PROCEEDINGS OF SPIE

SPIDigitalLibrary.org/conference-proceedings-of-spie

Front Matter: Volume 10676

, "Front Matter: Volume 10676," Proc. SPIE 10676, Digital Optics for Immersive Displays, 1067601 (31 July 2018); doi: 10.1117/12.2501818

SPIE.

Event: SPIE Photonics Europe, 2018, Strasbourg, France

PROCEEDINGS OF SPIE

Digital Optics for Immersive Displays

Bernard C. Kress
Wolfgang Osten
Hagen Stolle
Editors

24–25 April 2018
Strasbourg, France

Sponsored by
SPIE

Cosponsored by
Strasbourg the Eurooptimist (France)
CNRS (France)
Investissements d'Avenir (France)
iCube (France)
Université de Strasbourg (France)

Cooperating Organisations
Photonics 21 (Germany)
EOS—European Optical Society (Germany)
Photonics Public Private Partnership (Belgium)
Comité National d'Optique et de Photonique (France)

Published by
SPIE

Volume 10676

Proceedings of SPIE 0277-786X, V. 10676

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

Digital Optics for Immersive Displays, edited by Bernard C. Kress, Wolfgang Osten,
Hagen Stolle, Proc. of SPIE Vol. 10676, 1067601 · © 2018 SPIE
CCC code: 0277-786X/18/\$18 · doi: 10.1117/12.2501818

Proc. of SPIE Vol. 10676 1067601-1

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 *Digital Optics for Immersive Displays*, edited by Bernard C. Kress, Wolfgang Osten, Hagen Stolle, Proceedings of SPIE Vol. 10676 (SPIE, Bellingham, WA, 2018) Seven-digit Article CID Number.

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

ISBN: 9781510618787
ISBN: 9781510618794 (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. 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

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	<i>Authors</i>
ix	<i>Conference Committee</i>
xi	<i>Conference Sponsors</i>

SESSION 1 OPTICAL CHALLENGES FOR NEXT-GENERATION AR/VR HEADSETS

10676 04	Field of view: not just a number [10676-3]
10676 05	Optical design challenges from satellite imaging to augmented reality displays [10676-4]
10676 06	Viewing optics for immersive near-eye displays: pupil swim/size and weight/stray light [10676-5]

SESSION 2 DESIGN, FABRICATION AND TESTING OF NOVEL OPTICS FOR AR/VR SYSTEMS

10676 07	Ultra-compact multichannel freeform optics for 4xWUXGA OLED microdisplays (Invited Paper) [10676-6]
10676 09	Casting technology for embedding optical elements into prescription spectacle lenses [10676-8]
10676 0B	Optical metrology for immersive display components and subsystems [10676-10]
10676 0C	HMD quality evaluation of projected image: hardware assessment and software evaluation for distortions correction [10676-11]

SESSION 3 HOLOGRAPHIC OPTICS FOR AR/VR SYSTEMS

10676 0D	Curved wedges and shearing gratings for augmented reality (Invited Paper) [10676-12]
10676 0E	Characterisation and optimisation of Volume Holographic Optical Elements (VHOEs) in AR combiners for ghost reduction [10676-13]
10676 0F	Bragg polarization gratings used as switchable elements in AR/VR holographic displays [10676-14]

- 10676 OG **DigiLens switchable Bragg grating waveguide optics for augmented reality applications** [10676-15]
- 10676 OH **Wavelength multiplexing recording of vHOEs in Bayfol HX photopolymer film** [10676-16]

SESSION 4 IMPROVING VISUAL COMFORT IN AR/VR SYSTEMS

- 10676 OJ **Varifocal technologies providing prescription and VAC mitigation in HMDs using Alvarez lenses (Invited Paper)** [10676-18]
- 10676 OL **Computationally efficient and antialiased dual-layer light-field displays** [10676-19]
- 10676 ON **Experimental evaluation of self-focusing image formation in unconventional near-eye display** [10676-22]

