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THE PHOTOVOLTAIC MANUFACTURING TECHNOLOGY PROJECT (PVMaT) AFTER THREE YEARS

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Abstract

The Photovoltaic Manufacturing Technology project (PVMaT) is a government/industry research and development R&D partnership involving joint efforts between the federal government (through the U.S. Department of Energy [DOE]) and members of the U.S. photovoltaic (PV) industry.[1] The project's 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 scaleup of U.S.-based PV manufacturing plant capacities.

PVMaT is being carried out in three separate phases, each designed to address separate 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 a Phase 2 procurement responsive to the industry's needs was begun. Phase 1 was completed in 1991.

Problem solution began in 1992, under Phase 2A, when DOE awarded multiyear subcontracts to Siemens Solar Industries of Camarillo, California; Solarex Corporation of Newport, Pennsylvania; ENTECH, Inc., of Dallas, Texas; Energy Conversion Devices of Troy, Michigan; AstroPower, Inc., of Newark, Delaware; Mobil Solar Energy Corporation of Billerica, Massachusetts; and Utility Power Group of Chatsworth, California. The subcontracts are cost-shared between the U.S. government and U.S. industrial participants and address process-specific problems encountered by the individual subcontractors. Technical accomplishments for PVMaT 2A are presented in this paper. Subcontracts were recently awarded for a second, overlapping, and similar process-specific solicitation (PVMaT 2B). PVMaT 2B was open to all U.S. PV industrial firms—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. The activities of these new subcontracts are also described.

Two subcontracts presently comprise the Phase 3 effort. Phase 3 addresses R&D problems that are relatively common to a number of PV companies or the PV industry as a whole. A teamed research approach is being used. Spire Corporation of Bedford, Massachusetts, and Springborn Laboratories of Enfield, Connecticut, head the teams working to improve automated module manufacturing lines and encapsulation materials used in module manufacturing, respectively. The first year's work on these subcontracts is also described in this paper.

The Photovoltaic Manufacturing Technology Project

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PVMaT is being carried out in three separate phases, each phase designed to address separate R&D requirements for achieving PVMaT goals. The 22 subcontracts awarded in Phase 1—the problem identification phase—were completed in 1991. Problem solution began in 1992, under Phase 2A, when seven subcon-

Table 1. PVMaT SUBCONTRACTS

Phase 2A			
Siemens Solar Industries	Photovoltaic Cz Silicon Manufacturing Technology Improvements	Terry Jester	$10.5 M
Solarex Corporation	Large-Area, Triple-Junction a-Si Alloy Production Scale-Up Project	Robert Oswald	$10.0 M
ENTECH, Inc.	Photovoltaic Manufacturing Technology (PVMaT) Improvements for ENTECH's Concentrator Module	Mark O'Neill	$ 3.1 M
AstroPower, Inc.	Silicon-Film Photovoltaic Manufacturing Technology	Sandi Collins	$ 7.1 M
Utility Power Group	a-Si PVMaT - Phase 2A	Michael Stern	$ 4.7 M
Energy Conversion Devices	Continuous Roll-to-Roll Amorphous Silicon Photovoltaic Manufacturing Technology	Masatsugu Izu	$10.8 M
Phase 2B			
Golden Photon, Inc.	Photovoltaic Manufacturing Technology Phase 2B - Process Specific Issues	Steve Johnson	$ 9.8 M
Solarex Corporation	Photovoltaic Manufacturing Technology Phase 2B - Process Specific Issues	John Wohlgemath	$ 6.3 M
Solar Cells, Inc.	High-Throughput Manufacturing of Thin-Film CdTe Photovoltaic Modules	Dan Sandwisch	$ 7.4 M
Texas Instruments	Photovoltaic Manufacturing Technology Phase 2B - Spheral Solar™ Technology	Jim Skelly	$16.6 M
Phase 3A			
Springborn Laboratories	Photovoltaic Manufacturing Technology	Bill Holley	$ 1.5 M
Spire Corporation	Automated Solar Cell Assembly Teamed Process Research	Mike Nowlan	$ 1.4 M

tracts were awarded. Four subcontracts were recently awarded for a second, overlapping, and similar process-specific solicitation (Phase 2B). Two subcontracts, addressing generic problem areas and utilizing a teamed approach, were awarded in 1993 under the Phase 3 solicitation. Table 1 above lists PVMaT subcontracts for the active project phases as well as the principle investigators and the total amount of the subcontracts, including the company cost-share. Progress in each of the individual phases is described in the following sections.

