PROCEEDINGS OF SPIE

SPIDigitalLibrary.org/conference-proceedings-of-spie

Front Matter: Volume 7048

, "Front Matter: Volume 7048," Proc. SPIE 7048, Reliability of Photovoltaic Cells, Modules, Components, and Systems, 704801 (3 October 2008); doi: 10.1117/12.814694

SPIE.

Event: Solar Energy + Applications, 2008, San Diego, California, United States

PROCEEDINGS OF SPIE

Reliability of Photovoltaic Cells, Modules, Components, and Systems

Neelkanth G. Dhere
Editor

**11–13 August 2008
San Diego, California, USA**

Sponsored and Published by
SPIE

Volume 7048

Proceedings of SPIE, 0277-786X, v. 7048

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

The papers included in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. The papers published in these proceedings reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from this book:

Author(s), "Title of Paper," in *Reliability of Photovoltaic Cells, Modules, Components, and Systems*, edited by Neelkanth G. Dhere, Proceedings of SPIE Vol. 7048 (SPIE, Bellingham, WA, 2008) Article CID Number.

ISSN 0277-786X

ISBN 9780819472687

Published by

SPIE

P.O. Box 10, Bellingham, Washington 98227-0010 USA

Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445

SPIE.org

Copyright © 2008, Society of Photo-Optical Instrumentation Engineers

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is \$18.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at copyright.com. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/08/\$18.00.

Printed in the United States of America.

Publication of record for individual papers is online in the SPIE Digital Library.

SPIDigitalLibrary.org

Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print and on CD-ROM. Papers are published as they are submitted and meet publication criteria. A unique, consistent, permanent citation identifier (CID) number is assigned to each article at the time of the first publication. Utilization of CIDs allows articles to be fully citable as soon they are published online, and connects the same identifier to all online, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- The first four digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc.

The CID number appears on each page of the manuscript. The complete citation is used on the first page, and an abbreviated version on subsequent pages. Numbers in the index correspond to the last two digits of the six-digit CID number.

Contents

- vii *Conference Committee*
- ix *Introduction*
- xi *Commercialization of large scale CPV: What lies ahead? (Plenary Paper) [7043-104]*
D. Holland, Solar Systems Pty. Ltd. (Australia)
- xvii *Nanostructures for high-efficiency photovoltaics (Plenary Paper) [7047-102]*
H. A. Atwater, California Institute of Technology (United States)

SOLAR ENERGY PLENARY SESSION

- 7048 02 **Reliability of PV systems (Plenary Paper) [7048-101]**
J. H. Wohlgemuth, BP Solar International Inc. (United States)

SESSION 1 METROLOGY AND CERTIFICATION

- 7048 03 **PV reliability determination from I-V measurement and analysis (Invited Paper) [7048-01]**
K. Emery, National Renewable Energy Lab. (United States)
- 7048 04 **Integrated quantum efficiency, topography, and stress metrology for solar cell manufacturing: real space approach [7048-02]**
W. J. Walecki, F. Szondy, Sunrise Optical LLC (United States)
- 7048 06 **Indoor and outdoor weathering of PV-modules [7048-04]**
M. Koehl, M. Heck, D. Philipp, K.-A. Weiss, Fraunhofer ISE (Germany); C. Ferrara, W. Herrmann, TUV Rheinland (Germany)
- 7048 07 **Advantages in using LEDs as the main light source in solar simulators for measuring PV device characteristics [7048-05]**
M. Bliss, T. R. Betts, R. Gottschalg, Loughborough Univ. (United Kingdom)
- 7048 08 **Reliability test of LED driven by PWM technique [7048-06]**
B. J. Huang, M. S. Wu, C. W. Tang, P. C. Hsu, J. W. Chen, K. Y. Chen, National Taiwan Univ. (Taiwan)

SESSION 2 RELIABILITY OF CONCENTRATOR OPTICS AND PV CELLS

- 7048 09 **Optical tests for reliability and efficiency of photovoltaic concentrators (Invited Paper) [7048-07]**
R. Leutz, H. P. Annen, L. Fu, Concentrator Optics GmbH (Germany)

- 7048 0A **Qualification and reliability of high efficiency multijunction concentrator solar cells for terrestrial applications (Invited Paper)** [7048-09]
P. Hebert, Spectrolab, Inc. (United States)

