PROCEEDINGS OF SPIE

33rd European Mask and Lithography Conference

Uwe F.W. Behringer
Jo Finders
Editors

26–28 June 2017
Dresden, Germany

Organized by
VDE/VDI GMM—The Society for Microelectronics,
Microsystems and Precision Engineering (Germany)

Published by
SPIE

Volume 10446

Proceedings of SPIE 0277-786X, V. 10446

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

33rd European Mask and Lithography Conference, edited by Uwe F.W. Behringer,
Jo Finders, Proc. of SPIE Vol. 10446, 1044601 · © 2017 SPIE
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2302899

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 *33rd European Mask and Lithography Conference*, edited by Uwe F.W. Behringer, Jo Finders, Proceedings of SPIE Vol. 10446 (SPIE, Bellingham, WA, 2017) Seven-digit Article CID Number.

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

ISBN: 9781510613560
ISBN: 9781510613577 (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 © 2017, 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/17/$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 *Authors*

ix *Conference Committee*

xiii *Foreword*

xv *Sponsors and Cooperating Partners*

xvii *Electron beam lithographic modeling assisted by artificial intelligence technology (Best Paper of PMJ 2017) (10454-41)*

WAFER LITHOGRAPHY (193i AND EUV)

10446 03 **Latest developments on EUV reticle and pellicle research and technology at TNO** [10446-10]

10446 04 **ILT optimization of EUV masks for sub-7nm lithography** [10446-22]

10446 05 **Improvements in the imaging performance of a high volume manufacturing EUV scanner with a special emphasis on the added value of the new illuminator for increased pupil flexibility** [10446-32]

MASK PATTERNING, METROLOGY, AND PROCESS

10446 07 **Multi-beam mask writer MBM-1000** [10446-35]

10446 08 **Multi-trigger resist for electron beam lithography** [10446-21]

10446 09 **Update on optical material properties for alternative EUV mask absorber materials** [10446-16]

10446 0B **The role of model-based MPC in advanced mask manufacturing** [10446-44]

10446 0C **Parallel compression/decompression-based datapath architecture for multibeam mask writers** [10446-20]

NON-IC APPLICATIONS

10446 0D **Technical trends of large-size photomasks for flat panel displays (Invited Paper)** [10446-5]

10446 0G **Challenges for scanning electron microscopy and inspection on the nanometer scale for non-IC application: and how to tackle them using computational techniques** [10446-3]

NANO-IMPRINT LITHOGRAPHY

10446 0I **SEM AutoAnalysis: enhancing photomask and NIL defect disposition and review** [10446-36]

10446 0J **Challenges of nanostructure-integration in Fabry-Pérot interferometers as alternative to Bragg reflectors: an example for Match 1:1-, eBeam-, and nanoimprint lithography** [10446-6]

MASK2WAFER METROLOGY

10446 0K **Line edge roughness measurement through SEM images: effects of image digitization and their mitigation** [10446-50]

10446 0L **Advanced metrology by offline SEM data processing** [10446-26]

10446 0M **Contour-based etch modeling enablement: from pattern selection to final verification** [10446-12]

USING THE DATA/BIG DATA

10446 0N **Splendidly blended: a machine learning set up for CDU control** [10446-1]

10446 0O **Machine learning for fab automated diagnostics** [10446-31]

POSTER SESSION: WAFTER LITHOGRAPHY

10446 0P **New overlay measurement technique with an i-line stepper using embedded standard field image alignment marks for wafer bonding applications** [10446-8]

POSTER SESSION: MASK PATTERNING, METROLOGY, AND PROCESS

10446 0T **Half circle chrome loss by electrochemical effects** [10446-14]

10446 0U **Characterizing electron beam induced damage in metrology and inspection of advance devices** [10446-17]

10446 0V **Aerial image metrology for OPC modeling and mask qualification** [10446-40]

POSTER SESSION: NON-IC APPLICATIONS

10446 0X **Experimental verification of sub-wavelength holographic lithography physical concept for single exposure fabrication of complex structures on planar and nonplanar surfaces** [10446-19]

POSTER SESSION: NANO-IMPRINT LITHOGRAPHY

10446 0Z **Function follows form: combining nanoimprint and inkjet printing** [10446-48]

POSTER SESSION: MASK2WAFER METROLOGY

10446 10 **Pattern sampling for etch model calibration** [10446-15]

POSTER SESSION: PHOTONICS

10446 13 **Depth-profiling of vertical material contrast after VUV exposure for contact-free polishing of 3D polymer micro-optics** [10446-18]

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.

