoped films. Film visible absorption and film conductivity were found to increase with film thickness. The ratio of conductivity to visibile absorption coefficient for doped films was between 0.1 Ω^{-1} and 1.1 Ω^{-1}. The band gap of the film changes from 3.3 eV to 3.7 eV when the film is doped with 0.012% diborane.

17. Document Analysis

a. Descriptors
amorphous silicon ; electrodes ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
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18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
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20. Price
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4. Title and Subtitle Research on Stable, High-Efficiency Amorphous Silicon Multijunction Modules			5. Publication Date February 1993 6.
7. Author(s) M. Ghosh, J. DelCueto, F. Kampas, J. Xi			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Advanced Photovoltaic Systems Princeton, New Jersey 08543			10. Project/Task/Work Unit No. PV241104 11. Contract (C) or Grant (G) No. (C) ZM-2-11091-1 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 December 1991 - 31 October 1992 14.

15. Supplementary Notes
NREL technical monitor: W. Luft

16. Abstract (Limit: 200 words)
This report describes results from the first phase of a three-phase contract for the development of stable, high-efficiency, same-band-gap, amorphous silicon (a-Si) multijunction photovoltaic (PV) modules. The research program involved improving the properties of individual layers of semiconductor and non-semiconductor materials and small-area single-junction and multijunction devices, as well as the multijunction modules. The semiconductor materials research was performed on a-Si p, i, and n layers, and on microcrystalline silicon n layers. These were deposited using plasma-enhanced chemical vapor deposition. The non-semiconductor materials studied were tin oxide, for use as a transparent-conducting-oxide (TCO), and zinc oxide, for use as a back reflector and as a buffer layer between the TCO and the semiconductor layers. Tin oxide was deposited using atmospheric-pressure chemical vapor deposition. Zinc oxide was deposited using magnetron sputtering. The research indicated that the major challenge in the fabrication of a-Si multijunction PV modules is the contact between the two p-i-n cells. A structure that has low optical absorption but that also facilitates the recombination of electrons from the first p-i-n structure with holes from the second p-i-n structure is required. Non-semiconductor layers and a-Si semiconductor layers were tested without achieving the desired result. Work in the second phase of the contract will concentrate on this issue.

17. Document Analysis
a. Descriptors
high efficiency ; amorphous silicon ; multijunction ; modules ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
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18. Availability Statement	19. No. of Pages
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4. Title and Subtitle Growth Mechanisms and Characterization of Hydrogenated Amorphous-Silicon-Alloy Films			5. Publication Date February 1993 6.
7. Author(s) A. Gallagher, R. Ostrom, G. Stutzin, D. Tanenbaum			8. Performing Organization Rept. No.
9. Performing Organization Name and Address National Institute of Standards and Technology			10. Project/Task/Work Unit No. PV241104 11. Contract (C) or Grant (G) No. (C) DD-H1001-1 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 14 February 1991–13 February 1992 14.

15. Supplementary Notes
NREL technical monitor: W. Luft

16. Abstract (Limit: 200 words)

This report describes an apparatus, constructed and tested, that allows measurement of the surface morphology of as-grown hydrogenated amorphous silicon films with atomic resolution using a scanning tunneling microscope. Surface topologies of 100-Å-thick intrinsic films, deposited on atomically flat, crystalline Si and GaAs, are reported. These film surfaces are relatively flat on the atomic scale, indicating fairly homogeneous, compact initial film growth. The effect of probe-tip size on the observed topology and the development of atomically sharp probes is discussed.

17. Document Analysis
a. Descriptors
characterization ; amorphous silicon ; alloy ; films ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
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18. Availability Statement	19. No. of Pages
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Document Control Page	1. NREL Report No. NREL/TP-451-5265	2. NTIS Accession No. DE93000051	3. Recipient's Accession No.
4. Title and Subtitle In-Situ Characterization of Growth and Interfaces in a-Si:H Devices			5. Publication Date December 1992 6.
7. Author(s) R.W. Collins, C.R. Wronski, I. An, Y. Li			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Materials Research Laboratory Pennsylvania State University University Park, Pennsylvania 16802			10. Project/Task/Work Unit No. PV341101 11. Contract (C) or Grant (G) No. (C) XG-1-10063-10 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 May 1991 - 30 April 1992 14.

15. Supplementary Notes
NREL technical monitor: B. von Roedern

16. Abstract (Limit: 200 words)

This report describes the in-situ characterization of growth and interfaces in amorphous silicon (a-Si:H) devices. The growth of a-Si:H by plasma-enhanced chemical vapor deposition (PECVD) is complex and involves many gas-phase and solid-surface chemical and physical processes, which are influenced by charged particle bombardment, ultraviolet light exposure, etc. The research consisted of two broad components. The first involved preparing a-Si:H by "optimum" PECVD and exposing the film to atomic hydrogen in-situ at the growth temperature. The processes of H-diffusion and incorporation in the exposed film were studied by spectroscopic ellipsometry, giving a picture of the processes by which the chemical potential in the film equilibrates with that in the gas phase. The properties of thin films were then prepared by alternating "optimum" PECVD growth and hydrogen exposure. Film properties were then studied again. The second component of the research is discussed only briefly in this report, as it is an outgrowth of previous work on single-wavelength ellipsometry. With the new spectroscopic capability developed at Penn State, it is now possible to quantify the nucleation and growth process of a-Si:H films

17. Document Analysis
a. Descriptors
characterization ; growth ; interfaces ; amorphous silicon ; devices ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
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18. Availability Statement	19. No. of Pages
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Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-5192	2. NTIS Accession No. DE93000050	3. Recipient's Accession No.

4. Title and Subtitle

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

5. Publication Date
December 1992

6.

7. Author(s)
R.A. Street, W.B. Jackson, N. Johnson, C. Nebel, M. Hack, P. Santos, R. Thompson, C.C. Tsai, J. Walker

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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Palo Alto, CA 94304

10. Project/Task/Work Unit No.
PV241101

11. Contract (C) or Grant (G) No.

(C) HG-1-10063-9

(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered

Technical Report
1 June 1991 - 31 May 1992

14.

15. Supplementary Notes
NREL technical monitor: B. von Roedern

16. Abstract (Limit: 200 words)

This report describes work to obtain a comprehensive understanding of the structure and electronic properties of a-Si:H as they apply to solar cells. The main emphasis is on the phenomena of metastability and thermal equilibrium, in which the density of electronic states depends on the electronic and thermal history of the material. Metastability effects are a major problem with solar cells and with other electronic devices. Our studies provide an understanding of the complex interaction between the electronic states and the atomic structure that causes these effects.

17. Document Analysis
a. Descriptors
amorphous silicon ; alloys ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
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18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
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19. No. of Pages
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20. Price
A04

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-5191	2. NTIS Accession No. DE93000049	3. Recipient's Accession No.

4. Title and Subtitle

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

5. Publication Date
December 1992

6.

7. Author(s)

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Institute of Energy Conversion
University of Delaware
Newark, DE 19716-3820

10. Project/Task/Work Unit No.
PV241101

11. Contract (C) or Grant (G) No.

(C) XG-1-10063-4

(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered

Technical Report
1 March 1991 - 31 January 1992

14.

15. Supplementary Notes
NREL technical monitor: B. von Roedern

16. Abstract (Limit: 200 words)

This report describes work on phase 1 of a three-phase project directed toward demonstrating amorphous silicon (a-Si:H) solar cells with high stabilized conversion efficiency. In the process, an intermediate objective was to resolve several key material and device issues. These key issues are (1) whether a reduction in hydrogen content in amorphous silicon intrinsic layers can lead to higher stabilized solar cell efficiencies, (2) how the performance of solar cells made with narrow-band-gap a-SiGe:H can be enhanced, (3) how the particular materials and device parameters determine stabilized performance of a-Si:H solar cells, and (4) how particular materials and device parameters may enhance the performance of a-SiGe:H based solar cells.

17. Document Analysis

a. Descriptors
amorphous silicon ; high efficiency ; hydrogen ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
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18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
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19. No. of Pages
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20. Price
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Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-411-5123	2. NTIS Accession No. DE93000023	3. Recipient's Accession No.
4. Title and Subtitle Electron Cyclotron Resonance Deposition of Amorphous Silicon Alloy Films and Devices			5. Publication Date October 1992 6.
7. Author(s) Y.-H. Shing			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Jet Propulsion Laboratory Pasadena, California 91109			10. Project/Task/Work Unit No. PV241101 11. Contract (C) or Grant (G) No. (C) DD-1-11002-1 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 April 1991 - 31 March 1992 14.

15. Supplementary Notes
NREL technical monitor: W. Luft

16. Abstract (Limit: 200 words)

This report describes work to develop a state-of-the-art electron cyclotron resonance (ECR) plasma-enhanced chemical vapor deposition (PECVD) system. The objective was to understand the deposition processes of amorphous silicon (a-Si:H) and related alloys, with a best-effort improvement of optoelectronic material properties and best-effort stabilization of solar cell performance. ECR growth parameters were systematically and extensively investigated; materials characterization included constant photocurrent measurement (CPM), junction capacitance, drive-level capacitance profiling (DLCP), optical transmission, light and dark photoconductivity, and small-angle X-ray scattering (SAXS). Conventional ECR-deposited a-Si:H was compared to a new form, a-Si:(Xe,H), in which xenon gas was added to the ECR plasma. a-Si:(Xe,H) possessed low, stable dark conductivities and high photosensitivites. Light-soaking revealed photodegradation rates about 35% lower than those of comparable radio frequency (rf)-deposited material. ECR-deposited p-type a-SiC:H and intrinsic a-Si:H films underwent evaluation as components of p-i-n solar cells with standard rf films for the remaining layers.

17. Document Analysis
a. Descriptors
amorphous silicon ; films ; electronic devices ; deposition ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
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18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	59 20. Price A04

Document Control Page	1. NREL Report No. NREL/TP-411-5063	2. NTIS Accession No. DE93000011	3. Recipient's Accession No.

4. Title and Subtitle

Research on Stable, High-Efficiency Amorphous Silicon Multijunction Modules

5. Publication Date

September 1992

6.

