PROCEEDINGS OF SPIE

Optifab 2015

Julie L. Bentley
Sebastian Stoebenau
Editors

12–15 October 2015
Rochester, New York, United States

Sponsored by
SPIE

Cosponsored by
The American Precision Optics Manufacturers Association

Published by
SPIE

Volume 9633

Proceedings of SPIE 0277-786X, V. 9633

Optifab 2015, edited by Julie L. Bentley, Sebastian Stoebenau, Proc. of SPIE Vol. 9633, 963301

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 2015*, edited by Julie L. Bentley, Sebastian Stoebenau, Proceedings of SPIE Vol. 9633 (SPIE, Bellingham, WA, 2015) Six-digit Article CID Number.

ISSN: 0277-786X
ISSN:1996-756X (electronic)
ISBN: 9781628418385

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 six-digit CID article numbering system structured as follows:

- 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.

Contents

ix *Authors*
xiii *Conference Committee*

PLENARY SESSION

9633 03 **Laser polishing of glass (Plenary Paper)** [9633-502]

GRINDING AND POLISHING PROCESSES I

9633 04 **The impact of layer thickness on the performance of additively manufactured lapping tools** [9633-1]

9633 05 **Nano alumina slurries for improved polishing on thermoset and thermoplastic resins** [9633-2]

9633 06 **The effect of diamond powder characteristics on lapping of sintered silicon carbide** [9633-3]

9633 07 **Advanced zirconia-coated carbonyl-iron particles for acidic magnetorheological finishing of chemical-vapor-deposited ZnS and other IR materials** [9633-4]

9633 08 **Comparison of various colloidal silica slurries and process parameters for fused silica finishing** [9633-5]

9633 09 **Material removal mechanism and material removal rate model of polishing process for quartz glass using soft particle** [9633-6]

GRINDING AND POLISHING PROCESSES II

9633 0A **Process for repairing large scratches on fused silica optics** [9633-7]

9633 0B **Industrial characterization of nano-scale roughness on polished surfaces** [9633-8]

9633 0C **Deterministic polishing from theory to practice** [9633-13]

9633 0D **Reduced cost and improved figure of sapphire optical components** [9633-14]

9633 0E **Precision machining of optical surfaces with subaperture correction technologies MRF and IBF** [9633-11]

GRINDING AND POLISHING PROCESSES III

9633 0F **Considerations in the evaluation and correction of mid-spatial frequency surface features** [9633-9]

9633 0G **Fine figure correction and other applications using novel MRF fluid designed for ultra-low roughness** [9633-10]

9633 0H **Developments in precision asphere manufacturing** [9633-15]

9633 0I **Reproducible and deterministic production of aspheres** [9633-16]

9633 0K **Satisloh centering technology developments past to present** [9633-18]

GRINDING AND POLISHING PROCESSES IV AND METROLOGY I

9633 0L **Ultrasonic precision optical grinding technology** [9633-19]

9633 0M **Femtosecond laser polishing of optical materials** [9633-20]

9633 0N **Smoothing of optical surface corners by abrasive polishing with a plate spring** [9633-21]

9633 0O **Gabor-domain optical coherence microscopy with integrated dual-axis MEMS scanner for fast 3D imaging and metrology** [9633-22]

9633 0P **Thickness estimation with optical coherence tomography and statistical decision theory** [9633-23]

9633 0Q **Constructive solutions of handheld probes with galvanometer scanners for biomedical and industrial imaging: applications in OCT** [9633-24]

OPTICAL DESIGN

9633 0R **Early considerations to aid later manufacturing** [9633-25]

9633 0S **Global optimization and desensitization** [9633-26]

9633 0T **Optical design constraints for the successful fabrication and testing of aspheres** [9633-27]

9633 0U **Cost-driven self-consistent fabrication and assembly tolerance classes** [9633-28]

9633 0V **Fabrication of EUVL micro-field exposure tools with 0.5 NA** [9633-98]

9633 0W **An XML file format for exchanging singlet lens specifications** [9633-30]

FABRICATION AND TESTING OF MIRRORS

9633 0X **The manufacturing and metrology of off-axis mirrors** [9633-31]

9633 0Y **Advances in diamond generating for 8.4 meter telescope mirrors** [9633-32]

9633 0Z **Lightweight mirror construction optimization** [9633-33]

9633 10 **A method to diagnose and combat index of refraction non-uniformity in evaporative optical coatings** [9633-55]

9633 11 **Polishability of thin electrolytic and electroless NiP layers** [9633-35]