Adam, Kostas, 0V
Arat, Kerim T., 0G
Ausserhuber, H., 0Z
Bahrig, L., 0T
Besacier, Maxime, 0L
Bilski, Bartosz, 05
Bolten, Jens, 0G
Borisov, Michael V., 0X
Bork, Ingo, 0B
Buck, Peter, 0B
Burbine, Andrew, 0V
Buttgereit, Ute, 0V
Caspary, D., 0T
Chaudhary, Narendra, 0C
Chelyubeev, Dmitry A., 0X
Chen, Ao, 0V
Chernik, Vitaly V., 0X
Chidambaram, N., 13
Chung, Angeline, 0V
Clifford, Chris, 0V
Constantoudis, Vassilios, 0K
Dawson, Guy, 08
De Bisschop, Peter, 0V
Ducoté, Julien, 0L
Egodage, Kokila, 0I
Ehrlich, Christian, 0I
Ekinci, Yasin, 08
Englard, Ilan, 0U
Erben, Jens W., 0J
Farys, Vincent, 0L
Faury, T., 0Z
Fechtig, D., 0Z
Feicke, A., 0T
Fliervoet, Timon, 05
Foong, Yee Mei, 0V
Fuchsbauer, A., 0Z
Garetto, Anthony, 0I
Giollo, Manuel, 0O
Gkorou, Dimitra, 0O
Haslinger, M. J., 0Z
Helke, Christian, 0J
Hiller, Karla, 0J
Hoekstra, R., 13
Hooker, Kevin, 04
Ikeda, M., 0Z
Jähne, S., 0T
Kaiser, M., 0T
Kamikubo, Takashi, xvii
Kastner, J., 0Z
Kazarian, Aram, 04
Kazazis, Dimitrios, 08
Kirchner, R., 13
Kleinjans, Herberth, 0J
Koepplmayr, T., 0Z
Koster, Norbert, 03
Kristlib, M., 0T
Kuechler, Bernd, 04
Kulse, P., 0P
Kurth, Steffen, 0J
Kurzmann, J., 0Z
Lakcher, Amine, 0L
Lam, Auguste, 0O
Laubis, Christian, 09
Le-Gratiet, Bertrand, 0L
Lemme, Max C., 0G
Liu, Xing Lan, 0O
Lorbeer, J., 0T
Lucas, Kevin, 04
Luong, Kim Vu, 09
Lutich, Andrey, 0M, 10
Malik, Nitin Singh, 0U
Matsumoto, Hiroshi, 07
McClelland, Alexandra, 08
McNamara, John, 05
Meinig, Marco, 0J
Miheev, Peter A., 0X
Miura, Satoru, xvii
Mohtashami, Abbas, 0U
Muehlberger, M., 0Z
Nakayamada, Noriaki, xvii
Navarro, Violeta, 0U
Nesladek, P., 0T
Nishimura, Rieko, xvii
Nomura, Haruyuki, xvii
Nowak, Christoph, 0J
Ohtoshi, Kenji, 07
Oorschot, Dorothe, 05
Otto, Thomas, 0J
Papavieros, George, 0K
Philipsen, Vicky, 09
Popescu, Carmen, 08
Porschatis, Caroline, 0G
Rakhovskii, Vadim I., 0X
Reuter, Danny, 0J
Robinson, Alex P. G., 08
Roth, John, 08
Sadeghian, Hamed, 0U
Sasai, K., 0P

