High Performance Photovoltaic Project: Identifying Critical Paths

Preprint

M. Symko-Davies, K. Zweibel, J. Benner, P. Sheldon, R. Noufi, S. Kurtz, T. Coutts, and R. Hulstrom

To be presented at the NCPV Program Review Meeting
Lakewood, Colorado
14-17 October 2001
NOTICE

The submitted manuscript has been offered by an employee of the Midwest Research Institute (MRI), a contractor of the US Government under Contract No. DE-AC36-99GO10337. Accordingly, the US Government and MRI retain a nonexclusive royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for US Government purposes.

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste
ABSTRACT

The High-Performance Photovoltaic (HiPerf PV) Project was initiated by the U.S. Department of Energy to substantially increase the viability of photovoltaics (PV) for cost-competitive applications so that PV can contribute significantly to our energy supply and our environment in the 21st century. To accomplish this, the NCPV directs in-house and subcontracted research in high-performance polycrystalline thin-film and multijunction concentrator devices. This paper describes the recent research accomplishments in the in-house directed efforts as well as the research efforts underway in the subcontracted area.

1. Introduction

The HiPerf PV Project aims at exploring the ultimate performance limits of existing PV technologies, approximately doubling their sunlight-to-electricity conversion efficiencies during its course. This work includes bringing thin-film tandem cells and modules toward 25% and 20% efficiencies, respectively; and developing multijunction pre-commercial concentrator modules able to convert more than one-third of the sun’s energy to electricity (i.e., 33% efficiency).

The project consists of three-phases that focus on a specific approach to solving the challenges associated with high efficiencies. Phase I, “Identifying Critical Paths,” seeks to identify problems, approaches, and alliances. The first HiPerf PV subcontract solicitation [1] was recently completed and allows the NCPV to provide 2 years of funding to the top-ranked companies and universities.

The in-house portion of HiPerf PV is coordinated through three teams. These include a High Performance Thin-Film Team which leads the investigation of tandem structures and low-flux concentrators; and the expansion of the High Efficiency Concepts and Concentrators Team, which leads the high-flux concentrator development. Thin-Film Process Integration, will perform fundamental process and characterization research, working toward resolving the complex issues of making thin-film multijunction devices successfully.

The HiPerf PV Project investigates a wide range of complex issues and provides initial modeling and baseline experiments of several advanced concepts to clarify the challenges and identify critical paths for the longer-term development and application of high-performance PV technologies. The first phase is critical as it provides a means to accelerating towards the most promising paths for implementation, followed by commercial-prototype products. Throughout the program’s time will be the opportunity to reach the established program targets by both revolutionary technology change and multiple incremental improvements. During the project period the alignment of paths with extensive collaboration should produce significant contributions to the entire PV industry.

2. Project Goals and Objectives

The HiPerf PV Project is expected to enable progress of high efficiency technologies towards commercial-prototype products. The following table summarizes the near-term key targets for the HiPerf PV Project. Throughout the course of the first phase, adjustments will be made to these targets as we learn more about the issues and potential research approaches.

<table>
<thead>
<tr>
<th>Near-Term Key Targets</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1. Demonstrate a 20% Efficiency Thin-Film Cell under Low Concentration (Completed)</td>
<td>2001</td>
</tr>
<tr>
<td>T2. Identify Key Issues and Pathways to Achieving a 25% Thin Film Multijunction Cell</td>
<td>2002</td>
</tr>
<tr>
<td>T3. Identify Key Issues and Pathways to Achieving a 33% Concentrator Module</td>
<td>2002</td>
</tr>
<tr>
<td>T4. Establish Diagnostic Development Workgroup Towards Implementation of Thin-Film Process Integration</td>
<td>2002</td>
</tr>
<tr>
<td>T5. Demonstrate a 34% Cell under Concentration</td>
<td>2003</td>
</tr>
<tr>
<td>T6. Full Implementation of Thin-Film Process Integration</td>
<td>2004</td>
</tr>
<tr>
<td>T7. Fabricate a Polycrystalline Thin-Film Tandem Cell of 15% Efficiency</td>
<td>2004</td>
</tr>
<tr>
<td>T8. Cultivate/solicit Industrial Partners towards 15%-Efficient Prototype Thin Film Tandem Cell Suitable for Integration into a Pre-Existing Concentrator Module Technology</td>
<td>2005</td>
</tr>
</tbody>
</table>

