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*Presented at the
23rd IEEE Photovoltaic Specialists Conference
May 9–14, 1993
Louisville, Kentucky*

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory operated for
the U.S. Department of Energy
under contract No. DE-AC02-83CH10093

Prepared under Task No. PV350101

October 1993

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Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Microfiche A01
Printed Copy A02

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Printed on recycled paper

PROGRESS IN PHASES 2 AND 3 OF THE PHOTOVOLTAIC MANUFACTURING TECHNOLOGY PROJECT (PVMAT)

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ABSTRACT

The first year of the process-specific activities of the Photovoltaic Manufacturing Technology (PVMaT) project has been completed, and the first subcontracts for teamed efforts on R&D of a general nature have been awarded. A second solicitation for process-specific research and development (R&D) is in the evaluation stage for award of subcontracts. This paper describes the technical accomplishments of the first process-specific subcontracts (Phase 2A), the status of the teamed research (Phase 3A), and the status of the solicitation for the second process-specific solicitation (Phases 2B).

INTRODUCTION

As has been described previously [1], the Photovoltaic Manufacturing Technology project (PVMaT) is a government/industry R&D partnership composed of joint efforts between the federal government (through the U.S. Department of Energy) and members of the U.S. photovoltaic (PV) industry. The project's immediate goal is to assist U.S. industry in retaining and extending its world leadership role in the manufacture and commercial development of PV components and systems. PVMaT is designed to do this by helping the U.S. PV industry improve manufacturing processes, accelerate manufacturing cost reductions for PV modules, improve commercial product performance, and lay the groundwork for a substantial scale-up of U.S.-based PV manufacturing plant capacities.

PVMaT is being carried out in three separate phases, each designed to address separate research and development (R&D) requirements for achieving PVMaT goals. Phase 1 was a problem-identification phase of about 3-months duration. In Phase 1, the status and needs of the U.S. PV manufacturing industry were identified, and the development of Phase 2 procurement responsive to the industry's needs was initiated. Phase 1 was completed in 1991.

Phase 2, the problem solution phase, which addresses process-specific problems of specific manufacturers, is now under way with an expected duration of 5 years. The first solicitation under this phase (PVMaT 2A) was open only to those organizations

that received awards in the Phase 1 solicitation, and seven resulting subcontracts were implemented in early 1992. The subcontracts are cost-shared between the U.S. government and U.S. industrial participants. Technical accomplishments for the first year of PVMaT 2A are presented below. Proposals for a second, overlapping, and similar process-specific solicitation (PVMaT 2B) were due in September of 1992. This second Phase 2 solicitation is in the evaluation stage, with awards planned for later this year. PVMaT 2B was open to all U.S. PV industrial firms, thus giving organizations that were not ready for the first Phase 2 procurement cycle another chance to "ramp on" and participate in the solution phase of the program.

Phase 3 addresses R&D problems that are relatively common to a number of PV companies or the PV industry as a whole. These "generic" problem areas are being addressed through a teamed-research approach. A solicitation (Phase 3A) for these teamed research efforts was released in October 1991. Two subcontracts for Phase 3A have recently been awarded. These research organizations are focusing on module-related R&D problems found to be common to a significant set of PV manufacturers, and these subcontract activities are described below.

PVMaT PROGRESS

Phase 2A

The winners in PVMaT 2A are listed in the Table 1 below. Following Table 1 is a description of the seven subcontractor projects and their first year PVMaT accomplishments.

Siemens Solar Industries Photovoltaic Cz Silicon Manufacturing Technology Improvements -Siemens Solar Industries (SSI) is improving Cz Si-ingot quality; increasing the materials use efficiency for crystalline-silicon (c-Si) wafer sawing; investigating improvements in device processing; investigating the introduction of automation to a significant portion of their c-Si module manufacturing lines; and reducing the amount of hazardous waste gener-

Table 1: PVMaT Phase 2A Participants

Subcontractor	Subcontract Title	Principal Investigator
Siemens Solar Industries Camarillo, California	<i>Photovoltaic Cz Silicon Manufacturing Technology Improvements</i>	T. Jester
Solarex Corporation Newtown, Pennsylvania	<i>Large-Area, Triple-Junction, a-Si Alloy Production Scale-Up Project</i>	R. Oswald
Mobil Solar Energy Corporation Billerica, Massachusetts	<i>Thin Edge-Defined Film-Fed Growth (EFG) Octagons</i>	J. Kalejs
ENTECH, Inc. Dallas, Texas	<i>Photovoltaic Manufacturing Technology (PVMaT) Improvements for ENTECH's Concentrator Module</i>	M. O'Neill
AstroPower, Inc. Newark, Delaware	<i>Silicon-Film Photovoltaic Manufacturing Technology</i>	W. Bottenberg
Utility Power Group Chatsworth, California	<i>a-Si Photovoltaic Manufacturing Technology—Phase 2A</i>	G. Duran
Energy Conversion Devices Troy, Michigan	<i>Continuous Roll-to-Roll Amorphous Silicon Photovoltaic Manufacturing Technology</i>	M. Izu

