# PROCEEDINGS OF SPIE

# Current Developments in Lens Design and Optical Engineering XX

R. Barry Johnson Virendra N. Mahajan Simon Thibault Editors

12 August 2019 San Diego, California, United States

Sponsored and Published by SPIE

**Volume 11104** 

Proceedings of SPIE 0277-786X, V. 11104

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

Current Developments in Lens Design and Optical Engineering XX, edited by R. Barry Johnson, Virendra N. Mahajan, Simon Thibault, Proc. of SPIE Vol. 11104, 1110401 · © 2019 SPIE CCC code: 0277-786X/19/\$21 · doi: 10.1117/12.2552088

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 *Current Developments in Lens Design and Optical Engineering XX*, edited by R. Barry Johnson, Virendra N. Mahajan, Simon Thibault, Proceedings of SPIE Vol. 11104 (SPIE, Bellingham, WA, 2019) Seven-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510629011

ISBN: 9781510629028 (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 © 2019, 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 \$21.00 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/19/\$21.00.

Printed in the United States of America by Curran Associates, Inc., under license from SPIE.

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



**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**

vii **Authors** Conference Committee ix LENS DESIGN THEORY AND APPLICATIONS 11104 02 Design of a head-mounted display with freeform mirrors [11104-1] 11104 03 Introducing a dynamic deep neural network to infer lens design starting points [11104-2] 11104 04 Application of GPUs in optical design software [11104-3] 11104 05 Wavefront coding with Jacobi-Fourier phase masks (Invited Paper) [11104-4] 11104 06 Consumer electronic optics: how small a lens can be using metasurfaces [11104-5] **NEW DEVELOPMENTS IN OPTICAL SYSTEM DESIGN I** 11104 07 Deployment of combined higher order aberrations to extend the depth of focus of lenses [11104-6] 11104 08 Optical systems for large-aperture phased laser array including diffractive optics [11104-7] 11104 0A Fundus camera versus smartphone camera attachment: image quality analysis [11104-9] 11104 OB A water-polydimethylsiloxane liquid lens for variable focus experiments in an undergraduate **laboratory** [11104-10] NEW DEVELOPMENTS IN OPTICAL SYSTEM DESIGN II 11104 0C Deconvolution process with GPU in a wavefront coding microscopy system [11104-11] 11104 0D Exposure of Restore-L camera optical elements to a simulated orbital radiation environment [11104-12] 11104 OE The design of a four-mirror anti-astigmatism astronomical telescope [11104-13]

## **ADVANCED TEST AND METHODS**

11104 OF	Method to determine refractive index by measurement of flat plates [11104-15]
11104 0G	Silicon Fresnel lens fabricated using greyscale lithography [11104-16]
11104 OH	Determination of rough microstructures on the surface of metals using the light scattering method in waveguides [11104-17]
	RECENT PROGRESS IN SSL AND PHOTOVOLTAIC SYSTEMS
11104 01	Fast measurement of chromatic BSDF and its application to LED lighting (Invited Paper) [11104-18]
11104 OJ	Freeform optics design of primary lens for uniform irradiance distribution of a concentrator photovoltaic system [11104-19]
11104 OK	A laser pumping double-light-source module with photon-recycling [11104-20]
11104 OL	Perovskite-on-polymer microspheres for optimized solid state lighting [11104-21]
11104 OM	Lighting design of an indoor sports field [11104-22]
	POSTER SESSION
11104 ON	POSTER SESSION  Laser strength multilayer interference coatings with the Gaussian profile for Nd:YAG lasers [11104-23]
11104 0N 11104 0O	Laser strength multilayer interference coatings with the Gaussian profile for Nd:YAG lasers
	Laser strength multilayer interference coatings with the Gaussian profile for Nd:YAG lasers [11104-23]  Contact lens design to third order to compensate the spherical aberration of the eye from
11104 00	Laser strength multilayer interference coatings with the Gaussian profile for Nd:YAG lasers [11104-23]  Contact lens design to third order to compensate the spherical aberration of the eye from Zernike polynomials [11104-24]
11104 0O 11104 0P	Laser strength multilayer interference coatings with the Gaussian profile for Nd:YAG lasers [11104-23]  Contact lens design to third order to compensate the spherical aberration of the eye from Zernike polynomials [11104-24]  General formula for aspheric collimator lens design free of spherical aberration [11104-25]
11104 0O 11104 0P 11104 0Q	Laser strength multilayer interference coatings with the Gaussian profile for Nd:YAG lasers [11104-23]  Contact lens design to third order to compensate the spherical aberration of the eye from Zernike polynomials [11104-24]  General formula for aspheric collimator lens design free of spherical aberration [11104-25]  Spatial resolution of an optical microscope with oblique illumination [11104-27]  Material selection for an achromatic and athermal design using the factor of determination on
11104 0O 11104 0P 11104 0Q 11104 0R	Laser strength multilayer interference coatings with the Gaussian profile for Nd:YAG lasers [11104-23]  Contact lens design to third order to compensate the spherical aberration of the eye from Zernike polynomials [11104-24]  General formula for aspheric collimator lens design free of spherical aberration [11104-25]  Spatial resolution of an optical microscope with oblique illumination [11104-27]  Material selection for an achromatic and athermal design using the factor of determination on optical glasses [11104-28]

Development of a calculation method of multi-color mixed phosphor spectrum prediction in white-light LED [11104-36]

