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MILESTONE REPORT #6

Project Title: Cost-effective Pilot Line for Flexible PV Modules		
Contract Number: RD3-53	**Milestone Number:** 6	**Report Date:** 10/22/2011
Reporting Period: February 23, 2011 to October 22, 2011		
Milestone Description: Reel-to-Reel Construction		
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Congressional District: 24		

LEGAL NOTICE

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MILESTONE 6 SUMMARY REPORT

Executive Summary

The project is directed to achieving a cost-effective manufacturing-oriented design for pilot production of PV modules. By leveraging the results of InterPhases' RD-78 project, the current research seeks to realize a commercially viable solar cell technology for large-scale renewable electricity generation.

The R&D has progressed along a dual path of process scale-up and simultaneous optimization, aimed at building a strong base for the pilot production. The scale-up research continues to simplify the fabrication, increase device stability and further reduce costs of large scale solar cell production. Fruitful relationships have been established with equipment vendors to develop roll-to-roll (R2R) deposition system and other necessary processing and characterization tools. Detailed characterization effort has been launched through various collaborations in order to better correlate the material and electro-optical properties with the PV performance.

Along with process scale-up and pilot line development, we have been investigating ways to enhance device performance. Considering that the electronic and structural quality of the copper indium selenide (CIS) absorbers is critical to the device performance, we continue to improve its deposition and recrystallization, taking advantage of the emerging annealing technologies. We also continue to investigate the compatibility of alternate junction partners and window materials for the CIS absorber. To make the next leap forward from the current level of performance, the research draws upon new developments in nanotechnology. The research has generated a large database of new information on process parameters, deposition cell geometry and component configurations. The new findings are being implemented in the design of scaled electrodeposition and annealing equipment. It is also revealing new phenomena for this interesting CIS PV system, which we are utilizing for further advances and process simplification.

This period, the project has constructed and installed a new in-house designed, R2R pilot line for CIS deposition. The effort focused on transitioning the critical steps for substrate preparation and absorber deposition to a continuous R2R processing line. This first R2R system will provide precise process parameters for advancing and refining the designs of the future large scale R2R system. This report summarizes the construction, assembly, and initial testing for the R2R processing line, and installation and testing of the subsequent steps for thermal annealing and buffer deposition systems.

Technical Progress

1. R2R line Construction, Installation and Testing

Much of the R&D performed in the preceding months has been integrated into the construction and optimization of the most innovative segment of the pilot line. It comprises the steps of:

(a) Substrate preparation, involving cleaning, activation and rinsing

(b) CIS absorber electrodeposition, based on InterPhases' proprietary process

(c) Thermal treatment by batch process

(d) Buffer deposition by batch or R2R process.

1.1 R2R line for substrate preparation and CIS absorber deposition

A new R2R plating system has been custom designed and constructed in-house. Prior to the installation, the facility was re-structured with the required utility lines. Water supply/drainage lines with plumbing connections to the R2R line were installed. Multiple electrical outlets and an exhaust system have also been installed. Fig. 1 shows an overview photograph of the complete R2R plating system, with its modules

for heating, pumping, cleaning, plating, rinsing, drying and draining. This modular design allows us to test key specifications for the different R2R components.

Tanks: The construction of the plating and solution tanks was outsourced. The tanks for the other modules were constructed in-house.

Supply and drain system: PVC pipes provide the connections for water and solution supply and drainage. Valves were installed at specific points to control the flow.

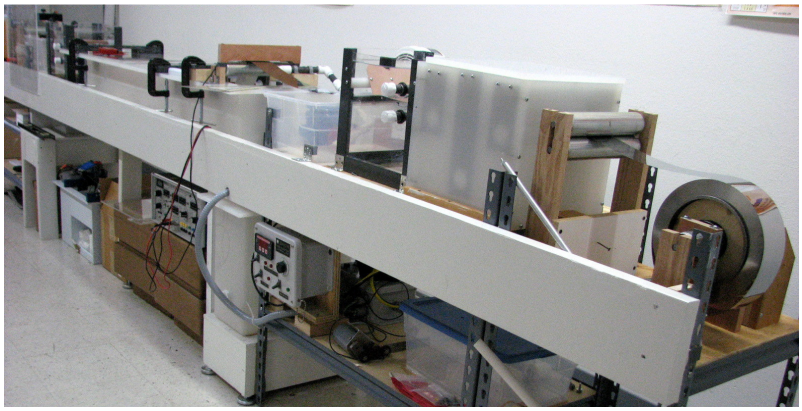

Figure 1. Assembled R2R plating system

Rinsing and draining: Spray-rinsing is used after acid activation to clean the substrate and residual acid, and after electrodeposition to clean residual plating solution. The two rinsing tanks are fitted with 2 sprays each to rinse both sides of the substrate. Drain holes in the tanks allow for quick drainage, so that there is no waste water buildup. Because the R2R system runs continuously, any water buildup can cause flooding.