OPTICAL ENGINEERING

9633 13 **Fabrication of metal mirror modules for snap-together VIS telescopes** [9633-37]

9633 14 **Strategies for active alignment of lenses** [9633-38]

9633 15 **Optimization of sub-cells orientation for assembly of a high-quality transmission sphere** [9633-39]

FREEFORM I

9633 16 **Coma full-field display for freeform imaging systems** [9633-40]

9633 17 **Why are freeform telescopes less alignment sensitive than a traditional unobscured TMA?** [9633-41]

9633 18 **Importance of fiducials on freeform optics** [9633-42]

9633 19 **Strategy for non-contact freeform measurements with a cylinder coordinate measuring instrument** [9633-43]

9633 1A **Freeform metrology using swept-source optical coherence tomography with custom pupil-relay precision scanning configuration** [9633-44]

9633 1B **Systematic error analysis for 3D nanoprofiler tracing normal vector** [9633-45]

FREEFORM II

9633 1C **New developments in the manufacture of large freeform surfaces with micro-structures** [9633-46]

9633 1D **Acylinder and freeform optical manufacturing** [9633-47]

9633 1E **New opportunities in freeform manufacturing using a long stroke fast tool system and integrated metrology** [9633-48]

9633 1F **Deterministic form correction of extreme freeform optical surfaces** [9633-49]

9633 1G **Freeform grinding and polishing with PROSurf** [9633-50]

DIAMOND TURNING AND MOLDED OPTICS

9633 1I **Surface finish in ultra-precision diamond turning of single-crystal silicon** [9633-51]

9633 1J **Diamond grooving of rapidly solidified optical aluminium** [9633-52]

9633 1K **Novel method for fabrication of monolithic multi-cavity molds and wafer optics** [9633-53]

9633 1L **Precision lens molding of asphero diffractive surfaces in chalcogenide materials** [9633-54]

METROLOGY II

9633 1M **Validation of accuracy and repeatability of UltraSurf metrology on common optical shapes** [9633-58]

9633 1N **Comparison of relay zoom and changing transmission spheres to change the lateral magnification of a Fizeau interferometer** [9633-59]

9633 1O **Fast optical 3D form measurement of aspheres including determination of thickness and wedge and decenter errors** [9633-60]

9633 1P **A simple device for sub-aperture stitching of fast convex surfaces** [9633-61]

9633 1Q **Non-null annular subaperture stitching interferometry for aspheric test** [9633-62]

9633 1R **Model-based phase-shifting interferometer** [9633-63]

METROLOGY III

9633 1S **Optical measurement of materials and lens assemblies at specific or varied temperatures** [9633-64]

9633 1T **Recent developments in IR metrology using quadri wave lateral shearing interferometry** [9633-65]

9633 1U **Automated full-field range OPD and MTF measurement bench for automotive objective benchmark** [9633-66]

9633 1V **Metrology of achromatic diffractive features on chalcogenide lenses** [9633-67]

9633 1W **Multimodal characterization of contact lenses** [9633-68]

9633 1X **Spherical aberration standards and measurement system stability over time** [9633-69]

POSTER SESSION

9633 1Z **Finite element analysis to evaluate optical mirror deformations** [9633-71]

9633 21 **Pixelated filters for spatial imaging (Best Student Paper)** [9633-74]

9633 24 **Cutting and shaping operations for optical glasses** [9633-77]

9633 25 **Ultra precision machining technique of off-axis optics for coastal water remote sensing** [9633-78]

9633 26 **Freeform correction polishing for optics with semi-kinematic mounting** [9633-79]

9633 27 **Recent progress in bound-abrasive polishing of fused silica glass** [9633-80]

9633 28 **Metrology system for inter-alignment of lasers, telescopes, and mechanical datum** [9633-82]

9633 29 **Compact wavefront diagnosis system based on the randomly encoded hybrid grating** [9633-84]

9633 2A **Adaptive position detection of optical vortex using a Shack-Hartmann wavefront sensor** [9633-85]

9633 2C **Ptychographic phase retrieval method for characterizing ultra-precise ellipsoidal mirrors** [9633-88]

9633 2D **Reverse optimization reconstruction method in non-null aspheric interferometry** [9633-89]

9633 2E **Homodyne displacement measuring interferometer probe for optical coordinate measuring machine with tip and tilt sensitivity (Best Student Paper)** [9633-90]

9633 2G **Retrieval of phase distributions from the quadriwave lateral shearing interferogram obtained by randomly encoded hybrid grating** [9633-92]

9633 2H **Aspheric surface reconstruction from curvature data along two orthogonal directions** [9633-93]

9633 2K **Optimization of polyetherimide processing parameters for optical interconnect applications** [9633-97]

9633 2N **A new error compensation strategy on Laser Displacement Sensor in free-form surface measurement** [9633-101]

9633 2O **Polishing performances of different optics with different size powder and different pH value slurries during CMP polishing** [9633-102]

9633 2P **The simulation of workpieces' surface in polishing** [9633-103]

Authors

Numbers in the index correspond to the last two digits of the six-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first four 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.

