

PROCEEDINGS OF SPIE

# **32nd European Mask and Lithography Conference**

**Uwe F.W. Behringer**  
**Jo Finders**  
*Editors*

**21–22 June 2016**  
**Dresden, Germany**

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

*Published by*  
SPIE

**Volume 10032**

Proceedings of SPIE 0277-786X, V. 10032

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

32nd European Mask and Lithography Conference, edited by Uwe F.W. Behringer,  
Jo Finders, Proc. of SPIE Vol. 10032, 1003201 · © 2016 SPIE  
CCC code: 0277-786X/16/\$18 · doi: 10.1117/12.2264270

Proc. of SPIE Vol. 10032 1003201-1

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 [SPIDigitalLibrary.org](http://SPIDigitalLibrary.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 *32nd European Mask and Lithography Conference*, edited by Uwe F.W. Behringer, Jo Finders, Proceedings of SPIE Vol. 10032 (SPIE, Bellingham, WA, 2016) Six-digit Article CID Number.

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

ISBN: 9781510604872  
ISBN: 9781510604889 (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](http://SPIE.org)

Copyright © 2016, 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](http://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/16/\$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**  
[SPIDigitalLibrary.org](http://SPIDigitalLibrary.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

- vii *Authors*
- ix *Conference Committee*
- xiii *Foreword*
- xv *Sponsors and Cooperating Partners*
- xvii *Etched multilayer EUV mask fabrication for sub-60nm pattern based on effective mirror width (Best Paper of PMJ 2016) (9984-26)*

---

## WAFER LITHOGRAPHY

---

- 10032 02 **Improving contact layer patterning using SEM contour based etch model** [10032-7]
- 10032 03 **A thick photoresist process for high aspect ratio MEMS applications** [10032-4]

---

## MASK PATTERNING, METROLOGY AND PROCESS

---

- 10032 04 **Advanced photomask fabrication by e-beam lithography for mask aligner applications** [10032-13]
- 10032 05 **Mask manufacturing of advanced technology designs using multi-beam lithography (Part 1)** [10032-5]
- 10032 06 **A parallel multibeam mask writing method and its impact on data volumes** [10032-12]
- 10032 07 **Towards expanding megasonic cleaning capability** [10032-15]

---

## NOVEL APPROACHES

---

- 10032 08 **The future of 2D metrology for display manufacturing (Invited Paper)** [10032-21]
- 10032 09 **Control the light where you need it: new development in accurate delivery of visible laser light** [10032-22]

---

## EUV I

---

- 10032 0A **Illumination pupil optimization in 0.33NA EUVL by intensity balancing for semi-iso dark field two-bar M1 building blocks (Invited Paper)** [10032-17]

10032 0B **Anamorphic imaging at high-NA EUV: mask error factor and interaction between demagnification and lithographic metrics** [10032-29]

---

**PHOTONICS**

---

10032 0C **High performance gratings for DFB lasers fabricated by direct-write e-beam lithography** [10032-18]

10032 0D **Photonic integrated circuits: new challenges for lithography** [10032-10]

---

**NANO-IMPRINT LITHOGRAPHY**

---

10032 0E **Nanoimprint system development and status for high volume semiconductor manufacturing** [10032-11]

10032 0F **SCIL nanoimprint solutions: high-volume soft NIL for wafer scale sub-10nm resolution** [10032-1]

---

**MODELING AND COMPUTATIONAL PROCESS CORRECTION**

---

10032 0G **Enhancing EUV mask blanks usability through smart shift and blank-design pairing optimization** [10032-26]

---

**USING THE DATA**

---

10032 0H **Translation of lithography variability into after-etch performance: monitoring of golden hotspot (Best Paper of EMLC 2016)** [10032-23]

10032 0I **Smart mask ship to control for enhanced on wafer CD performance** [10032-19]

---

**MORE THAN MOORE, IOT, AND MANUFACTURING CHALLENGES**

---

10032 0J **CHAM: weak signals detection through a new multivariate algorithm for process control** [10032-16]

