NREL Photovoltaic Subcontract Reports: Abstracts and Document Control Information

1 August 1991 – 31 July 1992

Photovoltaic Energy Program
L. Pohle, Coordinator

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MASTER

On September 16, 1991 the Solar Energy Institute was designated a national laboratory, and its name was changed to the National Renewable Energy Laboratory.

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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, 1991, through July 31, 1992. This report is published periodically, with the previous one covering the period from January 1, 1991, through July 31, 1991.

The purpose of continuing this type of publication is to help people keep 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.

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PV Manufacturing Technology Development Publications (manufacturing information for any PV material type)	28
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Amorphous Silicon Research

Document Control Page	1. SERI Report No. SERI/TP-214-4226	2. NTIS Accession No. DE91002167	3. Recipient's Accession No.
4. Title and Subtitle Research on Stable, High-Efficiency, Large-Area, Amorphous-Silicon-Based Submodules			5. Publication Date June 1991
			6.
7. Author(s) A.E. Delahoy, T. Tonon, J. Macneil			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Chronar Corporation PO Box 177 Princeton, New Jersey 08542			10. Project/Task/Work Unit No. PV141101
			11. Contract (C) or Grant (G) No. (C) ZB-7-06003-1 (G)
12. Sponsoring Organization Name and Address Solar Energy Research Institute 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical report, 16 March 1989 - 15 October 1990
			14.
15. Supplementary Notes SERI technical monitor: W. Luft, (303) 231-1452			
16. Abstract (Limit: 200 words) This report describes research to develop same-band-gap, amorphous silicon, tandem-junction photovoltaic modules with areas of at least 900 cm ² . The goals are to achieve aperture-area efficiencies of 9% and modules that retain 95% of their original power output under standard light-soaking conditions. The approach involved depositing SiO ₂ /SnO ₂ :F onto soda lime glass via atmospheric-pressure chemical vapor deposition (APCVD) to provide a textured, transparent electrode; single-chamber radio-frequency (RF) glow discharge deposition of the hydrogenated amorphous silicon (a-Si:H) layers onto vertical substrates; sputter deposition of highly reflecting ZnO-based back contacts; and laser scribing of the a-Si:H and electrodes with real-time scribe tracking to minimize area loss. Studies of film uniformity were also performed, and performance data are presented for various single- and tandem-junction cells and modules.			
17. Document Analysis a. Descriptors photovoltaics ; solar cells ; amorphous state ; silicon 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 62
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Document Control Page	1. SERI Report No. SERI/TP-214-4405	2. NTIS Accession No. DE91015002	3. Recipient's Accession No.
4. Title and Subtitle Research on Stable, High-Efficiency, Amorphous Silicon Multijunction Modules			5. Publication Date August 1991
			6.
7. Author(s) A. Catalano, M. Bennet, L. Chen, B. Fieselmann, Y. Li, J. Newton, R. Podlesny, S. Wiedeman, L. Yang			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. PV142101
			11. Contract (C) or Grant (G) No. (C) ZM-0-19033-1 (G)
12. Sponsoring Organization Name and Address Solar Energy Research Institute 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical report, 1 May 1990 - 30 April 1991
			14.
15. Supplementary Notes SERI technical monitor: W. Luft, (303) 231-1452			
16. Abstract (Limit: 200 words) This report describes work to develop modules with a stabilized aperture-area (900 cm ²) conversion efficiency of 8.8% after 600 hours of light exposure (at air mass 1.5 and 50° C). A 9.8% initial conversion efficiency was achieved with a submodule incorporating devices with thin middle-junction intrinsic layers (4000 Å). Devices with this design typically lose 10% of their initial performance after 1000 hours of exposure. Modules lose 18%-23%, largely because of light-induced shunting, and this is probably related to the contact metallization. Achieving long-term stabilized efficiencies of 12% or greater requires substantial improvements in the materials and devices. The present analysis indicates that substantial optical losses occur at both the front and rear contacts; we hope to address this with ZnO films prepared by chemical vapor deposition and sputtering processes now under development. Additional progress in doped layers and alloys is also needed. Fundamental studies of the relationship between material structure and processes (particularly the effect of hydrogen dilution) are reported here.			
17. Document Analysis a. Descriptors photovoltaics ; solar cells ; amorphous state ; high efficiency 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 72
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Document Control Page	1. SERI Report No. SERI/TP-214-4453	2. NTIS Accession No. DE92001197	3. Recipient's Accession No.
4. Title and Subtitle Research on Stable, High-Efficiency Amorphous Silicon Multijunction Modules		5. Publication Date December 1991	
		6.	
7. Author(s) S. Guha		8. Performing Organization Rept. No.	
9. Performing Organization Name and Address United Solar Systems Corporation 1100 West Maple Road Troy, Michigan 48084		10. Project/Task/Work Unit No. PV141101	
		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, Colorado 80401-3393		13. Type of Report & Period Covered Technical Report	
		14.	
15. Supplementary Notes NREL Technical Monitor: W. Luft (303/231-1452)			
16. Abstract (Limit: 200 words) <p>This report describes research to improve the understanding of amorphous silicon alloys and other relevant non-semiconductor materials for use in high-efficiency, large-area multijunction modules. The research produced an average subcell initial efficiency of 8.8% over a 1-ft² area using same-band-gap, dual-junction cells deposited over a ZnO/AlSi back reflector. An initial efficiency of 9.6% was achieved using a ZnO/Ag back reflector over smaller substrates. A sputtering machine will be built to deposit a ZnO/Ag back reflector over a 1-ft² area so that a higher efficiency can also be obtained on larger substrates. Calculations have been performed to optimize the grid pattern, bus bars, and cell interconnects on modules. With our present state of technology, we expect a difference of about 6% between the aperture-area and active-area efficiencies of modules. Preliminary experiments show a difference of about 8%. We can now predict the performance of single-junction cells after long-term light exposure at 50°C by exposing cells to short-term intense light at different temperatures. We find that single-junction cells deposited on a ZnO/Ag back reflector show the highest stabilized efficiency when the thickness of the intrinsic layers is about 2000 Å.</p>			
17. Document Analysis a. Descriptors photovoltaics ; multijunction modules ; high efficiency ; amorphous silicon ; 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 85	
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Document Control Page	1. SERI Report No. NREL/TP-214-4591	2. NTIS Accession No. DE92001177	3. Recipient's Accession No.
4. Title and Subtitle Research on the Structural and Electronic Properties of Defects in Amorphous Silicon, Final Subcontract Report, September 1989 - December 1990			5. Publication Date December 1991
			6.
7. Author(s) R.A. Street			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Xerox Palo Alto Research Center Palo Alto, California 94304			10. Project/Task/Work Unit No. PV141101
			11. Contract (C) or Grant (G) No. (C) HB-7-06056-1 (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, September 1989 - December 1990
			14.
15. Supplementary Notes NREL technical monitor: B. Stafford, (303) 231-7126			
16. Abstract (Limit: 200 words) The work performed for this contract focused on the saturation of light-induced effects, hydrogen-mediated metastability and growth, defects and electronic properties, and remote hydrogen plasma growth. This work included research on hydrogen chemical reactions, hydrogen density-of-states model and metastability, hydrogen bonding configurations, a model for the role of hydrogen complexes in the metastability, and hydrogen chemical potential and growth structure. This document also covers research on thermal generation currents in p-i-n diodes, field dependence of the generation current, metastability effects at contacts, and potential fluctuations in compensated a-Si:H. Information is included on plasma diagnostics using electron spin resonance and nuclear magnetic resonance measurements of remote hydrogen plasma films.			
17. Document Analysis a. Descriptors photovoltaics ; solar cells ; amorphous silicon ; density states ; defects 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 58
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Document Control Page	1. SERI Report No. NREL/TP-214-4592	2. NTIS Accession No. DE92001178	3. Recipient's Accession No.
4. Title and Subtitle Investigations of the Origins of Metastable Light-Induced Changes in Hydrogenated Amorphous Silicon			5. Publication Date December 1991
			6.
7. Author(s) J.D. Cohen			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Department of Physics and Materials Science Institute University of Oregon Eugene, Oregon			10. Project/Task/Work Unit No. PV141101
			11. Contract (C) or Grant (G) No. (C) XM-8-18061-1 (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 1991
			14.
15. Supplementary Notes NREL technical monitor: B. Stafford, (303) 231-7126			