Savari, Serap A., 0C
Schatz, Jirka, 0M, 10
Schift, H., 13
Schneider, Loïc, 0L
Scholze, Frank, 09
Schulz, K., 0P
Schulz, Kristian, 0I
Shamaev, Alexei S., 0X
Shemesh, Dror, 0U
Staring, Wilbert, 03
Sturtevant, John, 0V
Tabbone, Gilles, 0I
Tamura, Takao, 07
te Sligte, Edwin, 03
Thaler, Thomas, 0V
Theis, Wolfgang, 08
Ünal, Nezih, 0G
Utzny, Clemens, 0N
van de Kerkhof, Mark, 05
van Haren, Richard, 0O
Verberk, Rogier, 03
Wahlbrink, Thorsten, 0G
Wandel, T., 0T
Wang, Ziyang, 05
Weisbuch, François, 0M, 10
Wietstruck, M., 0P
Wittebrood, Friso, 05
Woegerer, C., 0Z
Xiao, Guangming, 04
Yamashita, Hiroshi, 07
Yoshida, Koichiro, 0D

Conference Committee

Conference Chairs

Uwe F.W. Behringer, UBC Microelectronics (Germany)
Jo Finders, ASML Netherlands B.V. (Netherlands)

Conference Co-Chairs

Brid Connolly, Toppan Photomasks, Inc. (Germany)
Chris Gale, Applied Materials GmbH (Germany)
Naoya Hayashi, Dai Nippon Printing Company, Ltd. (Japan)

Program Chairs

Ines A. Stolberg, Vistec Electron Beam GmbH (Germany)
Andreas Erdmann, Fraunhofer-Institut für Integrierte Systeme und Bauelementechnologie IISB (Germany)
José Pozo, European Photonics Industry Consortium (Belgium)

Program Co-Chairs

Rolf Seltmann, GLOBALFOUNDRIES Dresden (Germany)
Daniel Sarlette, Infineon Technologies Dresden (Germany)

Other Members

Carola Bläsing, Carl Zeiss SMS GmbH (Germany)
Parkson Chen, Taiwan Mask Corporation (Taiwan)
Albrecht Ehrmann, Carl Zeiss SMT GmbH (Germany)
Dave Farrar, HOYA Corporation (United Kingdom)
Rik Jonckheere, IMEC vzw (Belgium)
Barbara Lauche, Photronics MZD GmbH (Germany)
Carlos Lee, European Photonics Industry Consortium (Belgium)
Bertrand Le-Gratiet, STMicroelectronics (France)
Harry Levinson, GLOBALFOUNDRIES (United States)
Hans Löschner, IMS Nanofabrication AG (Austria)
Michael Muehlberger, Profactor GmbH (Austria)
Jan Hendrik Peters, BMBG-Consult (Germany)
Chris Progler, Photronics Inc. (United States)
Douglas J. Resnick, CNT-Canon (United States)
Klaus-Dieter Röth, KLA-Tencor MIE (Germany)
Thomas Scherübl, Carl Zeiss SMT GmbH (Germany)
Ronald Schnabel, VDE/VDI-GMM (Germany)
Steffen Schulze, Mentor Graphics Corporation (United States)

Yoshitake Shusuke, NuFlare (Japan)
Martin Tschinkl, AMTC (Germany)
Jacques Waelpoel, ASML Netherlands B.V. (Netherlands)
James N. Wiley, ASML US, Inc. (United States)
C. Grant Willson, University of Texas, Austin (United States)
Hermann Wolf, Photronics MZD GmbH (Germany)
Stefan Wurm, Atice LLC (United States)
Larry Zurbrick, Keysight (United States)

Session Chairs

Plenary Session I
Uwe F.W. Behringer, UBC Microelectronics (Germany)
Hans Löschner, IMS Nanofabrication AG (Austria)

Plenary Session II
Jo Finders, ASML Netherlands B.V. (Netherlands)
James N. Wiley, ASML US, Inc. (United States)

Wafer Lithography (193i and EUV)
Jo Finders, ASML Netherlands B.V. (Netherlands)
Rolf Seltmann, GLOBALFOUNDRIES Dresden (Germany)

