PROCEEDINGS OF SPIE

SPIDigitalLibrary.org/conference-proceedings-of-spie

Front Matter: Volume 10957

, "Front Matter: Volume 10957," Proc. SPIE 10957, Extreme Ultraviolet (EUV) Lithography X, 1095701 (3 April 2019); doi: 10.1117/12.2533503

SPIE.

Event: SPIE Advanced Lithography, 2019, San Jose, California, United States

PROCEEDINGS OF SPIE

Extreme Ultraviolet (EUV) Lithography X

Kenneth A. Goldberg
Editor

25–28 February 2019
San Jose, California, United States

Sponsored by
SPIE

Co-sponsored by
ASML US, Inc. (United States)

Published by
SPIE

Volume 10957

Proceedings of SPIE 0277-786X, V. 10957

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

Extreme Ultraviolet (EUV) Lithography X, edited by Kenneth A. Goldberg, Proc. of SPIE Vol. 10957,
1095701 · © 2019 SPIE · CCC code: 0277-786X/19/\$18 · doi: 10.1117/12.2533503

Proc. of SPIE Vol. 10957 1095701-1

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 *Extreme Ultraviolet (EUV) Lithography X*, edited by Kenneth A. Goldberg, Proceedings of SPIE Vol. 10957 (SPIE, Bellingham, WA, 2019) Seven-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510625617

ISBN: 9781510625624 (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 \$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/19/\$18.00.

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

THE FUTURE IS HIGH NA

10957 08	Overview and status of the 0.5NA EUV microfield exposure tool at Berkeley Lab (Invited Paper) [10957-4]
10957 09	High NA EUV lithography: next step in EUV imaging [10957-5]

INORGANIC RESISTS: JOINT SESSION WITH CONFERENCES 10960 AND 10957

10957 0B	The role of the organic shell in hybrid molecular materials for EUV lithography [10957-7]
10957 0D	Zinc-based metal oxoclusters: towards enhanced EUV absorptivity [10957-9]

STOCHASTICS AND EXPOSURE MECHANISMS: JOINT SESSION WITH CONFERENCES 10960 AND 10957

10957 0E	Stochastic printing failures in EUV lithography (Invited Paper) [10957-10]
10957 0F	Fundamentals of resist stochastics effect for single-expose EUV patterning [10957-11]

ORDER FROM CHAOS: STOCHASTIC MODELING

10957 0G	Impact of asymmetrically localized and cascading secondary electron generation on stochastic defects in EUV lithography [10957-12]
10957 0H	Impact of local variability on defect-aware process windows (Invited Paper) [10957-13]
10957 0I	Unraveling the EUV photoresist reactions: which, how much, and how do they relate to printing performance (Invited Paper) [10957-14]
10957 0J	OPC strategies to reduce failure rates with rigorous resist model stochastic simulations in EUVL [10957-15]

EUV MASK FIDELITY

- 10957 OK **Towards ultimate image placement accuracy for EUV mask writing with pattern shift process** [10957-16]
- 10957 OL **EUV mask challenges and requirements for ultimate single exposure interconnects (Invited Paper)** [10957-17]
- 10957 OM **Influence of mask line width roughness on programmed pattern defect printability** [10957-18]
- 10957 ON **Impact of EUV absorber variations on wafer patterning** [10957-19]
- 10957 OO **Ion beam etching of new absorber materials for sub-5nm EUV masks** [10957-20]

PRINTING AT THE EDGE: EUV PATTERNING APPLICATIONS

- 10957 OR **LCDU optimization of STT-MRAM 50nm pitch MTJ pillars for process window improvement** [10957-22]
- 10957 OS **Impact of sequential infiltration synthesis (SIS) on roughness and stochastic nano-failures for EUVL patterning** [10957-23]

EUV PATTERNING AND ETCH: JOINT SESSION WITH CONFERENCES 10957 AND 10963

- 10957 OT **Staggered pillar patterning using 0.33NA EUV lithography** [10957-25]

EUV MASKS, DEFECTS, AND PELLICLES

- 10957 OU **Advanced particle contamination control in EUV scanners** [10957-27]
- 10957 OV **Upgrade to the SHARP EUV mask microscope** [10957-28]
- 10957 OW **Absorber and phase defect inspection on EUV reticles using RESCAN** [10957-29]

EUV IMAGING ENHANCEMENT I

- 10957 OZ **3D mask effects in high NA EUV imaging** [10957-32]
- 10957 IO **Investigation of mask absorber induced image shift in EUV lithography (Invited Paper)** [10957-33]