16. Abstract (Limit: 200 words) The work performed for this contract continued investigations of the origins of metastable effects in a-Si:H through three kinds of studies: (1) the effect of carbon impurities in a-Si:H samples at low concentrations using drive-level capacitance profiling measurements on samples whose carbon content was intentionally modulated spatially during growth, (2) the characterization of metastable states in n-type doped a-Si:H samples caused by quench cooling and by light-soaking with partial annealing, and (3) the use of depletion-width-modulated ESR spectroscopy together with junction capacitance spectroscopy to investigate deep defect states for various metastable states of a 10- and an 80-Vppm PH ₃ -doped a-Si:H sample.			
17. Document Analysis a. Descriptors photovoltaics ; solar cells ; amorphous silicon b. Identifiers/Open-Ended Terms c. UC Categories 271			
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Document Control Page	1. SERI Report No. NREL/TP-451-4691	2. NTIS Accession No. DE92001212	3. Recipient's Accession No.
4. Title and Subtitle Studies on Relative Effects of Charged and Neutral Defects in Hydrogenated Amorphous Silicon			5. Publication Date February 1992
			6.
7. Author(s) Marvin Silver			8. Performing Organization Rept. No.
9. Performing Organization Name and Address University of North Carolina Department of Physics and Astronomy Chapel Hill, North Carolina 27599-3255			10. Project/Task/Work Unit No. PV241101
			11. Contract (C) or Grant (G) No. (C) XB-8-07183-1 (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.
15. Supplementary Notes NREL technical monitor: B. Stafford			
16. Abstract (Limit: 200 words) This report covers the third year of a continuing research study to understand the relative importance of charged and neutral defects in amorphous silicon. The objective of the study is to explore the electronic structure, including neutral and charged defects, and optoelectronic effects including the formation of Staebler-Wronski defects. The study concentrated on exploring electroluminescence experimentally and interpreting the results employing a simple guiding model. The simple guiding model assumes an exponential density of states and recombination rate constants (radiative and non-radiative) which are governed by hopping transitions. Measurements were also made as a function of photodegradation of the material. The results implicate that the radiative recombination processes are not distant pair tunneling but rather results from electrons hopping down due to the coulomb interactions. Preliminary experiments have been made on the effect of photodegradation on transient space charge limited currents in n/i/n structures. These experiments can directly yield information on the occupied defect centers induced by the photodegradation and are not a result of recombination processes. To date the results seems to be consistent with a picture which places the doubly occupied defects at quite a high energy (≈ 0.4 e.v. below the conduction band).			
17. Document Analysis a. Descriptors amorphous silicon ; defects ; 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 20
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Document Control Page	1. SERI Report No. NREL/TP-451-4720	2. NTIS Accession No. DE92001213	3. Recipient's Accession No.
4. Title and Subtitle Research on Stable, High Efficiency Amorphous Silicon Multijunction Modules			5. Publication Date February 1992
			6.
7. Author(s) A. Catalano, R.R. Arya, M. Bennett, L. Chen, R. D'Aiello, B. Fieselmann, Y. Li, J. Newton, R. Podlesny, S. Wiedeman, 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
			14.
15. Supplementary Notes NREL technical monitor: Werner Luft			
16. Abstract (Limit: 200 words) Improvements towards to goal of a 12.5% initial triple-junction module efficiency require the use of a wide gap top-layer for improved open circuit voltage, higher transmission from the transparent front contact and more highly transmitting doped layers. To address the first issue, there has been continued development of a-SiC:H with the utilization of several novel feedstocks to control the atomic structure of the solid. These films have transport properties superior to the best results reported for a-SiC:H. Preliminary results with devices exhibit a stability comparable to a-Si:H, while previous results with a-SiC:H have generally shown far higher rates of degradation. Module fabrication has been refined to the extent that comparable module and small area device efficiencies are readily obtained. Despite the high initial efficiencies (9% - 10%) obtained in 935 cm ² modules employing devices with 4000Å thick middle junctions, higher than expected rates of degradation were found. The cause of the anomalous degradation was traced to shunts present in the device arising from defects in the tin oxide coating. NREL degradation results of triple-junction modules showed stabilized performance of the initial efficiency for modules prepared during the period in which shunts were a problem.			
17. Document Analysis a. Descriptors amorphous silicon ; high efficiency ; modules ; 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 103
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Document Control Page	1. SERI Report No. NREL/TP-451-4751	2. NTIS Accession No. DE92001223	3. Recipient's Accession No.
4. Title and Subtitle Research on Defects and Transport in Amorphous Silicon-Based Semiconductors		5. Publication Date April 1992	
		6.	
7. Author(s) E.A. Schiff, H. Antoniadis, J.-K. Lee, Q. Wang		8. Performing Organization Rept. No.	
9. Performing Organization Name and Address Syracuse University Department of Physics Syracuse, NY 13244-1130		10. Project/Task/Work Unit No. PV241101	
		11. Contract (C) or Grant (G) No. (C) XG-1-10063-7 (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 20 February 1991-19 February 1992	
		14.	
15. Supplementary Notes NREL technical monitor: B. von Roedern			
16. Abstract (Limit: 200 words) This report describes the results from research on two topics: (1) the effects of light-soaking on the electron drift mobility in a-Si:H, and (2) modulated electron spin resonance measurements and their relationship to the electronic correlation energy of the D center in a-Si:H. Both of these projects were undertaken to better determine where the "standard" model for a-Si:H breaks down. The standard model is reasonably successful in accounting for the most elementary "deep trapping" aspects of electron and hole transport in a-Si:H, and it accounts adequately for the sub-band-gap optical properties. However, it is much less clear whether it provides a sufficient basis for understanding several effects which are crucial in operating solar cells: electron and hole mobilities and recombination in the presence of light-bias and space-charge. In the standard model, one would not expect significant effects on drift mobilities due to light-soaking, which would be envisioned as simply increasing the D-center density. Similarly, in the standard model one would not anticipate a significant temperature dependence to electron spin resonance, because essentially all spins are already detected. Discussions in the available literature on the evidence regarding both effects were inconclusive. The work reported here sets considerably more stringent constraints on the magnitude of the two effects.			
17. Document Analysis a. Descriptors amorphous silicon ; semiconductors ; photovoltaics ; solar cells ; defects ; transport 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 23	
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Document Control Page	1. NREL Report No. NREL/TP-411-4840	2. NTIS Accession No. DE92001244	3. Recipient's Accession No.
4. Title and Subtitle Research on Stable, High-Efficiency Amorphous Silicon Multijunction Modules			5. Publication Date April 1992
			6.
7. Author(s) A. Banerjee, E. Chen, R. Clough, T. Glatfelter, S. Guha, G. Hammond, M. Hopson, N. Jackett, M. Lycette, J. Noch, T. Palmer, A. Pawlikiewicz, I. Rosenstein, R. Ross, D. Wolf, X. Xu, J. Yang, K. Younan			8. Performing Organization Rept. No.
9. Performing Organization Name and Address United Solar Systems Corporation 1100 West Maple Road Troy, Michigan 48084			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 1991 - 31 December 1991
			14.
15. Supplementary Notes NREL technical monitor: W. Luft			
16. Abstract (Limit: 200 words) This report describes the progress made during Phase 1 of research and development program to obtain high-efficiency amorphous silicon alloy multijunction modules. Using a large-area deposition system, double- and triple-junction cells were made on stainless steel substrates of over 1 ft ² area with Ag and ZnO predeposited back reflector. Modules of over 1 ft ² were produced with between 9.2% and 9.9% initial aperture-area efficiencies as measured under a USSC Spire solar simulator. Efficiencies as measured under the NREL Spire solar simulator were found to be typically 15% to 18% lower. The causes for this discrepancy are now being investigated. The modules show about 15% degradation after 600 hours of one-sun illumination at 50°C. To optimize devices for higher stabilized efficiency, a new method was developed by which the performance of single-junction cells after long-term, one-sun exposure at 50°C can be predicted by exposing cells to short-term intense light at different temperatures. This method is being used to optimize the component cells of the multijunction structure to obtain the highest light-degraded efficiency.			
17. Document Analysis a. Descriptors high efficiency ; amorphous silicon ; multijunction ; modules ; 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 85
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Polycrystalline Thin Films