Table 1. Near-term key targets for the HiPerf PV Project

3. In-House Accomplishments

The first target listed in Table 1, “Demonstrate a 20% Efficiency Thin Film Cell under Low Concentration” has been completed in FY01. NREL through a combined effort of the CIS Team and High Performance PV task demonstrated a 21.5% CIGS-based solar cell on glass substrate under 14 suns (direct spectrum). This result indicates that CIGS devices may be a viable alternative to single-crystal Si devices for systems that provide low to...
moderate (5-100 suns) solar concentration, especially when
the device can be transferred to a metallic substrate without
loss of efficiency.

A significant contribution to tandem thin-film polycrystalline device modeling was made by combining
state-of-the-art J0 values with a multilayer optical model. Efficiency versus top and bottom cell bandgap contour maps were calculated under AM1.5 illumination. These results [2] have guided the polycrystalline team to identify materials with the optimum bandgaps suitable for a polycrystalline tandem device. This work was voted “Best Paper” at the 12th International PVSEC, 2001 in JeJu Korea.

4. Subcontract R&D

Eleven groups, selected competitively, were involved in
negotiations for the HiPerf PV Phase I, Identifying Critical Pathways. Ten of eleven awards have been completed and have begun activities. The in-house and subcontracted research activities are beginning to work closely together (i.e., through informal groups) toward the achievement of the project goals. The majority of the subcontracts have scheduled deliverables to NREL for the specific purpose of collaborating with the in-house teams.

The following is a table of the subcontracts currently active in Phase I, beginning with the polycrystalline thin film awards followed by the multi-junction concentrator awards.

<table>
<thead>
<tr>
<th>Subcontractor</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Astropower</td>
<td>InGaP/GaAs-on-Ceramic Thin-Film Monolithically Interconnected, Large Area, Tandem Solar Cell Array</td>
</tr>
<tr>
<td>University of Delaware</td>
<td>Thin Film Multijunction Solar Cells Development of a High Bandgap Cell</td>
</tr>
<tr>
<td>University of Toledo</td>
<td>Polycrystalline Thin-Film Tandem Photovoltaic Cells</td>
</tr>
<tr>
<td>University of South Florida</td>
<td>Development of a II-VI-Based High Performance, High Band Gap Device for Thin-Film Tandem Solar Cells</td>
</tr>
<tr>
<td>University of Florida</td>
<td>Identification of Critical Paths in the Manufacturing of Low-Cost High-Efficiency CGS/CIS Two-Junction Tandem Cells</td>
</tr>
<tr>
<td>Global Solar</td>
<td>Progress Toward 20% Efficient CuIn_{x}Ga_{1-x}Se_{2} Photovoltaic Devices on Foil Substrates</td>
</tr>
<tr>
<td>University of Illinois</td>
<td>Cu(In,Ga)Se_{2} Heterojunction Solar Cells for Extreme High-efficiency Photovoltaic Concentrators</td>
</tr>
<tr>
<td>Entech, Inc.</td>
<td>Near-Term Integration of III-V Cells Operating at 440X, Into Entech's Field Proven Concentrator Module</td>
</tr>
</tbody>
</table>

Table 2. Subcontracts currently Active in the HiPerf PV Project under Phase I, Identifying Critical Pathways. (* denotes currently under negotiations)

5. Conclusions

Phase I, Identifying Critical Paths, of the HiPerf PV Project is underway with in-house and subcontracted research efforts in high-performance polycrystalline thin-film and multijunction concentrator devices. The subcontracted effort has ten of eleven subcontracts active and are making headway.

Towards achieving long-term DOE-goals [3], the HiPerf PV Project is focused to assure that tandem thin film modules reach efficiency levels consistent with cost-competitive goals, and that concentrator cells reach performance levels that would allow concentrator PV to be deployed appropriately to produce cost-competitive electricity.

6. Acknowledgements

This work is supported under DOE Contract No. DE-AC36-99GO10337 with NREL. Many people have contributed to the development and implementation of the High Performance PV project and to the R&D efforts carried out in this program. The authors thank each of them and recognize that this paper represents their work.

REFERENCES