7. Author(s)

S. Guha

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

United Solar Systems Corporation
Troy, Michigan

10. Project/Task/Work Unit No.
PV241101

11. Contract (C) or Grant (G) No.

(C) ZM-1-19033-2

(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered
Technical Report
1 January 1992 - 30 June 1992

14.

15. Supplementary Notes
NREL technical monitor: W. Luft

16. Abstract (Limit: 200 words)

This report describes research on semiconductor and non-semiconductor materials to enhance the performance of multi-band-gap, multijunction, large-area, amorphous-silicon-based alloy modules. The goal is to demonstrate a stabilized module efficiency of 10% for a multijunction panel with an area greater than 900 cm^2 by 1992. Double-junction and triple-junction cells are made on a Ag/ZnO back reflector deposited on stainless steel substrates. An a-SiGe alloy is used for the i-layer in the bottom and the middle cells; the top cell uses an amorphous silicon alloy. After the evaporation of an antireflection coating, silver grids and bus bars are put on the top surface and the panel is encapsulated in an ethylene vinyl acetate (EVA)/Tefzel structure to make a 1-ft^2 monolithic module.

17. Document Analysis

a. Descriptors
high efficiency ; amrophous silicon ; modules ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
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18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
38

20. Price
A03

Document Control Page	1. NREL Report No. NREL/TP-411-4995	2. NTIS Accession No. DE92010599	3. Recipient's Accession No.

4. Title and Subtitle

Research on Stable, High-Efficiency, Amorphous Silicon Multijunction Modules

5. Publication Date
August 1992

6.

7. Author(s)

A. Catalano, M. Bennett, L. Chen, R. D'Aiello, B. Fieselmann, Y. Li, J. Newton, R. Podlesny, L. Yang

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Solarex Thin Film Division
826 Newtown-Yardley Road
Newtown, PA 18940

10. Project/Task/Work Unit No.

PV241101

11. Contract (C) or Grant (G) No.

(C) ZM-0-19033-1

(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered

Technical Report
1 May 1991 - 30 April 1992

14.

15. Supplementary Notes
NREL technical monitor: W. Luft

16. Abstract (Limit: 200 words)

This report describes work to demonstrate a multijunction module with a "stabilized" efficiency (600 h, 50°C, AM1.5) of 10.5%. Triple-junction devices and modules using a-Si:H alloys with carbon and germanium were developed to meet program goals. ZnO was used to provide a high optical transmission front contact. Proof of concept was obtained for several important advances deemed to be important for obtaining high (12.5%) stabilized efficiency. They were (1) stable, high-quality a-SiC:H devices and (2) high-transmission, textured ZnO. Although these developments were not scaled up and included in modules, triple-junction module efficiencies as high as 10.85% were demonstrated. NREL measured 9.62% and 9.00% indoors and outdoors, respectively. The modules are expected to lose no more than 20% of their initial performance.

17. Document Analysis
a. Descriptors
photovoltaics ; solar cells ; high efficiency ; amorphous silicon ; multijunction ; modules

b. Identifiers/Open-Ended Terms

c. UC Categories
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18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
57

20. Price
A04

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-4962	2. NTIS Accession No. DE92010593	3. Recipient's Accession No.
4. Title and Subtitle Recombination and Metastability in Amorphous Silicon and Silicon Germanium Alloys			5. Publication Date July 1992 6.
7. Author(s) M. Silver			8. Performing Organization Rept. No.
9. Performing Organization Name and Address University of North Carolina Chapel Hill, North Carolina 27599-3255			10. Project/Task/Work Unit No. PV241101 11. Contract (C) or Grant (G) No. (C) XG-1-10063-5 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 February 1991 - 31 January 1992 14.

15. Supplementary Notes
NREL technical monitor: B. von Roedern

16. Abstract (Limit: 200 words)

This report describes the first year of a continuing research study to understand how recombination, trapping, and band-mobility modification affecting the electronic properties of amorphous semiconductors can be measured, characterized, and described by an appropriate spectrum of defect states, and how light-induced defects in a-Si:H and native defects in a-SiGe:H affect transport properties in these materials. The objective was to determine how the Staebler-Wronski defects affect the electronic processes in a-Si:H and a-SiGe:H films. To do this, electroluminescence (EL) and forward bias current in p-i-n devices (i-layer thickness > 2 μm) were studied both experimentally and theoretically before and after light soaking. A simple picture was developed to compare forward bias current to the EL signal. The result was unexpected: the product of the final current times the rise time was not constant before and after light soaking as expected from the concept of gain band width, but instead changed radically. The rise time t_r increased by more than one order of magnitude while the final current I_f did not change significantly with light soaking. On the other hand, the $I_f t_r$ product did hold close to a constant when only the applied voltage changed.

17. Document Analysis

a. Descriptors
amorphous silicon ; silicon germanium ; photovoltaics ; solar cells ; recombination ; metastability

b. Identifiers/Open-Ended Terms

c. UC Categories
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National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	20 20. Price A03

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-4938	2. NTIS Accession No. DE92010588	3. Recipient's Accession No.
4. Title and Subtitle Microscopic Origins of Metastable Effects in a-Si:H and Deep Defect Characterization in a-Si,Ge:H Alloys			5. Publication Date July 1992 6.
7. Author(s) J. D. Cohen			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Dept. of Physics and Materials Science Institute University of Oregon Eugene, Oregon			10. Project/Task/Work Unit No. PV231101 11. Contract (C) or Grant (G) No. (C) XG-1-10063-1 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 February 1991 - 31 January 1992 14.

15. Supplementary Notes
NREL technical monitor: B. von Roedern

16. Abstract (Limit: 200 words)

This report describes works to use transient photocapacitance and photocurrent measurements to determine the deep defect distribution and processes in low-band-gap a-Si,Ge:H alloys. Samples for these studies were produced by the photochemical vapor deposition (photo-CVD) growth method and were obtained through a collaboration with researchers at the University of Delaware. This report discusses how a detailed comparison between the photocapacitance and photocurrent spectra can be used to separately examine the majority and minority carrier processes. The results are as follows: (1) The midgap defect densities in the alloy regime near 1.3 eV can be as low as 5×10^{16} cm^{-3} in such photo-CVD samples. (2) There exists a second defect band roughly 0.4 eV below E_C of a similar magnitude to the midgap defect density that exhibits significant lattice relaxation behavior in its electron trapping dynamics. (3) The hole $\mu\tau$ products determined for the lowest defect sample are roughly 5×10^{-10} cm^2/V, comparable with the highest hole $\mu\tau$ products reported in sandwich geometry measurements for alloys in this composition range. (4) The hole $\mu\tau$ is found to be roughly inversely proportional to the midgap defect density for the samples studied. This is consistent with the fact that the effective minority carrier lifetime for such measurements is limited by the deep state trapping time.

17. Document Analysis
a. Descriptors
amorphous silicon ; characterization ; photovoltaics ; solar cells ; defects

b. Identifiers/Open-Ended Terms

c. UC Categories
271

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	28 20. Price A03

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-4852	2. NTIS Accession No. DE92010560	3. Recipient's Accession No.

4. Title and Subtitle

Fundamental Studies of Defect Generation in Amorphous Silicon Alloys Grown by Remote Plasma-Enhanced Chemical-Vapor Deposition (Remote PECVD)

5. Publication Date

April 1992

6.

7. Author(s)

G. Lucovsky, R.J. Nemanich, J. Bernholc, J. Whitten, C. Wang, B. Davidson, M. Williams, D. Lee, C. Bjorkman, Z. Jing

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.

PV221103

11. Contract (C) or Grant (G) No.

(C) XM-9-18141-2

(G)

12. Sponsoring Organization Name and Address

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

13. Type of Report & Period Covered

Technical Report
1 September 1990 - 31 August 1991

14.

15. Supplementary Notes

NREL technical monitor: J. Benner

16. Abstract (Limit: 200 words)

This report describes major research accomplishments during Phase II of this subcontract. (1) We demonstrated that the remote PECVD process can be used to deposit heavily doped n-type and p-type a-Si:H thin films. (2) We optimized conditions for depositing undoped, near-intrinsic and heavily doped thin films of μc-Si by remote PECVD. (3) We extended the remote PECVD process to the deposition of undoped and doped a-Si,C:H and μc-Si,C alloy films. (4) We analyzed transport data for the dark conductivity in undoped and doped a-Si:H, a-Si,C:H, μc-Si and μc-Si,C films. (5) We studied the properties of doped a-Si:H and μc-Si in MOS capacitors using ~10 Ω-cm p-type crystalline substrates and thermally grown SiO_2 dielectric layers. (6) We collaborated with a group at RWTH in Aachen, Germany, and studied the contributions of process-induced defect states to the recombination of photogenerated electron pairs. (7) We applied a tight-binding model to Si-Bethe lattice structures to investigate the effects of bond angle, and dihedral angle disorder. (8) We used ab initio and empirical calculations to study non-random bonding arrangements in a-Si,O:H and doped a-Si:H films.

17. Document Analysis

a. Descriptors

amorphous silicon ; alloys ; PECVD deposition ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories

271

18. Availability Statement

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages

48

20. Price

A03

Form No. 0069E (6-30-87)

Polycrystalline Thin Films

Document Control Page	1. NREL Report No. NREL/TP-413-5581	2. NTIS Accession No. DE93010037	3. Recipient's Accession No.

4. Title and Subtitle
Development of Large-Area Monolithically Integrated Silicon-Film Photovoltaic Modules

5. Publication Date
June 1993

6.

7. Author(s)
J.A. Rand, J.E. Cotter, A.E. Ingram, T.R. Ruffins, K.P. Shreve, R.B. Hall, A.M. Barnett

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
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10. Project/Task/Work Unit No.
PV331101

11. Contract (C) or Grant (G) No.
(C) ZR-1-11064-1
(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered
Technical Report
16 November 1992 - 31 December 1993

14.