Document Control Page	1. SERI Report No. NREL/TP-214-4433	2. NTIS Accession No. DE91002192	3. Recipient's Accession No.
4. Title and Subtitle Investigations of CuInSe ₂ Thin Films and Contacts			5. Publication Date October 1991
			6.
7. Author(s) M-A. Nicolet			8. Performing Organization Rept. No.
9. Performing Organization Name and Address California Institute of Technology Pasadena, California			10. Project/Task/Work Unit No. PV131101
			11. Contract (C) or Grant (G) No. (C) XB-8-07133-1 (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 1990 - 28 February 1991
			14.
15. Supplementary Notes NREL technical monitor: R. Mitchell, (303) 231-1379			
16. Abstract (Limit: 200 words) This report describes research into electrical contacts for copper indium diselenide (CuInSe ₂) polycrystalline thin films used for solar cell applications. Molybdenum contacts have historically been the most promising for heterojunction solar cells. This program studied contact stability by investigating thermally induced bilayer reactions between molybdenum and copper, indium, and selenium. Because selenization is widely used to fabricate CuInSe ₂ thin films for photovoltaic cells, a second part of the program investigated how the morphologies, phases, and reactions of pre-selenization Cu-In structures are affected by the deposition process and heat treatments.			
17. Document Analysis a. Descriptors photovoltaics ; solar cells ; copper indium diselenide ; thin films ; electrical contacts 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 14
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Document Control Page	1. SERI Report No. SERI/TP-214-4468	2. NTIS Accession No. DE92001168	3. Recipient's Accession No.
4. Title and Subtitle Role of Polycrystallinity in CdTe and CuInSe ₂ Photovoltaic Cells; Annual Subcontract Report, April 1, 1990 - March 31, 1991			5. Publication Date November 1991
			6.
7. Author(s) J. R. Sites			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Department of Physics Colorado State University Fort Collins, Colorado 80523			10. Project/Task/Work Unit No. PV131101
			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, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: H.S. Ullal, (303) 231-1486			
16. Abstract (Limit: 200 words) The polycrystalline nature of thin-film CdTe and CuInSe ₂ solar cells continues to be a major factor in several individual losses that limit overall cell efficiency. This report describes progress in the quantitative separation of these losses, including both measurement and analysis procedures. It also applies these techniques to several individual cells to help document the overall progress with CdTe and CuInSe ₂ cells. Notably, CdTe cells from Photon Energy have reduced window photocurrent losses to 1 mA/cm ² ; those from the University of South Florida have achieved a maximum power voltage of 693 mV; and CuInSe ₂ cells from International Solar Electric Technology have shown a hole density as high as 7×10^{16} cm ⁻³ , implying a significant reduction in compensation.			
17. Document Analysis a. Descriptors Photovoltaic cells ; polycrystalline thin films ; cadmium telluride ; copper indium diselenide ; cell efficiency ; 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 29
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Document Control Page	1. SERI Report No. SERI/TP-214-4502	2. NTIS Accession No. DE92001171	3. Recipient's Accession No.
4. Title and Subtitle Polycrystalline Thin Film Materials and Devices			5. Publication Date November 1991
			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			10. Project/Task/Work Unit No. PV131101
			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, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: H.S. Ullal, (303) 231-1486			
16. Abstract (Limit: 200 words) This report covers Phase I of a multiyear research program on polycrystalline thin-film solar cells. IEC investigated the relationships between processing, material properties, and device performance of CuInSe ₂ and CdTe solar cells. IEC studied the formation of CuInSe ₂ by selenization with hydrogen selenide and fabricated a CuInSe ₂ /CdS solar cell. IEC also reacted the deposited copper-indium-selenium layers to obtain single-phase CuInSe ₂ films and a cell efficiency of 7%. Studies of the open-circuit voltage (V_{oc}) of CuInSe ₂ solar cells showed that a simple Shockley-Read-Hall recombination mechanism cannot account for the limitations in V_{oc} . Examining the influence of CuInSe ₂ thickness on cell performance showed that the back contact is significant when the CuInSe ₂ is less than 1 micron thick. CdTe/CdS solar cells with efficiencies approaching 10% can be fabricated repeatedly. Improvements in short-circuit current of CdTe solar cells to levels approaching 25 mA/cm ² are achievable by making the CdS window layer thinner. CdTe/CdS cells stored without protection from the atmosphere degraded because of the metal contact. CdTe cells with ZnTe:Cu contacts to the CdTe were more stable.			
17. Document Analysis a. Descriptors Polycrystalline thin films ; copper indium diselenide ; cadmium telluride ; solar cells ; photovoltaics 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 75
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Document Control Page	1. SERI Report No. NREL/TP-214-4580	2. NTIS Accession No. DE92001198	3. Recipient's Accession No.
4. Title and Subtitle High-Efficiency Cadmium and Zinc Telluride-Based Thin-Film Solar Cells			5. Publication Date February 1992
			6.
7. Author(s) A. Rohatgi, R. Sudharsanan, S. Ringel			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Georgia Institute of Technology School of Electrical Engineering Atlanta, GA 30332			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
			14.
15. Supplementary Notes NREL technical monitor: R. Mitchell			
16. Abstract (Limit: 200 words) This report describes research into polycrystalline CdTe solar cells grown by metal-organic chemical vapor deposition. Efficiencies of ~10% were achieved using both p-i-n and p-n structures. A pre-heat treatment of CdS/SnO ₂ /glass substrates at 450°C in hydrogen atmosphere prior to the CdTe growth was found to be essential for high performance because this heat treatment reduces oxygen-related defects from the CdS surface. However, this treatment also resulted in a Cd-deficient CdS surface, which may in part limit the CdTe cell efficiency to 10% due to Cd vacancy-related interface defects. Preliminary model calculations suggest that removing these states can increase the cell efficiency from 10% to 13.5%. Photon absorption in the CdS film also limits the cell performance, and eliminating this loss mechanism can result in CdTe efficiencies in excess of 18%. Polycrystalline, 1.7-e, CdZnTe films were also grown for tandem-cell applications. CdZnTe/CdS cells processed using the standard CdTe cell fabrication procedure resulted in 4.4% efficiency, high series resistance, and a band-gap shift to 1.55 eV. The formation of Zn-O at and near the CdZnTe surface is the source of high contact resistance. A saturated dichromate etch prior to contact deposition was found to solve the contact resistance problem. The CdCl ₂ treatment was identified as the cause of the observed band-gap shift due to the preferred formation of ZnCl ₂ .			
17. Document Analysis a. Descriptors high efficiency ; thin films ; photovoltaics ; solar cells b. Identifiers/Open-Ended Terms c. UC Categories 274			
18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161			19. No. of Pages 90
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Document Control Page	1. SERI Report No. NREL/TP-411-4752	2. NTIS Accession No. DE92001222	3. Recipient's Accession No.
4. Title and Subtitle Novel Thin-Film CuInSe ₂ Fabrication			5. Publication Date February 1992
			6.
7. Author(s) G.D. Mooney and A.M. Hermann			8. Performing Organization Rept. No.
9. Performing Organization Name and Address University of Colorado Department of Physics Boulder, CO 80309-0390			10. Project/Task/Work Unit No. PV231101
			11. Contract (C) or Grant (G) No. (C) XC-0-10012-1 (G)
			13. Type of Report & Period Covered Technical Report 1 March 1990 - 30 April 1991
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			14.
15. Supplementary Notes NREL technical monitor: R. Mitchell			
16. Abstract (Limit: 200 words) This report describes research in Rapid Thermal Processing (RTP), a process that allows the formation of CuInSe ₂ without the use of H ₂ Se. RTP is a well-established method of rapidly achieving temperatures necessary to melt and recrystallize materials such as Si and silicides. RTP processes can rapidly and uniformly heat large surface areas to hundreds of degrees Celsius. RTP is the most promising method of rapid recrystallization studied to date, being readily scalable from the research to the production level. The approach to the experiment was divided into two sections: (1) fabricating the precursor film and (2) processing the precursor film. The objective of the first phase of the work was to fabricate the thin films by RTP, then fully characterize them, to demonstrate the viability of the process as a method by which to make device-quality CuInSe ₂ . The second phase was to demonstrate that material made by this method could be used to make an active photovoltaic device.			
17. Document Analysis a. Descriptors thin films ; CuInSe ₂ ; photovoltaics ; solar cells ; fabrication ; processing 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 69
			20. Price A04

