

PROCEEDINGS OF SPIE

Nonimaging Optics: Efficient Design for Illumination and Solar Concentration IX

Roland Winston
Jeffrey M. Gordon
Editors

12–14 August 2012
San Diego, California, United States

Sponsored and Published by
SPIE

Volume 8485

Proceedings of SPIE 0277-786X, V.8485

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

Nonimaging Optics: Efficient Design for Illumination and Solar Concentration IX,
edited by Roland Winston, Jeffrey M. Gordon, Proc. of SPIE Vol. 8485, 848501
© 2012 SPIE · CCC code: 0277-786/12/\$18 · doi: 10.1117/12.2011752

Proc. of SPIE Vol. 8485 848501-1

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 *Nonimaging Optics: Efficient Design for Illumination and Solar Concentration IX*, edited by Roland Winston, Jeffrey M. Gordon, Proceedings of SPIE Vol. 8485 (SPIE, Bellingham, WA, 2012) Article CID Number.

ISSN: 0277-786X

ISBN: 9780819492029

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 © 2012, 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/12/\$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 as 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*

SESSION 1 THERMODYNAMIC BASIS OF NONIMAGING OPTICS

- 8485 02 **Thermodynamically efficient solar concentrators (Invited Paper)** [8485-1]
R. Winston, Univ. of California, Merced (United States)

SESSION 2 NONIMAGING OPTICS FOR CONCENTRATOR PHOTOVOLTAICS

- 8485 04 **Practical implementation of a planar micro-optic solar concentrator** [8485-3]
K. Baker, Univ. of California, San Diego (United States); J. Karp, Univ. of California, San Diego (United States) and Pacific Integrated Energy (United States); J. Hallas, Univ. of California, San Diego (United States) and GE Global Research (United States); J. Ford, Univ. of California, San Diego (United States)
- 8485 05 **Beam-steering array optics designs with the SMS method** [8485-4]
W. Lin, Univ. Politécnica de Madrid (Spain); P. Benítez, J. C. Miñano, Univ. Politécnica de Madrid (Spain) and Light Prescriptions Innovators, LLC (United States)

SESSION 3 GRADIENT-INDEX OPTICS

- 8485 06 **Nanolayered polymer diffusive spectral filters** [8485-5]
J. Bortz, N. Shatz, SAIC (United States)
- 8485 07 **Planar single-element gradient-index solar lenses for concentrator photovoltaics** [8485-6]
P. Kotsidas, V. Modi, Columbia Univ. (United States); J. M. Gordon, Ben-Gurion Univ. of the Negev (Israel)
- 8485 08 **Design of spherical symmetric gradient index lenses (Invited Paper)** [8485-7]
J. C. Miñano, Univ. Politécnica de Madrid (Spain) and Light Prescriptions Innovators, LLC (United States); D. Grabovičkić, Univ. Politécnica de Madrid (Spain); P. Benítez, Univ. Politécnica de Madrid (Spain) and Light Prescriptions Innovators, LLC (United States); J. C. González, A. Santamaría, Univ. Politécnica de Madrid (Spain)

SESSION 4 NOVEL APPLICATIONS AND FUNDAMENTAL LIMITS

- 8485 09 **On the challenge of flux concentration at grazing incidence for neutrons and x-rays (Invited Paper)** [8485-8]
B. Khaykovich, D. Liu, G. Resta, D. E. Moncton, Massachusetts Institute of Technology (United States); M. V. Gubarev, NASA Marshall Space Flight Ctr. (United States)

- 8485 0A **Spatial coherence of sunlight: first direct measurement** [8485-9]
H. Mashaal, A. Goldstein, D. Feuermann, J. M. Gordon, Ben-Gurion Univ. of the Negev (Israel)
- 8485 0B **Thermal analysis in a solar pumped laser for Mg energy cycle** [8485-10]
B. Bagheri, S. Uchida, The Univ. of Tokyo (Japan)
- 8485 0C **Improvement of luminescent solar concentrators using liquid crystal polymer** [8485-11]
M. N. Ricketts, Univ. of California, Merced (United States)
- 8485 0D **Solar receiver with integrated optics** [8485-12]
L. Jiang, R. Winston, Univ. of California, Merced (United States)

SESSION 5 NONIMAGING OPTIMIZATION PROCEDURES

- 8485 0E **Implementation of the linear programming algorithm for freeform reflector design** [8485-13]
C. Canavesi, The Institute of Optics, Univ. of Rochester (United States); W. J. Cassarly, Synopsys, Inc. (United States); J. P. Rolland, The Institute of Optics, Univ. of Rochester (United States)
- 8485 0F **Optimization of LED-based non-imaging optics with orthogonal polynomial shapes** [8485-14]
P. Brick, OSRAM Opto Semiconductors GmbH (Germany); C. Wiesmann, OSRAM AG (Germany)
- 8485 0G **Free-form glass reflectors for non-trivial illumination applications with extended sources** [8485-15]
T. Heßling, U. Geyer, A. Hellwig, M. C. Hübner, Auer Lighting GmbH (Germany)
- 8485 0H **Irradiance tailoring with two-sided Fresnel-type freeform optics** [8485-16]
A. Bruneton, RWTH Aachen Univ. (Germany); A. Bäuerle, RWTH Aachen Univ. (Germany) and Fraunhofer Institute for Laser Technology (Germany); M. Traub, R. Wester, Fraunhofer Institute for Laser Technology (Germany); P. Loosen, RWTH Aachen Univ. (Germany) and Fraunhofer Institute for Laser Technology (Germany)
- 8485 0I **Reverse radiance: a fast, accurate method for determining luminance** [8485-17]
K. E. Moore, R. F. Rykowski, S. Gangadhara, Radiant Zemax, LLC (United States)

