

PROCEEDINGS OF SPIE

# ***New Concepts in Solar and Thermal Radiation Conversion and Reliability***

**Jeremy N. Munday**  
**Peter Bermel**  
**Michael D. Kempe**  
*Editors*

**19–21 August 2018**  
**San Diego, California, United States**

*Sponsored and Published by*  
SPIE

**Volume 10759**

Proceedings of SPIE 0277-786X, V. 10759

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

New Concepts in Solar and Thermal Radiation Conversion and Reliability, edited by Jeremy N. Munday,  
Peter Bermel, Michael D. Kempe, Proc. of SPIE Vol. 10759, 1075901 · © 2018 SPIE  
CCC code: 0277-786X/18/\$18 · doi: 10.1117/12.2516804

Proc. of SPIE Vol. 10759 1075901-1

The papers 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. Additional papers and presentation recordings may be available online in the SPIE Digital Library at SPIEDigitalLibrary.org.

The papers 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 these proceedings:

Author(s), "Title of Paper," in *New Concepts in Solar and Thermal Radiation Conversion and Reliability*, edited by Jeremy N. Munday, Peter Bermel, Michael D. Kempe, Proceedings of SPIE Vol. 10759 (SPIE, Bellingham, WA, 2018) Seven-digit Article CID Number.

ISSN: 0277-786X  
ISSN: 1996-756X (electronic)

ISBN: 9781510620896  
ISBN: 9781510620902 (electronic)

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 © 2018, 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](http://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/18/\$18.00.

Printed in the United States of America.

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

**SPIE. DIGITAL  
LIBRARY**

[SPIEDigitalLibrary.org](http://SPIEDigitalLibrary.org)

---

**Paper Numbering:** *Proceedings of SPIE* follow an e-First publication model. A unique citation identifier (CID) number is assigned to each article at the time of publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online and print versions of the publication. SPIE uses a seven-digit CID article numbering system structured as follows:

- The first five 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.

# Contents

v *Authors*  
vii *Conference Committee*

---

## THIN-FILM PV MATERIALS RELIABILITY

---

10759 05 **Outdoor performance of CIGS modules at multiple temperatures over three years** [10759-39]

---

## FIELD EVALUATION FOR PV DURABILITY

---

10759 07 **Risk priority number for PV module defects: influence of climatic condition (Invited Paper)**  
[10759-2]

10759 08 **A novel climate-specific field accelerated testing of PV modules** [10759-40]

10759 09 **Addressing potential-induced degradation of field-installed PV modules by reducing surface conductivity** [10759-41]

---

## PV MODULE ACCELERATED STRESS TESTING

---

10759 0B **Acceleration factor for damp heat testing of PV modules** [10759-4]

---

## PV MODULE PACKAGING

---

10759 0E **Analysis of glass-glass modules (Invited Paper)** [10759-1]

10759 0G **Feasibility and reliability of a single layer polymeric PV backsheet in white, transparent, or luminescent concentrator options** [10759-43]

10759 0H **Optical and thermal analysis of PVB encapsulant polymer functionalized with luminescent organic dyes** [10759-7]

10759 0I **Determination of glass transition temperature of PVB encapsulant material as host material for nanotechnology application in photovoltaic conversion** [10759-8]

---

**THERMAL RADIATION ENHANCEMENT**

---

- 10759 OK **Reconfigurable metasurfaces for dynamic tuning of thermal sources** [10759-15]
- 10759 OL **Design, control, and characterisation of switchable radiative cooling (Invited Paper)** [10759-16]
- 10759 ON **Thermodynamic limits of energy harvesting from outgoing thermal radiation** [10759-18]

---

**NOVEL CONCEPTS IN SOLAR ENERGY CONVERSION**

---

- 10759 OW **Volume hologram replication system for photovoltaic applications** [10759-26]
- 10759 OX **Coupled spectral-hybridizable-discontinuous-Galerkin modeling of thin-film photovoltaic solar cells** [10759-28]

---

**PHOTON MANAGEMENT FOR SOLAR POWER**

---

- 10759 11 **Two-layer anti-reflection coatings with optimized sub-bandgap reflection for solar modules (Invited Paper)** [10759-33]

---

**POSTER SESSION**

---

- 10759 15 **Durability evaluation of PV modules using image processing tools** [10759-36]
- 10759 16 **Study on pointing stability control and photoelectric conversion ratio for wireless laser energy transmission** [10759-37]

# Authors

Numbers in the index correspond to the last two digits of the seven-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first five digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