Document Control Page	1. NREL Report No. NREL/TP-413-4791	2. NTIS Accession No. DE92001237	3. Recipient's Accession No.
4. Title and Subtitle Thin Film Cadmium Telluride, Zinc Telluride, and Mercury Zinc Telluride Solar Cells			5. Publication Date April 1992
			6.
7. Author(s) T. L. Chu			8. Performing Organization Rept. No.
9. Performing Organization Name and Address University of South Florida Tampa, Florida 33620			10. Project/Task/Work Unit No. PV231102
			11. Contract (C) or Grant (G) No. (C) XL-8-18091-1 (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 July 1988 - 31 December 1991
			14.
15. Supplementary Notes NREL technical monitor: H. S. Ullal			
16. Abstract (Limit: 200 words) This report describes research to demonstrate (1) thin film cadmium telluride solar cells with a quantum efficiency of 75% or higher at 0.44 μm and a photovoltaic efficiency of 11.5% or greater, and (2) thin film zinc telluride and mercury zinc telluride solar cells with a transparency to sub-band-gap radiation of 65% and a photovoltaic conversion efficiency of 5% and 8%, respectively. Work was directed at (1) depositing transparent conducting semiconductor films by solution growth and metal-organic chemical vapor deposition (MOCVD) techniques, (2) depositing CdTe films by close-spaced sublimation (CSS) and MOCVD techniques, (3) preparing and evaluating thin film CdTe solar cells, and (4) preparing and characterizing thin film ZnTe, $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$, and $\text{Hg}_{1-x}\text{Zn}_x\text{Te}$ solar cells. The deposition of CdS films from aqueous solutions was investigated in detail, and their crystallographic, optical, and electrical properties were characterized. CdTe films were deposited from DMCd and DIPTe at 400°C using TEGa and AsH_3 as dopants. CdTe films deposited by CSS had significantly better microstructures than those deposited by MOCVD. Deep energy states in CdTe films deposited by CSS and MOCVD were investigated. Thin films of ZnTe, $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$, and $\text{Hg}_{1-x}\text{Zn}_x\text{Te}$ were deposited by MOCVD, and their crystallographic, optical, and electrical properties were characterized.			
17. Document Analysis a. Descriptors thin film ; cadmium telluride ; zinc telluride ; mercury zinc 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 98
			20. Price A05

Document Control Page	1. NREL Report No. NREL/TP-451-4797	2. NTIS Accession No. DE92001239	3. Recipient's Accession No.
4. Title and Subtitle Thin Film Cadmium Telluride Photovoltaic Cells		5. Publication Date April 1992	
		6.	
7. Author(s) A. Compaan and R. Bohn		8. Performing Organization Rept. No.	
9. Performing Organization Name and Address University of Toledo Department of Physics and Astronomy Toledo, OH 43606		10. Project/Task/Work Unit No. PV231101	
		11. Contract (C) or Grant (G) No. (C) ZN-1-19019-3 (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 23 July 1990 - 31 October 1991	
		14.	
15. Supplementary Notes NREL technical monitor: B. von Roedern			
16. Abstract (Limit: 200 words) This report describes research to develop two vacuum-based growth techniques for CdTe thin-film solar cells: (1) laser-driven physical vapor deposition (LDPVD) and (2) radio-frequency (rf) sputtering. The LDPVD process was successfully used to deposit thin films of CdS, CdTe, and CdCl ₂ , as well as related alloys and doped semiconductor materials. The laser-driven deposition process readily permits the use of several target materials in the same vacuum chamber and, thus, complete solar cell structures were fabricated on SnO ₂ -coated glass using LDPVD. The rf sputtering process for film growth became operational, and progress was made in implementing it. Time was also devoted to enhancing or implementing a variety of film characterization systems and device testing facilities. A new system for transient spectroscopy on the ablation plume provided important new information on the physical mechanisms of LDPVD. The measurements show that, e.g., Cd is predominantly in the neutral atomic state in the plume but with a large fraction that is highly excited internally (≥ 6 eV), and that the typical neutral Cd translational kinetic energies perpendicular to the target are 20 eV and greater.			
17. Document Analysis a. Descriptors thin films ; 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 42	
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Document Control Page	1. NREL Report No. NREL/TP-413-4835	2. NTIS Accession No. DE92001242	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 April 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 Purdue University School of Electrical Engineering West Lafayette, IN 47907		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 1990 - 31 December 1990	
		14.	
15. Supplementary Notes NREL technical monitor: H. S. Ullal			
16. Abstract (Limit: 200 words) This report describes work to develop a highly accurate numerical model for CuInSe ₂ and CdTe solar cells. ADEPT (A Device Emulation Program and Toolbox), a one-dimensional semiconductor device simulation code developed at Purdue University, was used as the basis of this model. An additional objective was to use ADEPT to analyze the performance of existing and proposed CuInSe ₂ and CdTe solar cell structures. The work is being performed in two phases. The first phase involved collecting device performance parameters, cell structure information, and material parameters. This information was used to construct the basic models to simulate CuInSe ₂ and CdTe solar cells. This report is a tabulation of information gathered during the first phase of this project on the performance of existing CuInSe ₂ and CdTe solar cells, the material properties of CuInSe ₂ , CdTe, and CdS, and the optical absorption properties of CuInSe ₂ , CdTe, and CdS. The second phase will entail further development and the release of a version of ADEPT tailored to CuInSe ₂ and CdTe solar cells that can be run on a personal computer. In addition, ADEPT will be used to analyze the performance of existing and proposed CuInSe ₂ and CdTe solar cell structures.			
17. Document Analysis a. Descriptors polycrystalline thin films ; thin films ; CuInSe ₂ ; CdTe ; photovoltaics ; solar cells ; computer models ; numerical model 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 41	
		20. Price A03	

Document Control Page	1. NREL Report No. NREL/TP-413-4873	2. NTIS Accession No. DE92010564	3. Recipient's Accession No.
4. Title and Subtitle Module Process Optimization and Device Efficiency Improvement for Stable, Low-Cost, Large-Area, Cadmium Telluride-Based, Photovoltaic Module Production			5. Publication Date April 1992
			6.
7. Author(s) S.P. Albright, B. Ackerman, R.R. Chamberlin, J.F. Jordan			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Photon Energy, Inc. El Paso, TX 79924			10. Project/Task/Work Unit No. PV231101
			11. Contract (C) or Grant (G) No. (C) ZN-9-19019 (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 1990 - 31 December 1991
			14.
15. Supplementary Notes NREL technical monitor: H. S. Ullal			
16. Abstract (Limit: 200 words) This report describes work under a three-year phased subcontract to develop CdS/CdTe devices and modules and to further improve the technology base at Photon Energy, Inc. (PEI) to better address the commercialization issues and objectives of the PEI and the U.S. Department of Energy. During this reporting period we (1) achieved efficiencies of 12.7% on small area devices, (2) achieved 1-ft ² modules with over 8% aperture-area efficiency (and active area efficiencies up to ~10%), (3) tested 4-ft ² modules at NREL at 23.1 (21.3) watts, normalized (6.3% efficiency), and (4) found no inherent stability problems with CdTe technology during life testing, at both NREL and PEI.			
17. Document Analysis a. Descriptors module ; device ; efficiency ; cadmium telluride ; photovoltaics ; solar cells ; thin film 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 58
			20. Price A04

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 National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161		19. No. of Pages 76	
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Crystalline Materials and Advanced Concepts