Phase 1: Problem Identification

Phase 1 of the project was completed in early 1991. The 22 subcontracts awarded under this phase were worth up to $50,000 each. This identification phase was designed to single out and prioritize those areas in U.S. manufacturing processes where R&D was needed to achieve cost reductions in PV module production.

Phase 2: Problem Solution for Process-Specific R&D

Phase 2 is a solution phase of the PVMaT project and primarily addresses the process-specific problems of U.S. manufacturers. Subcontracted R&D projects under this phase last for up to 3 years and involve U.S.-based companies addressing problems within their manufacturing processes. Each Phase 2 subcontract is for up to $5 million, with industry participants contributing a similar amount of money. The initial competition for Phase 2 subcontracts—Phase 2A—was only open to Phase 1 subcontractors. It resulted in seven awards. A second solicitation for additional process-specific activities—Phase 2B—was open to all U.S. companies. Four awards were made early in 1994. Significant technical accomplishments for the Phase 2B subcontracts follows.

Siemens Solar Industries reported a total module cost reduction of 22% resulting from work under the

PVMaT program. Contributions to these reduced costs include increased Cz grower productivity, reduced wafer costs, reduced solar cell processing costs, reduce module fabrication costs, and reduced caustic use and waste. Siemens also developed, designed, and placed into production a more efficient and larger 75-W module that has contributed to this overall cost reduction. In the vitally important area of Environment, Safety, and Health, Siemens reported the complete elimination of CFC chemicals in its manufacturing facility during the second year of its PVMaT Phase 2A subcontract.

Utility Power Group (UPG) reported the elimination of 30 steps from its PV module termination and encapsulation processes. These improvements, when combined with a 50% increase in module output power, result in a 72% reduction in encapsulation costs, an 81% reduction in costs for the termination process, and an overall module production costs reduction of 28%. The new encapsulation scheme, which is applicable to PV modules with a superstrate structure, consists of silicone impregnated with 100 micron glass spheres, thus allowing the encapsulant to possess scratch resistance not found in pure silicone. This also eliminates the need for a second panel (back panel) of glass. APS, a lower-tier subcontractor to the UPG Phase 2A subcontract, has also achieved a major goal. A complete thin-film processing was carried out on two runs of the new APS facility in Fairfield, California. Plates were fully processed and all systems were tested. This is a major step toward a full up-and-running manufacturing facility.

AstroPower, Inc., achieved a 1030 cm^2 15-V 75.1-W_{Max} thin-film module (measured by NREL on November 8, 1993). AstroPower's modules use PVMaT-developed 15-cm x 15-cm cells and represent both a two-fold increase in the module size and a relative efficiency increase of around 95%. This has resulted in an increase in module power output of almost 350%.

ENTECH, Inc., recently fabricated two 3.66-m (12-ft) modules ("fourth generation") with its latest manufacturing process. The modules are being tested at the Sandia National Laboratories. In addition, ENTECH now utilizes a patented prism cover that eliminates grid obscuration losses with the concentrator cells.

Mobil Solar Energy Corporation delivered 12 complete modules to NREL. These 1.22-m x 1.83-m (4-ft x 6-ft) modules were tested outdoors at NREL, and aperture area efficiencies for the 12 varied from 11.8% to 12.9%. The measurements correspond to maximum power outputs of up to 310 W.