- 10957 12 **Implementation of different cost functions for EUV mask optimization for next generation beyond 7 nm** [10957-35]

EUV IMAGING ENHANCEMENT II

- 10957 13 **Compatibility assessment of novel reticle absorber materials for use in EUV lithography systems** [10957-36]
- 10957 15 **Advanced multilayer mirror design to mitigate EUV shadowing** [10957-38]

EUV OPC AND MODELING: JOINT SESSION WITH CONFERENCES 10957 AND 10962

- 10957 1C **Mask 3D effect reduction and defect printability of etched multilayer EUV mask** [10957-46]
- 10957 1D **Development of fast rigorous simulator for large-area EUV lithography simulation** [10957-45]

POSTER SESSION

- 10957 1G **Actinic inband EUV reflectometry AIMER compared to ALS blank qualification and applied to structured masks** [10957-47]
- 10957 1I **High-precision MoSi multilayer coatings at high-volume for continued EUVL infrastructure development** [10957-49]
- 10957 1J **The defect mitigation on EUV stack by track based technology** [10957-50]
- 10957 1K **EUV-LET 2.0: a compact exposure tool for industrial research at a wavelength of 13.5 nm** [10957-51]
- 10957 1L **Photon detector calibration in the EUV spectral range at PTB** [10957-52]
- 10957 1N **Line-edge roughness on fin-field-effect-transistor performance for below 10nm patterns** [10957-54]
- 10957 1O **Calibrated PSCAR stochastic simulation** [10957-56]
- 10957 1P **Novel technologies in coater/developer to enhance the CD stability and to improve the defectivity toward N7 and smaller nodes** [10957-57]
- 10957 1Q **Simulation of statistical effects in exposure and development of EUV photoresists using the percolation and diffusion limited aggregation model** [10957-58]

- 10957 1S **Update of the development progress of the high power LPP-EUV light source using a magnetic field** [10957-61]
- 10957 1X **Achieving diffraction-limited performance on the Berkeley MET5** [10957-67]

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.

Abe, Tamotsu, 1S
Akiteru, Ko, 1J
Allezy, Arnaud, 08
Anderson, Christopher, 08, 1X
Arps, J., 1G
Babalik, A., 1L
Babuschkin, A., 1L
Bahrenberg, Lukas, 1K
Banine, Vadim, 0U
Barboutis, A., 1L
Barouch, Eytan, 1D
Bekaert, Joost, 0H
Bender, Markus, 0K
Benk, Markus, 0V
Biafore, John J., 0J
Biermanns-Föth, A., 1G
Biesemans, Serge, 1O
Bilski, Bartosz, 09
Blanc, Romuald, 0T
Blanco, Victor, 0S
Blankenship, David, 0J
Bonam, Ravi, 0L
Bottiglieri, Gerardo, 09, 0Z
Brose, Sascha, 1K
Buchholz, C., 1L
Burkhardt, Martin, 10
Cantrell, G. R., 0K
Carcasi, Michael, 1O
Castellanos, Sonia, 0B, 0D
Cerbu, Dorin, 0H
Cerio, Frank, 0O
Chao, Weilun, 08, 0V, 1X
Charley, Anne-Laure, 0T
Choi, Yohan, 0L
Church, Jennifer, 10
Cloin, Christian, 0U
Cork, Carl, 08, 1X
Cork, Will, 08
Corliss, Daniel, 0L
Crotti, Davide, 0R
Danylyuk, Serhiy, 1K
De Bisschop, Peter, 0E, 0I, 1O
Dejkameh, Atoosa, 0W
Delano, Rene, 08
Demand, Marc, 1P
DePonte, Jason, 08
de Poortere, Etienne, 0S
de Roest, David, 0S
de Rooij-Lohmann, Veronique, 13

