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High Performance Photovoltaic Project: Identifying Critical Paths

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

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1617 Cole Boulevard
Golden, Colorado 80401-3393

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High Performance Photovoltaic Project: Identifying Critical Paths

Martha Symko-Davies, Ken Zweibel, John Benner, Pete Sheldon, Rommel Noufi,
Sara Kurtz, Tim Coutts, and Roland Hulstrom
National Renewable Energy Laboratory
1617 Cole Blvd. Golden, CO 80401

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.

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

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 CI(G)S 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 J_0 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.

Subcontractor	Title
*Astropower	InGaP/GaAs-on-Ceramic Thin-Film Monolithically Interconnected, Large Area, Tandem Solar Cell Array
University of Delaware	Thin Film Multijunction Solar Cells Development of a High Bandgap Cell
University of Toledo	Polycrystalline Thin-Film Tandem Photovoltaic Cells
University of South Florida	Development of a II-VI-Based High Performance, High Band Gap Device for Thin-Film Tandem Solar Cells
University of Florida	Identification of Critical Paths in the Manufacturing of Low-Cost High-Efficiency CGS/CIS Two-Junction Tandem Cells
Global Solar	Progress Toward 20% Efficient $CuIn_xGa_{1-x}Se_2$ Photovoltaic Devices on Foil Substrates
University of Illinois	$Cu(In,Ga)Se_2$ Heterojunction Solar Cells for Extreme High-efficiency Photovoltaic Concentrators
Entech, Inc.	Near-Term Integration of III-V Cells Operating at 440X, Into Entech's Field Proven Concentrator Module
SunPower Corporation	Lens-Based Concentrator Modules: Exploring Critical Optical and System Integration Issues
Spectrolab, Inc.	High Efficiency, Low Cost, III-V Concentrator PV Cell & Receiver Module
Emcore	A Three-Junction Solar Cell for High Concentration Applications

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

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REFERENCES

[1] V. Riddell, and K. Zweibel, "High Performance Photovoltaics, Phase I: Identifying Critical Paths," *Solicitation for Letters of Interest (LOI)* No. RDJ-0-30620-00, June 2000.

[2] T. J. Coutts, J. S. Ward, D. L. Young, T. A. Gessert, and R. Noufi, "The search for and potential impact of improved transparent conducting oxides on thin-film solar cells," *Technical Digest of the 12th. International Photovoltaic Science and Engineering Conference*, Jeju, Korea, June 11-15/2001.

[3] R. H. Annan, "U.S. Photovoltaic Program Plan," *Proceedings of the 23th IEEE Photovoltaics Specialists Conference*, Louisville, KY, 1993.