15. Supplementary Notes
NREL technical monitor: H. S. Ullal

16. Abstract (Limit: 200 words)
This report describes work to develop Silicon-Film™ Product III into a low-cost, stable solar cell for large-scale terrestrial power applications. The Product III structure is a thin (<100-μm) polycrystalline layer of silicon on a durable, insulating, ceramic substrate. The insulating substrate allows the silicon layer to be isolated and metallized to form a monolithically interconnected array of solar cells. High efficiency is achievable with the use of light trapping and a passivated back surface. The long-term goal for the product is a 1200-cm^2, 18%-efficient, monolithic array. The short-term objectives are to improve material quality and to fabricate 100 cm^2 monolithically interconnected solar cell arrays. Low minority-carrier diffusion length in the silicon film and series resistance in the interconnected device structure are presently limiting device performance. Material quality is continually improving through reduced impurity contamination. Metallization schemes, such as a solder-dipped interconnection process, have been developed that will allow low-cost production processing and minimize R_s effects. Test data for a nine-cell device (16 cm^2) indicated a V_{oc} of 3.72 V. These first-reported monolithically interconnected multicrystalline silicon-on-ceramic devices show low shunt conductance (<0.1 mA/cm^2) due to limited conduction through the ceramic and no process-related metallization shunts.

17. Document Analysis
a. Descriptors
large-area ; silicon film ; modules ; photovoltaics ; solar cells
b. Identifiers/Open-Ended Terms
c. UC Categories
273

18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
23

20. Price
A03

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-413-5406	2. NTIS Accession No. DE93000085	3. Recipient's Accession No.
4. Title and Subtitle Innovative Sputtering Techniques for CIS and CdTe Submodule Fabrication			5. Publication Date March 1993 6.
7. Author(s) J.M. Armstrong, M.S. Misra, B. Lanning			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Martin Marietta P.O. Box 179 Denver, CO 80201			10. Project/Task/Work Unit No. PV331101 11. Contract (C) or Grant (G) No. (C) YG-1-11070-1 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 September 1991 - 31 August 1992 14.
15. Supplementary Notes NREL technical monitor: H.S. Ullal			

16. Abstract (Limit: 200 words)

This report describes work done during Phase 1 of the subject subcontract. The subcontract was designed to study innovative deposition techniques, such as the rotating cylindrical magnetron sputtering system and electrodeposition for large-area, low-cost copper indium diselenide (CIS) and cadmium telluride (CdTe) devices. A key issue for photovoltaics (PV) in terrestrial and future space applications is producibility, particularly for applications using a large quantity of PV. Among the concerns for fabrication of polycrystalline thin-film PV, such as CIS and CdTe, are production volume, cost, and minimization of waste. Both rotating cylindrical magnetron (C-Mag™) sputtering and electrodeposition have tremendous potential for the fabrication of polycrystalline thin-film PV due to scaleability, efficient utilization of source materials, and inherently higher deposition rates. In the case of sputtering, the unique geometry of the C-Mag™ facilitates innovative cosputtering and reactive sputtering that could lead to greater throughput, reduced health and safety risks, and, ultimately, lower fabrication cost. Electrodeposited films appear to be adherent and comparable with low-cost fabrication techniques. Phase 1 involved the initial film and device fabrication using the two techniques mentioned herein. Devices were tested by both internal facilities, as well as NREL and ISET.

17. Document Analysis

a. Descriptors

copper indium diselenide ; cadmium telluride ; submodule ; sputtering ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories

273

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	63 20. Price A04

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-413-5334	2. NTIS Accession No. DE93000078	3. Recipient's Accession No.

4. Title and Subtitle

Non-H_2Se, Ultra-Thin CIS Devices

5. Publication Date
February1993

6.

7. Author(s)
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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.
PV331101

11. Contract (C) or Grant (G) No.

(C) XG-2-12051-1

(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered

Technical Report
10 March 1992 - 9 November 1992

14.

15. Supplementary Notes
NREL technical monitor: H. S. Ullal

16. Abstract (Limit: 200 words)

This report describes work done during Phase I of a 3-phase, cost-shared contract. The objective of the subcontract is to demonstrate 12% total-area efficiency copper indium diselenide (CIS) solar cells and 50-W CIS modules averaging at least 8 W/ft^2 in the third year. At the end of Phase I, EPV delivered to NREL a 1.1 cm^2 CIS cell with an active area efficiency of 10.5%. The correspondong total-area efficiency is 7.9%.

17. Document Analysis

a. Descriptors
copper indium diselenide ; thin devices ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
273

18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
71

20. Price
A04

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-413-5332	2. NTIS Accession No. DE93000077	3. Recipient's Accession No.

4. Title and Subtitle

Research on High Efficiency, Large-Area $CuInSe_2$-Based Thin Film Modules

5. Publication Date
February 1993

6.

7. Author(s)
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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.
PV331101

11. Contract (C) or Grant (G) No.

(C) ZN-1-19019-5

(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered

Technical Report
1 May 1991 - 30 April 1992

14.

15. Supplementary Notes
NREL technical monitor: H. S. Ullal

16. Abstract (Limit: 200 words)

This report describes a 3-year, 3-phase cost-shared contract to demonstrate 12.5% aperture-efficient, large-area (3900-cm^2) encapsulated thin-film $CuInSe_2$ modules. During Phase 1, Siemens Solar Industries (SSI) demonstrated a new world record of 37.7 W and 9.7% aperture efficiency for a 3883-cm^2 (126.9 x 30.6 cm) encapsulated $CuInSe_2$ module, which was verified at NREL. Unencapsulated $CuInSe_2$ module plate performance achieved 40.8 W and 10.5% aperture efficiency. Excellent measurement agreement was verified between SSI and NREL.

17. Document Analysis
a. Descriptors
high efficiency ; thin film ; modules ; copper indium diselenide ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
273

18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
57

20. Price
A04

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-5190	2. NTIS Accession No. DE93000045	3. Recipient's Accession No.

4. Title and Subtitle

Role of Polycrystallinity in CdTe and $CuInSe_2$ Photovoltaic Cells

5. Publication Date
November 1992

6.

7. Author(s)
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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.
PV241101

11. Contract (C) or Grant (G) No.

(C) XC-0-10046-1

(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered

Technical Report
1 April 1991 - 31 March 1992

14.

15. Supplementary Notes
NREL technical monitor: B. von Roedern

16. Abstract (Limit: 200 words)

This report describes work by Colorado State University (CSU) to perform comparative quantitative analyses of individual loss mechanisms for a large number of CdTe and $CuInSe_2$ solar cells from a variety of laboratories. The limiting role of polycrystallinity in thin-film solar cells has been reduced somewhat during the past year, and efficiencies of both CdTe and $CuInSe_2$ cells are approaching 15%. A quantitative separation of loss mechanisms shows that individual losses, with the exception of forward recombination current, can be made comparable to their single-crystal counterparts. One general manifestation of the extraneous trapping states is that the voltage of all polycrystalline thin-film cells drifts upward by 10-50 mV following the onset of illumination.

17. Document Analysis

a. Descriptors
cadmium telluride ; copper indium diselenide ; polycrystalline ; thin films ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
273

18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
34

20. Price
A03

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-5094	2. NTIS Accession No. DE93000022	3. Recipient's Accession No.
4. Title and Subtitle Polycrystalline Thin Film Materials and Devices			5. Publication Date October 1992 6.
7. Author(s) B.N. Baron, R.W. Birkmire, J.E. Phillips, W.N. Shafarman, S.S. Hegedus, B.E. McCandless			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Institute of Energy Conversion University of Delaware Newark, Delaware 19716			10. Project/Task/Work Unit No. PV231101 11. Contract (C) or Grant (G) No. (C) XN-0-10023-1 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 16 January 1991 - 15 January 1992 14.

15. Supplementary Notes
NREL technical monitor: B. von Roedern

16. Abstract (Limit: 200 words)

This report describes research to obtain an understanding of the materials processing, properties, and performance of polycrystalline thin-film $CuInSe_2$ and CdTe solar cells. Such an understanding is needed to achieve the goals for efficiency, reliability, and cost for flat-plate thin-film photovoltaic (PV) systems as defined in the national PV program, and to support the development of a competitive U.S. PV industry through collaboration with engineers and scientists at other laboratories. The report presents results and conclusions of Phase II of a multiyear research program on polycrystalline thin-film heterojunction solar cells. The research consisted of investigating the relationships between processing, materials properties, and device performance. The relationship was quantified by device modeling and analysis. The analysis of thin-film polycrystalline heterojunction solar cells explains how minority carrier recombination at the metallurgical interface and at grain boundaries can be greatly reduced by the proper doping of the window and absorber layers. Additional analysis and measurements show that the present solar cells are limited by the magnitude of the diode current that appears to be caused by recombination in the space-charge region.

17. Document Analysis
a. Descriptors
polycrystalline ; thin films ; electronic materials ; electronic devices ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
273

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	113 20. Price A06

Document Control Page	1. NREL Report No. NREL/TP-413-5092	2. NTIS Accession No. DE92016444	3. Recipient's Accession No.

4. Title and Subtitle

Development of a Computer Model for Polycrystalline Thin-Film $CuInSe_2$ and CdTe Solar Cells

5. Publication Date
September 1992

6.

7. Author(s)
J.L. Gray, R.J. Schwartz, Y.J. Lee

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.
PV231101

11. Contract (C) or Grant (G) No.

(C) XN-0-10013-1

(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered

Technical Report
1 January 1991 - 31 December 1991

14.

15. Supplementary Notes
NREL technical monitor: H.S. Ullal

16. Abstract (Limit: 200 words)

This report describes work to develop an accurate numerical model for $CuInSe_2$ (CIS) and CdTe-based solar cells capable of running on a personal computer. Such a model will aid researchers in designing and analyzing CIS- and CdTe-based solar cells. ADEPT (A Device Emulation Program and Tool) was used as the basis for this model. An additional objective of this research was to use the models developed to analyze the performance of existing and proposed CIS- and CdTe-based solar cells. The development of accurate numerical models for CIS- and CdTe-based solar cells required the compilation of cell performance data (for use in model verification) and the compilation of measurements of material parameters. The development of the numerical models involved implementing the various physical models appropriate to CIS and CdTe, as well as some common window materials. A version of the model capable of running on an IBM-compatible personal computer was developed (primary code development is on a SUN workstation). A user-friendly interface with pop-up menus is continuing to be developed for release with the IBM-compatible model.