DOID STUDENT OPTICAL DESIGN CHALLENGE FOR VR/AR AND MR: POSTER PRESENTATIONS

- 10676 OQ **Improving image quality of 360-degree viewable holographic display system by applying a speckle reduction technique and a spatial filtering** [10676-20]
- 10676 OS **Design of a freeform gradient-index prism for mixed reality head mounted display** [10676-101]
- 10676 OT **Optical design, assembly, and characterization of a holographic head mounted display** [10676-103]
- 10676 OU **Mitigating vergence-accommodation conflict for near-eye displays via deformable beamsplitters (1st Place, DOID Student Optical Design Challenge)** [10676-104]
- 10676 OV **Designing of a monocular see-through smart glass imaging system** [10676-105]
- 10676 OX **A reflective prism for augmented reality with large field of view** [10676-109]
- 10676 OY **Design of a spatially multiplexed light field display on curved surfaces for VR HMD applications** [10676-110]
- 10676 OZ **See-through smart glass with adjustable focus** [10676-111]
- 10676 12 **Ultrathin full color visor with large field of view based on multilayered metasurface design (1st Place, DOID Student Optical Design Challenge)** [10676-117]
- 10676 13 **A vergence accommodation conflict-free virtual reality wearable headset** [10676-119]
- 10676 14 **Ultrathin optical combiner with microstructure mirrors in augmented reality (2nd Place, DOID Student Optical Design Challenge)** [10676-120]

- 10676 15 **Wide field-of-view waveguide displays enabled by polarization-dependent metagratings (1st Place, DOID Student Optical Design Challenge)** [10676-121]
- 10676 16 **Over-designed and under-performing: design and analysis of a freeform prism via careful use of orthogonal surface descriptions** [10676-122]
- 10676 17 **Shape scanning displays: tomographic decomposition of 3D scenes** [10676-124]
- 10676 18 **Polarization-dependent metasurfaces for 2D/3D switchable displays** [10676-125]
- 10676 19 **High-performance integral-imaging-based light field augmented reality display** [10676-126]
- 10676 1A **Design and stray light analysis of a lenslet-array-based see-through light-field near-eye display** [10676-127]
- 10676 1B **High-resolution head mounted display using stacked LCDs and birefringent lens (2nd Place, DOID Student Optical Design Challenge)** [10676-128]
- 10676 1C **A retinal-projection-based near-eye display for virtual reality** [10676-129]
- 10676 1D **Understanding waveguide-based architecture and ways to robust monolithic optical combiner for smart glasses** [10676-131]
- 10676 1E **Compact see-through AR system using buried imaging fiber bundles (2nd Place, DOID Student Optical Design Challenge)** [10676-132]
- 10676 1F **Design of an immersive head mounted display with coaxial catadioptric optics** [10676-133]
- 10676 1G **Ultra-compact pancake optics based on ThinEyes super-resolution technology for virtual reality headsets (3rd Place, DOID Student Optical Design Challenge)** [10676-134]
- 10676 1H **Solving the vergence-accommodation conflict in head mounted displays with a magnifier system** [10676-135]
- 10676 1I **Augmented reality display system for smart glasses with streamlined form factor** [10676-139]
- 10676 1J **High-resolution optical see-through vari-focal-plane head-mounted display using freeform Alvarez lenses (3rd Place, DOID Student Optical Design Challenge)** [10676-140]
- 10676 1K **Super multi-view augmented reality glasses** [10676-142]
- 10676 1L **PARA: experimental device for virtual and augmented reality (3rd Place, DOID Student Optical Design Challenge)** [10676-143]

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.