Abel-Tiberini, Laetitia, 21
Abou-El-Hossein, Khaled, 1I, 1J
Aguirre-Aguirre, D., 1P, 1Z, 24
Aharon, Oren, 28
Allen, M. A., 0Z
Ament, Craig, 10
Ayomoh, M., 1I
Bagwell, Joel, 10, 1L, 1V
Bai, Jian, 1Q, 1R, 2A, 2D
Bartlett, Kevin, 0D
Bauer, Aaron, 16
Bechtold, Michael J., 0L
Bechtold, Rob, 0L
Beier, Matthias, 11, 13
Benea, Ion C., 06
Berger, G., 1O
Berthon, Jacques, 21
Beutler, A., 19
Bissacco, Giuliano, 0B
Boffa, Christopher C., 05
Bolton, J., 0Z
Boucher, W., 1T, 1U
Bourgeade, Antoine, 0A
Bourgeois, G., 1T
Bradu, A., 0Q
Brahmi, D., 1U
Bremer, Mark, 0V
Brophy, Matthew R., 0D
Brunelle, Matt, 18
Burkam, Eric, 06
Burmeister, Frank, 13
Butler, Sam C., 2E
Cahill, Michael J., 0L
Campaignolle, S., 08
Canavesi, Cristina, 0O
Cao, Jun, 2O
Carrasco-Licea, E., 1P, 24
Cavaro, Sandy, 0A
Cernat, R., 0Q
Chen, Guanglin, 09
Cheng, Yuan-Chieh, 1J
Chong, Shiyao, 1Q, 1R, 2D
Cirucci, Nick, 0P
Cogliati, Andrea, 0O
Compertore, David, 1W, 1X
Cook, Chris, 10
Cormont, Philippe, 0A
Cruz-Zavala, E., 1P
Dahl, R. J., 0Z
Danger, Thomas, 1E
Davis, Johnathan M., 0Y
DeFisher, Scott, 1D, 1G, 1M
DeGroote Nelson, Jessica, 0D, 18, 1F
Demian, D., 0Q
Deprez, M., 1T, 1U
Devries, Gary, 1N
Dobre, G., 0Q
Doualle, Thomas, 0A
Duma, V.-F., 0Q
Dumas, Paul, 0G
Dun, Aihuan, 2O
Eberhardt, Ramona, 13
Ellis, Jonathan D., 2E
Endo, Katsuyoshi, 1B
Escolas, John, 0C
Feidenhans'l, Nikolaj A., 0B
Feldkamp, Roman, 0E
Fess, Edward, 0H, 0L, 1D, 1G, 1M
Gaborit, Gael, 0A
Gallais, Laurent, 0A
Gangadhara, Sanjay, 0W
Gascon, A., 1U
Gay, Shawn C., 0W
Gebhardt, Andreas, 11, 13
Ghobashy, Sameh, 1J
Giannechini, L. J., 07
Gibson, Donald S., 1W
Girard, Luc, 0V
Golini, N., 07
Granados-Agustín, F. S., 1P, 24
Hagen, Jeffery R., 0Y
Hahne, Felix, 14
Hall, Christopher A., 0F
Han, Jeong-Yeol, 25
Hansen, Poul-Erik, 0B
Hardy, Sam, 0V
Hartung, Johannes, 13
Hayes, Adam, 0O
Heidrich, Sebastian, 03
Heinisch, Josef, 14
Herbrand, Matthew E., 1W
Ho, Cheng-Fang, 15, 26
Hobbs, Zachary, 0C
Hoffmann, Nathan N., 0C
Homassel, E., 1T
Hooper, Abigail R., 05, 0C
Hsu, Ming-Ying, 26