17. Document Analysis

a. Descriptors
computer model ; thin films ; copper indium diselenide ; cadmium telluride ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
273

18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
53

20. Price
A04

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-5014	2. NTIS Accession No. DE92016440	3. Recipient's Accession No.

4. Title and Subtitle Novel Thin-Film $CuInSe_2$ Fabrication	5. Publication Date September 1992 6.
7. Author(s) A. Gabor, A. Hermann	8. Performing Organization Rept. No.
9. Performing Organization Name and Address University of Colorado Office of Contracts and Grants 206 Armory, Campus Box 19 Boulder, CO 80309-0019	10. Project/Task/Work Unit No. PV231101 11. Contract (C) or Grant (G) No. (C) XC-0-10012-1 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393	13. Type of Report & Period Covered Technical Report 1 May 1991 - 30 April 1992 14.

15. Supplementary Notes
NREL technical monitor: B. von Roedern

16. Abstract (Limit: 200 words)

This report describes work to form thin films of $CuInSe_2$ (CIS) by annealing precursor films containing Cu, In, and Se in a rapid thermal processor. This involves two steps: (1) a precursor containing Cu, In, and Se is deposited on unheated substrates such that CIS does not form during this deposition step, and (2) the precursor is annealed in a rapid thermal processor to crystallize the CIS. Advantages of this process are that (1) no H_2Se is used; (2) concentration gradients can potentially be built into the film due to the rapid anneal; and (3) the precursor can potentially be deposited using scalable methods such as sputtering, solution growth, and electrodeposition. The deposition method used was three-source, elemental physical vapor deposition. At room temerature, such a method was considered to be a flexible way to deposit a precursor that would be fairly typical of precursors deposited by more scalable techniques. Precursors were made both by the stacked elemental layer approach, where one element at a time was evaporated, as well as by a co-evaporation method. Adhesion problems limited device performance, and the co-evaporated precursors displayed unintended segregation of Cu and In in a direction normal to the film plane. The best cell efficiency was 3.5%.

17. Document Analysis
a. Descriptors
thin films ; $CuInSe_2$; photovoltaics ; solar cells ; fabrication

b. Identifiers/Open-Ended Terms

c. UC Categories
273

18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	19. No. of Pages 19 20. Price A03

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-413-5012	2. NTIS Accession No. DE92016439	3. Recipient's Accession No.

4. Title and Subtitle
Research on Polycrystalline Thin-Film $CuGaInSe_2$ Solar Cells

5. Publication Date
November 1992

6.

7. Author(s)
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8. Performing Organization Rept. No.

9. Performing Organization Name and Address
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10. Project/Task/Work Unit No.
PV231101

11. Contract (C) or Grant (G) No.
(C) ZH-1-19019-6
(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered
Technical Report
3 May 1991 - 2 May 1992

14.

15. Supplementary Notes
NREL technical monitor: H.S. Ullal

16. Abstract (Limit: 200 words)
This report describes research to fabricate high-efficiency $CdZnS/CuInGaSe_2$ (CIGS) thin-film solar cells, and to develop improved transparent conductor window layers such as ZnO. A specific technical milestone was the demonstration of an air mass (AM) 1.5 global, 13% efficient, 1-cm^2-total-area CIGS thin-film solar cell. Our activities focused on three areas. First, a CIGS deposition system was modified to double its substrate capacity, thus increasing throughput, which is critical to speeding the process development by providing multiple substrates from the same CIGS run. Second, new tooling was developed to enable an investigation of a modified aqueous CdZnS process. The goal was to improve the yield of this critical step in the device fabrication process. Third, our ZnO sputtering system was upgraded to improve its reliability, and the sputtering parameters were further optimized to improve its properties as a transparent conducting oxide. The characterization of the new CIGS deposition system substrate fixturing was completed, and we produced good thermal uniformity and adequately high temperatures for device-quality CIGS deposition. Both the CIGS and ZnO deposition processes were refined to yield a $ZnO/Cd_{0.82}Zn_{0.18}S/CuIn_{0.80}Ga_{0.20}Se_2$ cell that was verified at NREL under standard testing conditions at 13.1% efficiency with V_{oc} = 0.581 V, J_{sc} = 34.8 mA/cm^2, FF = 0.728, and a cell area of 0.979 cm^2.

17. Document Analysis
a. Descriptors
polycrystalline ; thin films ; photovoltaics ; solar cells ; copper ; gallium ; Indium ; selenide

b. Identifiers/Open-Ended Terms

c. UC Categories
273

18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
23

20. Price
A03

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-413-5011	2. NTIS Accession No. DE92016445	3. Recipient's Accession No.

4. Title and Subtitle

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

5. Publication Date

September 1992

6.

7. Author(s)

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.

PV231101

11. Contract (C) or Grant (G) No.

(C) ZR-1-11059-1

(G)

12. Sponsoring Organization Name and Address

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

13. Type of Report & Period Covered

Technical Report
10 May 1991 - 9 May 1992

14.

15. Supplementary Notes

NREL technical monitor: H.S. Ullal

16. Abstract (Limit: 200 words)

This report describes work to produce 60 cm x 120 cm solar power modules based on thin-film CdTe. The method of choice for semiconductor deposition is condensation from high-temperature vapors. Early work focused on close-spaced sublimation and chemical vapor deposition using elemental sources. Small-area conversion efficiency was confirmed by NREL at 9.3% on a 0.22-cm^2 device (V_{oc} = 825 mV, J_{sc} = 18.2 mA/cm^2, and FF = 0.62) deposited on a 100-cm^2 substrate. On 8 cells, (64 cm^2 submodules), the best result to date is 7.3% (V_{oc} = 5.9 V, I_{sc} = 130 mA, and FF = 0.61). CdS, CdTe, and ZnTe films were deposited onto 60 cm x 120 cm substrates; single cells produced from this material exceeded 8% efficiency, and 64-cm^2 submodules exceeded 5%. Module efficiency is limited by mechanical defects (mostly shunts) associated with processing after the semiconductor layers are deposited. The present best result is 1.4% total-area efficiency with a power output of 10 W. Further optimization should improve the performance of the modules.

17. Document Analysis

a. Descriptors

thin films ; modules ; cadmium telluride ; photovoltaics ; solar cells ; large area

b. Identifiers/Open-Ended Terms

c. UC Categories

273

18. Availability Statement

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages

21

20. Price

A03

Document Control Page	1. NREL Report No. NREL/TP-413-5010	2. NTIS Accession No. DE92016438	3. Recipient's Accession No.
4. Title and Subtitle Low-Cost $CuInSe_2$ Submodule Development			5. Publication Date October 1992 6.
7. Author(s) B.M. Basol, V.K. Kapur, A. Halani, C. Leidholm			8. Performing Organization Rept. No.
9. Performing Organization Name and Address International Solar Electric Technology 8635 Aviation Blvd. Inglewood, CA 90301			10. Project/Task/Work Unit No. PV231101 11. Contract (C) or Grant (G) No. (C) ZN-0-19019-2 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 9 July 1990 - 31 January 1992 14.

15. Supplementary Notes
NREL technical monitor: H.S. Ullal

16. Abstract (Limit: 200 words)

This report describes work to develop and demonstrate the processing steps necessary to fabricate high-efficiency $CuInSe_2$ solar cells and submodules by the two-stage technique (also called the selenization method). We optimized the processing parameters of this method and demonstrated $CuInSe_2$/CdS/ZnO devices with 1–4 cm^2 areas and up to 12.4% active-area efficiency. We also developed a novel approach for preparing Cu/In precursors that improved the stoichiometric and morphological uniformity in these films. We developed processing steps and tooling for handling up to 1-ft^2 substrates and, as a result, demonstrated our first monolithically integrated submodule of 1 ft^2 area.

17. Document Analysis
a. Descriptors
submodules ; copper indium diselenide ; photovoltaics ; solar cells ; thin films ; modules ; low cost

b. Identifiers/Open-Ended Terms

c. UC Categories
273

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	39 20. Price A03

Document Control Page	1. NREL Report No. NREL/TP-451-4999	2. NTIS Accession No. DE92016403	3. Recipient's Accession No.

4. Title and Subtitle

High-Efficiency Cadmium Telluride and Zinc Telluride Based Thin-Film Solar Cells

5. Publication Date

October 1992

6.

7. Author(s)

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.

PV231101

11. Contract (C) or Grant (G) No.

(C) XL-7-06031-1

(G)

12. Sponsoring Organization Name and Address

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

13. Type of Report & Period Covered

Technical Report
1 March 1990 - 28 February 1992

14.

15. Supplementary Notes

NREL technical monitor: B. von Roedern

16. Abstract (Limit: 200 words)

This report describes work to improve the basic understanding of CdTe and ZnTe alloys by growing and characterizing these films along with cell fabrication. The major objective was to develop wide-band-gap (1.6-1.8 eV) material for the top cell, along with compatible window material and transparent ohmic contacts, so that a cascade cell design can be optimized. Front-wall solar cells were fabricated with a glass/SnO_2/CdS window, where the CdS film is thin to maximize transmission and current. Wide-band-gap absorber films (E_g = 1.75 eV) were grown by molecular beam epitaxy (MBE) and metal-organic chemical vapor deposition (MOCVD) techniques, which provided excellent control for tailoring the film composition and properties. CdZnTe films were grown by MBE, and CdTe films were grown by both MBE and MOCVD. All the as-grown films were characterized by several techniques (surface photovoltage spectroscopy, Auger electron spectroscopy [AES], and x-ray photoelectron spectroscopy [XPS]) for composition, bulk uniformity, thickness, and film and interface quality. Front-wall-type solar cells were fabricated in collaboration with Ametek Materials Research Laboratory using CdTe and CdZnTe polycrystalline absorber films. The effects of processing on ternary films were studied by AES and XPS coupled with capacitance voltage and current voltage measurements as a function of temperature. Bias-dependent spectral response and electrical measurements were used to test some models in order to identify and quantify dominant loss mechanisms.