De Silva, Anuja, 0F, 10
De Simone, Danilo, 0I, 0R, 0S, 0T, 1O
Devasahayam, Adrian J., 0O
Dickinson, Michael, 08, 1X
Dinh, Cong Que, 1O
Dunn, Derren, 0L
Ekinci, Yasin, 0B, 0D, 0W
Enomoto, Masashi, 1P
Ercken, Monique, 0R
Erdmann, Andreas, 0Z
Evanschitzky, Peter, 0Z
Fallica, Roberto, 0T
Felix, Nelson M., 0F, 0L, 10, 1J
Fernandez, Sara, 0W
Finken, Michael, 0K
Fischer, A., 1L
Fliervoet, Timon, 09, 0Z
Foubert, Philippe, 1O, 1P
Frommhold, Andreas, 0H, 0N
Fühner, Tim, 0N
Fukuda, Hiroshi, 0G
Gaines, Geoff, 08, 1X
Gallagher, Emily, 0N
Gamsby, Jeff, 08, 1X
Goldberg, Kenneth, 0V
Goldfarb, Dario L., 0F
Graeupner, Paul, 09
Graves, Trey, 0J
Green, Michael, 0L
Gullikson, Eric, 08
Halder, Sandip, 0R
Ham, Young, 0L
Hara, Arisa, 0H
Hayashi, Hideyuki, 1S
Helfenstein, Patrick, 0W
Hendrickx, Eric, 0E, 0H, 0S
Hetzer, Dave, 1J
Hody, Hubert, 0R
Hori, Tsukasa, 1S
Hsu, Stephen, 09
Hubbard, Alex, 1J
Huli, Lior, 1J
Ide, Hiroyuki, 1O
Iida, Susumu, 1C
Ip, Vincent, 0O
Jaroslawzew, S., 1L
Jayaram, Srividya, 12
Jiang, Fan, 12
Jones, Gideon, 08, 1X

Juschkin, Larissa, 1K
 Kai, Akiko, 1J
 Kamberian, Henry, 0L
 Kamei, Yuya, 1O, 1P
 Kamo, Takashi, 0M, 1C
 Kandel, Yudhishthir, 0N
 Kasproicz, Bryan, 0L
 Kawakami, Shinichiro, 1J, 1P
 Kazazis, Dimitrios, 0W
 Kim, Sang-Kon, 1N
 Kissoon, Nicola, 0S
 Kodama, Takeshi, 1S
 Kohli, Sandeep, 0O
 Kondo, Yoshihiro, 1O
 Kriese, Michael, 1I
 Laubis, C., 1L
 Lazzarino, Frederic, 0S, 0T
 Lebert, Rainer, 1G, 1K
 Lee, Junghyung, 0T
 Lee, Kilyoung, 0T
 Lee, Meng H., 0O
 Lee, Patrick, 0J
 Lehnert, J., 1L
 Lemley, Corey, 1J
 Lercel, Michael, 0U
 Li, Yang, 1I
 Lim, Chang-Moon, 0T
 Locans, Uldis, 0W
 Loosen, Peter, 1K
 Lorusso, Gian, 0T
 Magoshi, Shunko, 1C
 Mao, Ming, 0S
 Maslow, Mark John, 0H
 Mc Manus, Moyra, 0S
 McNamara, John, 09
 Meli, Luciana, 0F, 0L, 1O, 1J
 Meliorisz, Balint, 1O
 Melvin, Lawrence S., III, 0N
 Mentzel, H., 1L
 Meyers, Stephen, 08
 Minekawa, Yukie, 1O
 Missalla, T., 1G
 Miyakawa, Ryan, 08, 0V, 1X
 Miyao, Kenichi, 1S
 Miyata, Yuichiro, 1J
 Mizoguchi, Haku, 1S
 Mochi, Iacopo, 0W
 Morikawa, Yasutaka, 0M, 1C
 Moriya, Teruhiko, 1O
 Muramatsu, Makoto, 1P
 Murray, Cody, 1J
 Nafus, Kathleen, 1O, 1P
 Nagahara, Seiji, 1O
 Nagai, Shinji, 1S
 Nakarai, Hiroaki, 1S
 Naulleau, Patrick, 08, 0V, 15, 1X
 Nebling, Ricarda, 0W
 Neureuther, Andrew, 15
 Nikipelov, Andrey, 0U
 Oh, Sharon, 1X