Hsu, Wei-Yao, 15, 1J, 26
Hu, Qing, 09
Huang, Chien-Yao, 15, 26
Huang, Hongxin, 2A
Huang, Jinxin, 0P
Huang, Wei, 1Q, 1R
Hutiu, Gh., 0Q
Huttenhuis, Stephan, 1E
Hyun, Sang-Won, 25, 2H
Ignatovich, Filipp V., 1W, 1X
Inoue, Takashi, 2A
Ivanov, Trevor, 0P
Izazaga-Pérez, R., 1P, 1Z, 24
Jacobs, Ben, 1C
Jacobs, S. D., 07
Jeon, Min-Woo, 25
Jiang, Jiabin, 29, 2G
Johnson, Peter, 2K
Kenagy, Kurtis L., 0Y
Kennon, Jim, 0V
Kestner, Bob, 0V
Kim, ByoungChang, 2H
Kim, Dae Wook, 0Y
Kim, Geon-Hee, 25, 2H
Kinast, Jan, 11, 13
Kudo, Ryota, 1B
Kumler, Jay, 0T
Kuo, Ching-Hsiang, 15, 26
Küpper, Lutz, 0X
Lambropoulos, J. C., 07
Langehanenberg, Patrik, 14
Lavergne, O., 1U
Lee, SeoungWon, 2H
Leitz, Ernst Michael, 0I, 0K
Lequime, Michel, 21
Li, Bing, 2N
Li, Yaguo, 27
Liebl, Johannes, 0X
Light, Brandon, 0R
Ling, Tong, 29, 2G
Lintz, E. A., 0Z
Liu, Defu, 09
Liu, Dong, 1Q, 1R, 29, 2D, 2G
Liu, Shijie, 2O, 2P
Loeff, Adrian R., 0Y
López-Cortés, V., 24
López-Hernández, N., 24
Lüerß, Bernd, 14
Lumeau, Julien, 21
Luo, Jia, 2A
Lynch, Timothy P., 1F
Madsen, Morten H., 0B
Maloney, Chris, 0G
Marchetti, Lou, 0V
Marcus, Michael A., 1W, 1X
Martin, Hubert M., 0Y
Mathieu, Karine, 21
Matsui, Yoshinori, 2A
Matthews, Greg, 0H, 1M
Maunier, C., 08
Mckenna, P., 1V
Medicus, Kate, 0D, 18, 1F
Miao, Liang, 1Q, 1R
Mimura, Hidekazu, 2C
Mkoko, Zwelinzima, 1J
Mooney, J. T., 0Z
Moos, Steffen, 0K
Mouri, Naoki, 0N
Murphy, Paul E., 0F, 1N
Myer, Brian W., 1F
Nakano, Motohiro, 1B
Neauport, J., 08
Negrutiu, M. L., 0Q
Nelson, J., 1L, 1V
Nemechek, John J., 1S
Niehaus, Frank, 1E
Onyenemezu, Clement, 06
Oswald, Eric S., 0G
Peng, Wei-Jei, 15, 26
Penzkofer, Karlheinz, 0X
Percino-Zacarías, M. E., 1P, 24
Petersen, Jan C., 0B
Petter, J., 1O
Pilný, Lukáš, 0B
Podoleanu, A., 0Q
Qiao, Jie, 0M
Qiao, Jun, 0M
Quechol-López, J. T., 24
Rascher, Rolf, 0X
Ricci, Michael A., 2E
Risse, Stefan, 11, 13
Roblee, Jeff, 1C
Rogers, John, 0S
Rolland, Jannick P., 0O, 0P, 0Q, 0U, 16, 17, 1A
Romanofsky, H. J., 07
Rosczyk, Benjamin, 06
Ross, James, 1D, 1G
Rullier, Jean-Luc, 0A
Saito, Takahiro, 2C
Saito, Yusuke, 0N
Salazar-Morales, M. T., 1P
Salzman, S., 07
Santhanam, Anand P., 0O
Sarkas, Harry W., 05, 0C
Savin De Larclause, Isabelle, 21
Schiesser, Eric, 17
Schmelzer, Olaf, 0E
Schwalb, Fabian, 0I
Schwertz, K., 1L, 1V
Scordato, M., 1L, 1V
Shao, Jianda, 2O, 2P
Shen, Yibing, 1Q, 1R, 2D
Shi, Tu, 1Q, 1R, 2D
Sinescu, C., 0Q
Sisk, Raymond W., 0Y
Stephenson, Dave, 0T
Stover, E., 1O
Stroh, Carsten, 0I
Sun, Bin, 2N
Taboryski, Rafael, 0B