17. Document Analysis

a. Descriptors

high efficiency ; cadmium telluride ; zinc telluride ; thin films ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Term

c. UC Categories

273

18. Availability Statement

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages

109

20. Price

A06

Document Control Page	1. NREL Report No. NREL/TP-413-4996	2. NTIS Accession No. DE92010600	3. Recipient's Accession No.

4. Title and Subtitle

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

5. Publication Date

July 1992

6.

7. Author(s)

J.A. Rand, C. Bacon, J.E. Cotter, T.H. Lampros, A.E. Ingram, T.R. Ruffins, R.B. Hall, A.M. Barnett

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.

PV231101

11. Contract (C) or Grant (G) No.

(C) ZR-1-11064-1

(G)

12. Sponsoring Organization Name and Address

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

13. Type of Report & Period Covered

Technical Report
1 May 1991 - 15 November 1991

14.

15. Supplementary Notes

NREL technical monitor: H. S. Ullal

16. Abstract (Limit: 200 words)

This report describes work to develop Silicon-Film Product III into a low-cost, stable device for large-scale terrestrial power applications. The Product III structure is a thin (< 100 μm) polycrystalline silicon layer on a non-conductive supporting ceramic substrate. The presence of the substrate allows cells to be isolated and interconnected monolithically in various series/parellel configurations. The long-term goal for the product is efficiencies over 18% on areas greater than 1200 cm^2. The high efficiency is made possible through the benefits of using polycrystalline thin silicon incorporated into a light-trapping structure with a passivated back surface. Short-term goals focused on the development of large-area ceramics, a monolithic interconnection process, and 100 cm^2 solar cells. Critical elements of the monolithically integrated device were developed, and an insulating ceramic substrate was developed and tested. A monolithic interconnection process was developed that will isolate and interconnect individual cells on the ceramic surface. Production-based, low-cost process steps were used, and the process was verified using free-standing silicon wafers to achieve an open-circuit voltage (V_{oc}) of 8.25 V over a 17-element string. The overall efficiency of the silicon-film materials was limited to 6% by impurities. Improved processing and feedstock materials are under investigation.

17. Document Analysis

a. Descriptors

large area ; silicon films ; modules ; photovoltaics ; solar cells ; thin films

b. Identifiers/Open-Ended Terms

c. UC Categories

273

18. Availability Statement

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages

28

20. Price

A03

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-413-4906	2. NTIS Accession No. DE92010584	3. Recipient's Accession No.
4. Title and Subtitle Research on Polycrystalline Thin Film Submodules Based on $CuInSe_2$ Materials			5. Publication Date May 1992 6.
7. Author(s) A. Catalano, R. Arya, L. Carr, B. Fieselmann, T. Lommasson, R. Podlesny, L. Russell, S. Skibo, A. Rothwarf, R. Birkmire			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Solarex Thin Film Division 826 Newtown-Yardley Road Newtown, PA 18940			10. Project/Task/Work Unit No. PV231101 11. Contract (C) or Grant (G) No. (C) ZN-1-19019-4 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 11 November 1990 - 31 October 1991 14.

15. Supplementary Notes
NREL technical monitor: H.S. Ullal

16. Abstract (Limit: 200 words)

This report describes progress during the first year of a three-year research program to develop 12%-efficient $CuInSe_2$ (CIS) submodules with area greater than 900 cm^2. To meet this objective, the program was divided into five tasks: (1) windows, contacts, substrates; (2) absorber material; (3) device structure; (4) submodule design and encapsulation; and (5) process optimization. In the first year of the program, work was concentrated on the first three tasks with an objective to demonstrate a 9%-efficient CIS solar cell.

17. Document Analysis
a. Descriptors
polycrystalline thin films ; submodules ; $CuInSe_2$; photovoltaics ; solar cells ; efficiency

b. Identifiers/Open-Ended Terms

c. UC Categories
273

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	76 20. Price A05

Crystalline Materials and Advanced Concepts

Document Control Page	1. NREL Report No. NREL/TP-451-5414	2. NTIS Accession No. DE93000098	3. Recipient's Accession No.
4. Title and Subtitle Growth and Development of GaInAsP for Use in High-Efficiency Solar Cells			5. Publication Date April 1993 6.
7. Author(s) Paul R. Sharps			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Research Triangle Institute P.O. Box 12194 Research Triangle Park, NC 27709			10. Project/Task/Work Unit No. PV321101 11. Contract (C) or Grant (G) No. (C) XM-0-19142-3 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 July 1991 - 30 June 1992 14.

15. Supplementary Notes
NREL technical monitor: J. Benner

16. Abstract (Limit: 200 words)

This report describes work done during Phase II of the subcontract. Goals for Phase II include the following: (1) Optimize the GaInAsP cell on GaAs and demonstrate a 500-sun at air mass (AM) 1.5 efficiency of >23%. (2) Develop a window layer, including the evaluation of AlGaAs, GaInP, AlGaAsP, AlGaInP, and GaP. (3) Develop a front-surface contact, with a grid designed for 500-sun concentration, and a goal of a contact resistivity of ~10^5 ohm-cm^2. (4) Grow GaInAsP cells on Ge, with a goal of a 1-sun (AM 1.5) efficiency of >15%. Accomplishments reported herein include (1) the fabrication of p-on-n and n-on-p GaInAsP cells on GaAs, with the n-on-p cell demonstrating a 10-sun (AM 1.5) active-area efficiency of 23.4% as measured at NREL; (2) the evaluation of $Al_xGa_{(1-x)}As$, $GaInP_2$, and $AlInP_2$ window layers; and (3) the fabrication of GaInAsP cells on Ge, with the demonstration of a p-on-n GaInAsP cell grown on Ge with a 1-sun (AM 1.5) active-area efficiency of 14.4%.

17. Document Analysis
a. Descriptors
high efficiency ; gallium indium arsenide ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
273

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	24 20. Price A03

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-5355	2. NTIS Accession No. DE93000097	3. Recipient's Accession No.

4. Title and Subtitle

New III-V Cell Design Approaches for Very High Efficiency

5. Publication Date

April 1993

6.

7. Author(s)

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.

PV321101

11. Contract (C) or Grant (G) No.

(C) XM-0-19142-1

(G)

12. Sponsoring Organization Name and Address

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

13. Type of Report & Period Covered

Technical Report
1 August 1991 - 31 July 1992

14.

15. Supplementary Notes

NREL technical monitor: J. Benner

16. Abstract (Limit: 200 words)

This report describes research to examine new solar cell design approaches for achieving very high conversion efficiencies. The program consists of two elements. The first centers on exploring new thin-film approaches specifically designed for III-V semiconductors. Substantial efficiency gains may be possible by employing light trapping techniques to confine the incident photons, as well as the photons emitted by radiative recombination. The thin-film approach is a promising route for achieving substantial performance improvements in the already high-efficiency, single-junction, III-V cell. The second element of the research involves exploring design approaches for achieving high conversion efficiencies without requiring extremely high-quality material. This work has applications to multiple-junction cells, for which the selection of a component cell often involves a compromise between optimum band gap and optimum material quality. It could also be a benefit in a manufacturing environment by making the cell's efficiency less dependent on material quality.

17. Document Analysis

a. Descriptors

photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories

270

18. Availability Statement

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages

124

20. Price

A06

Document Control Page	1. NREL Report No. NREL/TP-451-5354	2. NTIS Accession No. DE93010049	3. Recipient's Accession No.

4. Title and Subtitle

Gallium-Arsenide-Based Ternary Compounds and Multi-Band-Gap Solar Cell Research

5. Publication Date
July 1993

6.

7. Author(s)
Stanley Vernon

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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Bedford, MA 01730-2396

10. Project/Task/Work Unit No.
PV321101

11. Contract (C) or Grant (G) No.

(C) XL-8-18063-1

(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered

Technical Report
1 April 1988 - 31 March 1990

14.

15. Supplementary Notes
NREL technical monitor: J. Benner

16. Abstract (Limit: 200 words)

This report describes work to achieve a high-efficiency, low-cost solar cell. The basic approach to the problem is centered upon the heteroepitaxial growth of a III-V compound material onto a single-crystal silicon wafer. The growth technique employed throughout this work is metal-organic chemical vapor deposition. The silicon wafer may serve as a mechanical substrate and ohmic contact for a single-junction device, or it may contain a p-n junction of its own and form the bottom cell of a two-junction tandem solar cell structure. The III-V material for the single-junction case is GaAs, and for the two-junction case it is either GaAlAs or GaAsP, either material having the proper composition to yield a band gap of approximately 1.7 eV. Results achieved in this contract include (1) a 17.6%-efficient GaAs-on-Si solar cell; (2) an 18.5%-efficient GaAs-on-Si concentrator solar cell at 400 suns; (3) a 24.8%-efficient GaAs-on-GaAs solar cell; (4) a 28.7%-efficient GaAs-on-GaAs concentrator solar cell at 200 suns; (5) the measurement of the effects of dislocation density and emitter doping on GaAs cells; and (6) improvements in the growth process to achieve reproducible thin AlGaAs window layers with low recombination velocities and environmental stability.

17. Document Analysis

a. Descriptors
gallium arsenide ; ternary compounds ; multiple band gaps ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
272

18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
171

20. Price
A08

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-5353	2. NTIS Accession No. DE93000096	3. Recipient's Accession No.
4. Title and Subtitle Low-Cost, High-Efficiency Solar Cells Utilizing GaAs-on-Si Technology			5. Publication Date April 1993 6.
7. Author(s) S.M. Vernon			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Spire Corporation One Patriots Park Bedford, MA 01730-2396			10. Project/Task/Work Unit No. PV321101 11. Contract (C) or Grant (G) No. (C) XM-0-19142-7 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 August 1991 - 31 July 1992 14.