Agroui, Kamel, 0H, 0I  
Akbar, Rafia, 05  
Alers, Glenn, 0G  
Amin, Ahmad, 09  
Anderson, Ingrid, 0G  
Anderson, Tom H., 0X  
Arfi, Walid, 0H  
Arnold, Matthew, 0L  
Bala Subramaniyan, Arun, 0B  
Baretta, Chiara, 0H  
Bednarzhevskiy, Andrey, 05  
Bermel, Peter, 0K  
Buddhiraju, Siddharth, 0N  
Chan, Eric, 15  
Choudhury, Kaushik Roy, 0E  
Chrysler, Benjamin D., 0W  
Civiletti, Benjamin J., 0X  
Collins, George, 0I  
Cortie, Michael, 0L  
Deceglie, Michael G., 11  
Fan, Shanhui, 0N  
Felder, Thomas C., 0E  
Ferry, Vivian E., 11  
Gambogi, William J., 0E  
Garreau-Iles, Lucie, 0E  
Gentle, Angus, 0L  
Gopalakrishna, Hamsini, 0B, 15  
Hacke, Peter, 0G  
Hu, Hongjie, 0E  
Huan, Guoqiang, 16  
Israr, Kiran, 09  
Jaunich, Matthias, 0H  
Khalid, Muhammad Shoaib, 09  
Khan, Adel, 0H  
Khan, Rahmanullah, 09  
Köll, Bernd, 0I  
Kostuk, Raymond K., 0W  
Kuitche, Joseph, 07, 08  
Lakhtakia, Akhlesh, 0X  
Libby, Cara, 07  
Liu, Bo, 16  
Liu, Liyuan, 05  
MacMaster, Steven, 0E  
Metacarpa, David, 05  
Miller, David, 0G  
Monk, Peter B., 0X  
Moulai, Fateh, 0H  
Oh, Jaewon, 09  
Oreski, Gernot, 0H  
Pan, Rong, 0B  
Pore, Shantanu, 0B  
Qamar, Afshan, 05  
Raj, Akash, 05  
Rosenthal, Jessica, 0G  
Sakr, Enas, 0K  
Sanghvi, Ankil, 05  
Santhanam, Parthiban, 0N  
Shahzad, Khuram, 09  
Shi, Bingxin, 16  
Silverman, Timothy J., 11  
Sinha, Archana, 0B  
Slauch, Ian M., 11  
Smith, Geoff, 0L  
Sun, Zhiwei, 16  
Sundarajan, Prasanna, 07  
Sundaramoorthy, Rajalakshmi, 05  
Tai, Matthew, 0L  
TamizhMani, GovindaSamy, 05, 07, 08, 09, 0B, 15  
Tatapudi, Sai, 05, 07, 08, 09  
Terwilliger, Kent, 0G  
Trout, T. John, 0E  
White, Simon, 0L  
Wu, Jiawei, 15  
Yadav, Raginee, 15  
Yan, Shuang, 16  
Yang, Fufei, 16



# Conference Committee

## *Program Track Chair*

**Peter Bermel**, Purdue University (United States)

## *Conference Chairs*

**Jeremy N. Munday**, University of Maryland, College Park  
(United States)

**Peter Bermel**, Purdue University (United States)

**Michael D. Kempe**, National Renewable Energy Laboratory  
(United States)

## *Conference Program Committee*

**David S. Albin**, National Renewable Energy Laboratory  
(United States)

**Mowafak M. Al-Jassim**, National Renewable Energy Laboratory  
(United States)

**Harry A. Atwater Jr.**, Caltech (United States)

**Fiona Beck**, The Australian National University (Australia)

**Neelkanth G. Dhere**, University of Central Florida (United States)

**Takuya Doi**, National Institute of Advanced Industrial Science and  
Technology (Japan)

**Partha Dutta**, Rensselaer Polytechnic Institute (United States)

**Nicholas J. Ekins-Daukes**, The University of New South Wales  
(United Kingdom)

**Andrew J. Ferguson**, National Renewable Energy Laboratory  
(United States)

**Katherine T. Fountaine**, Northrop Grumman Aerospace Systems  
(United States)

**Vivek S. Gade**, Jabil Circuit, Inc. (United States)

**William J. Gambogi**, DuPont Photovoltaic Solutions (United States)

**Gautam Gupta**, University of Louisville (United States)

**Werner Herrmann**, TÜV Rheinland Group (Germany)

**Aravinda Kar**, CREOL, The College of Optics and Photonics, University  
of Central Florida (United States)

**Michael Köhl**, Fraunhofer-Institut für Solare Energiesysteme (Germany)

**Xavier Mathew**, Centro de Investigación en Energía (Mexico)

**Robert McConnell**, Consultant (United States)

**Owen D. Miller**, Yale University (United States)

**Aditya D. Mohite**, Rice University (United States)

**Laure-Emmanuelle Perret-Aebi**, Centre Suisse d'Electronique et de  
Microtechnique SA (Switzerland)

**Keiichiro Sakurai**, National Institute of Advanced Industrial Science and Technology (Japan)  
**Sean E. Shaheen**, University of Colorado Boulder (United States)  
**Sheng Shen**, Carnegie Mellon University (United States)  
**Wilfried G. J. H. M. van Sark**, Utrecht University (Netherlands)  
**Xiaobo Yin**, University of Colorado Boulder (United States)  
**Zongfu Yu**, University of Wisconsin-Madison (United States)  
**Jia Zhu**, Nanjing University (China)

*Session Chairs*

- 1 Thin-Film PV Materials Reliability  
**Michael D. Kempe**, National Renewable Energy Laboratory (United States)
- 2 Field Evaluation for PV Durability  
**Keiichiro Sakurai**, National Institute of Advanced Industrial Science and Technology (Japan)
- 3 PV Module Accelerated Stress Testing  
**Michael D. Kempe**, National Renewable Energy Laboratory (United States)  
**Keiichiro Sakurai**, National Institute of Advanced Industrial Science and Technology (Japan)
- 4 PV Module Packaging  
**Michael D. Kempe**, National Renewable Energy Laboratory (United States)
- 5 Thermal Radiation Enhancement  
**Peter Bermel**, Purdue University (United States)  
**Owen D. Miller**, Yale University (United States)  
**Mowafak M. Al-Jassim**, National Renewable Energy Laboratory (United States)
- 6 Novel Phenomena in Thermal Radiation  
**Peter Bermel**, Purdue University (United States)  
**Owen D. Miller**, Yale University (United States)  
**Mowafak M. Al-Jassim**, National Renewable Energy Laboratory (United States)
- 7 Keynote Session  
**Peter Bermel**, Purdue University (United States)
- 8 Novel Concepts in Solar Energy Conversion  
**Matthew T. Sheldon**, Texas A&M University (United States)



- 9 High Efficiency Sunlight to Power  
**Jeremy N. Munday**, University of Maryland, College Park  
(United States)
- 10 Photon Management for Solar Power  
**Jeremy N. Munday**, University of Maryland, College Park  
(United States)