Takeo, Yoko, 2C
Takino, Hideo, 0N
Tankam, Patrice, 0O
Taroux, Daniel, 0A
Taylor, B., 07
Taylor, Lauren L., 0M
Thompson, Kevin P., 0U, 16, 17
Tierson, Jay, 0H
Titov, Artem, 06
Tokuta, Yusuke, 1B
Torres, Josh, 1G
Toyoda, Haruyoshi, 2A
Tsuji, Kazuya, 0N
Tünnermann, Andreas, 11, 13
Villalobos-Mendoza, B., 1P, 1Z, 24
Vishnia, Itai, 28
Wall, Christopher, 2K
Walter, Mark, 1C
Walters, Mark, 0D
Wang, Chen, 2E
Wattellier, B., 1T, 1U
Wei, Chaoyang, 2O, 2P
Wei, Qun, 2E
Weingarten, Christian, 03
Wendel, M., 1O
Wielandts, Marc, 1K
Wielandts, Remi, 1K
Wilde, Chrisitan, 14
Willenborg, Edgar, 03
Williams, Wesley B., 04
Wolfs, Franciscus, L., 0L, 1D, 1G
Wu, Lunzhe, 2P
Wu, Yingchao, 03
Xu, Di, 1A
Xu, Xueke, 2O, 2P
Yamamura, Kazuya, 1B
Yang, Minghong, 2O, 2P
Yang, Yongying, 1Q, 1R, 29, 2D, 2G
Yao, Jianing, 0P, 1A
Yonnet, M., 1U
Yu, Zong-Ru, 15, 26
Yuan, Joe, 18
Yue, Xiumei, 29, 2G
Zeitner, Uwe D., 13
Zhang, Lei, 1Q, 1R, 2D
Zhao, Nan, 1A
Zhao, Wei, 2K

Conference Committee

Symposium Chairs

Julie L. Bentley, University of Rochester (United States)
Sebastian Stoebenau, OptoTech Optikmaschinen GmbH (Germany)

Conference Chairs

Julie L. Bentley, University of Rochester (United States)
Sebastian Stoebenau, OptoTech Optikmaschinen GmbH (Germany)

Conference Program Committee

Thomas Battley, New York Photonics Industry Association (United States)
Michael J. Bechtold, OptiPro Systems (United States)
Christopher T. Cotton, ASE Sailing Inc. (United States)
Walter C. Czajkowski, Edmund Optics, Inc. (United States)
Thomas Danger, Schneider GmbH & Company KG (Germany)
Michael A. DeMarco, QED Technologies, Inc. (United States)
Apostolos Deslis, JENOPTIK Optical Systems, LLC (United States)
Toshihide Dohi, OptiWorks, Inc. (Japan)
Tom Godin, Satisloh North America Inc. (United States)
Heidi Hofke, OptoTech Optical Machinery Inc. (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)
Paul Meier-Wang, AccuCoat Inc. (United States)
Ted Mooney, Harris Geospatial Systems (United States)
Rick A. Nasca, Corning Tropel Corporation (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)
Buzz Nesti, Naked Optics Corporation (United States)
Matthias Pfaff, OptoTech Optikmaschinen GmbH (Germany)
Paul Tolley, Smart System Technology & Commercialization Center (United States)
Martin J. Valente, Arizona Optical Systems, LLC (United States)
Kirk J. Warden, LaCroix Optical Company (United States)
Robert Wiederhold, Optimax Systems, Inc. (United States)

Session Chairs

Plenary Session
Julie L. Bentley, University of Rochester (United States)

1 Grinding and Polishing Processes I
Jessica DeGroote Nelson, Optimax Systems, Inc. (United States)

2 Grinding and Polishing Processes II
Michael J. Bechtold, OptiPro Systems (United States)

3 Grinding and Polishing Processes III
Sebastian Stoebenau, OptoTech Optikmaschinen GmbH (Germany)

4 Grinding and Polishing Processes IV and Metrology I
Matthias Pfaff, OptoTech Optikmaschinen GmbH (Germany)

5 Optical Design
Richard N. Youngworth, Riyo LLC (United States)

6 Fabrication and Testing of Mirrors
Paul Dumas, QED Technologies, Inc. (United States)

7 Optical Engineering
Theodore Tienvieri, Corning Tropel Corporation (United States)

8 Freeform I
Dave Stephenson, JENOPTIK Optical Systems, Inc. (United States)

9 Freeform II
John Rogers, Synopsis, Inc. (United States)

10 Diamond Turning and Molded Optics
Jonathan D. Ellis, University of Rochester (United States)

12 Metrology II
Michael A. Marcus, Lumetrics, Inc. (United States)

13 Metrology III
Kate Medicus, Optimax Systems, Inc. (United States)