15. Supplementary Notes
NREL technical monitor: J. Benner

16. Abstract (Limit: 200 words)

This report describes work to develop technology to deposit GaAs on Si using a nucleation layer of atomic-layer-epitaxy-grown GaAs or AlAs on Si. This ensures two-dimensional nucleation and should lead to fewer defects in the final GaAs layer. As an alternative, we also developed technology for depositing GaAs on sawtooth-patterned Si. Preliminary studies showed that this material can have a very low defect density, $\approx 1 \times 10^5$ cm^{-2}, as opposed to our conventionally grown GaAs on Si, which has a typical defect density of over 1×10^7 cm^{-2}. Using these two new methods of GaAs-on-Si material growth, we made solar cells that are expected to show higher efficiencies than those of previous cells.

17. Document Analysis
a. Descriptors
low-cost ; high efficiency ; gallium arsenide ; silicon ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
272

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	31 20. Price A03

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-5333	2. NTIS Accession No. DE93000084	3. Recipient's Accession No.
4. Title and Subtitle Gallium-Arsenide-Based Ternary Compounds and Multi-Band-Gap Solar Cell Research			5. Publication Date February 1993 6.
7. Author(s) Stanley Vernon			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Spire Corporation One Patriots Park Bedford, MA 01730-2396			10. Project/Task/Work Unit No. PV321103 11. Contract (C) or Grant (G) No. (C) XL-8-18063-1 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 15 April 1988 - 14 June 1990 14.

15. Supplementary Notes
NREL technical monitor: J. Benner

16. Abstract (Limit: 200 words)

The aim of this contract is the achievement of a high-efficiency, low-cost solar cell. The basic approach to the problem is centered on the heteroepitaxial growth of a III-V compound material onto a single-crystal silicon wafer. The growth technique employed throughout this work is metal-organic chemical vapor deposition. The silicon wafer may serve as a mechanical substrate and ohmic contact for a single-junction device, or may contain a p-n junction of its own and form the bottom cell of a two-junction tandem structure. The III-V material for the single-junction case is GaAs, and for the two-junction case is either GaAlAs or GaAsP; either material has the proper composition to yield a band gap of approximately 1.7 eV. Results achieved in this contract include the following: (1) a 17.6%-efficient GaAs-on-Si solar cell; (2) an 18.5%-efficient GaAs-on-Si concentrator solar cell at 400 suns; (3) a 24.8%-efficient GaAs-on-GaAs solar cell; (4) a 28.7%-efficient GaAs-on-GaAs concentrator solar cell at 200 suns; (5) measurements of the effects of dislocation density and emitter doping on GaAs cells; and (6) improvements in the growth process to achieve reproducible thin AlGaAs window layers with low recombination velocities and environmental stability.

17. Document Analysis
a. Descriptors
gallium arsenide ; ternary compounds ; multiple band gaps ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
272

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	170 20. Price A07

Document Control Page	1. NREL Report No. NREL/TP-411-5289	2. NTIS Accession No. DE93000073	3. Recipient's Accession No.
4. Title and Subtitle An Inverted AlGaAs/GaAs Patterned-Ge Tunnel Junction Cascade Concentrator Solar Cell			5. Publication Date January 1993 6.
7. Author(s) R. Venkatasubramanian			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Research Triangle Institute P.O. Box 12194 Research Triangle Park, NC 27709-2194			10. Project/Task/Work Unit No. PV221104 11. Contract (C) or Grant (G) No. (C) XM-0-18110-2 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 January 1991 - 31 August 1992 14.

15. Supplementary Notes
NREL technical monitor: T.S. Basso

16. Abstract (Limit: 200 words)

This report describes work to develop inverted-grown $Al_{0.34}Ga_{0.66}As/GaAs$ cascades. Several significant developments are reported on as follows: (1) The AM1.5 1-sun total-area efficiency of the top $Al_{0.34}Ga_{0.66}As$ cell for the cascade was improved from 11.3% to 13.2% (NREL measurement [total-area]). (2) The "cycled" organometallic vapor phase epitaxy growth (OMVPE) was studied in detail utilizing a combination of characterization techniques including Hall-data, photoluminescence, and secondary ion mass spectroscopy. (3) A technique called eutectic-metal-bonding (EMB) was developed by strain-free mounting of thin GaAs-AlGaAs films (based on lattice-matched growth on Ge substrates and selective plasma etching of Ge substrates) onto Si carrier substrates. Minority-carrier lifetime in an EMB GaAs double-heterostructure was measured as high as 103 nsec, the highest lifetime report for a freestanding GaAs thin film. (4) A thin-film, inverted-grown GaAs cell with a 1-sun AM1.5 active-area efficiency of 20.3% was obtained. This cell was eutectic-metal-bonded onto Si. (5) A thin-film, inverted-grown, $Al_{0.34}Ga_{0.66}As/GaAs$ cascade with AM1.5 efficiency of 19.9% and 21% at 1-sun and 7-suns, respectively, was obtained. This represents an important milestone in the development of an AlGaAs/GaAs cascade by OMVPE utilizing a tunnel interconnect and demonstrates a proof-of-concept for the inverted-growth approach.

17. Document Analysis
a. Descriptors
concentrator ; tunnel junction ; gallium arsenide ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
275

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	76 20. Price A05

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-410-4960	2. NTIS Accession No. DE92010592	3. Recipient's Accession No.

4. Title and Subtitle

New Concepts for High Efficiency Energy Conversion: The Avalanche Heterostructure and Superlattice Solar Cells

5. Publication Date

June 1992

6.

7. Author(s)

C. J. Summers, A. Rohatgi, A. Torabi, H. M. Harris

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Physical Sciences Laboratory
Georgia Tech Research Institute
Atlanta, Georgia 30332

10. Project/Task/Work Unit No.

PV221104

11. Contract (C) or Grant (G) No.

(C) XL-7-06074-1

(G)

12. Sponsoring Organization Name and Address

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

13. Type of Report & Period Covered

Technical Report
1 June 1987 - 31 January 1990

14.

15. Supplementary Notes

NREL technical monitor: T. S. Basso

16. Abstract (Limit: 200 words)

This report describes investigation into the theory and technology of a novel heterojunction or superlattice, single-junction solar cell, which injects electrons across the heterointerface to produce highly efficient impact ionization of carriers in the low-band-gap side of the junction, thereby conserving their total energy. Also, the superlattice structure has the advantage of relaxing the need for perfect lattice matching at the p-n interface and will inhibit the cross diffusion of dopant atoms that typically occurs in heavy doping. This structure avoids the use of tunnel junctions that make it very difficult to achieve the predicted efficiencies in cascade cells, thus making it possible to obtain energy efficiencies that are competitive with those predicted for cascade solar cells with reduced complexity and cost. This cell structure could also be incorporated into other solar cell structures designed for wider spectral coverage.

17. Document Analysis

a. Descriptors

high efficiency ; heterostructure ; superlattice ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories

270

18. Availability Statement

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages

118

20. Price

A06

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-410-4959	2. NTIS Accession No. DE92010591	3. Recipient's Accession No.

4. Title and Subtitle	5. Publication Date
Novel Ways of Depositing ZnTe Films by a Solution Growth Technique	June 1992
	6.
7. Author(s)	8. Performing Organization Rept. No.
R. W. Birkmire, B. E. McCandless, T. A. Yokimcus, A. Mondal	
9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
Institute of Energy Conversion University of Delaware Newark, Delaware 19716-3820	PV221104
	11. Contract (C) or Grant (G) No. (C) XM-0-18110-2 (G)
12. Sponsoring Organization Name and Address	13. Type of Report & Period Covered
National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393	Technical Report 1 January 1990 - 1 January 1992
	14.

15. Supplementary Notes
NREL technical monitor: T. S. Basso

16. Abstract (Limit: 200 words)

This report describes research to develop novel processes for the deposition of thin (<500Å) ZnTe layers suitable as transparent ohmic contacts for CdS/CdTe solar cells. The processes developed for ZnTe deposition were also applied to the deposition of other II-VI semiconductor layers for polycrystalline thin film solar cells. Three processes for the deposition of ZnTe were investigated: (1) surface exchange with CdTe, where Cd is replaced by Zn from an aqueous bath to form a ZnTe layer; (2) solution growth; and (3) galvanic deposition from an aqueous bath. The galvanic deposition technique proved to be the only method in which ZnTe films were successfully and reproducibly formed. The formation of ZnSe and CdS films using this galvanic deposition method was attempted, and encouraging results were achieved for the formation of CdS films on SnO_2/glass substrates. The development of this method, and the optimization of key processing steps in the fabrication of CdS/CdTe/ZnTe:Cu devices, resulted in cell performance results of > 70% fill factor and ~ 10% efficiency.

17. Document Analysis
a. Descriptors
deposition ; ZnTe ; photovoltaics ; solar cells ; solution growth ; thin films ; polycrystalline

b. Identifiers/Open-Ended Terms

c. UC Categories
273

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	152
	20. Price A08

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-4854	2. NTIS Accession No. DE92010561	3. Recipient's Accession No.

4. Title and Subtitle

Photon and Ion Assisted Doping and Growth of II-VI Compound Thin Films

5. Publication Date

April 1992

6.

7. Author(s)

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.

PV221103

11. Contract (C) or Grant (G) No.

(C) XM-0-18141-4

(G)

12. Sponsoring Organization Name and Address

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

13. Type of Report & Period Covered

Technical Report
1 July 1989 - 31 June 1990

14.

15. Supplementary Notes

NREL technical monitor: J. Benner

16. Abstract (Limit: 200 words)

This report describes research on ion-assisted doping (IAD) and photon-assisted doping (PAD) as techniques to grow p-type conducting thin layers. P-type dopants P and As are difficult to incorporate by vacuum evaporation, due in part to their low sticking coefficients. Segregation at the growing film surface during deposition further reduces incorporation. In addition, self-compensation occurs in CdTe, reducing the electrical activity of the dopant atoms that are incorporated. Several years ago, we chose IAD as a promising technique to circumvent these difficulties. However, the doped films had small minority carrier diffusion lengths (L_d) and were not suitable for efficient solar cells. The low L_d motivated us to look for a technique which would allow a high level of doping, in addition to long minority carrier diffusion lengths and good crystalline quality. PAD appeared to be a good candidate for this purpose, and we began research on PAD as an alternative to IAD. In the past year, good control of the micro-stoichiometry of CdTe films has become an important issue, for both IAD and PAD, because it affects not only the doping and self-compensation, but also the crystalline quality.

