

PROCEEDINGS OF SPIE

Optifab 2019

Blair L. Unger
Jessica DeGroot Nelson
Editors

14–17 October 2019
Rochester, New York, United States

Sponsored by
SPIE

Cosponsored by
The American Precision Optics Manufacturers Association (United States)

Published by
SPIE

Volume 11175

Proceedings of SPIE 0277-786X, V. 11175

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

Optifab 2019, edited by Blair L. Unger, Jessica DeGroot Nelson, Proc. of SPIE Vol. 11175,
1117501 · © 2019 SPIE · CCC code: 0277-786X/19/\$21 · doi: 10.1117/12.2559224

Proc. of SPIE Vol. 11175 1117501-1

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 *Optifab 2019*, edited by Blair L. Unger, Jessica DeGroot Nelson, Proceedings of SPIE Vol. 11175 (SPIE, Bellingham, WA, 2019) Seven-digit Article CID Number.

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

ISBN: 9781510630635
ISBN: 9781510630642 (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.

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 *Authors*
ix *Conference Committee*

PLENARY SESSION

- 11175 04 **Apprenticeship: precision optics manufacturing technician (Plenary Paper)** [11175-17]

ADVANCEMENTS IN CONVENTIONAL FABRICATION METHODS

- 11175 05 **Creating sub angstrom surfaces on planar and spherical substrates** [11175-1]
11175 06 **A method to discriminate between upper and lower side material removal in double-side polishing** [11175-2]
11175 07 **Three-dimensional configurable IC optic material for precision CNC optical polishing** [11175-3]
11175 08 **Subsurface damage measurement of single crystal germanium and borosilicate glass BK-7** [11175-4]
11175 0A **Particle distribution characterization on material removal uniformity in chemical mechanical polishing** [11175-6]

INTEGRATING AUTOMATION AND LASERS INTO OPTICS FABRICATION

- 11175 0B **Robotic polishing in asphere manufacturing** [11175-7]
11175 0D **Ultra precision glass machining through ultrasonic assisted diamond turning** [11175-9]
11175 0E **High speed ultraprecision machining of germanium** [11175-10]
11175 0F **Micro-laser assisted single point diamond turning of fused silica glass** [11175-11]

DETERMINISTIC PROCESSING OF OPTICS

- 11175 0H **Precision machining of strong aspheres made of calcium fluoride and fused silica** [11175-13]

- 11175 OI **Material removal for small compressions on fused silica on an OptiPro UltraForm finishing machine** [11175-14]
- 11175 OK **Fabrication of continuous phase plates based on bonnet polishing** [11175-16]

DETERMINISTIC FINISHING PROCESSES

- 11175 OL **Wavefront improvement by IBF-processed correction surfaces** [11175-24]
- 11175 OM **Study on the performances of dwell time algorithms in ion beam figuring** [11175-26]
- 11175 ON **Extending magnetorheological finishing to address short radius concave surfaces and mid-spatial frequency errors** [11175-28]
- 11175 OO **Accounting for MRF spot removal rate variation caused by plunge depth deviation** [11175-30]
- 11175 OP **Polishing ultra-precision ground aspherical surfaces with MRF** [11175-32]
- 11175 OQ **New meter-class MRF platforms offer multiple size and capability options** [11175-34]

OPTICAL ENGINEERING

- 11175 OW **Design, simulation and manufacturing a CFRP prototype mirror for active/adaptive optics** [11175-23]

FREEFORM MANUFACTURING

- 11175 OZ **Freeform testability considerations for subaperture stitching interferometry** [11175-35]
- 11175 10 **Definitions of criteria for assessing feasibility and measurability of freeform surfaces** [11175-36]
- 11175 11 **Advances in freeform manufacturing** [11175-37]
- 11175 12 **Near-conformal window assembly for airborne payloads: improved time on-station and optical performance** [11175-38]
- 11175 13 **Measurement of form and mid-spatial-frequency errors of specular freeform surfaces** [11175-39]
- 11175 14 **Scaling-up freeform manufacturing: challenges and solutions** [11175-40]

