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High-Performance Photovoltaic Project Overview

Conference Paper
NREL/CP-520-37013
January 2005

M. Symko-Davies and R. McConnell

Presented at the 2004 DOE Solar Energy Technologies Program Review Meeting
October 25-28, 2004
Denver, Colorado

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High-Performance Photovoltaic Project Overview

Martha Symko-Davies and Robert McConnell
National Renewable Energy Laboratory (NREL)
1617 Cole Blvd. Golden, CO 80401
Martha_Symko_Davies@nrel.gov

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 environment in the 21st century. To accomplish this, the National Center for Photovoltaics (NCPV) directs in-house and subcontracted research in high-performance polycrystalline thin-film and multijunction concentrator devices. In this paper, we describe the recent research accomplishments in the in-house directed efforts and the research efforts under way in the subcontracted area.

1. Objectives

The HiPerf PV Project aims to explore 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.

The project is expected to enable progress of high efficiency technologies toward commercial-prototype products. This begins with the investigations of a wide range of complex issues and provides initial modeling and baseline experiments of several advanced concepts [1]. Near-term milestones for the polycrystalline thin-film tandems and III-V multijunction concentrator R&D under the project are shown by year (see Tables I & II) and are also listed in the Solar Program Multi-Year Technical Plan. Throughout the project's term, there will be opportunities to reach established program goals by both disruptive technology advances and/or multiple incremental improvements.

Table I. Near-term key targets for the HiPerf PV Project: Polycrystalline Thin-Film Tandems

Date	Milestone
2003	Compare Device Design in Terms of Monolithic/Mechanical Structure for Polycrystalline Thin-Film Tandems (Completed)
2004	Assess Research on Exploring Pathways
2005	Demonstrate 14%-Efficient Polycrystalline Thin-Film Tandem
2006	Demonstrate 15%-Efficient, $1.5 < E_{gap} < 1.8$ eV Polycrystalline Thin-Film Tandem

Table II. Near-term key targets for the HiPerf PV Project: III-V Mulitjunction Concentrators

Date	Milestone
2003	Demonstrate a 34%-Efficient Cell under Concentration (Completed)
2004	Assess Research on Exploring Pathways
2004	Demonstrate a 37%-Efficient Cell under Concentration (Completed)
2005	Demonstrate a 38%-Efficient Cell under Concentration
2006	Demonstrate a 27%-Efficient Concentrator Module

2. Technical Approach

The project consists of three phases that focus on a specific approach to solving the challenges associated with high efficiencies. The second HiPerf PV subcontract solicitation was recently completed; it allows the NCPV to provide 3 years of funding to the top-ranked companies and universities. The first phase is critical as it provides a means to accelerating toward the most promising paths for implementation, followed by commercial-prototype products.

3. Results and Accomplishments

Fourteen groups, selected competitively, were involved in negotiations for the HiPerf PV Phase IB, Accelerating and Exploring Ultimate Pathways. All awards have been completed and project activities have commenced (see Tables III and IV).

Table III. Subcontracts currently active in the polycrystalline thin-film tandems

Subcontractor	Title
Georgia Institute of Technology	Thin-Film Si Bottom Cells for Tandem Device Structures
University of Delaware (IEC)	High-Performance PV-Polycrystalline Thin-Film Tandem Cells
University of Toledo	Sputtered II-VI Alloys and Structures for Tandem PV

University of Florida	Identification of Critical Paths in the Manufacturing of Low-Cost High-Efficiency CGS/CIS Tandems
University of Oregon	Identifying the Electronic Properties Relevant to Improving the Performance of High Band-Gap Copper-Based I-III-VI_2 Chalcopyrite Thin-Film PV Devices
Oregon State	Novel Materials Development for Polycrystalline Thin-Film Solar Cells
Light Spin Technologies	Novel Polycrystalline Thin-Film Solar Cells