---

**POSTER SESSION: WAFER LITHO**

---

10032 0K **SRAF insertion for VIA-like layers using IaSRAF method** [10032-8]

---

**POSTER SESSION: EUV LITHOGRAPHY**

---

10032 0L **Researching new EUV pellicle films for source powers beyond 250 watts** [10032-30]

---

**POSTER SESSION: NANO-IMPRINT LITHOGRAPHY**

---

10032 0M **Critical dimension uniformity characterization of nanoimprinted trenches for high volume manufacturing qualification** [10032-28]

---

**POSTER SESSION: MODELING AND COMPUTATIONAL PROCESS CORRECTION**

---

10032 0N **Bayesian analysis for OPC modeling with film stack properties and posterior predictive checking** [10032-25]

---

**POSTER SESSION: USING THE DATA, MORE THAN MOORE, IOT, AND MANUFACTURING CHALLENGES**

---

10032 0O **A study of SU-8 photoresist in deep trenches for silicon-embedded microinductors** [10032-3]

10032 0P **Industrial implementation of spatial variability control by real-time SPC** [10032-24]

10032 0Q **Combination of direct laser writing and soft lithography molds for combined nano- and microfabrication** [10032-9]

10032 0R **CD process control through machine learning** [10032-20]



# 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.

Abegg, Erik, 0L  
Anthony, Ricky, 03  
Baier, L., 0Q  
Banasch, M., 04  
Becker, M., 0Q  
Bergeret, François, 0J  
Bolten, Jens, 0D  
Borde, M., 0P  
Bos, S., 0M  
Bottiglieri, Gerardo, 0B  
Bourgin, Y., 04  
Buck, Peter, 0G  
Burbine, Andrew, 0N  
Chalom, Daniel, 05  
Chaudhary, N., 06  
Choi, Jin, 0E  
Choi, Yohan, 05  
Colina, Alberto, 0B  
Dattilo, Davide, 07  
de Winter, L., 0A  
Dietze, Uwe, 07  
Dillon, Brian, 05  
Eibelhuber, M., 0M  
Emoto, Keiji, 0E  
Fenger, Germain, 0N  
Ferstl, Berthold, 07  
Finders, Jo, 0A, 0H  
Förthner, M., 0Q  
Frey, L., 0Q  
Fryer, David, 0N  
Geuzebroek, Douwe, 09  
Giesecke, Anna Lena, 0D  
Green, Michael, 05  
Ham, Young, 05  
Han, Zhenxing, 07  
Hayashi, Naoya, xvii  
Hertzsch, Tino, 02  
Hiura, Hiromi, 0E  
Hudek, Peter, 05  
Hur, Ik Boum, 05  
Iida, Noriko, xvii  
Jurkovic, Michal, 05  
Kamberian, Henry, 05  
Kamo, Takashi, xvii  
Kasprowicz, Bryan, 05  
Kiers, Ton, 0H  
Klikovits, Jan, 05  
Kollmuss, M., 0Q  
Laforge, Elias, 03, 0O  
Lakcher, Amine, 0H  
Landis, S., 0M  
Last, Thorsten, 0A, 0B  
Laure, M., 0M  
Le Grafiet, Bertrand, 0H, 0J  
Leinse, Arne, 09  
Lerch, Holger, 0D  
Luo, Y., 06  
Lutich, Andrey, 02, 0K  
McCloskey, Paul, 03, 0O  
McMurrin, Jeff, 05  
Michel, F., 0Q  
Moll, Hans-Peter, 02  
Morikawa, Yasutaka, xvii  
Nasalevich, Maxim, 0L  
Oetter, Günter, 07  
O'Mathúna, Cian, 03, 0O  
Pain, L., 0M  
Paninjath, Sankaranarayanan, 0G  
Park, Joong Hee, 05  
Park, Youngjin, 08  
Pasqualini, F., 0P  
Pavlovic, Zoran, 0O  
Pereira, Mark, 0G  
Péter, Mária, 0L  
Porschatis, Caroline, 0D  
Prinzen, Andreas, 0D  
Rabot, Caroline, 0O  
Rispens, Gijsbert, 0B  
Rommel, M., 0Q  
Roule, O., 0P  
Rumler, M., 0Q  
Samayoa, Martin, 07  
Sandstrom, Tor, 08  
Savari, S. A., 06  
Schatz, Jirka, 02  
Schauer, V., 0M  
Schumacher, Karl, 0I  
Schumaker, Phil, 0E  
Seltmann, Rolf, 0I  
Soni, Rakesh Kumar, 0G  
Soual, Carole, 0J  
Steingrüber, R., 0C  
Sturtevant, John, 0N  
Takabayashi, Yukio, 0E  
Takai, Kosuke, xvii  
Takashima, Tsuneo, 0E  
Teyssedre, H., 0M  
Thanner, C., 0M