Mask Patterning, Metrology, and Process
Martin Tschinkl, AMTC (Germany)
Jan Hendrik Peters, BMBG-Consult (Germany)

Plenary Session III
Uwe F.W. Behringer, UBC Microelectronics (Germany)
Serap Savari, Texas A&M University (United States)

Non-IC Applications
Andreas Erdmann, Fraunhofer-Institut für Integrierte Systeme und Bauelementechnologie IISB (Germany)
Vassilios Constantoudis, Institute of Nanoscience and Nanotechnology (Greece), Nanometrisis p.c. (Greece), and Aristotle University of Thessaloniki (Greece)

Nano-Imprint Lithography
Ines A. Stolberg, Vistec Electron Beam GmbH (Germany)
Michael Muehlberger, Profactor GmbH (Austria)

Mask2Wafer Metrology
Jan Hendrik Peters, BMBG-Consult (Germany)
François Weisbuch, GLOBALFOUNDRIES Dresden (Germany)

Using the Data/Big Data
Bertrand Le-Gratiet, STMicroelectronics (France)
Izak Kapilevich, Applied Materials Inc. (United States)

Foreword

On behalf of VDE/VDI-GMM, the EMLC2017 sponsors, and the EMLC2017 organizing and international program committees, we welcome you to the proceedings from the 33rd European Mask and Lithography Conference, EMLC2017, at the Hilton Hotel in Dresden, Germany.

The conference has annually brought together scientists, researchers, engineers, and technologists from research institutes and companies from around the world to present innovations at the forefront of mask lithography and mask technology. The two and a half day conference is dedicated to the science, technology, engineering, and application of mask and lithography technologies and associated processes, giving an overview of the present status in mask and lithography technologies and the future strategy where mask producers and users have the opportunity of becoming acquainted with new developments and results. This year's sessions included: Wafer Lithography (193i and EUV), Mask Patterning, Metrology, and Process, Non-IC Applications, Nano-Imprint Lithography, Mask2Wafer Metrology, and Using the Data / Big Data.

Mathias Kamolz from Infineon Technologies (Germany) was the welcome speaker. He presented, "The Power of Power-Semiconductors."

Jim Wiley from ASML US, Inc. (United States) was the first keynote speaker. His talk was titled "The Status and Challenges of the EUV photomask ecosystem."

The second keynote speaker was Bryan Rice from Globalfoundries Dresden (Germany) who presented "Breaking the Paradigm: FDX Technology at Globalfoundries."

The third keynote speaker was Paul Ackmann from Globalfoundries Inc. (United States). The title of his presentation was "Integral Nature of Masks through five Decades."

We invited Kurt Ronse from IMEC (Belgium) who presented a talk titled "Recent EUV developments at IMEC."

As every year, the Best Paper and Best Poster from BACUS 2016 were presented, followed by the Best Paper from PMJ 2017. A total of 47 papers—3 keynotes, 9 invited, 20 orals and 15 posters—were presented.

Tutorials

For the first time, the conference included two tutorials. Andreas Erdmann from Fraunhofer IISB (Germany) gave the first tutorial on "General introduction into lithographic imaging by projection optics." The second tutorial, "Interaction of

mask and scanner in EUV projection optics," was presented by Jo Finders from ASML Netherlands B.V.

Technical Exhibition

Parallel to the conference presentations, a technical exhibition took place on Tuesday and Wednesday where companies (mask suppliers, material suppliers, and equipment suppliers) exhibited their companies and products. To foster the exchange between the conference attendees and the exhibitors, the exhibition area was also the place for all coffee and lunch breaks.

We hope that you enjoyed the technical sessions of the EMLC2017 as well as the technical exhibition, but also allowed yourself to visit the beautiful city of Dresden.

Uwe F.W. Behringer
EMLC2017 Conference Chair

Sponsors and Cooperating Partners

The 33rd European Mask and Lithography Conference, EMLC 2017, would like to express its sincere appreciation to all the sponsors and coopering partners mentioned below for their support