SESSION 3 ENCAPSULANTS, BACK SHEET

- 7048 0B **Accelerated test for effect of moisture and temperature on glass-encapsulant interface (Invited Paper)** [7048-12]
S. Wu, J. Chen, B. Weaver, B. Sumner, V. Juarez, The Dow Chemical Co. (United States)
- 7048 0C **Bio-based backsheet** [7048-13]
S. B. Levy, BioSolar, Inc. (United States)
- 7048 0D **Low-cost single-layer replacement for the back-sheet and encapsulant layers** [7048-14]
M. D. Kempe, National Renewable Energy Lab. (United States); P. Thapa, BRP Manufacturing (United States)
- 7048 0E **Accelerated degradation studies of encapsulation polymers** [7048-15]
K.-A. Weiss, J. P. Huelsmann, T. Kaltenbach, D. Philipp, T. Schuhmacher, J. Wirth, M. Koehl, Fraunhofer Institute for Solar Energy Systems (Germany)
- 7048 0F **Observation of polymer degradation processes in photovoltaic modules via luminescence detection** [7048-16]
B. Röder, E. A. Ermilov, Humboldt Univ. of Berlin (Germany); D. Philipp, M. Köhl, Fraunhofer Institute for Solar Energy Systems (Germany)
- 7048 0G **Characterization of encapsulant materials for photovoltaic solar energy conversion** [7048-17]
K. Agroui, Unité de Developpement de la technologie du Silicium (Algeria); B. Koll, Kuraray Specialities Europe GmbH (Germany); G. Collins, Medical Device Lab. Conception (United States); M. Salama, The Pennsylvania State Univ. (United States); A. Hadj Arab, Ctr. de Developpement des Energies renouvelables (Algeria); A. Belghachi, Ctr. Universitaire de Béchar (Algeria); N. Doulache, M. W. Khemici, Univ. des Sciences et de la Technologie Houari Boumediene (Algeria)

SESSION 4 c-SI PV, GLASS

- 7048 0J **Optimizing photovoltaic module glass reliability (Invited Paper)** [7048-21]
C. R. Cording, AGC North America (United States)
- 7048 0K **Hot spot evaluation of photovoltaic modules** [7048-22]
G. TamizhMani, S. Sharma, Arizona State Univ. (United States)

SESSION 5 THIN FILM PV

- 7048 0M **Design of high-reliability low-cost amorphous silicon modules for high energy yield (Invited Paper)** [7048-24]
K. W. Jansen, A. Varvar, E. Twesme, T. Berens, EPV Solar, Inc. (United States); N. G. Dhere, Florida Solar Energy Ctr. (United States)

- 7048 ON **Accelerated stress testing and diagnostic analysis of degradation in CdTe solar cells** [7048-25]
D. S. Albin, National Renewable Energy Lab. (United States)
- 7048 OO **Approaches to encapsulation of flexible CIGS cells** [7048-26]
L. C. Olsen, M. E. Gross, G. L. Graff, S. N. Kundu, Pacific Northwest National Lab. (United States); X. Chu, S. Lin, Vitex Systems, Inc. (United States)
- 7048 OP **Degradation of ZnO-based window layers for thin-film CIGS by accelerated stress exposures (Invited Paper)** [7048-27]
F. J. Pern, National Renewable Energy Lab. (United States); R. Noufi, SoloPower, Inc. (United States); B. To, C. DeHart, X. Li, S. H. Glick, National Renewable Energy Lab. (United States)
- 7048 OQ **Characterisation of photovoltaic modules based on thin film solar cells in environmental operating conditions of Algerian Sahara** [7048-28]
K. Agroui, Unité de Développement de la Technologie du Silicium (Algeria);
I. Hadj Mahammed, Unité de Recherche Appliquée aux Energies Renouvelables (Algeria);
A. Hadj Arab, Ctr. de Développement des Energies renouvelables (Algeria); A. Belghachi, Ctr. Universitaire de Bechar (Algeria)

SESSION 6 RELIABILITY OF FLEXIBLE PACKAGING: JOINT SESSION WITH CONFERENCE 7052

- 7048 OR **Flexible packaging for PV modules (Invited Paper)** [7048-29]
N. G. Dhere, Univ. of Central Florida (United States)
- 7048 OS **Methodology and systems to ensure reliable thin-film PV modules (Invited Paper)** [7048-30]
J. Call, U. Varde, A. Konson, M. Walters, C. Kotarba III, T. Kraft, S. Guha, United Solar Ovonic, LLC (United States)
- 7048 OT **Statistical data analysis of thin film photovoltaic modules deployed in hot and humid climate of Florida** [7048-31]
S. A. Pethe, A. Kaul, N. G. Dhere, Univ. of Central Florida (United States)

SESSION 7 RELIABILITY OF ORGANIC PHOTOVOLTAICS: JOINT SESSION WITH CONFERENCE 7052

- 7048 OU **Relationship between encapsulation barrier performance and organic solar cell lifetime** [7048-32]
S. Cros, S. Guillerez, R. de Bettignies, N. Lemaître, S. Bailly, P. Maisse, CEA/LITEN/DTS/LCS, Institut National de l'Energie Solaire (France)

POSTER SESSION

- 7048 OW **Photovoltaic performance models: an evaluation with actual field data** [7048-34]
G. Tamizhmani, J.-P. Ishioye, A. Voropayev, Y. Kang, Arizona State Univ. (United States)
- 7048 OX **Outdoor monitoring of a-Si:H thin film photovoltaic modules in the hot and humid climate of Florida** [7048-35]
A. Kaul, S. A. Pethe, N. G. Dhere, Univ. of Central Florida (United States)