Thwaite, Peter, 0G  
Utzny, Clemens, 0I, 0R  
van Adrichem, P., 0A  
van Brakel, R., 0F  
van der Zande, Wim, 0L  
van Ingen Schenau, Koen, 0B  
van Kerkhof, Joost, 09  
van Schoot, Jan, 0B  
van Setten, Eelco, 0B  
van Zwol, Pieter Jan, 0L  
Vermeulen, Hans, 0L  
Verschuuren, M. A., 0F  
Vles, David, 0L  
Voorkamp, R., 0F  
Voorthuijzen, Pim, 0L  
Wahlbrink, Thorsten, 0D  
Wahlsten, Mikael, 08  
Wang, Ningning, 0O  
Weichelt, T., 04  
Weisbuch, François, 02  
Wimplinger, M., 0M  
Zeitner, U. D., 04  
Zhang, Z., 0C  
Zorbach, W., 0M

# Conference Committee

## *Conference Chair*

**Jo Finders**, ASML Netherlands B.V. (Netherlands)

## *Conference Co-chairs*

**Brid Connolly**, Toppan Photomasks GmbH (Germany)

**Chris Gale**, Applied Materials (Germany)

**Naoya Hayashi**, Dai Nippon Printing Company, Ltd. (Japan)

## *Program Chairs*

**Uwe F.W. Behringer**, UBC Microelectronics (Germany)

**Ines Stolberg**, Vistec Electron Beam GmbH (Germany)

**Rolf Seltmann**, GLOBALFOUNDRIES (Germany)

**Daniel Sarlette**, Infineon Technologies Dresden GmbH (Germany)

## *Other Members*

**Carola Bläsing**, Carl Zeiss SMS GmbH (Germany)

**Parkson Chen**, Taiwan Mask Corporation (Taiwan)

**Albrecht Ehrmann**, Carl Zeiss SMS GmbH (Germany)

**Andreas Erdmann**, Fraunhofer IISB (Germany)

**Dave Farrar**, HOYA Corporation (United Kingdom)

**Rik Jonckheere**, IMEC vzw (Belgium)

**Barbara Lauche**, Photonics MZD GmbH (Germany)

**Carlos Lee**, EPIC – European Photonics Industry Consortium (Belgium)

**Bertrand Le Gratiet**, STMicroelectronics (France)

**Harry Levinson**, GLOBALFOUNDRIES (United States)

**Hans Löschner**, IMS Nanofabrication AG (Austria)

**Michael Mühlberger**, Profactor GmbH (Austria)

**Jan Hendrik Peters**, Carl Zeiss SMS GmbH (Germany)

**Jose Pozo**, European Photonics Industry Consortium (Belgium)

**Chris Progler**, Photonics Inc. (United States)

**Douglas J. Resnick**, CNT-Canon (United States)

**Klaus-Dieter Röth**, KLA-Tencor MIE (Germany)

**Thomas Scherübl**, Carl Zeiss SMS GmbH (Germany)

**Ronald Schnabel**, VDE/VDI-GMM (Germany)

**Steffen Schulze**, Mentor Graphics Corporation (United States)

**Martin Tschinkl**, AMTC (Germany)

**Jacques Waelpoel**, ASML Netherlands B.V. (Netherlands)

**Jim Wiley**, ASML US, Inc. (United States)

**C. Grant Willson**, University of Texas, Austin (United States)

**Hermann Wolf**, Photronics MZD GmbH (Germany)  
**Stefan Wurm**, SEMATECH (United States)  
**Larry Zurbrick**, Agilent Technologies (United States)