17. Document Analysis

a. Descriptors

II-VI ; thin films ; photovoltaics ; solar cells ; cadmium telluride ; doping

b. Identifiers/Open-Ended Terms

c. UC Categories

273

18. Availability Statement

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19. No. of Pages

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20. Price

A02

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-4853	2. NTIS Accession No. DE92010562	3. Recipient's Accession No.
4. Title and Subtitle Low-Temperature Metal-Organic Chemical Vapor Deposition Growth Processes for High-Efficiency Solar Cells			5. Publication Date February 1993 6.
7. Author(s) P. D. Dapkus			8. Performing Organization Rept. No.
9. Performing Organization Name and Address University of Southern California Departments of Electrical Engineering and Materials Science Los Angeles, California 90089-0483			10. Project/Task/Work Unit No. PV221103 11. Contract (C) or Grant (G) No. (C) XB-5-05009-3 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 September 1985-30 November 1989 14.

15. Supplementary Notes
NREL technical monitor: J. Benner

16. Abstract (Limit: 200 words)
This report describes the results of a program to develop a more complete understanding of the physical and chemical processes involved in low-temperature growth of III-V compounds by metal-organic chemical vapor deposition (MOCVD) and to develop a low-temperature process that is suitable for the growth of high-efficiency solar cells. The program was structured to develop a better understanding of the chemical reactions involved in MOCVD growth, to develop a model of the processes occurring in the gas phase, to understand the physical kinetics and reactions operative on the surface of the growing crystal, and to develop an understanding of the means by which these processes may be altered to reduce the temperature of growth and the utilization of toxic hydrides. The basic approach was to develop the required information about the chemical and physical kinetics operative in the gas phase and on the surface by the direct physical measurement of the processes whenever possible. The program included five tasks: (1) MOCVD growth process characterization, (2) photoenhanced MOCVD studies, (3) materials characterization, (4) device fabrication and characterization, and (5) photovoltaic training. Most of the goals of the program were met, and significant progress was made in defining an approach that would allow both high throughput and high uniformity growth of compound semiconductors at low temperatures. The technical activity was focused on determining the rates of thermal decomposition of trimethyl gallium, exploring alternate arsenic sources for use in MOCVD, and empirical studies of atomic layer epitaxy as an approach.

17. Document Analysis
a. Descriptors
low temperature ; MOCVD ; high efficiency ; photovoltaics ; solar cells ; metal organic ; chemical vapor deposition
b. Identifiers/Open-Ended Terms
c. UC Categories
273

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	297 20. Price A13

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-4851	2. NTIS Accession No. DE92010558	3. Recipient's Accession No.
4. Title and Subtitle New III-V Cell Design Approaches for Very High Efficiency			5. Publication Date April 1992 6.
7. Author(s) M.S. Lundstrom, M.R. Melloch, G.B. Lush, G.J. O'Bradovich, M.P. Young			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Purdue University West Lafayette, Indiana 47907			10. Project/Task/Work Unit No. PV221103 11. Contract (C) or Grant (G) No. (C) XM-0-19142-1 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 August 1990 - 31 July 1991 14.

15. Supplementary Notes
NREL technical monitor: J. Benner

16. Abstract (Limit: 200 words)

This report describes progress during the first year of a three-year project. The objective of the research is to examine new design approaches for achieving very high conversion efficiencies. The program is divided into two areas. The first centers on exploring new thin-film approaches specifically designed for III-V semiconductors. The second area centers on exploring design approaches for achieving high conversion efficiencies without requiring extremely high quality material. Research activities consisted of an experimental study of minority carrier recombination in n-type, metal-organic chemical vapor deposition (MOCVD)-deposited GaAs, an assessment of the minority carrier lifetimes in n-GaAs grown by molecular beam epitaxy, and developing a high-efficiency cell fabrication process.

17. Document Analysis
a. Descriptors
high efficiency ; photovoltaics ; solar cells ; semiconductors ; gallium arsenide

b. Identifiers/Open-Ended Terms

c. UC Categories
272

18. Availability Statement	19. No. of Pages
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Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-451-4850	2. NTIS Accession No. DE92010563	3. Recipient's Accession No.

4. Title and Subtitle	5. Publication Date
Basic Studies of III-V High Efficiency Cell Components	April 1992
	6.

7. Author(s)	8. Performing Organization Rept. No.
M.S. Lundstrom, M.R. Melloch, R.F. Pierret, M.S. Carpenter, H.L. Chuang, P.E. Dodd, A. Keshavarzi, M.E. Klausmeier-Brown, G.B. Lush, T.B. Stellwag	

9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
Purdue University School of Electrical Engineering West Lafayette, Indiana 47907	PV221103
	11. Contract (C) or Grant (G) No. (C) XL-5-0518-1 (G)

12. Sponsoring Organization Name and Address	13. Type of Report & Period Covered
National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393	Technical Report 15 August 1989 - 14 August 1990
	14.

15. Supplementary Notes
NREL technical monitor: J. Benner

16. Abstract (Limit: 200 words)

This report describes research activities on this subcontract for the last year. Other research is described in the reprints contained in Appendix 1. Chapter 1 describes experimental and theoretical work on perimeter and surface recombination. It describes measurements to characterize such recombination as well as the extension of the PUPHS2D model to treat these effects. Chapter 2 describes a new surface passivation treatment, As_2S_3, which appears to produce a permanent reduction of surface recombination. Chapter 3 describes collaboration with outside laboratories to fabricate and characterize a variety of high-efficiency cells using films grown by molecular beam epitaxy. Chapter 4 presents some thoughts on how innovative designs might be used to advantage for III-V cells. Appendix 1 is a complete list of the publications that have resulted during the course of the project.

17. Document Analysis
a. Descriptors
III-V cells ; high efficiency ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
273

18. Availability Statement	19. No. of Pages
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	20. Price A04

Form No. 0069E (6-30-87)

PV Manufacturing Technology Development

Document Control Page	1. NREL Report No. NREL/TP-411-5455	2. NTIS Accession No. DE93010008	3. Recipient's Accession No.

4. Title and Subtitle

Silicon Film™ Photovoltaic Manufacturing Technology

5. Publication Date
April 1993

6.

7. Author(s)
W.R. Bottenberg, R.B. Hall, E.L. Jackson, S. Lampo, W.P. Mulligan, A.M. Barnett

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

AstroPower, Inc.
Solar Park
Newark, Delaware 19716

10. Project/Task/Work Unit No.
PV350101

11. Contract (C) or Grant (G) No.

(C) ZM-2-11040-5

(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered

Technical Report
15 January 1992 - 15 July 1992

14.

15. Supplementary Notes
NREL technical monitor: R. Mitchell

16. Abstract (Limit: 200 words)

This report describes work on a project to develop an advanced, low-cost manufacturing process for a new utility-scale flat-plate module based on thin active layers of polycrystalline silicon on a low-cost substrate. This is called the Silicon-Film™ process. This new power module is based on a new large solar cell that is 675 cm^2 in area. Eighteen of these solar cells form a 170-W module. Twelve of these modules form a 2-kW array. The program has three components: (1) development of a Silicon-Film™ wafer machine that can manufacture wafers 675 cm^2 in size with a total product cost reduction of 70%; (2) development of an advanced solar cell manufacturing process that will turn the Silicon-Film™ wafer into a 14%-efficient solar cell; and (3) development of an advanced module design based on these large-area, efficient silicon solar cells with an average power of 170 watts. The completion of these three tasks will lead to a new power module designed for utility and other power applications with a substantially lower cost.

17. Document Analysis

a. Descriptors
silicon ; thin film ; manufacturing ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
271

18. Availability Statement
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20. Price
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Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-411-5454	2. NTIS Accession No. DE93010007	3. Recipient's Accession No.
4. Title and Subtitle Large-Area, Triple-Junction a-Si Alloy Production Scale-Up			5. Publication Date April 1993 6.
7. Author(s) R. Oswald, J. O'Dowd			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Solarex Thin Film Division 826 Newtown-Yardley Road Newtown, Pennsylvania 18940			10. Project/Task/Work Unit No. PV350101 11. Contract (C) or Grant (G) No. (C) ZM-2-11040-2 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 17 March 1992 - 18 September 1992 14.

15. Supplementary Notes
NREL technical monitor: R. Mitchell

16. Abstract (Limit: 200 words)

This report describes Solarex's work to advance its photovoltaic manufacturing technologies, reduce its a-Si:H module production costs, increase module performance, and expand the Solarex commercial production capacity. Solarex will meet these objectives by improving the deposition and quality of the transparent front contact; optimizing the laser patterning process; scaling up the semiconductor deposition process; improving the back-contact deposition; and scaling up and improving the encapsulation and testing of its a-Si:H modules. In the Phase 1 portion of this subcontract, Solarex focused on scaling up components of the chemical vapor deposition system for deposition of the front contact, scaling up laser scribing techniques; triple-junction recipes for module production; and metal-oxide back contacts. The goal of these efforts is to adopt all portions of the manufacturing line to handle substrates larger than 0.37 m^2.

17. Document Analysis
a. Descriptors
large area ; triple junction ; amorphous silicon ; production ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
271

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	40 20. Price A03

Document Control Page	1. NREL Report No. NREL/TP-411-5453	2. NTIS Accession No. DE93010006	3. Recipient's Accession No.
4. Title and Subtitle Continuous Roll-to-Roll a-Si Photovoltaic Manufacturing Technology			5. Publication Date April 1993 6.
7. Author(s) M. Izu			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Energy Conversion Devices 1675 West Maple Road Troy, Michigan 48084			10. Project/Task/Work Unit No. PV350101 11. Contract (C) or Grant (G) No. (C) ZM-2-11040-7 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Semiannual Technical Report 1 April 1992 - 30 September 1992 14.