ated. This effort is being addressed in three 1-year phases. Successful implementation of this program will result in decreasing SSI's c-Si module cost by more than half while doubling its U.S. manufacturing capability. SSI's accomplishments during the first phase of this subcontract include an increase in wire-saw production capacity by over 30% due to reduced kerf loss and thinner wafer processing; an increase in crystal-growth yields through polysilicon studies; elimination of Freon and replacement with a no-clean solder paste in SSI's module production by April 1993; and incorporation of graphite design changes into the SSI's crystal growers, resulting in a 30% cost savings (\$300K/yr).

Solarex Corporation Large-Area, Triple-Junction, a-Si Alloy Production Scale-Up Project - Solarex Corporation is improving the deposition and quality of its transparent front contact; optimizing its laser patterning process; scaling up the semiconductor deposition process; improving the back contact deposition; and scaling up and improving the encapsulation and testing of its a-Si:H modules. Successful implementation of this 3-year program will result in Solarex producing $\approx 0.56\text{-m}^2$ (6-ft²), 10% stabilized efficiency, 75-W a-Si:H modules with a total overall module yield of $\approx 75\%$. At a proposed production capacity of 10 MW/year, this would result in a potential cost reduction from the present price of \$11.05/W_p to \$1.14/W_p. Solarex's accomplishments during the first phase of this subcontract include; the design of an $\approx 0.56\text{-m}^2$ (6-ft²) plasma-enhanced chemical vapor deposition (PECVD) a-Si:H based deposition system; completion of light soaking tests; demonstration of a new laser-scribing system that does not cause module failures in the wet hi-pot tests; and the fabrication of a Frit Dispenser used in Solarex module fabrication.

Mobil Solar Energy Corporation Thin Edge-Defined Film-Fed Growth (EFG) Octagons - Mobil Solar Energy Corporation (MSEC) is reducing the cost of solar cell processing through a 50% reduction in its EFG Si-wafer thickness; increasing the throughput of the laser-cutting of the wafers; increasing the mechanical strength, and thus yield, of the wafers; and evaluating integrated computer-aided manufacturing control programs for the MSEC crystal growth manufacturing line to enhance productivity. Successful implementation of this 3-year program will allow Mobil Solar to produce octagonal Si tubes, producing 200- μm -thick Si wafers with a thickness variation of $\pm 50\text{ }\mu\text{m}$. The previous minimum wafer thickness for this process was 400 μm . MSEC will also develop laser wafer-cutting capabilities resulting in the processing of 12 wafers per minute. Its accomplishments during the first phase of this subcontract include testing and analysis that indicate potential materials cost reductions of 15% due to wafer thickness, 10% due to wafer flatness improvement, and 25% due to a growth rate; completing specifications for a factory prototype EFG octagon crystal growth furnace for 300- μm -thick Si wafers; designing and testing a laser cutting station that will increase pilot production line throughput by a factor of two; and demonstration of the cutting feasibility of silicon wafers near the low-damage threshold with a 585-nm high-power dye laser.

ENTECH, Incorporated Photovoltaic Manufacturing Technology Improvements for ENTECH's Concentrator Module - ENTECH is automating a significant portion of its manufacturing line, aiding key ENTECH vendors in improving the vendors'

technologies; scaling up the ENTECH manufacturing line to accommodate large volume production; and addressing ES&H issues throughout all of the associated manufacturing processes. The effort is being addressed in two 1-year phases. Successful implementation of this program will result in an initial linear concentrator module manufacturing plant with the capability of producing PV modules at a rate of 10 MW/yr. ENTECH's accomplishments during the first phase of this subcontract include; the development of laboratory prototype work stations for PV cell assemblies and receivers; the identification and delivery of process-compatible advanced-cell samples from four separate vendors; the development of an improved prismatic lens cover for cells that resulted in a 90% reduction in both material and labor costs for that step; the development of a continuous, prelaminated, rolled Fresnel lens that resulted in both a 20% materials cost reduction and the elimination of solvent use in the ENTECH process; and development of ribbon solder techniques that have resulted in an 80% reduction in materials costs with additional savings in labor.

AstroPower, Incorporated Silicon-Film_® Photovoltaic Manufacturing Technology - AstroPower is enhancing its Silicon-Film_® wafer production capabilities, optimizing its solar cell processing, and improving the polycrystalline silicon-film module assembly portion of its manufacturing line. Successful implementation of this 3-year program will result in an upgrade to AstroPower's facility that will allow it to reach a production rate of 19 MW/yr of 1.22-m² polycrystalline silicon modules with an output of 170 W_p each by the mid-1990s. AstroPower's accomplishments during the first phase of this subcontract include the demonstration of an 8.8% efficient 10-cm x 10-cm Silicon-Film_® solar cell; the fabrication of the first 15-cm x 45-cm Silicon-Film_® cell (the largest solar cell ever produced); the demonstration of a 0.48-MW/yr Silicon-Film_® machine operation rate, and 74% silicon feedstock use efficiency; the initial planning for 2.4-MW/year wafer fabrication machine; and planning for the introduction of new 225-cm² Silicon-Film_® solar cell product in 1993.

