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MILESTONE REPORT #5

Project Title: Cost-effective Pilot Line for Flexible PV Modules		
Contract Number: RD3-53	**Milestone Number:** 5	**Report Date:** 2/22/2011
Reporting Period: July 22, 2010 to Feb 22, 2011		
Milestone Description: Pilot design for R2R components		
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Congressional District: 24		

LEGAL NOTICE

PROJECT FUNDING WAS PROVIDED BY CUSTOMERS OF XCEL ENERGY THROUGH
A GRANT FROM THE RENEWABLE DEVELOPMENT FUND

MILESTONE 5 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 continues to progress along a dual path of process scale-up and simultaneous optimization, aimed at building a strong base for the pilot production. Along with pilot development, we have been investigating ways to enhance device performance. The device research has been conducted in continuous iterative loop for optimizing the process parameters to achieve the high performance, low cost manufacturability goals. The scale-up research continues to simplify the fabrication, increase device stability and further reduce costs of large scale solar cell production. Detailed characterization effort has been launched through various collaborations in order to better correlate the material and electro-optical properties with the PV 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 steps, concentrating on refining the process parameters needed to design the roll-to-roll (R2R) equipment for these steps. Significant interactions with the equipment manufacturers have led to fruitful relationships to develop R2R deposition system and other necessary processing and characterization tools. We also continue to investigate the compatibility of alternate junction partners, window materials and device configurations for the CIS based cells. 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 information database on process parameters, deposition cell geometry and component configurations. The new findings are being implemented in the design of equipment for the R2R processing line. It is also revealing new phenomena for this interesting CIS PV system, which we are utilizing for further advances and process simplification.

The project is now advancing to the stage of designing components for R2R plot line. This report summarizes the technical designs and processes developed for continuous R2R processing lines.

Technical Progress

1. R2R line and Equipment layout

The pilot line layout designed for R2R production of CIS solar modules comprises two sequential lines. This period we have advanced specific aspects for each line:

Line I. Developed Engineering design for Line I installation at InterPhases facilities.

Line II. Designed the Technical system for R2R fabrication and assembly of PV modules.

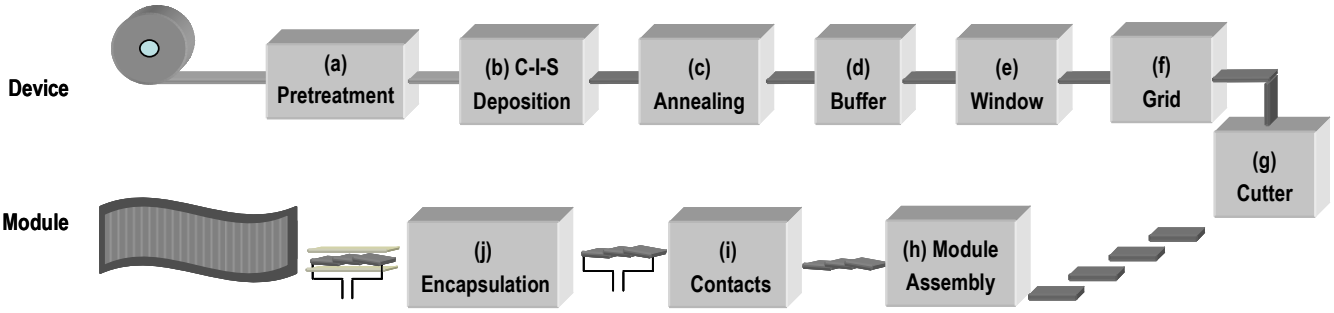

Figure 1. R2R processing schematic shows (top) PV roll fabrication, and (bottom) module construction

Technical designs and specifications for modular components of each of the 2 lines have been obtained.

Line I comprises the steps (a)-(d), represented in Fig. 1. Much of the R&D performed in the preceding months has been directed into designing and developing the most innovative Line I portion of the pilot line. The research focused on producing CIS devices on large substrates in the intermediary stage of scaling up the processes. The results are being integrated into technical designs and specifications for each component of the R2R system in Fig. 1. We have expanded technical interactions with various suppliers of components and manufacturers of pilot production equipment. Efforts are underway to finalize the engineering design and installation of the R2R steps (a)-(d).

Further research on Tasks 3–6 was directed at attaining the proposed Milestone 5 and the subsequent Milestones. It has been extended to design the equipment and process layout for subsequent processing of the PV roll created by the R2R line. Fig. 2 shows overall equipment layout design for the complete pilot line to be installed at our facility. Detailed layout design (deliverable) includes re-structuring of the facility with the required utility lines, such as water, drainage, electrical, air and exhaust, etc.