7048 0Y **Design and construction evaluation of a photovoltaic DC LED lighting system** [7048-36]
J. Bhamidipati, The Pennsylvania State Univ. (United States)

Author Index

Conference Committee

Symposium Chair

Ravi Durvasula, Lightfleet Corporation (United States)

Conference Chair

Neelkanth G. Dhere, Florida Solar Energy Center, University of Central Florida (United States)

Conference Cochairs

John H. Wohlgemuth, BP Solar International LLC (United States)

Scott Stephens, U.S. Department of Energy (United States)

Program Committee

David Albin, National Renewable Energy Laboratory (United States)

John Crisman, EMCORE Corporation (United States)

Michael DeBergalis, DuPont Company (United States)

Alan E. Delahoy, EPV Solar, Inc. (United States)

Steve Hogan, Spire Corporation (United States)

Ralf Leutz, Concentrator Optics (Germany) and Universität Marburg (Germany)

Xavier Mathew, Universidad Nacional Autónoma de México (Mexico)

Robert McConnell, Amonix (United States)

John Pern, National Renewable Energy Laboratory (United States)

Kevin Shreve, Blue Square Energy (United States)

Session Chairs

Solar Energy Plenary Session

Ravi Durvasula, Lightfleet Corporation (United States)

- 1 Metrology and Certification
David S. Albin, National Renewable Energy Laboratory (United States)
- 2 Reliability of Concentrator Optics and PV Cells
Scott Stephens, U.S. Department of Energy (United States)
- 3 Encapsulants, Back Sheet
Steve Hogan, Spire Corporation (United States)

- 4 c-Si PV, Glass
John H. Wohlgemuth, BP Solar International LLC (United States)
- 5 Thin Film PV
Chung-hei Yeung, The Dow Chemical Company (United States)
- 6 Reliability of Flexible Packaging: Joint Session with Conference 7052
John Pern, National Renewable Energy Laboratory (United States)
- 7 Reliability of Organic Photovoltaics: Joint Session with Conference 7052
Neelkanth G. Dhere, Florida Solar Energy Center, University of Central Florida (United States)

Introduction

With photovoltaic (PV) technology being widely launched all over the world, its final success would ultimately rest upon the reliability of the final product. However, it has not been given adequate weight until recently after the PV community realized that without giving a reliable and durable product to the customers it will not be possible to meet the long term goal, set by the U.S. Department of Energy, of reliable PV technology that can last for 30 years.

The SPIE 2008 Optics and Photonics event has made a pioneering step in this direction by tailoring a conference that has addressed vital issues in this regard by setting up a stage to allow intense interaction between the budding PV researchers and the expertise in the PV community.

37 presentations and 28 papers were received for this conference. The conference was divided into seven sessions extending over a three-day period during August 11 to August 13, 2008. Session one titled Metrology and Certification began with a talk on PV reliability determination from I-V measurement and analysis. The measurement and analysis of current vs. voltage (I-V) characteristics of PV cells and modules for reliability determination were discussed along with the error sources in the measurements and the strategies to minimize their influence.

Since III-V cells having >40% efficiency have already been developed, the session topic Reliability of Concentrator Optics and PV Cells is becoming increasingly important. With an attempt to reduce the cost of c-Si solar cell by reducing the wafer thickness, wafer breakage becomes a major reliability concern. The influence of microcracks on wafer strength and the role of reduced wafer strength on the reliability of solar modules were discussed along with a wafer screening technique that can isolate wafers that have a propensity for breakage.

There was an interesting invited plenary paper, "Reliability of PV Systems," during the Plenary Session. Three posters were presented as part of this conference that initiated an interactive session between students and researchers from the PV community.

Regarding Encapsulants, Back Sheet, c-Si and Glass, Thin Film PV—good packaging is synonymous with long term reliability. Good encapsulation and packaging schemes are, therefore, essential for the long term reliability of PV modules. With a greater thrust on minimizing our dependence on petroleum, it is essential to work toward developing backsheets from organic sources instead of producing them from petro-based chemicals as is being done currently. Attempts in this direction are being carried out by choosing PLA film made from corn, a cellulosic paper made from cotton, and nylon 11 made from castor oil.

Two joint sessions on Reliability of Flexible Packaging and Reliability of Organic Photovoltaics were organized in collaboration with conference 7052: Organic Photovoltaics IX.

There was also a short course on Design and Reliability of Photovoltaic Modules that turned out to be a grand success with a record enrollment of 34 students for the class. It was very well received and appreciated by the attendees. The tutorial's main discussion centered on the purpose of module packaging with typical configurations, concepts of physics of failures and their applicability in the PV systems, a brief history of field failures, development of accelerated tests, present status of module reliability, and, finally, the application of this knowledge to new products and technologies.

Neelkanth G. Dhere