Utility Power Group a-Si Photovoltaic Manufacturing Technology—Phase 2A - The Utility Power Group (UPG) is conducting research on encapsulation of their a-Si:H modules, with consideration given to approaches that do not require a second glass layer, and automation of module termination. Additionally, UPG's lower-tier subcontractor, Advanced Photovoltaic Systems (APS), is optimizing the automation of its Eureka_® manufacturing line; improving the encapsulation of the Eureka_® module, and introduc-

ing real-time processing and quality control to the Eureka_® production line. Successful implementation of this 3-year effort will result in increasing the module manufacturing yield over the current level by 35% while decreasing the direct cost by about 25%. The accomplishments of the UPG-APS team during the first phase of this subcontract include the completion of POWERGLASS module qualification testing for candidate encapsulation materials; reduced POWERGLASS module termination and encapsulation manufacturing costs by 50%; the introduction of three new Eureka_® module products (25-W and 50-W products for 12-V applications); completion of the automation of about 60% of the Eureka_® production encapsulation line; and completion of a design for full-scale enhanced Eureka_® modules.

Energy Conversion Devices, Incorporated Continuous Roll-to-Roll Amorphous Silicon Photovoltaic Manufacturing Technology - Energy Conversion Devices (ECD) is developing the production of 0.3-m x 1.22-m (1-ft x 4-ft) triple-junction a-Si-Ge alloy modules with 11% stable efficiency, reducing its manufacturing costs through utilization of its high deposition rate techniques to enhance the production throughput, and reducing material and labor costs. The effort is being addressed in three 1-year phases. Successful implementation of this program will allow ECD to work toward an ultimate goal of building a 100-MW/yr roll-to-roll, automated a-Si module manufacturing facility. At this anticipated production capacity, ECD could reduce the cost of PV-generated electricity to less than \$1.00/W_p. ECD's accomplishments during the first phase of this subcontract include completion of improvements to the ECD a-Si-Ge alloy deposition system, establishing the first roll-to-roll a-Si-Ge production line facility; demonstration of 7.2% stabilized efficiency on ≥ 1.22 -m (4-ft²) triple-junction a-Si alloy modules; and significant efforts toward increasing the effective manufacturing throughput.

Phase 3A

The winners in PVMaT 3A are listed in the Table 2 below. Both contracts began in early January 1993. Following Table 2 is a description of the seven subcontractor projects.

Spire Corporation Automated Solar Cell Assembly Teamed Process Research - Spire will conduct manufacturing R&D to improve crystalline and polycrystalline Si PV module manufacturing processes with a goal of substantially reducing module manufacturing costs. Areas that will be addressed include processing

Table 2: PVMaT Phase 3A Participants

Subcontractor	Subcontract Title	Principal Investigator
Spire Corporation Bedford, Massachusetts	<i>Automated Solar Cell Assembly Teamed Process Research</i>	M. Nowlan
Springborn Laboratories, Inc. Enfield, Connecticut	<i>Photovoltaic Manufacturing Technology (PVMaT)</i>	W. Holley

rates, process control, yield, throughput, material utilization efficiency, and increased use of automation. These issues are being addressed for thin ($\leq 200\text{-}\mu\text{m}$) silicon wafers. To conduct these efforts, Spire will team with Solec International (a PV module manufacturer) and the University of Massachusetts-Lowell/Center for Productivity Enhancement (automation specialists) who will act as lower-tier subcontractors. The effort is being addressed in two, 1-year phases.

Springborn Laboratories Photovoltaic Manufacturing Technology (PVMaT) - Springborn will try to solve problems related to the PV module encapsulant ethylene-vinyl-acetate (EVA) discoloration and/or degradation. Areas that will be addressed include a case history study and problem definition, identification of discoloration and/or degradation mechanisms, development of

EVA-stabilization strategies, accelerated testing of new laminates, and pilot scale production and field-testing of new laminates. To conduct these efforts, Springborn is teaming with the SSI; Photocomm, Inc.; United Solar Systems Corp.; Solarex Corp.; Texas Instruments; Solec International, Inc.; UPG; APS; Global Photovoltaic Specialists, Inc.; Arizona State University; Arizona Public Service Company; and the University of Connecticut. The effort is being addressed in three 1-year phases.

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1. C.E. Witt, L.O. Herwig, R. Mitchell, and G.D. Mooney. Status of the Photovoltaic Manufacturing Technology (PVMaT) Project. *Proc. 22nd IEEE PVSC*, Las Vegas, NV (1991).