Avayu, Ori, 12	Grant, Alastair J., 0G
Benítez, Pablo, 07	Gritsai, Yuri, 0F
Bentley, Julie L., 0S, 0Y, 16, 11	Gu, Luo, 1F
Bodell, S. Yvonne, 0S	Gurabardhi, Entela, 0C
Bolotova, A., 1K	Gurganos, Dustin, 0Z
Brac de la Perrière, Vincent, 1D	Haeberlé, Olivier, 0N
Bruder, Friedrich-Karl, 0H	Hansen, Sven, 0H
Bryars, Brett, 06	Hasnain, A., 0J
Buljan, Marina, 07	Häussler, R., 0T
Capasso, Federico, 15, 18	Herkommer, Alois M., 1E
Cardenas, Nelson, 06	Hong, Keehoon, 0Q
Casarin, Julien, 1L	Horvath, Nicholas, 0Z
Chakravarthula, Praneeth, 0U	Hovis, Clark, 0Z
Chan, Ning, 06	Hua, Hong, 14, 19, 1J
Charrière, S., 13	Huang, Hekun, 19
Chen, Bo, 0X	Jin, Peng, 1B
Chen, Chao Ping, 1C	Jo, Youngjin, 17
Chen, Wei Ting, 15	Kim, Hayan, 0Q
Cheng, Dewen, 1A, 1F	Kim, Jinwoong, 0Q
Cho, Jaebum, 17	Kochan, Nicholas S., 0Y
Choi, Stephen, 04	Kolchin, Konstantin, 0L
Chu, Jiaqi, 0D	Koneva, Tatiana A., 0V
Deck, Leslie L., 0B	Körner, L., 09
de Groot, Peter J., 0B	Krotov, Vladimir, 0N
Ditcovski, Ran, 12	Kurilin, Ilya, 0L
Dong, Qian, 0U	Laffont, P.-Y., 0J
Druzhin, V., 1K	Lam, Wai Sze Tiffany, 06
Dunn, David, 0U	Lanman, Douglas, 06
Duveau, L., 13	Larroque, Stan, 1L
Ellenbogen, Tal, 12	Lee, Byoungcho, 17
Fix, Alexander, 06	Lee, Dukho, 17
Fleck, B., 0T	Lee, Seungjae, 17
Francardi, Marco, 0C, 0E	Lewis, Brant, 06
Francesca, Enzo, 0C, 0E	Li, Yang, 1C
Fu, Yijing, 06	Lim, Yongjun, 0Q
Fuchs, Henry, 0U	López, Jesús, 07
Gantes-Núñez, Francisco Javier, 1H	Luanava, Selso, 04
Gao, Liang, 1B	Maitlo, Nizamuddin, 1C
Gao, Weichuan, 04	Malacara-Hernández, Daniel, 1H
Gärtner, A., 0T	Malacara-Hernández, Zacarías, 1H
Geng, Ying, 04, 06	Manecke, Christel, 0H
Georgiou, Andreas, 0D	Martinez, Christophe, 0N
Gešer, P., 1E	McEldowney, Scott, 06
Giartosio, Francesco, 0C, 0E	Mi, Lantian, 1C
Giessen, H., 1E	Miletti, Thomas, 0C, 0E
Gollier, Jacques, 04, 06	Milyukov, Gleb, 0L
González, Juan Carlos, 07	Miñano, Juan Carlos, 07
Gorospe, Jorge, 07	Mohedano, Rubén, 07
Grabovičkić, Dejan, 07	Moore, Duncan T., 0S, 0Y, 16, 11

Muff, D., 09
 Narasimhan, Bharathwaj Appan, 07, 1G
 Ni, Yunhui, 0S
 Nikolić, Milena, 07
 Noste, Todd, 0Z
 Noui, Louahab, 05
 Orselli, Enrico, 0H
 Park, Minsik, 0Q
 Peng, Fenglin, 06
 Pérez, Eduardo, 07
 Popov, Mikhail, 0L
 Popovich, Milan M., 0G
 Putilin, A., 1K
 Qiao, Wei, 1B
 Rewitz, Christian, 0H
 Rhodes, D. P., 0J
 Rolland, Jannick P., 0S, 16
 Rölle, Thomas, 0H
 Romanova, Galina E., 0V
 Rychagov, Mikhail, 0L
 Ryu, Jaeyeol, 0L
 Sahm, Hagen, 0F
 Sakhno, Oksana, 0F
 Sanchez, Eduardo, 07
 Schmidt, Greg, 0Y, 1I
 Shahinian, Hossein, 0Z
 Shanmugam, Prithiviraj, 0Z
 Shi, Zhujun, 15, 18
 Shtykov, Stanislav, 0L
 Sizemore, Nicholas, 0Z
 Sohn, Alexander, 06
 Song, Wanyue, 0S, 16
 Steven, Samuel J., 0Y, 1I
 Stevens, R. E., 0J
 Stolle, H., 0T
 Stumpe, Joachim, 0F
 Sulai, Yusufu, 04, 06
 Takaki, Nicholas, 0S, 16
 Thiele, S., 1E
 Travis, A. R. L., 0D
 Truant, Nicola, 0C, 0E
 Turko, Sergey, 0L
 Waldern, Jonathan D., 0G
 Wang, Yongtian, 1A, 1F
 Wegener, Michael, 0F
 Wewer, Brita, 0H
 Wheelwright, Brian, 04, 06
 Wilson, Austin, 1J
 Xu, Miaomiao, 14
 Yang, Tianyi, 0S, 0Y
 Yao, Cheng, 1A
 Yee, Anthony J., 0S, 16
 Yoo, Dongheon, 17
 Yoon, Youngshik, 06
 Yu, Bing, 1C
 Zamora, Pablo, 07
 Zhang, Wenbo, 1C
 Zhao, Yang, 0S, 1I
 Zhou, Yuanchao, 1C
 Zhu, Shuaishuai, 1B

