PROCEEDINGS OF SPIE

Thermal Radiation Management for Energy Applications

Peter Bermel
Mowafak M. Al-Jassim
Editors

9–10 August 2017
San Diego, California, United States

Sponsored and Published by
SPIE

Volume 10369

Proceedings of SPIE 0277-786X, V. 10369

Thermal Radiation Management for Energy Applications, edited by Peter Bermel,
Mowafak M. Al-Jassim, Proc. of SPIE Vol. 10369, 1036901 · © 2017 SPIE
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2295635

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 *Thermal Radiation Management for Energy Applications*, edited by Peter Bermel, Mowafak M. Al-Jassim, Proceedings of SPIE Vol. 10369 (SPIE, Bellingham, WA, 2017) Seven-digit Article CID Number.

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

ISBN: 9781510611955
ISBN: 9781510611962 (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

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

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

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.

Conference Committee

Program Track Chair

Oleg V. Sulima, GE Global Research (United States)

Conference Chairs

Peter Bermel, Purdue University (United States)
Mowafak M. Al-Jassim, National Renewable Energy Laboratory (United States)

Conference Program Committee

Partha Dutta, Rensselaer Polytechnic Institute (United States)

Session Chairs

1 Solar Thermal Selective Absorbers
Mowafak M. Al-Jassim, National Renewable Energy Laboratory (United States)
Peter Bermel, Purdue University (United States)

2 High-Temperature Metamaterials
Peter Bermel, Purdue University (United States)
Zongfu Yu, University of Wisconsin-Madison (United States)

3 Novel Experiments in Radiative Cooling
Mowafak M. Al-Jassim, National Renewable Energy Laboratory (United States)
Peter Bermel, Purdue University (United States)

4 Novel Concepts in Radiative Cooling
Peter Bermel, Purdue University (United States)
Zubin Jacob, Purdue University (United States)

5 Novel Applications for Thermal Radiation
Mowafak M. Al-Jassim, National Renewable Energy Laboratory (United States)
Katherine Fountaine, Northrop Grumman Aerospace Systems (United States)

Introduction

The inaugural symposium for *Thermal Radiation Management for Energy Applications* sought to capture the diverse roles that thermal radiation can play in many sustainable energy systems. In this context, achieving control over thermal radiation offers many novel phenomena, such as enhancing or suppressing emission through novel physical mechanisms at selected wavelengths, angles, or polarizations. Recent developments in material science, nanophotonics, plasmonics, and metasurfaces have made this a uniquely promising time to develop new understanding and capabilities in this direction. These new capabilities can then find clear applications across a range of fields.

The primary areas covered in this year's symposium were selective solar thermal absorbers; high-temperature metamaterials; radiative cooling; and novel applications for thermal radiation.

Selective solar thermal absorbers allow for one to capture sunlight while minimizing thermal re-radiation, improving the operating temperature and the overall conversion efficiency of solar thermal devices. Particular highlights include generalized theory of selective solar absorber design (Shen et al.) and solar absorbers for steam generation and water purification (Jia Zhu et al.).

High-temperature metamaterials have value in terms of creating more efficient and selective infrared sources, which can be used by themselves or coupled with thermophotovoltaics to generate electric power from heat. Novel work presented used graphene as the basis for selective thermal emission using gap plasmon modes with voltage tuning (Kate Fountaine et al.), as well as in combination with epsilon-near-zero materials (Zubin Jacob et al.)

Another key area requiring careful control of thermal radiation is radiative cooling, whether for terrestrial or space-based applications. Radiative cooling allows both for daytime passive cooling above and beyond standard convective processes, as well as below-ambient cooling for night time power generation. Significant work presented showed a mass-manufacturable path for radiative coolers based on nanostructured polymers (Xiaobo Yin et al.), as well as paints (Marc Gali et al.) and 3D-printed structures (A. Gentle et al.).

Finally, novel applications for thermal radiation were covered, which included more efficient incandescent lighting (Leroy et al.), thermoradiative conversion of heat to electricity (Bingnan Wang et al.), and 24%-efficient thermophotovoltaics (Woolf et al.).

In summary, this inaugural symposium on achieving control over thermal radiation explored several multi-faceted, multidisciplinary problems that impact both basic science and practical applications. This effort has set the stage for exploring the role of additional novel materials with even higher potential performance at both near-ambient and highly-elevated temperatures, as well as developing further connection and scaling of these techniques to use in practical applications.

Peter Bermel
Mowafak M. Al-Jassim