Proc. of SPIE Vol. 11104 1110401-6

# **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.

Acosta, E., 05 Alvarado-Cruz, L. B., 0U

Álvarez, J., 0H

Añonuevo, Johannes F., OB

Arines, J., 05

Arreola-Esquivel, M., OU, OW

Arthurs, Eugene, OT Barritt, Nicole, 0A Boomhower, Oliver, 0G Borovytsky, Volodymyr, 0Q Brown, Stephen K., 0D Castro-Ortega, R., 0U Chen, Cheng-Po, 0G Chen, Wei-Hsin, Ol Côté, Geoffroi, 03 Croce, Alessandra, 04 Curley, Michael J., 0F

Dekate, Sachin, OG Delgadillo-Herrera, M., 0U, 0W de Lima Monteiro, Davies William, 07

de Oliveira Costa, Rodolfo Felipe, 07

Dong, Yajie, OL Duy, N. N., 0J Erlikhman, Jacob, 08 Espinosa, N., 0H Faruq, Ibrahim, 0A, 0T Garcia-Lievanos, O., 00 González-Acuña, Rafael G., 0P González-Amador, E., 05 Goswami, Shubhodeep, 0G Guerrero, Raphael A., 0B

Gutiérrez-Vega, Julio C., 0P He, Zigian, OL

Heaney, James B., 0D Hernandez-Flores, Luis A., 00

Hettel, Will, 08 Hu, Tiantian, 02 Huana, Jiun-Woei, 0E Johnson, R. Barry, OF Karp, Jason, 0G Kim, Kum-Ho, OR Kretchmer, Jim, 0G Krogen, Peter, 08

Kuppuswamy Parthasarathy, Mohana, OA, OT

Kuznetsov, E. V., ON

Lakshminarayanan, Vaseudevan, OA, OT

Lalonde, Jean-François, 03 Lauenstein, Jean-Marie, 0D Lee, Xuan-Hao, OI, OK, OM

Lim, Tae-Yeon, OR Lin, Shih-Kang, OK, OM Lin, Yong-Sheng, 0X Lubin, Philip, 08 Ma, Shih-Hsin, OX Ma, Suodong, 02

León, P., 0H

Meinhold, Peter, 08 Melk de Carvalho, Luiz, 07

Miller, Kevin H., 0D

Miller, Sharon K., 0D Mischuck, Brian, 04 Novopashin, V. V., 0N O'Connor, Kenneth M., 0D Olvera-Angeles, M., 05 Ortega-Sánchez, K., 0C

Padilla-Vivanco, A., 05, 0C, 0U, 0W

Page, Erik, 04

Park, Sung-Chan, OR Pham, Thanh Tuan, 0J Rui, Congshan, 02

Sanchez-Gonzalez, Leticia, 00

Shestakov, A. V., 0N Shin, Seoyong, 0J Srinivasan, Prashant, 08

Su, Yu-Wen, 0K

Sun, Ching-Cherng, 0I, 0K, 0M Teran-Bobadilla, Emiliano, 00 Thibault, Simon, 03, 06

Toepfer, Tim, 0G

Toxqui-Quitl, C., 05, 0C, 0U, 0W

Tsakalakos, Loucas, 0G Tseng, Chun-Ming, 0X

Vega, C., 0H Vila, J., 0H Vu, Ngoc Hai, 0J Wu, Shin-Tson, OL

Yang, Tsung-Hsun, OI, OK, OM

Yu, Yeh-Wei, 0I, 0K, 0M Zelek, John, 0A Zeng, Chunmei, 02 Zhang, Caicai, 0L

Proc. of SPIE Vol. 11104 1110401-8

# **Conference Committee**

#### Program Track Chair

José Sasián, James C. Wyant College of Optical Sciences, The University of Arizona (United States)

#### Conference Chairs

 R. Barry Johnson, Alabama A&M University (United States)
 Virendra N. Mahajan, James C. Wyant College of Optical Sciences, The University of Arizona (United States)
 Simon Thibault, Université Laval (Canada)

### Conference Program Committee

Julie L. Bentley, University of Rochester (United States)
Florian Bociort, Technische Universiteit Delft (Netherlands)
Robert M. Bunch, Rose-Hulman Institute of Technology (United States)
Pierre H. Chavel, Institut d'Optique (France)
Apostolos Deslis, JENOPTIK Optical Systems (United States)
José Antonio Díaz Navas, University de Granada (Spain)
James E. Harvey, Photon Engineering LLC (United States)
Lakshminarayan Hazra, University of Calcutta (India)
Irina L. Livshits, ITMO University (Russian Federation)
Steven A. Macenka, Jet Propulsion Laboratory (United States)
Michael Mandina, Optimax Systems, Inc. (United States)
Pantazis Mouroulis, Jet Propulsion Laboratory (United States)
Alfonso Padilla-Vivanco, Universidad Politécnica de Tulancingo (Mexico)

Ching-Cherng Sun, National Central University (Taiwan)
Yuzuru Takashima, James C. Wyant College of Optical Sciences, The
University of Arizona (United States)

Yongtian Wang, Beijing Institute of Technology (China)
Cornelius Willers, Consultant (South Africa)
Andrew P. Wood, Qioptia Ltd. (United Kingdom)

María J. Yzuel, Universidad Autònoma de Barcelona (Spain)

#### Session Chairs

Lens Design Theory and Applications
 R. Barry Johnson, Alabama A&M University (United States)

- New Developments in Optical System Design I Virendra N. Mahajan, James C. Wyant College of Optical Sciences, The University of Arizona (United States)
- 3 New Developments in Optical System Design II Robert M. Bunch, Rose-Hulman Institute of Technology (United States)
- 4 Advanced Test and Methods
  Simon Thibault, Université Laval (Canada)
- Recent Progress in SSL and Photovoltaic Systems
   Ching-Cherng Sun, National Central University (Taiwan)