SESSION 6 DAYLIGHTING

- 8485 0J **Using multimode interference in visible spectrum transmission** [8485-18]
A. J.-W. Whang, K.-Y. Chen, W.-N. Chen, National Taiwan Univ. of Science and Technology (Taiwan)
- 8485 0K **Sollektor: progress in fiber optic daylighting** [8485-19]
H. Poisel, K. Hofbeck, M. Bloos, M. Lippenberger, Univ. of Applied Sciences (Germany); S. Schütz, A. Kist, Bavarian Optics GmbH (Germany)

8485 0L **Embedded microstructures for daylighting and seasonal thermal control** [8485-20]
A. Kostro, M. Geiger, N. Jolissaint, M. A. Gonzalez Lazo, J.-L. Scartezini, Y. Leterrier,
A. M. Schüler, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

8485 0M **A new device for dynamic luminance mapping and glare risk assessment in buildings**
[8485-21]
A. Borisuit, M. Münch, L. Deschamps, J. Kämpf, J.-L. Scartezini, Ecole Polytechnique
Fédérale de Lausanne (Switzerland)

SESSION 7 ILLUMINATION OPTICS

8485 0N **Fiber optic illumination by laser activated remote phosphor** [8485-23]
U. Hartwig, Osram AG (Germany)

8485 0P **Optical design using luminance in ray data sets** [8485-25]
J. Muschaweck, OSRAM AG (Germany)

8485 0Q **Primary optics for efficient high-brightness LED colour mixing** [8485-26]
A. Cvetkovic, R. Mohedano, Light Prescriptions Innovators Europe, S. L. (Spain); O. Dross,
Philips Research (Netherlands); M. Hernandez, Light Prescriptions Innovators Europe, S. L.
(Spain); P. Benítez, J. C. Miñano, Univ. Politécnica de Madrid (Spain) and Light Prescriptions
Innovators, LLC (United States); J. Vilaplana, J. Chaves, Light Prescriptions Innovators
Europe, S. L. (Spain)

POSTER SESSION

8485 0T **Optical design of wavelength selective CPVT system with 3D/2D hybrid concentration**
[8485-29]
N. Ahmad, T. Ijiri, N. Yamada, Nagaoka Univ. of Technology (Japan); T. Kawaguchi,
T. Maemura, H. Ohashi, Mitsui Engineering & Shipbuilding Co., Ltd. (Japan)

8485 0U **High-performance illumination module of RGB LEDs pico-projector with dual double side
micro lens array** [8485-30]
C.-C. Chen, Instrument Technology Research Ctr. (Taiwan); H.-C. Wu, M.-L. Wu, National
Central Univ. (Taiwan); Y.-C. Cheng, W.-Y. Hsu, Instrument Technology Research Ctr.
(Taiwan)

8485 0Y **Optical characteristic of the light guide plate with microstructures engraved by laser**
[8485-34]
T.-C. Teng, National Taiwan Normal Univ. (Taiwan); M.-F. Kuo, Coretronic Corp. (Taiwan)

Author Index

Conference Committee

Program Track Chair

Ian T. Ferguson, The University of North Carolina at Charlotte (United States)

Conference Chairs

Roland Winston, University of California, Merced (United States)
Jeffrey M. Gordon, Ben-Gurion University of the Negev (Israel)

Conference Program Committee

Pablo Benítez, Universidad Politécnica de Madrid (Spain) and Light Prescriptions Innovators LLC (United States)
William J. Cassarly, Synopsys, Inc. (United States)
Daniel Feuermann, Ben-Gurion University of the Negev (Israel)
Ralf Leutz, Concentrator Optics GmbH (Germany)
Juan Carlos Miñano, Universidad Politécnica de Madrid (Spain) and Light Prescriptions Innovators LLC (United States)
Narkis Shatz, SAIC (United States)

Session Chairs

- 1 Thermodynamic Basis of Nonimaging Optics
Jeffrey M. Gordon, Ben-Gurion University of the Negev (Israel)
- 2 Nonimaging Optics for Concentrator Photovoltaics
Narkis Shatz, SAIC (United States)
- 3 Gradient-Index Optics
Hans Philipp Annen, Concentrator Optics GmbH (Germany)
- 4 Novel Applications and Fundamental Limits
Juan Carlos Miñano, Universidad Politécnica de Madrid (Spain) and Light Prescriptions Innovators LLC (United States)
- 5 Nonimaging Optimization Procedures
Pablo Benítez, Universidad Politécnica de Madrid (Spain) and Light Prescriptions Innovators LLC (United States)

- 6 Daylighting
Daniel Feuermann, Ben-Gurion University of the Negev (Israel)
- 7 Illumination Optics
William J. Cassarly, Synopsys, Inc. (United States)

Introduction

Welcome to the 2012 Nonimaging Optics conference. The first conference convened in 1991, so this represents our 21st year.

The conference had more submissions and more attendees than in the recent past, which is a good indicator of the vitality of the field. From the beginning, the subject was differentiated from classical optics. In the first book on nonimaging optics in 1978, the great Walter T. Welford of Imperial College London inserted the Stefan-Boltzmann law of radiation by a black body on page one. When an optics book starts with a thermodynamic relation, you know something interesting is going to happen, and it has! From the beginning, concepts like maximum etendue, concentration, and thermodynamic efficiency were common themes. The connections between information and entropy inspire the design of optimal nonimaging optics devices. And that is why the fusion of the science of light (optics) with the science of heat (thermodynamics), is where much of the excitement is today.

So on behalf of Jeffrey Gordon and myself, please enjoy the next two days of exciting new contributions to this vibrant field of nonimaging optics.

Roland Winston
Jeffrey M. Gordon