ADVANCES IN FREEFORM AND NOVEL METROLOGY TECHNIQUES

- 11175 15 **Advancements in non-contact freeform metrology with datum structures** [11175-41]
- 11175 16 **Advantages of a low coherence interferometer for optical testing** [11175-43]
- 11175 17 **Spectrally controlled interferometry for improved radius of curvature measurement** [11175-44]

SURFACE ROUGHNESS AND OPTICAL ALIGNMENT

- 11175 19 **Sub-angstrom surface roughness metrology with the white light interferometer** [11175-46]
- 11175 1B **Rotation-free centration measurement for fast and flexible inspection of optical lens systems** [11175-48]
- 11175 1C **Novel active alignment technique for measuring tilt errors in aspheric surfaces during optical assembly using Lens Alignment Station (LAS)** [11175-49]
- 11175 1D **Beyond centration: how to create, read, and use a datum system per ISO-10110-6 (2015)** [11175-50]

MID-SPATIAL FREQUENCY AND WAVEFRONT ERROR MEASUREMENT METHODS

- 11175 1E **Analysis of mid-spatial frequency errors in two dimensions at metal mirror fabrication** [11175-51]
- 11175 1I **Measurement of a concave spherical mirror with 50 mm radius of curvature by three dimensional nanoprofiler using normal vector tracing** [11175-55]

OPTICAL COATINGS

- 11175 1L **Large-scale freeform surface ultra-thin film coating uniformity measurement based on a dynamic spectroscopic ellipsometer** [11175-58]
- 11175 1O **Influence of ion assistance on optical properties, residual stress and laser induced damage threshold of HfO₂ thin film by use of different ion sources** [11175-61]

STRUCTURED OPTICAL SURFACES

- 11175 1P **Microlens array based three-dimensional light field projection and possible applications in photolithography** [11175-62]

- 11175 1S **Multi-functional immersion grating by homemade freeform cutting machine** [11175-65]
- 11175 1U **Molded anti-reflective structures of chalcogenide glasses for infrared optics by precision glass molding** [11175-67]
- 11175 1V **Approaches and methodologies for process development of thin glass forming** [11175-68]

POSTER SESSION

- 11175 1Y **Silicone grating fabricated using photoresist mold** [11175-71]
- 11175 20 **An effective way to calibrate the external errors which are contributed in the interferometric test for spherical surfaces** [11175-73]
- 11175 21 **Experimental investigation on processing of fused silica microchannels by high repetition rate femtosecond laser** [11175-74]
- 11175 23 **Study of thermal deformation monitoring system with long short term memory network in alignment turning system** [11175-76]
- 11175 26 **Development of a reflective spiral phase plate based on MRF polishing** [11175-80]
- 11175 29 **Study on wear behavior of grinding wheel for the generating process of UV grade fused silica** [11175-83]
- 11175 2B **High precision interferometric measurement of freeform surfaces from the well-defined sub-aperture surface profiles** [11175-85]
- 11175 2C **Diamond turning of aluminum image slicers for astronomical applications** [11175-86]
- 11175 2E **Compensation of thermal drift during the single-point diamond turning process based on the LSTM** [11175-89]

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.