*Session Chairs*

Plenary Session I

**Rolf Seltmann**, GLOBALFOUNDRIES (Germany)  
**Jo Finders**, ASML Netherlands B.V. (Netherlands)

Plenary Session II

**Ines Stolberg**, Vistec Electron Beam GmbH (Germany)  
**Martin Tschinkl**, AMTC (Germany)

Wafer Lithography

**Rolf Seltmann**, GLOBALFOUNDRIES (Germany)  
**Carmen Jaehnert**, Infineon Technologies AG (Germany)

Mask Patterning, Metrology, and Process

**Naoya Hayashi**, Dai Nippon Printing Company Ltd. (Japan)  
**Klaus-Dieter Röth**, KLA-Tencor MIE (Germany)

Novel Approaches

**Albrecht Ehrmann**, Carl Zeiss SMS GmbH (Germany)  
**Hermann Wolf**, Photronics MZD GmbH (Germany)

EUV I

**Stefan Wurm**, SEMATECH (United States)  
**Jo Finders**, ASML Netherlands B.V. (Netherlands)

EUV II and Advanced 193i

**Rolf Seltmann**, GLOBALFOUNDRIES (Germany)  
**Thomas Scherübl**, Carl Zeiss SMS GmbH (Germany)

Photonics

**Jose Pozo**, European Photonics Industry Consortium (Belgium)  
**Andreas Erdmann**, Fraunhofer IISB (Germany)

Nano-Imprint Lithography

**Naoya Hayashi**, Dai Nippon Printing Company Ltd. (Japan)  
**Michael Mühlberger**, Profactor GmbH (Austria)

Modeling and Computational Process Correction

**Andreas Erdmann**, Fraunhofer IISB (Germany)  
**Germain Fenger**, Mentor Graphics Corporation (United States)

Using the Data

**Jan Hendrik Peters**, Carl Zeiss SMS GmbH (Germany)

**Bryan Kasprovicz**, Photronics, Inc. (United States)

Moor than Moore, IoT, and Manufacturing Challenges

**Uwe F.W. Behringer**, UBC Microelectronics (Germany)

**Bertrand Le Gratiet**, STMicroelectronics (France)



## Foreword

On behalf of VDE/VDI-GMM, the sponsors, and the organizing committee, we would like to welcome you to the proceedings from the 32nd European Mask and Lithography Conference, EMLC2016, 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 and wafer lithography. The two-day conference was dedicated to the science, technology, engineering and application of mask and lithography technologies and associated processes—giving an overview of the present status of mask and lithography technologies, while also providing future strategies where mask producers and users have the opportunity of becoming acquainted with new developments and results. This year's sessions included: Mask Patterning, Metrology and Process, Wafer Lithography, EUV, Modelling and Computational Process Correction, Photonics, More than Moore, IoT and Manufacturing Challenges, Using the Data, Novel Approaches, and Nano-Imprint Lithography.

Rutger Wijburg from Globalfoundries (Dresden) was the welcome speaker and first keynote speaker. He presented, "The Semiconductor Industry in Transition: A European Perspective."

The second keynote speaker was Naoya Hayashi from Dai Nippon Printing, Japan. His talk was titled, "Challenges and Prospects of Next Generation Masks" The status of the worldwide mask technologies."

The third keynote speaker was You Cao from ASML Brion Inc. (USA) who presented "Computational Lithography and Applications in Process Window Enhancement and Control."

On Monday morning, the Best Poster from BACUS 2015 was presented, followed by the Best Paper from PMJ 2016.

### 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) presented 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 EMLC2016 as well as the technical exhibition, but also allowed yourself to visit the beautiful city of Dresden.

**Uwe F.W. Behringer**  
EMLC2016 Program Chair

## Sponsors and Cooperating Partners

The 32nd European Mask and Lithography Conference, EMLC 2016, would like to express its sincere appreciation to all the sponsors and cooperating partners mentioned below for their support