Oikawa, Noriaki, 0H
 Okamoto, Takeshi, 1S
 Pak, Murat, 0R
 Park, Chan-Ha, 0T
 Park, Sarohan, 0T
 Pathak, Abhinav, 0H, 0S
 Petersen, John S., 0I, 1O
 Petrillo, Karen, 1J
 Phiesel, C., 1G
 Piel, C., 1G
 Piumi, Daniele, 0S
 Platonov, Yuriy, 1I
 Pollentier, Ivan, 0I
 Progler, Chris, 0L
 Proske, Stefan, 0K
 Puls, J., 1L
 Rajeev, Rajendran, 0W
 Ramadan, Mohamed, 0L
 Rassoul, Nouredine, 0T
 Rekawa, Seno, 08, 1X
 Rincon Delgadillo, Paulina, 0S
 Rispens, Gijsbert, 0H, 0S
 Robertson, Stewart A., 0J
 Robinson, Chris, 1O
 Roesch, Matthias, 09
 Ronse, Kurt, 0T
 Rook, Katrina, 0O
 Saito, Takashi, 1S
 Salmassi, Farhad, 08
 Sankar Kar, Gouri, 0R
 Sano, Yohei, 1P
 Sasaki, Akira, 1Q
 Schiffelers, Guido, 0H, 0S
 Scholze, F., 1L
 Schönstedt, A., 1L
 Sherwin, Stuart, 15
 Shibata, Naoki, 1J
 Shimada, Ryo, 1O
 Shiozawa, Takahiro, 1J
 Shiraishi, Gousuke, 1O
 Shiraishi, Yutaka, 1S
 Shusuke, Yoshitake, 0N
 Sidorkin, Vadim, 0K
 Sintschuk, M., 1L
 Slachter, Bram, 0H
 Smeets, Christophe, 0U
 Sonoda, Akihiro, 1J, 1P
 Souriau, Laurent, 0R
 Srinivasan, Narasimhan, 0O
 Stadelhoff, C., 1L
 Steele, Jeffery, 1I
 Stock, Hans-Jürgen, 1O
 Stollenwerk, Jochen, 1K
 Storm, Arnold, 13
 Stortelder, Jetske, 13
 Sun, Yuyang, 12
 Tadokoro, Masahide, 1P
 Tagbo, C., 1L
 Takeshita, Kazuhiro, 1O
 Tamaddon, Amir-Hossein, 0T

Tanaka, Satoshi, 1C
 Thakur, Neha, 0D
 Tomczak, Yoann, 0S
 Tomono, Masaru, 1O
 Tritchkov, Alexander, 12
 Troost, Kars, 09
 Tseng, Li-Ting, 0W
 Uchiyama, Takayuki, 1C
 Ueda, Atsushi, 1S
 Ueda, Kenichi, 1J
 Vaglio Pret, Alessandro, 0J
 van de Kerkhof, Mark, 0U
 Van de Kerkhove, Jeroen, 0T
 Vandenberghe, Geert, 0I, 0S, 0T, 1O
 Vandenbroeck, Nadia, 0T
 van de Wetering, Ferdi, 0U
 Vanelderen, Pieter, 0R, 0S, 0T
 van Empel, Tjarko, 0U
 Van Look, Lieve, 0T
 Van Roey, Frieda, 0T
 van Schaik, Willem, 13
 van Schoot, Jan, 09
 van Setten, Eelco, 09, 0Z
 Vockenhuber, Michaela, 0B, 0D
 Vollmer, Brandon, 08
 Wada, Toshiharu, 1J
 Wahlisch, Felix, 0H
 Waller, Laura, 15
 Watanabe, Yukio, 1S
 Wei, Alex, 12
 Welling, Ulrich, 0N
 Word, James, 12
 Wu, Chien-Ching, 13
 Wu, Lianjia, 0B
 Yaegashi, Hidetami, 0H
 Yakunin, Andrei, 0U
 Yamane, Takeshi, 0M, 1C
 Yamauchi, Takashi, 1P
 Yanagida, Tatsuya, 1S
 Yano, Hidetsugu, 1J
 Yasin, Farrukh, 0R
 Yeung, Michael, 1D
 Yoon, So-Won, 1N
 Yoshida, Keisuke, 0H
 Yoshida, Yuichi, 1O
 Yoshihara, Kosuke, 1O
 Zehm, Daniel, 08
 Zekry, Joseph, 09
 Zhang, Xima, 12
 Zhu, Wenhua, 08, 1X
 Zimmermann, Joerg, 09
 Zimmermann, Stephan, 0K

Conference Committee

Symposium Chair

Will Conley, Cymer, an ASML Company (United States)

Symposium Co-chair

Kafai Lai, IBM Thomas J. Watson Research Center (United States)

Conference Chair

Kenneth A. Goldberg, Lawrence Berkeley National Laboratory
(United States)

Conference Co-chair

Nelson M. Felix, IBM Corporation (United States)

Conference Program Committee

Jos P. Benschop, ASML Netherlands B.V. (Netherlands)

Robert L. Brainard, SUNY CNSE/SUNYIT (United States)

Martin Burkhardt, IBM Thomas J. Watson Research Center
(United States)

Sonia Castellanos Ortega, Advanced Research Center for
Nanolithography (Netherlands)

Xuemei Chen, KLA Corporation (United States)