Auger, Hugues, 2C
Baghsiahi, Hadi, 0W
Beier, Matthias, 1E
Bergs, Thomas, 1U, 1V
Berkson, Joel D., 12
Binkele, T., 13
Blalock, Todd, 14
Bodlapati, Charan, 0E, 0F
Brooks, David, 0W
Brousseau, Denis, 2C
Brunelle, Matt, 14
Bulla, B., 0D
Chabot, Tristan, 2C
Chang, Jiun-Lee, 29
Chang, Shenq-Tsong, 20
Chen, Fong-Zhi, 23
Chen, Hua-Lin, 20, 29
Chen, Hung-Pin, 20, 29
Chen, Jun-Cheng, 23
Chen, Wei-Chun, 20
Chen, Xian-hua, 0A, 0K
Coniglio, Jen, 14
Da Costa Fernandes, B., 06
Dambon, O., 0D
DeFisher, Scott, 11, 15
DeGroot Nelson, Jessica, 14
DeMarco, Mike, 0O
Dembele, Vamara, 1L
Deng, Wen-hui, 0K
Doel, Peter, 0W
Doetz, M., 0D
du Jeu, Christian, 10
Dumas, Paul, 0Q
El Handrioui, Hassan, 10
Endo, Katsuyoshi, 11
Essameldin, M., 13
Feldkamp, Roman, 0L
Ferralli, Ian, 14
Fleischmann, F., 13
Fourez, Julien, 10
Freischlad, Klaus R., 16
Garden, Rognvald, 1C
Gemmill, William R., 07
Gilles, Matthieu, 10
Green, Mark, 1C
Gross, Herbert, 1E
Grunwald, Tim, 1U, 1V
Hahne, F., 1B
Hall, Chris, 0O
Hartung, Johannes, 1E
Hashimoto, Kota, 1I
Heinisch, J., 1B
Henning, T., 13
Hilbig, D., 13
Hinrichs, Keith M., 12
Huang, Chien-Yao, 23, 29
Huang, Lei, 0M
Hyun, Sang-Won, 26, 2B, 2E
Idir, Mourad, 0M
Ikeda, Yusuke, 1Y
Iles, Shawn, 05, 19
Je, Soonkyu, 2B
Jeon, Min-Woo, 26
Jeong, Byeong-Jun, 2E
Jeong, Seok-Kyeong, 26, 2E
Jones, Martyn, 0W
Kang, Di, 0E, 0F
Kang, Jong-Gyun, 26, 2E
Kang, Jungmin, 1I
Kim, Daesuk, 1L
Kim, Geon-Hee, 26, 2B, 2E
Knight, Terry, 07
Kolopoulos, Chris L., 16
Kraft, Nicholas, 07
Lambropoulos, John C., 08, 0I
Lammers, Tom, 1E
Lang, W., 13
Langehanenberg, P., 1B
Lee, Won-Kyun, 2E
Leibowitz, Noah, 0I
Li, Shugang, 1O
Liao, Defeng, 0A
Liao, Kai, 21
Lin, Wei-Cheng, 20, 23, 29
Lin, Yu-Wei, 20
Liu, Bin, 21
Liu, Mincai, 1O
Liu, Zhichao, 1O
Lucas, Felix, 0H
Luo, Jing, 1O
Lynch, Tim, 14
Maloney, Chris, 0N, 0Q
Mandina, Mike, 04
Martin, Tony R., 07
Maunier, C., 06
Mei, Xuesong, 21
Mende, Hendrik, 1V
Messner, William, 0N

Murphy, Paul E., 0Z
Myer, Brian, 14
Navare, Jayesh, 0E, 0F
Neauport, J., 06
Nelson, Jayson, 05, 19
Okura, Yukinobu, 1S
Olszak, Artur G., 17
Pan, Aifei, 21
Pan, Feng, 1O
Pomerantz, Michael, 08, 0I
Qiao, Jie, 08
Quattrociochi, Nick, 14
Ravindra, Deepak, 0E, 0F
Redien, M., 06
Rinkus, M., 0B
Rojacher, Cornelia, 1U
Roll, Christopher D., 12
Ross, James, 11, 15
Rumpel, Armin, 0P
Ruppel, Thomas, 0P
Salsbury, Chase, 17
Schmelzer, Olaf, 0H
Schmitt, Robert Heinrich, 1V
Sebastian, Thomas, 12
Shahinian, Hossein, 0E, 0F
Sukegawa, Takashi, 1S
Sung, Cheng-Kuo, 20
Supranowitz, Chris, 0Z
Tayabaly, Kashmira, 0M
Taylor, Lauren, 08
Thibault, Simon, 2C
Toyoshi, Yui, 1I
VanKouwenberg, Jim, 04
Vogel, Paul-Alexander, 1V
Vu, Anh-Tuan, 1U, 1V
Waak, Thomas, 0H
Wang, Chung-Ying, 23
Wang, Jian, 0A, 1O
Wang, Jung Hsing, 23
Wang, Tianyi, 0M
Wang, Wenjun, 21
Wang, Zheng, 1O
Watson, Stephen, 0O
Wei, Yaowei, 1O
Wen, Sheng-lin, 0K
Wen, Sy-Bor, 1P
Williamson, Ray, 1D
Wolfs, Franciscus, 11
Wu, Qian, 1O
Wu, Wen-Hong, 29
Xie, Ruiqing, 0A
Xu, Jing, 08
Xu, Qiao, 0A
Yamada, Itsunari, 1Y
Yeo, Woo-Jong, 26, 2E
Zaytsev, Dmytro, 0E, 0F
Zhang, Fei, 1O
Zhang, Hongjie, 1P
Zhang, Qinghua, 0A
Zhao, Shijie, 0A
Zheng, Nan, 0K
Zhong, Bo, 0K