Table IV. Subcontracts currently active in the III-V multijunction concentrators

Subcontractor	Title
Spectrolab Inc.	Ultra-High-Efficiency Multijunction Cell and Receiver Module
Amonix	Design and Demonstration of a Greater than 33% Efficiency High-Concentration Module Using 40% III-V Multijunction Devices
California Institute of Technology	Four-Junction Solar Cell with 40% Target Efficiency Fabricated by Wafer Bonding and Layer Transfer
JX Crystals	Toward 40%-Efficient Mechanically Stacked III-V Terrestrial Concentrator Cells
Georgia Institute of Technology	Novel High Efficiency PV Devices Based on the III-N Material System
Ohio State	Optimized III-V Multijunction Concentrator Solar Cells on Patterned Si and Ge Substrates
Concentrating Technologies	A Scalable High-Concentration PV System

3.1 Polycrystalline thin-film tandem accomplishments

The Polycrystalline Thin-Film PV Group at NREL has demonstrated that a surface-modified CGS top cell exhibits the following NREL-confirmed device operating parameters: V_{oc} = 0.82, J_{sc} = 18.61 mA/cm^2, fill factor = 66.8%, and total-area efficiency = 10.2%. Recently, the group demonstrated a CdTe-based top-cell material with a greater than 50% transmission that showed greater than 13% efficiency.

Solar cells were fabricated at IEC using the structure glass/Mo/Cu(InGa)$(SeS)_2$/CdS/ZnO/ITO with Ni-Al collection grids and total area, defined by mechanical scribes, of 0.47–0.51 cm^2. The best cell from one run had an efficiency = 10.9% with V_{oc} = 0.826 V, J_{sc} = 20.4 mA/cm^2, and fill factor = 64.5. From the other run, the best cell had an efficiency = 10.9% with V_{oc} = 0.836 V, J_{SC} = 20.4 mA/cm^2, and fill factor = 64.

Tandems have been demonstrated both monolithically and mechanically, and R&D focuses on both structures in parallel.

3.2 III-V multijunction concentrator accomplishments

Boeing Spectrolab has achieved a record efficiency of 37.3% for a 3-junction terrestrial concentrator cell. This is the highest NREL-confirmed efficiency yet measured for a PV device. This record used 3-junction GaInP/GaInAs/Ge concentrator solar cells grown on a Ge substrate incorporating epitaxial device features to optimize their performance under the concentrated terrestrial spectrum. The device was processed at Boeing Spectrolab.

Amonix has been working toward the design of a greater than 33%-efficient high-concentration module. Recently, they completed a prototype package for testing that included a sun shield, sun-shield base, substrate, diode, and multijunction cell.

The III-V Multijunction Concentrator Group at NREL has focused on the addition of a 1-eV GaInAsN junction to a GaInP/GaAs/Ge cell. This structure has the potential of reaching efficiencies in the 35%–40% range [2]. Other device structures are being investigated in parallel.

4. Conclusions

Phase IB, "Exploring and Accelerating Ultimate Pathways," of the HiPerf PV Project is under way, with in-house and subcontracted research efforts in high-performance polycrystalline thin-film tandems and III-V multijunction concentrators.

The developments under the High-Performance PV Project reported here are progress toward achieving long-term DOE goals. The project is focused to ensure that tandem thin-film polycrystalline modules and III-V multijunction concentrators reach efficiency levels consistent with cost-competitive goals.

ACKNOWLEDGEMENTS

This work is supported under DOE Contract No. DE-AC36-99GO10337 to 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 the NREL High-Performance Polycrystalline Thin-Film Tandem Group and III-V Multijunction Concentrator Group. The authors also thank all the listed subcontractors.

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
January 2005

2. REPORT TYPE
Conference Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
High-Performance Photovoltaic Project Overview

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
M. Symko-Davies and R. McConnell

5d. PROJECT NUMBER
NREL/CP-520-37013

5e. TASK NUMBER
PVA50001

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/CP-520-37013

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
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15. SUBJECT TERMS
PV; high-performance; polycrystalline; thin-film; solar cell; multijunction concentrator; device;

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
Unclassified	Unclassified	Unclassified	UL		19b. TELEPHONE NUMBER *(Include area code)*