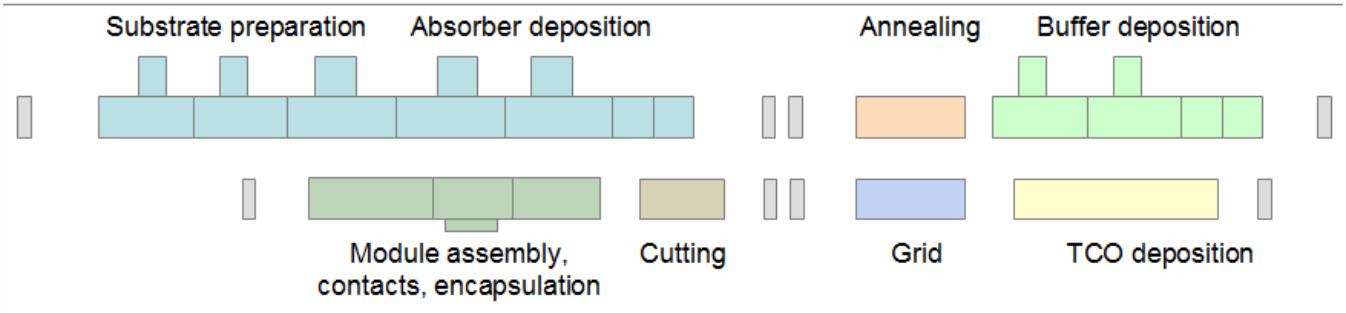

Figure 2. Equipment layout

The technical designs for Line I components were previously presented in Milestone 4. The R&D results of prior months feed directly into developing detailed procedures and process parameters for the steps (a)-(d), Fig. 1. Customized tools and equipment are being designed for this portion of the pilot line, which employs InterPhases' proprietary technology. Since the pilot line needs to be optimized for the process steps, the R2R operations for Line I have been initially divided into two sections. Each section requires unwinding and rewinding steps, as well as rinsing and drying between the major process steps.

- *Section A* comprises:

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

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

- *Section B* comprises:

  (c) Annealing step, using appropriate conditions to recrystallize the CIS films for optimum performance

  (d) Surface processing treatment step, followed by the deposition a buffer layer of complementary conductivity.

In parallel with the Line I development, the project continues to refine the process steps, as well as investigate alternate materials and device structures to achieve the high performance, low cost manufacturability goals. Much of the R&D has been centered on the design and optimization of the recrystallization system and process. The research, conducted in continuous iterative loops, attempts to optimize the process parameters for enhanced device performance. It is revealing new phenomena which

we are exploiting for further advances in device components, structure and process simplification. The new findings are being implemented in the design of equipment for R2R production.

Line II includes the steps of:

(e) Transparent conducting oxide (TCO) window deposition,

(f) Grid application

(g) Cutting the PV roll

(h) Module assembly

(i) Contact application, and

(j) Encapsulation of the modules.

Most module fabrication processes in Line II employ relatively standard industrial procedures that can be easily adapted to produce CIS solar modules, unlike the Line I technology. Therefore, in the early stage pilot line, we have been using batch processing tools in a sequence similar to R2R fabrication. This approach ensures that processes developed in the laboratory can easily be transferred to R2R production tooling. Suppliers have been identified to provide the equipment and tooling for the steps (e)-(j). The steps can be automated with CPU control to handle different module dimensions and to provide optimum processing conditions for particular materials and configurations, including flexible modules.

Regarding step (e) for window deposition, we have devoted considerable effort to develop suitable TCOs and optimum conditions for its deposition on our devices. Our spray deposition system was advanced for easy manufacturability, minimum waste, drastic cost reduction and device applications. The sputtering system was implemented to provide comparative and complementary data for the spray deposited ZnO and other relevant TCO films. The process parameters were identified for both methods to achieve improved device performance.

The research sustained advances in both spray and sputter deposition systems that provide: comparative advantages, ♦ compatibility assessment with device components, ♦ a solid foundation of the scientific knowledge, and ♦ a sound engineering base to launch the pilot scale process development. Progress was made in two main directions: (i) to provide a low cost, large area window deposition tool, amenable to R2R processing, and (ii) deposition of *n-,i-,p-* ZnO and *n*-ITO windows for various configurations of CIS based solar cells. Notable differences between the two processes can be used to advantage. For example the spray deposition avoids sputtering process induced damage to soft buffer layers, hence is more compatible with the organic buffer components. On the other hand, sputtering process provides an alternate lower temperature approach for specific temperature-sensitive applications. These findings will be used to adapt commercially available R2R systems for TCO deposition.

Other Activities:

InterPhases team activities this period include:

- Visits to UCLA for potential collaborations to develop simulation/modeling for advanced device configurations, and optimize our electro-optical characterization set-ups.
- Collaborations with University of Notre Dame, to develop nanotechnology concepts for PV.
- Participation in a presentation on “Photovoltaic Solar Power Technology: Challenges and Opportunities” by Dr. Lori Greene, Director of R&D and Outreach at the UCI Center for Solar Energy, on October 6, 2010. It covered various photovoltaic cell types, production processes, and their cost/ performance challenges, and highlighted the most promising new technologies to meet those challenges. This event included a tour of the center’s laboratories as well as the university’s 1MW PV installation.

New Awards:

InterPhases has received 2 new awards from the National Science Foundation (NSF). The first award provides support for two science students at UCB and UCLA to participate in InterPhases' solar cell R&D, The second award, which extends a current NSF project to develop a low cost, TCO window deposition process for integration into the Xcel pilot line project, was leveraged by RDF project funds.

Project Status:

Pilot development tasks for achieving low cost PV electricity with CIS solar cells are progressing on schedule.

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.