Conference Committee

Symposium Chairs

Francis Berghmans, Vrije Universiteit Brussel (Belgium)
Thierry Georges, Oxxius SA (France)
Harald Giessen, Universität Stuttgart (Germany)
Paul Montgomery, Université de Strasbourg (France)

Conference Chairs

Bernard C. Kress, Microsoft Corporation (United States)
Wolfgang Osten, Institut für Technische Optik (Germany)
Hagen Stolle, SeeReal Technologies GmbH (Germany)

Conference Program Committee

Tibor Balogh, Holografika Kft. (Hungary)
Christian Bosshard, Centre Suisse d'Electronique et de Microtechnique SA (Switzerland)
Federico Capasso, Harvard School of Engineering and Applied Sciences (United States)
Jerome Carollo, Google, Inc. (United States)
Arie den Boef, ASML Netherlands B.V. (Netherlands)
Andreas Hermerschmidt, HOLOEYE Photonics AG (Germany)
Hans Peter Herzig, Ecole Polytechnique Fédérale de Lausanne (Switzerland)
Tobias Haist, Institut für Technische Optik (Germany)
Marc D. Himmel, JENOPTIK Optical Systems, LLC (United States)
Hong Hua, College of Optical Sciences, The University of Arizona (United States)
Fu-Chung Huang, NVIDIA Corporation (United States)
Norbert Kerwien, Carl Zeiss AG (Germany)
Lutz Körner, INTERGLASS Technology AG (Switzerland)
Byoungcho Lee, Seoul National University (Korea, Republic of)
Cindy Lee, KHD Ltd. (China)
Scott McEldowney, Oculus VR, LLC (United States)
Juan C. Miñano, Limbak 4PI S.L. (Spain)
Ilmars Osmanis, Lightspace Technologies, SIA (Latvia)
Silvania F. Pereira, Technische Universiteit Delft (Netherlands)
Christophe Peroz, Magic Leap, Inc. (United States)
Pascal Picart, Université du Maine (France)
Demetri Psaltis, Ecole Polytechnique Fédérale de Lausanne (Switzerland)
Monika Ritsch-Marte, Medizinische Universität Innsbruck (Austria)
Khaled Sarayeddine, Optinvent (France)

Robert Stevens, Adlens Ltd. (United Kingdom)
Hagen Stolle, SeeReal Technologies GmbH (Germany)
Adrian Travis, Microsoft Corporation (United States)
Reinhard Voelkel, SUSS MicroOptics SA (Switzerland)
Angus Wu, Huawei Technologies Company, Ltd. (United States)
Frank Wyrowski, Friedrich-Schiller-Universität Jena (Germany)

Session Chairs

- 1 Optical Challenges for Next-generation AR/VR headsets
Bernard C. Kress, Microsoft Corporation (United States)
- 2 Design, Fabrication and Testing of Novel Optics for AR/VR systems
Lutz Körner, INTERGLASS Technology AG (Switzerland)
- 3 Holographic Optics for AR/VR Systems
Friedrich-Karl Bruder, Covestro AG (Germany)
- 4 Improving visual comfort in AR/VR systems
Hong Hua, College of Optical Sciences, The University of Arizona
(United States)

Conference Sponsors

GOLD

Google, Inc. (United States)
LightTrans GmbH (Germany)
Microsoft Corporation (United States)
Oculus VR, LLC (United States)
Zemax, LLC (United States)
Huawei Technologies Company, Ltd. (China)
Jenoptik GmbH (Germany)

SILVER

Leia Inc. (United States)
Amazon.com, Inc. (United States)
Zeiss GmbH (Germany)
Synopsys Inc. (United States)
Applied Materials, Inc. (United States)

EQUIPMENT AND SOFTWARE

Lambda Research Corporation (United States)
NVIDIA Corporation (United States)
Zemax, LLC (United States)
LightTrans (Germany)