Drying: An air drying system is installed at the pre-plating station to dry the thin substrate foil after the acid activation and spray rinse. A similar system is used to dry the CIS/foil at the post-plating station. It uses a warm air drying system to completely dry the film before re-winding.

Heating and Pumping System: The plating solution is circulated to achieve uniformity of temperature and chemical concentrations. This is done by pumping the solution from the reservoir to the plating tank and back. The system has controls for solution flow speed, temperature, and low liquid level protection. The circulation also provides agitation in the plating tank, which is required for the electrodeposition.

Roll-to-roll System: consists of mainly unwind and rewind sections for the substrate spool, together with multiple rollers and roller guides distributed along the line. The R2R transport for the foil is driven by a DC motor which also serves to rewind the foil on a roller after deposition. The use of rollers at various points along the line allows easy movement of the foil and fine-tuning the levels to prevent substrate deformation. A brake system controls the foil tension at the unwind station. A sprocket roller driven by a motor/gearbox system through a roller chain at the rewind station pulls the foil at a predetermined speed. A controller and a gearbox speed reducer control the speeds of the motor and the driving chain to provide a flexible range of deposition time. A chain sprocket roller drives the motor to run from 1 – 42 RPM. The speed reducer gearbox further reduces the speed to the 0.07 – 3 RPM range, thus providing sufficient electrodeposition time for the foil to pass through the plating tank.

R2R process: As the substrate roll unwinds, it goes through a series of steps for acid activation, spray-rinsing and air drying, before CIS deposition in the plating tank. As it exits the tank, the CIS coated substrate is rinsed and dried before rewinding into a finished roll.

Initial test-runs have been performed to assure proper operations, e.g. optimize speed and temperature, check and fix leaks, etc. The testing phase led to further modifications in the technical design, components and system construction. Some components have been replaced, to achieve the desired speed control and better synchronicity and compatibility with the overall R2R processing line.

1.2 Installation & testing of Thermal Processing System

InterPhases engineers designed a viable furnace system for incorporation into the R2R line. The annealing system is based upon our results for recrystallizing the CIS films for optimum performance. Its design and

processing conditions were established in collaboration with thermal system manufacturers. System drawings and specifications were submitted to various vendors for furnace construction. The price quote for this system is currently too high and beyond the scope of the current project. Thus, we have constructed an in-house thermal system for batch processing sections of the R2R electrodeposited CIS/foil. It includes various components for controlling the temperature, vapor pressure, etc. Fig. 2. Preliminary experiments show that good control of various processing variables can be achieved with the batch system. This design provides additional parameters for future construction of an optimum R2R furnace system.

Figure 2. Thermal processing system

1.3 Junction/buffer equipment installation & testing

The R2R line for junction formation and buffer deposition uses a smaller processing tank than the plating tank in Fig. 1. This tank is followed by rinse and dry modules as in Fig. 1. However, since the annealing step following the R2R CIS deposition is a batch process, the CIS film roll needs to be cut for thermal processing. Thus we currently continue to use batch processes for the subsequent steps of (a) surface treatment for junction formation, and (b) the deposition a *p*-type buffer layer.

Other Activities:

The company has relocated its facilities to Moorpark, California. This facility was appropriately selected for implementing the R2R lines. Its open layout facilitates better arrangement of the various assembly lines and their integration with other testing equipment. New partnerships have been established with substrate suppliers and furnace manufacturers.

Milestone	Name	% Completed
1	Scaled fabrication for absorber CIS and cell	100%. Research continues to optimize and scale up the deposition and post thermal treatments for CIS films.
2	Scaled strip cell	100%. Research on alternate materials and device configurations.
3	Module assembly	100%. Design module assembly and encapsulation technology.
4	Pilot equipment design	100%. Technical design parameters for continuous RTP equipment.
5	Module assembly design	100%. Design of modules, interconnects and encapsulation.
6	Reel-to-reel construction	100%. R2R deposition line installation and testing.

Project Status

Pilot development tasks for achieving low cost PV electricity with CIS solar cells have advanced to produce a cutting edge R2R processing tool. The no-cost extension period will enable testing and improving the R2R system and process to achieve high quality films on a moving foil. It will generate sufficient experimental data to establish the scalability and R2R manufacturability of electrodeposited CIS solar cells.