Energy Conversion Devices (ECD) designed, constructed, and began optimization of a new multipurpose, continuous roll-to-roll amorphous silicon (a-Si) alloy cell deposition machine at its own expense. This 200-kW machine is part of the resources ECD agreed to provide for the performance of its PVMaT subcontract. In accordance with the most recent modification of the subcontract, a serpentine deposition chamber was also designed for this machine. This serpentine configuration is intended to demonstrate a compact, low-cost deposition machine with improved throughput and gas utilization. A single-junction small-area cell produced utilizing the serpentine technology has already shown an initial conversion efficiency of 8.3% with improved gas utilization of 20% to 30%. ECD also reported having developed an improved textured Ag/ZnO back-reflector system, demonstrating a 26% gain in J_{sc} over its previous textured Al back-reflector system. ECD also developed a new back-reflector evaluation technique to characterize optical losses. ECD developed a new grid/bus-bar design utilizing thin wire grids to improve the relative module efficiency by approximately 3% to 4% and reduce the grid/bus-bar material cost by approximately 50%. ECD states that the module manufacturing improvements developed during the first 2 years of its PVMaT subcontract will result in a cumulative material cost reduction of 56%.

Under Phase 2B of the PVMaT Project, NREL recently awarded four subcontracts for 3 years each. This includes two awards in CdTe and one on Spheral Solar™ Cells. These subcontracts represent new technology additions to the PVMaT Project. The four companies and their manufacturing process technologies are as follows:

- Solarex Corporation, Rockville, Maryland. Cast ingot polysilicon photovoltaic (PV) modules
- Solar Cells, Inc., Toledo, Ohio. Thin-film cadmium telluride PV modules produced using close-spaced sublimation
- Golden Photon, Golden, Colorado. Cadmium sulfide-cadmium telluride thin-film PV modules produced using spray deposition
- Texas Instruments, Dallas, Texas. Spheral Solar™ silicon PV technology

Each subcontract is expected to total $6–10 million. The total company cost-share for the four awards is approximately 58%.

Phase 3: Teamed R&D

Many module-related problems in PV manufacturing are common to a number of companies and even to the entire PV community. These include advanced module engineering related to materials, manufacturing processes, fabrication equipment, and efficient assembly and installation. Phase 3 of the project is designed to address these more generic problems. Under Phase 3, teams of U.S. organizations work together under subcontracts running for at least 1 year. Recent results from the Phase 3 subcontractors include the following.

Springborn discovered that glass supplied recently (over the last several years) by one particular supplier transmits significantly less UV radiation than glass obtained during the 1980s. During this entire period, many PV manufacturers used glass quite extensively from this supplier. However, the information relating to the altered glass formulation (and consequently, lessened UV transmission) was apparently not known by the PV manufacturers. Because glass that is less transparent to UV should help prevent encapsulant degradation and improve PV module lifetime, PV manufacturers were enjoying a serendipitous (and what could have been fleeting if it had not been for this Springborn discovery) improvement in module lifetime. In addition, because PV manufacturers were not aware of these changes, there may be confusion in recent studies on PV encapsulants. The Springborn effort will help the PV industry solidify advantages of the improved glass.

Spire completed the development of the SPITAB™ Assembler subsystems, including an automatic ribbon feeder, automatic ribbon cutting, and an automated cell placement system. This part of its Phase 3A effort is intended to improve crystalline and polycrystalline Si PV module manufacturing processes with a goal of substantially reducing module manufacturing costs. Areas being addressed include processing rates, process control, yield, throughput, material utilization efficiency, and increased use of automation for thin (less than or equal to 200 microns) Si wafers. To address these areas, Spire is teaming with Solec International (a PV module manufacturer) and the University of Massachusetts–Lowell's Center for Productivity Enhancement (automation specialists) as lower-tier subcontractors.

Summary

The Photovoltaic Manufacturing Technology Project is now in its fifth year. Companies representing a wide spectrum of PV technologies competed successfully to participate in this industry-government partnership. Further, more significant technological advances were experienced throughout the diversity of companies, as can be seen from the results of Siemens (Cz silicon), ENTECH (concentrators), and ECD (a-Si). New partnerships were established in other thin films (e.g., CdTe-based cells) and the Texas Instruments Spheral Solar™ technology. As module manufacturing becomes more mature, the PVMaT project is moving to a product-driven orientation to encompass the improvement of balance-of-systems components needed to make PV systems a truly competitive energy source in widespread applications of electrical energy.

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