April 1999 • NREL/CP-520-29584

Conference Paper

Basic Research Opportunities in Photovoltaics Workshop

Preprint

J. Benner, S. Deb, and R.D. McConnell

To be presented at the Electrochemical Society International Symposium
Seattle, Washington
May 2-6, 1999

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-99-GO10337

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.doe.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

BASIC RESEARCH OPPORTUNITIES IN PHOTOVOLTAICS WORKSHOP

J. Benner, S. Deb, and R.D. McConnell
National Renewable Energy Laboratory
Golden, CO 80401-3393

Preface and Executive Summary

Photovoltaic (PV) technology for conversion of sunlight to electricity is the most cost-effective method for meeting the electric power needs of many consumers around the world today. This is due in large part to more than 25 years of research and development supported by nations throughout the world with the vision to provide a clean, renewable source of energy. The U.S. PV research program was by far the largest during the first decade of development. U.S. based manufacturers today hold the major market share of this successful, rapidly growing worldwide business that generated nearly a billion dollars in sales during 1998. Most of the product serves applications some distance from the utility power grid or in installations that compete with retail prices for electricity. Consistent with the time horizon needed for any major change in national infrastructure, another 25 years of sustained, aggressive growth will be required for PV to displace a significant fraction of conventional energy generation sources. This growth will rely on continuous introduction of new technology, underpinned by sound fundamental research. As we enter this phase, unfortunately, U.S. programs lag fundamental research efforts in Europe and Japan in both scope and funding.

As we embark on this phase of development, both the National PV Program within the DOE Office of Energy Efficiency and Renewable Energy and Basic Energy Science within the Office of Science are focusing increasing attention on the basic research issues that must be addressed to maintain the PV growth rate as well as on opportunities to accelerate this pace. The Basic Research Opportunities in Photovoltaics Workshop, held May 3, 1999 in Seattle, Washington, brought together experts in PV and related fields to offer guidance for initiatives on high payoff research programs.

The expediency of a one-day meeting was made possible by a number of factors. First, this workshop built on the findings of a prior meeting. A Research Assistance Task Force, chaired by Alex Zunger, met during July 27-29, 1992 to discuss Research Opportunities in Photovoltaic Semiconductors. These extended interactions were documented in a special issue of the Journal of Electronic Materials (Volume 22, number 1, January 1993). Second, the 195th Meeting of the Electrochemical Society, which included a special Symposium focused on photovoltaics, provided a venue which attracted many of workshop participants such that costs and inconvenience of travel could be minimized. Finally, and most importantly, the workshop participants carried out extensive dialogue by phone, fax, and e-mail prior to arriving on May 3 and after the meeting as they identified their key research issues and prepared the final manuscripts.

The workshop was structured into eight topics. Each topic area opened with a presentation in which the participants were asked to address the following areas:

- A brief introduction of the area of research
- Key research issues that were identified in the previous workshop of July 1992
- What fundamental research has been done since then or is currently being done to address those issues
- What are the research issues that are still relevant in light of advances made since the first workshop
- Identification of new fundamental research opportunities that will lead to important advances and innovations

- Identification of significant commonalties and common research issues that have a cross-cutting impact such as logically exist in silicon-based thin films, II-VI and related materials.

Participants in each topic area broke out into separate discussion groups to develop a concise set of issues and opportunities in light of their own views along with input from questions and comments from the other workshop participants that followed the presentation. Many of the attendees roved between groups to share in discussion of several topics. Results of the discussions were captured on flip-charts for presentation to the entire workshop as we reconvened at the end of the day.

After the meeting, participants in each working topic continued discussions by electronic means completing journal articles which are to be published as a separate section in the ECS Proceedings of the PV for the 21st Century Symposium.

For executive review, the key issues and opportunities identified by the topic area participants are highlighted below. These are not necessarily in order of priority.

Amorphous and micro-crystalline silicon (these three bullets are in priority order)
- Understanding and control of Si and alloy film structure, with increasing emphasis on high deposition rate as the structural order increases.
- Understand the role of H in establishing nanostructure, in alloying and doping, in metastability, and as a structural modifier during solar cell operation.
- Understand and control the gas phase chemistry, the reactions on the growing surface, and their effects on device properties

Crystalline Silicon
- Fundamentals of impurities and defects
- Interface and passivation issues for screen-printed contacts
- Impurity separation technology
- Thin-layer crystalline silicon of high quality, deposited at high growth rate using either low-temperature processing or a low-cost substrate compatible with high temperature processing
- Control of light – texturing, light trapping, and optical modeling

Cadmium Telluride
- Understand the basic nature of polycrystalline CdTe needed for truly predictive models, alternative process pathways, and meaningful process monitors and control.
- Measurements on samples prepared with systematic variation of process variables and incorporation of extrinsic dopants to elucidate the role of impurity atoms (Cl, O, Cu) and defects on bulk CdTe properties and nanoscale variations of the polycrystalline material and its related alloys
- CdS/CdTe junction modeling and analysis with controlled degree of interdiffusion and other process variables.
- Transparent conducting oxide front layers and their impact on subsequent depositions.
- Understanding the role of Cu in back contacts and exploration of Cu-free contact

Copper Indium Diselenide
- Development of an integrated predictive understanding of CIGSS materials and devices
- Development of novel deposition techniques and characterization of mechanisms of growth in existing and novel processes
- Novel materials, especially with wide energy gaps (>1.7 eV) other than CIGSS alloys

- Development of real-time material characterization for process control
- Alternative front and rear contact materials

III-V Materials
- Investigation of the influence of InGaAsN growth conditions on materials properties such as background impurity incorporation, carrier trap density and energies, and minority carrier properties.
- Fundamental properties of 1 eV semiconductors for high efficiency, multiple junction devices.
- Details transport studies in compensated InGaAsN to determine if electron localization is intrinsic to InGaAsN
- Development of technology capable of measuring I-V performance of multiple junction device.

Novel Materials and Energy Conversion Approaches
- Nano/molecular composites – hierarchical structures
- Organic semiconductors
- Hot carrier devices

Semiconducting Oxides
- Synthesis, characterization, and understanding of new compositions and phases of TCOs
- Investigate scattering mechanisms to guide development of TCOs with higher electron mobilities
- Investigate the role of impurities and defects
- All oxide devices

Characterization
- Atomic and nanoscale characterization of impurity, native defects, extended defects, and interfaces – higher spatial resolution and trace impurities
- Performance characterization of developing technologies – high flux operation, multijunction, lower bandgap
- In-situ probes for diagnostics and process control – immediate response, integrated to ensure relevance