Document Control Page	1. SERI Report No. SERI/TP-214-4503	2. NTIS Accession No. DE92001172	3. Recipient's Accession No.
4. Title and Subtitle The Effectiveness and Stability of Impurity/Defect Interactions and Their Impact on Minority Carrier Lifetime			5. Publication Date December 1991
			6.
7. Author(s) G. A. Rozgonyi, F. Shimura, A. Buczkowski, T.-Q. Zhon			8. Performing Organization Rept. No.
9. Performing Organization Name and Address North Carolina State University Raleigh, North Carolina 27695			10. Project/Task/Work Unit No. PV121101
			11. Contract (C) or Grant (G) No. (C) XL-8-18097-2 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: B. Sopori, (303) 231-1383			
16. Abstract (Limit: 200 words) This report covers the investigation and understanding of electrical activity of "clean" and metallic impurity decorated defects. A heterostructure containing a controlled number of deliberately introduced misfit dislocations is used as a model system to simulate a variety of defect/impurity interactions in photovoltaic materials. In addition, a noncontact laser/microwave deep-level transient spectroscopy technique is applied to characterize the minority carrier lifetime and determine the energy levels of defects.			
17. Document Analysis a. Descriptors Photovoltaics ; minority carriers ; manufacturing ; defect/impurity interactions ; 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 63
			20. Price A04

Document Control Page	1. NREL Report No. NREL/TP-451-4855	2. NTIS Accession No. DE92010559	3. Recipient's Accession No.
4. Title and Subtitle Advanced High Efficiency Concentrator Cells		5. Publication Date June 1992	
		6.	
7. Author(s) R. Gale		8. Performing Organization Rept. No.	
9. Performing Organization Name and Address Varian Research Center 3075 Hansen Way Palo Alto, California 94304-1025		10. Project/Task/Work Unit No. PV221103	
		11. Contract (C) or Grant (G) No. (C) XL-9-18103-1 (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 October 1988 - 31 March 1990	
		14.	
15. Supplementary Notes NREL technical monitor: J. Benner			
16. Abstract (Limit: 200 words) This report describes research to develop the technology needed to demonstrate a monolithic, multijunction, two-terminal, concentrator solar cell with a terrestrial power conversion efficiency greater than 35%. Under three previous subcontracts, Varian developed many of the aspects of a technology needed to fabricate very high efficiency concentrator cells. The current project was aimed at exploiting the new understanding of high efficiency solar cells. Key results covered in this report are as follows. (1) A 1.93-eV AlGaAs/1.42-eV GaAs metal-interconnected cascade cell was manufactured with a one-sun efficiency of 27.6% at air mass 1.5 (AM1.5) global. (2) A 1.0-eV InGaAs cell was fabricated on the "reverse" side of a low-doped GaAs substrate with a one-sun efficiency of 2.5% AM1.5 diffuse and a short-circuit current of 14.4 mA/cm ² . (3) Small-scale manufacturing of GaAs p/n concentrator cells was attempted and obtained an excellent yield of high-efficiency cells. (4) Grown-in tunnel junction cell interconnects that are transparent and thermally stable using C and Si dopants were developed.			
17. Document Analysis a. Descriptors high efficiency ; concentrators ; photovoltaics ; solar cells ; gallium arsenide b. Identifiers/Open-Ended Terms c. UC Categories 275			
18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161		19. No. of Pages 50	
		20. Price A03	

PV Manufacturing Technology Development (PVMaT)

Document Control Page	1. SERI Report No. SERI/TP-214-4476	2. NTIS Accession No. DE91015026	3. Recipient's Accession No.
4. Title and Subtitle Photovoltaic Manufacturing Technology Program			5. Publication Date November 1991
			6.
7. Author(s) S. Hogan			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Spire Corporation One Patriots Park Bedford, Massachusetts 01730			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-1 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: R. Mitchell, (303) 231-1379			
16. Abstract (Limit: 200 words) The work performed in this contract was focused on two areas: an economic analysis of present manufacturing methods and the conceptualization of advanced equipment. The economic analysis was built on our experience with tabbing and connecting thick cells. This experience was used to generate the cost analysis that clearly points to the importance of improvements in yield and throughput to make PV manufacturing more cost effective.			
17. Document Analysis a. Descriptors Photovoltaic modules ; manufacturing ; design ; economic analysis ; 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 38
			20. Price A03

Document Control Page	1. SERI Report No. SERI/TP-214-4477	2. NTIS Accession No. DE91015028	3. Recipient's Accession No.
4. Title and Subtitle Low-Cost Manufacturing of the Point-Focus Concentrating Module and Its Key Component, the Fresnel Lens			5. Publication Date November 1991
			6.
7. Author(s) S. T. Saifee, A. Konnerth III			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Solar Kinetics Inc. 10635 King William Dr. Dallas, Texas			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-15 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: R. Mitchell, (303) 231-1379			
16. Abstract (Limit: 200 words) Solar Kinetics, Inc. (SKI) has been developing point-focus concentrating PV modules since 1986. SKI is currently in position to manufacture between 200 and 600 kilowatts annually of the current design by a combination of manual and semi-automated methods. This report reviews the current status of module manufacture and specifies the required approach to achieve a high-volume manufacturing capability and low cost. The approach taken will include process development concurrent with module design for automated manufacturing. The current effort reviews the major manufacturing costs and identifies components and processes whose improvements would produce the greatest effect on manufacturability and cost reduction. The Fresnel lens is one such key component. Investigating specific alternative manufacturing methods and sources has substantially reduced the lens costs and has exceeded the DOE cost-reduction goals.			
17. Document Analysis a. Descriptors Point focus concentrating photovoltaic modules ; manufacturing ; Fresnel lens ; components ; photovoltaics ; solar cells b. Identifiers/Open-Ended Terms c. UC Categories 275			
18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161			19. No. of Pages 100
			20. Price A05

Document Control Page	1. SERI Report No. SERI/TP-214-4478	2. NTIS Accession No. DE91015027	3. Recipient's Accession No.
4. Title and Subtitle Final Technical Report, Phase 1, Photovoltaic Manufacturing Technology			5. Publication Date November 1991
			6.
7. Author(s) J. Brown			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Solar Cells, Inc. 2650 N. Reynolds Rd. Toledo, Ohio 43615			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-19 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: R. Mitchell, (303) 231-1379			
16. Abstract (Limit: 200 words) A development/manufacturing program is described for achieving photovoltaic modules at a cost less than \$.50/Watt and solar generating fields at a total installed system cost of less than \$1.50/Watt. The basic approach is to construct a fully automated continuous production line based on close spaced sublimation (CSS) deposition of CdTe to produce 60 cm x 120 cm thin-film PV modules. The high deposition rate possible with CSS opens up the possibility of obtaining very high throughput in the range of hundreds of megawatts per year. This leads to dramatic reductions in the capital, labor and overhead cost per unit. The program includes a development phase, an initial production line of about 5-MW/year capacity, a 5 MW solar generating field, and a high-throughput production line with a capacity in the range of hundreds of megawatts per year.			
17. Document Analysis a. Descriptors Photovoltaic panels ; manufacturing ; close spaced sublimation ; amorphous silicon ; 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 49
			20. Price A03

Document Control Page	16. NREL Report No. NREL/TP-214-4479	2. NTIS Accession No. DE92001151	3. Recipient's Accession No.
4. Title and Subtitle Cost Effective Manufacturing of the SEA 10X Concentrator Array			5. Publication Date November 1991
			6.
7. Author(s) N. Kaminar, J. McEntee, D. Curchod			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Solar Engineering Application Corporation 2010 Fortune Drive, Suite 102 San Jose, California 95131			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-21 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Boulevard Golden, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: R. Mitchell			
16. Abstract (Limit: 200 words) This report describes a low-cost, mass-producible 10X concentrator system that has been claimed to produce electricity at \$0.04/kWh. It details changes in manufacturing techniques that could produce a concentrator system at a selling price of \$0.71/W. (A simple design and a minimum number of parts and manufacturing steps reduced production costs.) Present production techniques, changes to improve these techniques, impediments to changes, and solutions to the impediments are described. This 10X concentrator system uses available components and manufacturing processes and one-sun solar cells in conjunction with inexpensive plastic lenses to generate about eight times the amount of electricity normally produced by these cells.			
17. Document Analysis a. Descriptors concentrators ; arrays ; photovoltaics ; manufacturing ; concentrator modules ; one-sun cells ; tracking ; solar cells b. Identifiers/Open-Ended Terms c. UC Categories 275			
18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161			19. No. of Pages 103
			20. Price A06