Conference Committee

Conference Chairs

Blair L. Unger, Rochester Precision Optics, LLC (United States)
Jessica DeGroote Nelson, Optimax Systems, Inc. (United States)

Conference Program Committee

Thomas Battley, New York Photonics Industry Association
(United States)
Michael J. Bechtold, OptiPro Systems, LLC (United States)
Rebecca Wilson Borrelli, Harris Corporation (United States)
Christopher T. Cotton, ASE Sailing Inc. (United States)
John P. Deegan, Rochester Precision Optics, LLC (United States)
Michael A. DeMarco, QED Optics (United States)
Apostolos Deslis, JENOPTIK Optical Systems, LLC (United States)
Dan Gauch, Schneider Optical Machines Inc. (United States)
Tom M. Godin, Satisloh North America Inc. (United States)
Heidi Hofke, OptoTech Optical Machinery Inc. (United States)
Dhananjay Joshi, Clemson University (United States)
Jay Kumler, JENOPTIK Optical Systems, LLC (United States)
Justin J. Mahanna, Universal Photonics Inc. (United States)
Michael A. Marcus, Lumetrics, Inc. (United States)
Michael N. Naselaris, Sydor Optics, Inc. (United States)
Richard Nastasi, Universal Photonics Inc. (United States)
John J. Nemechek, Metrology Concepts LLC (United States)
Matthias Pfaff, OptoTech Optikmaschinen GmbH (Germany)
Paul Tolley, Stretford End Solutions (United States)
Martin J. Valente, Arizona Optical Systems, LLC (United States)
Kirk J. Warden, LaCroix Precision Optics (United States)

Session Chairs

Plenary Session
Jessica DeGroote Nelson, Optimax Systems, Inc. (United States)

Advancements in Conventional Fabrication Methods
Blair L. Unger, Rochester Precision Optics, LLC (United States)

Integrating Automation and Lasers into Optics Fabrication
Matthew J. Brunelle, Optimax Systems, Inc. (United States)

Deterministic Processing of Optics
Dan Gauch, Schneider Optical Machines Inc. (United States)

Deterministic Finishing Processes

Kirk J. Warden, LaCroix Precision Optics (United States)

New Advances in Optical Materials

Nicholas Bilis, Ohara Corporation (United States)

Optical Engineering

Jamie L. Ramsey, Rochester Precision Optics, LLC (United States)

Freeform Manufacturing

Scott DeFisher, OptiPro Systems, LLC (United States)

Advances in Freeform and Novel Metrology Techniques

Edward Fess, Corning Inc. (United States)

Surface Roughness and Optical Alignment

Matthias Pfaff, OptoTech Optikmaschinen GmbH (Germany)

Mid-spatial Frequency and Wavefront Error Measurement Methods

John J. Nemecek, Metrology Concepts LLC (United States)

Optical Coatings

Thomas Battley, New York Photonics Industry Association
(United States)

Structured Optical Surfaces

Dhananjay Joshi, Clemson University (United States)