Deniz Elizabeth Civay, GLOBALFOUNDRIES Inc. (United States)

Daniel Corliss, IBM Corporation (United States)

Yasin Ekinici, Paul Scherrer Institut (Switzerland)

Andreas Erdmann, Fraunhofer-Institut für Integrierte Systeme und
Bauelementetechnologie IISB (Germany)

Allen H. Gabor, IBM Corporation (United States)

Emily E. Gallagher, IMEC (Belgium)

Florian Gstrein, Intel Corporation (United States)

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

Eric Hendrickx, IMEC (Belgium)

Soichi Inoue, Toshiba Corporation (Japan)

Bryan S. Kasprovicz, Photonics, Inc. (United States)

Insung Kim, SAMSUNG Electronics Company, Ltd.
(Korea, Republic of)

Seong-Sue Kim, SAMSUNG Electronics Company, Ltd.
(Korea, Republic of)

Toshio Konishi, Toppan Printing Company, Ltd. (Japan)

Ted Liang, Intel Corporation (United States)
Chang-Moon Lim, SK Hynix, Inc. (Korea, Republic of)
Anna Lio, Intel Corporation (United States)
Luciana Meli, IBM Corporation (United States)
Lawrence S. Melvin III, Synopsys, Inc. (United States)
Hiroaki Morimoto, Toppan Printing Company, Ltd. (Japan)
Patrick P. Naulleau, Lawrence Berkeley National Laboratory
 (United States)
Christopher S. Ngai, Applied Materials, Inc. (United States)
Shinji Okazaki, ALITECS Company, Ltd. (Japan)
Eric M. Panning, Intel Corporation (United States)
Moshe E. Preil, KLA Corporation (United States)
Kurt G. Ronse, IMEC (Belgium)
Akiyoshi Suzuki, Gigaphoton Inc. (Japan)
Thomas I. Wallow, ASML Brion (United States)
Obert R. Wood II, GLOBALFOUNDRIES Inc. (United States)

Session Chairs

- 1 Keynote Session
Kenneth A. Goldberg, Lawrence Berkeley National Laboratory
 (United States)
Nelson M. Felix, IBM Corporation (United States)
- 2 The Future is High NA
Patrick P. Naulleau, Lawrence Berkeley National Laboratory
 (United States)
Jos P. Benschop, ASML Netherlands B.V. (Netherlands)
- 3 Inorganic Resists: Joint session with conferences 10960 and 10957
Robert L. Brainard, SUNY CNSE/SUNYIT (United States)
Jason K. Stowers, Inpria Corporation (United States)
- 4 Stochastics and Exposure Mechanisms: Joint session with
 conferences 10960 and 10957
Florian Gstrein, Intel Corporation (United States)
Thomas I. Wallow, ASML Brion (United States)
- 5 Order from Chaos: Stochastic Modeling
Sonia Castellanos Ortega, Advanced Research Center for
 Nanolithography (Netherlands)
Shinji Okazaki, ALITECS Company, Ltd. (Japan)
- 6 EUV Mask Fidelity
Martin Burkhardt, IBM Thomas J. Watson Research Center
 (United States)
Bryan S. Kasprovicz, Photronics, Inc. (United States)

- 7 Printing at the Edge: EUV Patterning Applications
 Christopher S. Ngai, Applied Materials, Inc. (United States)
 Luciana Meli, IBM Corporation (United States)
- 8 EUV Patterning and Etch: Joint session with conferences 10957 and 10963
 Rich S. Wise, Lam Research Corporation (United States)
 Anna Lio, Intel Corporation (United States)
- 9 EUV Masks, Defects, and Pellicles
 Emily E. Gallagher, IMEC (Belgium)
 Moshe E. Preil, KLA-Tencor Corporation (United States)
- 10 EUV Imaging Enhancement I
 Andreas Erdmann, Fraunhofer-Institut für Integrierte Systeme und Bauelementetechnologie IISB (Germany)
 Eric Hendrickx, IMEC (Belgium)
- 11 EUV Imaging Enhancement II
 Naoya Hayashi, Dai Nippon Printing Company, Ltd. (Japan)
 Kurt G. Ronse, IMEC (Belgium)
- 12 Progress in EUV Sources
 Akiyoshi Suzuki, Gigaphoton Inc. (Japan)
 Anna Lio, Intel Corporation (United States)
- 13 EUV OPC and Modeling: Joint session with conferences 10957 and 10962
 Kevin Lucas, Synopsys, Inc. (United States)
 Soichi Inoue, Toshiba Corporation (Japan)