Document Control Page	1. SERI Report No. SERI/TP-214-4480	2. NTIS Accession No. DE92001152	3. Recipient's Accession No.
4. Title and Subtitle Photovoltaics Manufacturing Technology Phase I, Final Report			5. Publication Date November 1991
			6.
7. Author(s) H. Sornberg			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Global Photovoltaic Specialists, Inc. 21525 Parthenia St. Canoga Park, California 91304			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-8 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: R. Mitchell, (303) 231-1379			
16. Abstract (Limit: 200 words) This report describes existing integrated processes for solar cell manufacturing and lists as the primary opportunity for improvement the following areas: low-cost silicon sheets with improved characteristics; improved large-scale and automated solar cell processes that can lead to cell efficiencies in the range of 14% (encapsulated) for direct-cast wafers; improved handling and lamination of large-area modules for the emerging utility market. The proposed solutions can lead to finished module costs on the order of \$1.55 per square meter or a selling price of less than \$2.00/Watt. The problems that may be considered generic to the industry and that have been addressed in this work are as follows: gettering and passivation of silicon wafers; spray-on diffusion sources and combined emitter/back surface field formation using rapid thermal processing; spray-on passivation layers; dual antireflection coatings; ink-jet printing of metallizations; and automated handling of large-area modules and associated vertical lamination.			
17. Document Analysis a. Descriptors Manufacturing ; crystal growth ; wafer formation ; solar cell processes ; module assemblies ; 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 34
			20. Price A03

Document Control Page	1. SERI Report No. SERI/TP-214-4481	2. NTIS Accession No. DE92001153	3. Recipient's Accession No.
4. Title and Subtitle Research on Advanced Photovoltaic Manufacturing Technology			5. Publication Date November 1991
			6.
7. Author(s) T. Jester, C. Eberspacher			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Siemens Solar Industries P. O. Box 6032 Camarillo, California 93011			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-4 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: R. Mitchell, (303) 231-1379			
16. Abstract (Limit: 200 words) This report outlines opportunities for significantly advancing the scale and economy of high-volume manufacturing of high-efficiency photovoltaic (PV) modules. We propose to pursue a concurrent effort to advance existing crystalline silicon module manufacturing technology and to implement thin film CuInSe ₂ (CIS) module manufacturing. This combination of commercial-scale manufacturing of high-efficiency crystalline silicon modules and of pilot-scale manufacturing of low-cost thin film CIS technology will support continued, rapid growth of the U.S. PV industry.			
17. Document Analysis a. Descriptors photovoltaic modules ; thin films ; manufacturing ; crystal growth ; 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 48
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Document Control Page	1. SERI Report No. SERI/TP-214-4482	2. NTIS Accession No. DE92001169	3. Recipient's Accession No.
4. Title and Subtitle Photovoltaic Manufacturing Technology Phase 1			5. Publication Date November 1991
			6.
7. Author(s) M. J. Stern			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Utility Power Group Chatsworth, California			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-6 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: R. Mitchell, (303) 231-1379			
16. Abstract (Limit: 200 words) This report documents Utility Power Group's (UPG) contract under Phase 1 of the Photovoltaic Manufacturing Technology (PVMaT) project. Specifically, the report contains the results of a manufacturing technology cost analysis based on an existing PV module production facility. It also projects the cost analysis of a future production facility based on a larger module area, a larger production rate, and the elimination of several technical obstacles. With a coordinated 18-month engineering effort, the technical obstacles could be overcome. Therefore, if solutions to the financial obstacles concerning production expansion were found, UPG would be able to manufacture PV modules at a cost of under \$1.25 per watt by 1994.			
17. Document Analysis a. Descriptors photovoltaic modules ; thin films ; manufacturing ; 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 22
			20. Price A03

Document Control Page	1. SERI Report No. NREL/TP-214-4483	2. NTIS Accession No. DE92001166	3. Recipient's Accession No.
4. Title and Subtitle Photovoltaic Manufacturing Technology, Phase I, Final Report			5. Publication Date December 1991
			6.
7. Author(s) J.H. Wohlgemuth, D. Whitehouse, S. Wiedeman, A.W. Catalano, R. Oswald			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Solarex Corporation Crystalline Division 630 Solarex Ct. Frederick, Maryland 21701 Thin Films Division 826 Newtown-Yardley Rd. Newtown, Pennsylvania 18940			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-3 (G)
			13. Type of Report & Period Covered Technical Report
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			14.
15. Supplementary Notes NREL technical monitor: R. Mitchell			
16. Abstract (Limit: 200 words) This report identifies steps leading to manufacturing large volumes of low-cost, large-area photovoltaic (PV) modules. Both crystalline silicon and amorphous silicon technologies were studied. Cost reductions for each step were estimated and compared to Solarex Corporation's manufacturing costs. A cost model, a simple version of the SAMICS methodology developed by the Jet Propulsion Laboratory (JPL), projected PV selling prices. Actual costs of materials, labor, product yield, etc., were used in the cost model. The JPL cost model compared potential ways of lowering costs. Solarex identified the most difficult technical challenges that, if overcome, would reduce costs. Preliminary research plans were developed to solve the technical problems.			
17. Document Analysis a. Descriptors photovoltaic manufacturing ; amorphous silicon ; solar cells ; crystalline silicon ; silicon wafers ; low-cost manufacturing ; photovoltaics ; cost analysis 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 48
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Document Control Page	1. SERI Report No. NREL/TP-214-4484	2. NTIS Accession No. DE92001167	3. Recipient's Accession No.
4. Title and Subtitle Thin Edge-Defined Film-Fed Growth (EFG) Octagons			5. Publication Date March 1992
			6.
7. Author(s) J.P. Kalejs			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Mobil Solar Energy Corp. 4 Suburban Park Dr. Billerica, MA 01821			10. Project/Task/Work Unit No. PV250101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-12 (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 - 18 May 1991
			14.
15. Supplementary Notes NREL technical monitor: R. Mitchell			
16. Abstract (Limit: 200 words) Mobil Solar Energy Corp. investigated manufacturing crystalline silicon wafers using the edge-defined film-fed growth (EFG) technique. This report identifies the following: (1) current capabilities for manufacturing 200-micron-thick crystalline silicon wafers (10 cm x 10 cm) produced by growing octagons using the EFG technique and laser cutting them into wafers; (2) potential manufacturing improvements from decreasing the thickness of the wafers, improving the quality of the laser cut edge, and increasing cutting speed, all of which lead to reduced manufacturing costs, improved performance, and increased production capacities; (3) problems that impede achieving these potentials; and (4) costs and other requirements involved in overcoming the problems.			
17. Document Analysis a. Descriptors wafer manufacturing ; cost-effective manufacturing ; solar cells ; edge-defined film-fed growth ; crystalline silicon ; octagon wafers ; photovoltaics b. Identifiers/Open-Ended Terms c. UC Categories 274			
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

Document Control Page	1. SERI Report No. NREL/TP-214-4485	2. NTIS Accession No. DE92001165	3. Recipient's Accession No.
4. Title and Subtitle Development of a Fixed Abrasive Slicing Technique (FAST) for Reducing the Cost of Photovoltaic Wafers			5. Publication Date December 1991
			6.
7. Author(s) F. Schmid			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Crystal Systems Inc. 27 Congress St. Salem, Massachusetts 01970			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-17 (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.
15. Supplementary Notes NREL technical monitor: R. Mitchell			
16. Abstract (Limit: 200 words) This report examines a wafer slicing technique developed by Crystal Systems, Inc. that reduces the cost of photovoltaic wafers. This fixed, abrasive slicing technique (FAST) uses a multiwire bladepack and a diamond-plated wirepack; water is the coolant. FAST is in the prototype production stage and reduces expendable material costs while retaining the advantages of a multiwire slurry technique. The cost analysis revealed that costs can be decreased by making more cuts per bladepack and slicing more wafers per linear inch. Researchers studied the degradation of bladepacks and increased wirepack life.			
17. Document Analysis a. Descriptors fixed, abrasive slicing ; photovoltaic wafers ; wafer slicing ; cost-effectiveness ; manufacturing ; photovoltaics ; solar cells b. Identifiers/Open-Ended Terms c. UC Categories 274			
18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161			19. No. of Pages 64
			20. Price A04