15. Supplementary Notes
NREL technical monitor: R. Mitchell

16. Abstract (Limit: 200 words)

This report describes work performed by ECD to advance its roll-to-roll, triple-junction photovoltaic manufacturing technologies; to reduce the module production costs; to increase the stabilized module performance; and to expand the commercial capacity utilizing ECD technology. The 3-year goal is to develop advanced large-scale manufacturing technology incorporating ECD's earlier research advances with the capability of producing modules with stable 11% efficiency at a cost of approximately $\$1/W_p$. Major efforts during Phase 1 are (1) the optimization of the high-performance back-reflector system, (2) the optimization of a-Si-Ge narrow band-gap solar cell, and (3) the optimization of the stable efficiency of the module. The goal is to achieve a stable 8% efficient 0.3-m x 1.2-m (1-ft x 4-ft) module. Also, the efforts include work on a proprietary, high-deposition-rate, microwave plasma, CVD manufacturing technology; and on the investigation of material cost reduction.

17. Document Analysis
a. Descriptors
amorphous silicon ; manufacturing ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
271

18. Availability Statement	19. No. of Pages
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Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-411-5019	2. NTIS Accession No. DE93000027	3. Recipient's Accession No.
4. Title and Subtitle Photovoltaic Manufacturing Technology Report, Phase 1			5. Publication Date October 1992 6.
7. Author(s) A.V. Mason, D.R. Lillington			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Spectrolab, Inc. 12500 Gladstone Ave. Sylmar, CA 91342			10. Project/Task/Work Unit No. PV250101 11. Contract (C) or Grant (G) No. (C) XC-1-10057-22 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 9 January 1991 - 14 April 1992 14.

15. Supplementary Notes
NREL technical monitor: R.L. Mitchell

16. Abstract (Limit: 200 words)

This report describes subcontracted research by Spectrolab, Inc., to address tasks outlined in the National Renewable Energy Laboratory's (NREL) letter of solicitation RC-0-10057. These tasks include the potential of making photovoltaics (PV) a more affordable energy source, as set forth in the goal of the PVMaT project. Spectrolab believes that the DOE cost goals can be met using three different types of cells: (1) silicon concentrator cells, (2) high efficiency GaAs concentrator cells, and (3) mechanically stacked multijunction cells.

17. Document Analysis
a. Descriptors
manufacturing ; photovoltaics ; solar cells ; gallium arsenide ; silicon

b. Identifiers/Open-Ended Terms

c. UC Categories
270

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	139 20. Price A07

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-411-5018	2. NTIS Accession No. DE93000026	3. Recipient's Accession No.
4. Title and Subtitle Photovoltaic Manufacturing Technology Phase 1			5. Publication Date October 1992 6.
7. Author(s)			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Chronar Corporation 195 Clarksville Road Lawrenceville, NJ 08648			10. Project/Task/Work Unit No. PV250101 11. Contract (C) or Grant (G) No. (C) XC-1-10057-16 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 1 May 1991 - 10 May 1991 14.

15. Supplementary Notes
NREL technical monitor: R.L. Mitchell

16. Abstract (Limit: 200 words)
This report describes subcontracted research by the Chronar Corporation, prepared by Advanced Photovoltaic Systems, Inc. (APS) for Phase 1 of the Photovoltaic Manufacturing Technology Development project. Amorphous silicon is chosen as the PV technology that Chronar Corporation and APS believe offers the greatest potential for manufacturing improvements, which, in turn, will result in significant cost reductions and performance improvements in photovoltaic products. The APS "Eureka" facility was chosen as the manufacturing system that can offer the possibility of achieving these production enhancements. The relationship of the "Eureka" facility to Chronar's "batch" plants is discussed. Five key areas are also identified that could meet the objectives of manufacturing potential that could lead to improved performance, reduced manufacturing costs, and significantly increased production. The projected long-term potential benefits of these areas are discussed, as well as problems that may impede the achievement of the hoped-for developments. A significant number of the problems discussed are of a generic nature and could be of general interest to the industry. The final section of this document addresses the cost and time estimates for achieving the solutions to the problems discussed earlier. Emphasis is placed on the number, type, and cost of the human resources required for the project.

17. Document Analysis
a. Descriptors
manufacturing ; photovoltaics ; solar cells ; amorphous silicon

b. Identifiers/Open-Ended Terms

c. UC Categories
270

18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	50 20. Price A03

Form No. 0069E (6-30-87)

Document Control Page	1. NREL Report No. NREL/TP-411-5017	2. NTIS Accession No. DE92016441	3. Recipient's Accession No.
4. Title and Subtitle Cost Analysis Methodology			5. Publication Date September 1992 6.
7. Author(s) Richard A. Whisnant			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Research Triangle Institute Research Triangle Park, North Carolina 27702			10. Project/Task/Work Unit No. PV250101 11. Contract (C) or Grant (G) No. (C) XR-1-11039-1 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 11 March 1991 - 11 November 1991 14.

15. Supplementary Notes
NREL technical monitor: R.L. Mitchell

16. Abstract (Limit: 200 words)

This report describes work done under Phase 1 of the Photovoltaic Manufacturing Technology (PVMaT) Project. PVMaT is a five-year project to support the translation of research and development in PV technology into the marketplace. PVMaT, conceived as a DOE/industry partnership, seeks to advanced PV manufacturing technologies, reduce PV module production costs, increase module performance, and expand U.S. commercial production capacities. Under PVMaT, manufacturers will propose specific manufacturing process improvements that may contribute to the goals of the project, which is to lessen the cost, thus hastening entry into the larger scale, grid-connected applications. Phase 1 of the PVMaT project is to identify obstacles and problems associated with manufacturing processes. This report describes the cost analysis methodology required under Phase 1 that will allow subcontractors to be ranked and evaluated during Phase 2.

17. Document Analysis
a. Descriptors
cost analysis ; manufacturing ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
270

18. Availability Statement	19. No. of Pages
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ADDITIONAL PUBLICATIONS AND SOURCES

The following publications were produced under the DOE Photovoltaics Program or are publications that include reports on activities that were largely supported by the DOE program. Many of these publications can be obtained through local libraries or can be ordered directly from the stated source.

Alonso, R. G.; Mascarenhas, A.; Froyen, S.; Horner, G. S.; Bertness, K.; Olson, J. M. (January 1993). "Polarized Piezomodulated Reflectance Study of Spontaneous Ordering in $GaInP_2$." *Solid State Communications* (85:12); Pergamon Press Ltd, Great Britain; pp. 1021-1024. NREL/TP-451-5166.

Arent, D. J.; Bode, M.; Bertness, K. A.; Kurtz, S. R.; Olson, J. M. (April 1993). "Band-Gap Narrowing in Ordered $Ga_{0.47}In_{0.53}As$." *Applied Physics Letters* (62:15); American Institute of Physics; pp. 1806-1808. TP-451-5128.

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Branz, H. M.; Asher, S. E.; Nelson, B. P. (March 1993). "Light-Enhanced Deep Deuterium Emission and the Diffusion Mechanism in Amorphous Silicon." *Physical Review B*, (47:12); American Physical Society; pp. 7061-7066. NREL/TP-451-4726.

Ciszek, T. F.; Burrows, R. W.; Wang, T. H. (October 1992). "High Temperature Solution Growth of Thin Crystalline Silicon Layers." *Eleventh E.C. Photovoltaic Solar Energy Conference Proceedings, Proceedings of the International Conference, 12-16 October 1992, Montreux, Switzerland.* Hardwood Academic Publishers, Montreux, Switzerland; pp. 423-426. SERI/TP-451-4783.

Coutts, T. J.; Lundstrom, M. S. (January 1993). "Research Opportunities in Crystalline III-V Photovoltaics." SERI/TP-413-5062. *Journal of Electronic Materials* (22:1); pp. 57-64. TP-413-5062.

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Green, M. A.; Emery, K. (January 1993). "Solar Cell Efficiency Tables." *Progress in Photovoltaics: Research and Applications* (1:1); pp. 25-29. NREL/TP-412-5122.

Horner, G. S.; Mascarenhas, A.; Froyen, S.; Alonso, R. G.; Bertness, K.; Olson, J. M. (February 1993). "Photoluminescence-Excitation-Spectroscopy Studies in Spontaneously Ordered GaInP2." *Physical Review B* (47:7); American Physical Society; pp 4041-4043. TP-451-5170.

Laks, D. B.; Wei, S.-H.; Zunger, A. (December 1992). "Evolution of Alloy Properties with Long-Range Order."

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Olson, J. M.; Kurtz, S. R., Inventors (November 1992). *Tunnel Junction Multiple Wavelength Light-Emitting Diodes, U.S. Patent No. 5,166,761.* 4 pp. Assignee: Midwest Research Institute, Kansas City, Missouri.

Osorio, R.; Lu, Z.-W.; Wei, S.-H.; Zunger, A. (April 1993). "First-Principles Phase Diagrams of Pseudoternary Chalcopyrite/Zinc-Blende Alloys." *Physical Review B, Rapid Communications* (47:15); American Physical Society; pp. 9985-9988. NREL/TP-451-5194.

Osorio, R.; Froyen, S. (January 1993). "Interaction Parameters and a Quenched-Disorder Phase Diagram for (GaAs)*1-x* Ge*2x* Alloys." *Physical Review B* (47:4); American Physical Society; pp. 1889-1897. TP-451-5004.

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Vanecek, M.; Mahan, A. H.; Nelson, B. P.; Crandall, R. S. (January 1993). "Influence of Hydrogen and Microstructure on Increased Stability of Amorphous Silicon." *Proceedings of the 11th E.C. Photovoltaic Solar Energy Conference, 12-16 October 1992, Montreux, Switzerland*, Gunmaressm L.; Palz, W.; DeRezy, C.; Kiess, H.; Helin, P., eds. Harwood Academic Publishers, Switzerland; pp. 96-99.

Wells, C. V. (November 1992). *Principles and Applications of Measurement Uncertainty Analysis in Research and Calibration.* SERI/TP-411-5165. 19 pp. Prepared for the 3rd Annual Infrared Radiometric Sensor Calibration Symposium, 14-17 September 1992, Logan, Utah. Available NTIS: Order No. DE93000034.

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