Document Control Page	1. SERI Report No. SERI/TP-214-4486	2. NTIS Accession No. DE92001170	3. Recipient's Accession No.
4. Title and Subtitle Photovoltaic Manufacturing Technology (PVMaT) Improvements for ENTECH's Concentrator Module			5. Publication Date November 1991
			6.
7. Author(s) M. J. O'Neill, A. J. McDanal, J. L. Perry, M. C. Jackson, R. R. Walters			8. Performing Organization Rept. No.
9. Performing Organization Name and Address ENTECH, Inc. 1015 Royal Lane P.O. Box 612246 DFW Airport, Texas 75261			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-0-10057-13 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: R. Mitchell, (303) 231-1379			
16. Abstract (Limit: 200 words) This final technical report documents ENTECH's Phase I contract under the Photovoltaic Manufacturing Technology (PVMaT) project. Under this project we prepared a detailed description of our current manufacturing process for making our unique linear Fresnel lens photovoltaic concentrator modules. In addition, we prepared a detailed description of an improved manufacturing process, which will simultaneously increase module production rates, enhance module quality, and substantially reduce module costs. We also identified potential problems in implementing the new manufacturing process, and we proposed solutions to these anticipated problems. Before discussing the key results of our program, however, we present a brief description of our unique photovoltaic technology. The key conclusion of our PVMaT Phase 1 study is that our module technology, without further breakthroughs, can realistically meet the near-term DOE goal of 12 cents/kWh levelized electricity cost, provided that we successfully implement the new manufacturing process at a production volume of at least 10 megawatts per year. The key recommendation from our Phase 1 study is to continue our PVMaT project into Phase 2A, which is directed toward the actual manufacturing technology development required for our new module production process.			
17. Document Analysis a. Descriptors Photovoltaics ; photovoltaic concentrator modules ; solar cells ; manufacturing ; Fresnel lens b. Identifiers/Open-Ended Terms c. UC Categories 275			
18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161			19. No. of Pages 35
			20. Price A03

Document Control Page	1. SERI Report No. NREL/TP-214-4487	2. NTIS Accession No. DE92001164	3. Recipient's Accession No.
4. Title and Subtitle Photovoltaic Manufacturing Technology, Phase 1, Final Report			5. Publication Date December 1991
			6.
7. Author(s) J.R. Easoz and R.H. Herlocher			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Westinghouse Electric Corporation Advanced Energy Systems P.O. Box 10864 Pittsburgh, Pennsylvania 15236			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-5 (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
			14.
15. Supplementary Notes NREL technical monitor: R. Mitchell			
16. Abstract (Limit: 200 words) This report examines the cost-effective manufacture of dendritic-web-based photovoltaic modules. It explains how process changes can increase production and reduce manufacturing costs. Long-range benefits of these improved processes are also discussed. Problems are identified that could impede increasing production and reducing costs; approaches to solve these problems are presented. These approaches involve web growth throughput, cell efficiency, process yield, silicon use, process control, automation, and module efficiency. Also discussed are the benefits of bifacial module design, unique to the dendritic web process.			
17. Document Analysis a. Descriptors dendritic web ; silicon crystal production ; solar cells ; bifacial module ; photovoltaics ; cost-effective manufacturing ; photovoltaic manufacturing b. Identifiers/Open-Ended Terms c. UC Categories 274			
18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161			19. No. of Pages 115
			20. Price A06

Document Control Page	1. SERI Report No. NREL/TP-214-4488	2. NTIS Accession No. DE92001163	3. Recipient's Accession No.
4. Title and Subtitle Monolithic Amorphous Silicon Modules on Continuous Polymer Substrate		5. Publication Date March 1992	
		6.	
7. Author(s) D.P. Grimmer		8. Performing Organization Rept. No.	
9. Performing Organization Name and Address Iowa Thin Film Technologies Suite 607, ISIS ISU Research Park Ames, Iowa 50010		10. Project/Task/Work Unit No. PV250101	
		11. Contract (C) or Grant (G) No. (C) XC-1-10057-18 (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 1991	
		14.	
15. Supplementary Notes NREL technical monitor: R. Mitchell			
16. Abstract (Limit: 200 words) This report examines manufacturing monolithic amorphous silicon modules on a continuous polymer substrate. Module production costs can be reduced by increasing module performance, expanding production, and improving and modifying production processes. Material costs can be reduced by developing processes that use a 1-mil polyimide substrate and multilayers of low-cost material for the front encapsulant. Research to speed up a-Si and ZnO deposition rates is needed to improve throughputs. To keep throughput rates compatible with depositions, multibeam fiber optic delivery systems for laser scribing can be used. However, mechanical scribing systems promise even higher throughputs. Tandem cells and production experience can increase device efficiency and stability. Two alternative manufacturing processes are described: (1) wet etching and sheet handling and (2) wet etching and roll-to-roll fabrication.			
17. Document Analysis a. Descriptors amorphous silicon ; manufacturing ; modules ; continuous polymer substrate ; solar cells ; photovoltaics 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 113	
		20. Price A06	

Document Control Page	1. SERI Report No. SERI/TP-214-4489	2. NTIS Accession No. DE91015025	3. Recipient's Accession No.
4. Title and Subtitle Photovoltaic Manufacturing Technology-Phase I			5. Publication Date November 1991
			6.
7. Author(s) S. Brown, D. S. Shen, N. Heeke			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Glasstech Solar 6800 Joyce St. Golden, Colorado 80403			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-7 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: R. Mitchell, (303) 231-1379			
16. Abstract (Limit: 200 words) This report describes the Glasstech Solar design concepts for improved thin-film module production, including three process steps: (1) The front-end step includes washing, transparent conductive oxide (TCO) deposition, and patterning. (2) The P-I-N-M step is that in which the photovoltaic cell structure is deposited, including the back contact, without breaking vacuum. (3) The back end step includes masking, etching, washing, subcell testing and repair, interconnection, and encapsulation. The design is flexible and can be configured to a variety of applications. The front and back sections (steps 1 and 3) include a number of rotate modules and spacer conveyors. These modules and conveyors enable the line to hold and release glass panels according to the requirements of the process stations.			
17. Document Analysis a. Descriptors Photovoltaic panels ; photovoltaics ; solar cells ; manufacturing ; amorphous silicon modules ; thin-film module production 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 63
			20. Price A04

Document Control Page	1. SERI Report No. SERI/TP-214-4498	2. NTIS Accession No. DE91015029	3. Recipient's Accession No.
4. Title and Subtitle Improved Techniques for Manufacturing the Alpha Solarco Concentrating Photovoltaic System			5. Publication Date November 1991
			6.
7. Author(s) E. Schmidt			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Alpha Solarco 11534 Gondola Drive Cincinnati, Ohio 45241			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-9 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, Colorado 80401-3393?			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: R. Mitchell			
16. Abstract (Limit: 200 words) This report describes the overall procedure involved in the manufacture of photovoltaic cells and modules; identifies and describes potential cell and module manufacturing processes that can lead to improved performance, reduced manufacturing costs and significantly increased production, and notes the long-range potential benefits of these improvements; identifies and describes any problems that may impede the achievement of the long-range benefits; and identifies and describes the approaches for solving the identified implementation problems, including time and cost estimates.			
17. Document Analysis a. Descriptors photovoltaics ; solar cells ; photovoltaic modules ; cell and module manufacturing ; concentrating photovoltaic system b. Identifiers/Open-Ended Terms c. UC Categories 275			
18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161			19. No. of Pages 36
			20. Price A03

Document Control Page	1. NREL Report No. NREL/TP-214-4568	2. NTIS Accession No. DE91015031	3. Recipient's Accession No.
4. Title and Subtitle Photovoltaic Manufacturing Technology: Phase I			5. Publication Date November 1991
			6.
7. Author(s) W. R. Bottenberg			8. Performing Organization Rept. No.
9. Performing Organization Name and Address AstroPower Inc. Solar Park Newark, Delaware 19716-2000			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XE-1-10057-2 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Boulevard Golden, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: R. Mitchell			
16. Abstract (Limit: 200 words) This report describes the development of a process for preparing thin crystalline silicon on a low-cost substrate. Three cells derived from this process are described; two incorporate light trapping and back surface passivation. Wafer, solar cell, and module fabrication processes and improvements of those processes by using the wafer forming process developed by AstroPower also are described. Solar cells fabricated from AstroPower's Silicon-Film wafers use less material, eliminate ingot sawing, and have the potential to achieve high production rates. Problems in fabrication processes are identified and their solutions are explained. AstroPower proposes a 3-year plan (Phase 2) to develop a high-performance, low-cost solar cell used for terrestrial power applications.			
17. Document Analysis a. Descriptors photovoltaic manufacturing; silicon film; solar cell; crystalline silicon; silicon wafers; wafer fabrication b. Identifiers/Open-Ended Terms c. UC Categories 274			
18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161			19. No. of Pages 22
			20. Price A03

Document Control Page	1. NREL Report No. NREL/TP-214-4569	2. NTIS Accession No. DE91015032	3. Recipient's Accession No.
4. Title and Subtitle Final Report for Photovoltaic Manufacturing Technology Phase I			5. Publication Date November 1991
			6.
7. Author(s) S. Albright			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Photon Energy, Inc. 9650A Railroad Drive El Paso, Texas 79924			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-10 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Boulevard Golden, Colorado 80401-3393			13. Type of Report & Period Covered Technical Report
			14.
15. Supplementary Notes NREL Technical Monitor: R. Mitchell			
16. Abstract (Limit: 200 words) This report summarizes the analysis of photovoltaic module manufacturing done by Photon Energy, Inc. Photon Energy's four-stage expansion plan for photovoltaic module manufacturing is explained. Explored and studied were the following: current capabilities in manufacturing and process development, potential for increasing production and reducing manufacturing costs, problems likely to impede increased production and reduced manufacturing costs, and costs and other requirements involved in overcoming problems in manufacturing technology.			
17. Document Analysis a. Descriptors photovoltaics; manufacturing; modules; cost analysis; float glass plants; solar cells; automation 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 17
			20. Price A03

Document Control Page	1. SERI Report No. NREL/TP-214-4579	2. NTIS Accession No. DE92001199	3. Recipient's Accession No.
4. Title and Subtitle Photovoltaic Manufacturing Technology, Phase 1			5. Publication Date March 1992
			6.
7. Author(s) M. Izu			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Energy Conversion Devices, Inc. 1675 W. Maple Rd. Troy, MI 48084			10. Project/Task/Work Unit No. PV250101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-11 (G)
			13. Type of Report & Period Covered Technical Report 9 January 1991 - 14 April 1991
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			14.
15. Supplementary Notes NREL technical monitor: R. Mitchell			
16. Abstract (Limit: 200 words) This report examines manufacturing multiple-band-gap, multiple-junction solar cells and photovoltaic modules. Amorphous silicon alloy material is deposited (using microwave plasma-assisted chemical vapor deposition) on a stainless-steel substrate using a roll-to-roll process that is continuous and automated. Rapid thermal equilibration of the metal substrate allows rapid throughput of large-area devices in smaller production machines. Potential improvements in the design, deposition, and module fabrication process are described. Problems are also discussed that could impede using these potential improvements. Energy Conversion Devices, Inc. (ECD) proposes cost and time estimates for investigating and solving these problems. Manufacturing modules for less than \$1.00 per peak watt and stable module efficiencies of greater than 10% are near-term goals proposed by ECD.			
17. Document Analysis a. Descriptors photovoltaic manufacturing ; amorphous silicon ; stainless-steel substrate ; solar cells ; photovoltaics ; multiple-band-gap cells ; multijunction 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 92
			20. Price A05

Document Control Page	1. SERI Report No. NREL/TP-214-4606	2. NTIS Accession No. DE92001176	3. Recipient's Accession No.
4. Title and Subtitle Manufacturing Technology Development for CuInGaSe ₂ Solar Cell Modules			5. Publication Date November 1991
			6.
7. Author(s) B.J. Stanbery			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Boeing Aerospace & Electronics P.O. Box 3999 Seattle, WA 98124-2499			10. Project/Task/Work Unit No. PV150101
			11. Contract (C) or Grant (G) No. (C) XC-1-10057-14 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Subcontract Report 9 January 1991 - 14 April 1991
			14.
15. Supplementary Notes NREL technical monitor: R. Mitchell, (303) 231-1379			
16. Abstract (Limit: 200 words) The report describes research performed by Boeing Aerospace and Electronics under the Photovoltaic Manufacturing Technology project. We anticipate that implementing advanced semiconductor device fabrication techniques to the production of large-area CuIn _{1-x} Ga _x Se ₂ (CIGS)/Cd _{1-y} Zn _y S/ZnO monolithically integrated thin-film solar cell modules will enable 15% median efficiencies to be achieved in high-volume manufacturing. We do not believe that CuInSe ₂ (CIS) can achieve this efficiency in production without sufficient gallium to significantly increase the band gap, thereby matching it better to the solar spectrum (i.e., $x \geq 0.2$). Competing techniques for CIS film formation have not been successfully extended to CIGS devices with such high band gaps. The SERI-confirmed intrinsic stability of CIS-based photovoltaics renders them far superior to a-Si:H-based devices, making a 30-year module lifetime feasible. The minimal amounts of cadmium used in the structure we propose, compared to CdTe-based devices, makes them environmentally safer and more acceptable to both consumers and relevant regulatory agencies. Large-area integrated thin-film CIGS modules are the product most likely to supplant silicon modules by the end of this decade and enable the cost improvements which will lead to rapid market expansion.			
17. Document Analysis a. Descriptors photovoltaics ; solar cells ; manufacturing ; thin films ; modules 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

Document Control Page	1. SERI Report No. NREL/TP-214-4608	2. NTIS Accession No. DE92001175	3. Recipient's Accession No.
4. Title and Subtitle Manufacturing of Ultra-High Efficiency Thin-Film Concentrator Cells		5. Publication Date February 1992	
		6.	
7. Author(s) Ronald Gale		8. Performing Organization Rept. No.	
9. Performing Organization Name and Address Kopin Corporation Taunton, Massachusetts		10. Project/Task/Work Unit No. PV150101	
		11. Contract (C) or Grant (G) No. (C) XC-1-10057-20 (G)	
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393		13. Type of Report & Period Covered Subcontract Report 9 January 1991 - 14 April 1991	
		14.	
15. Supplementary Notes NREL technical monitor: R. Mitchell, (303) 231-1379			
16. Abstract (Limit: 200 words) <p>This report describes a research project to study developments required to expedite commercializing the GaAs solar cell concentrator technology. We baseline the GaAs concentrator cell and 1000X module design into pilot operation at Kopin Corporation. To attain these improvements, we will use Kopin's existing pilot line to produce cleavage of lateral epitaxial film for transfer (CLEFT) GaAs solar cells; these cells already exhibit efficiencies of about 24% at air mass 1.5. We will modify the CLEFT cell to form concentrators that perform well at 500-1000 suns. We will derive the know-how for this modification from an integration of Kopin and VS Corporation technologies. The pilot line will be broadened to include cell receiver and module assembly, using VS Corporation technology obtained from Varian as a baseline. A second-generation design will be formulated to address improvements in the module, and these will be incorporated into the pilot line along with the CLEFT concentrator cell. In parallel, we integrate Kopin's CLEFT GaAs cell technology with the advanced AlGaAs and InGaAs material technology obtained by VS Corporation from Varian to develop a near-term, two-junction mechanical stack with an efficiency of 35%. The receiver thus developed will be compatible with a three-junction approach that has been proposed elsewhere by Kopin. Using a three-junction stack can yield an efficiency of over 40%, and when such cells become available, the pilot line process will have been designed to use them.</p>			
17. Document Analysis a. Descriptors photovoltaics ; solar cells ; manufacturing ; high efficiency ; thin films ; concentrators b. Identifiers/Open-Ended Terms c. UC Categories 275			
18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161		19. No. of Pages 30	
		20. Price A03	

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.

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