# PROCEEDINGS OF SPIE

# Advances in Patterning Materials and Processes XXXVI

Roel Gronheid Daniel P. Sanders Editors

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

Sponsored and Published by SPIE

Volume 10960

Proceedings of SPIE 0277-786X, V. 10960

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

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 SPIEDigital Library.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 Advances in Patterning Materials and Processes XXXVI, edited by Roel Gronheid, Daniel P. Sanders, Proceedings of SPIE Vol. 10960 (SPIE, Bellingham, WA, 2019) Sevendigit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510625679

ISBN: 9781510625686 (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.

Publication of record for individual papers is online in the SPIE Digital Library.



**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**

ix xii	Authors Conference Committee
	STOCHASTICS AND EXPOSURE MECHANISMS: JOINT SESSION WITH CONFERENCES 10960 AND 10957
10960 08	Multiscale approach for modeling EUV patterning of chemically amplified resist [10960-7]
10960 09	The hidden energy tail of low energy electrons in EUV lithography [10960-8]
	EUV RESISTS
10960 OA	PSCAR optimization to reduce EUV resist roughness with sensitization using Resist Formulation Optimizer (RFO) [10960-9]
10960 OB	Advanced EUV negative tone resist and underlayer approaches exhibiting sub-20nm half-pitch resolution [10960-10]
10960 OC	Multi-trigger resist: novel synthesis improvements for high resolution EUV lithography [10960-11]
10960 OD	Improvement of dual insolubilization resist performance through the incorporation of various functional units $[10960\text{-}12]$
	RESIST FUNDAMENTALS
10960 OG	Understanding the photoacid generator distribution at nanoscale using massive cluster secondary ion mass spectrometry [10960-15]
10960 01	Roughness power spectral density as a function of aerial image and basic process/resist parameter [10960-17]
	INTEGRATION
10960 OK	Addressing challenges in the mitigation of stochastic effects [10960-19]

10960 OL	Exploration of EUV-based self-aligned multipatterning options targeting pitches below 20nm [10960-20]
10960 ON	Self-aligned fin cut last patterning scheme for fin arrays of 24nm pitch and beyond [10960-22]
	MONOLAYER MATERIALS IN DEVICE FABRICATION
10960 OQ	Selective spin-on deposition of polymers on heterogeneous surfaces [10960-25]
10960 OR	Ultra-thin conformal coating for spin-on doping applications [10960-26]
	DIRECTED SELF-ASSEMBLY I: JOINT SESSION WITH CONFERENCES 10960 AND 10958
10960 OU	Post-polymerization modification of PS-b-PMMA for achieving directed self-assembly with sub-10nm feature size [10960-50]
	DIRECTED SELF-ASSEMBLY II: DEFECTIVITY
10960 OV	Kinetics of defect annihilation in chemo-epitaxy directed self-assembly [10960-30]
10960 OW	Pattern defect reduction for chemo-epitaxy DSA process [10960-31]
10960 OY	Defect mitigation in sub-20nm patterning with high-chi, silicon-containing block copolymers [10960-33]
10960 OZ	Accelerate the analysis and optimization of lamellar BCP process using machine learning [10960-34]
	STUDENT SESSION
10960 10	ToF-SIMS analysis of antimony carboxylate EUV photoresists [10960-35]
10960 11	Modeling of novel resist technologies [10960-36]
10960 12	Imaging behavior of highly fluorinated molecular resists under extreme UV radiation [10960-37]

## MATERIAL SUPPLIER

10960 13	Evolution of lithographic materials enabling the semiconductor industry [10960-38]
10960 15	Development of metal organic cluster EUV photoresists [10960-40]
10960 17	Expanding the lithographer's toolkit to reduce variability: filtration considerations [10960-42]
10960 18	Start-up performance and pattern defectivity improvement using 2nm rated nylon filter developed with lithography filtration expertise [10960-43]
	UNDERLAYERS
10960 19	High temperature spin on carbon materials with excellent planarization and CVD compatibility [10960-44]
10960 1A	Improved hemicellulose spin on carbon hardmask [10960-45]
10960 1B	Towards pure carbon: ultra-high carbon fullerene based spin-on organic hardmasks [10960-46]
10960 1D	Development of novel thick spin-on carbon hardmask [10960-48]
	POSTER SESSION: DSA
10960 1G	Micro-phase separation behavior study of the same system of a novel block copolymer (PS-b-PC) [10960-53]
10960 11	Influence of PDI and composition ratio for micro phase separation about PS-b-PMMA block copolymer [10960-55]
10960 1J	Phase behavior of polymer blend materials for polystyrene-b-polycarbonate (PS-b-PC) block copolymers and corresponding homopolymer polystyrene [10960-56]
10960 1L	Block copolymer line roughness and annealing kinetics as a function of chain stiffness [10960-80]
10960 1M	Mitigation of line edge roughness and line width roughness in block copolymer directed self-assembly through polymer composition molecular weight manipulation [10960-81]

# POSTER SESSION: EUV

10960 1N	Defect conscious approaches in EUV patterning [10960-58]
10960 1P	Robustness of interactive pattern fidelity error as a quality metric for integrated patterning [10960-60]
10960 1Q	Oligomers of MORE: Molecular Organometallic Resists for EUV [10960-61]
10960 1R	Radical sensitive zinc-based nanoparticle EUV photoresists [10960-62]
	POSTER SESSION: FILTRATION
10960 1U	An exploration of the use of fluoropolymers in photofiltration [10960-66]
10960 1V	Bridging the defect gap in EUV photoresist [10960-67]
10960 1X	Filter technology developments to address defectivity in leading-edge photoresists [10960-69]
10960 1Y	A new tailored point-of-use filter to reduce immersion lithography downtime and defects [10960-70]
	POSTER SESSION: FUNDAMENTALS
10960 21	Study of outgassing from the ArF CA chemically amplified resist ArF (193 nm) exposure [10960-73]
10960 22	Contact hole shrink of 193nm NTD immersion resist [10960-74]
	POSTER SESSION: UNDERLAYER
10960 23	Ordered polymer-based spin-on dopants [10960-75]
10960 24	Development of new maleimides applied to spin-on carbon hardmask with characteristics of high heat resistance and good planarization [10960-76]
10960 25	New silicon hard mask material development for sub-5nm node [10960-77]

- Application of downstream plasma generated radical methylation treatment to passive amorphous Si surface from TMAH etching during lithography process [10960-78]
- 10960 27 Charge dissipation by use of a novel aqueous based quaternary ammonium compound for use in electron beam lithography on non-conductive substrates [10960-79]

# **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.

Arisawa, You, 1A Asai, Masaya, 1A B. Carballo, V. M., 0L Babin, Sergey, 09 Baderot, J., 0Z

Bates, Christopher M., 0Q

Baudot, S., ON Bayana, Hareen, 1Y Bernard, G., OZ Biesemans, Serge, OA Borisov, Sergei, 09 Braggin, J., 17

Brainard, Robert L., 10, 1Q Breaux, Caleb L., 1L

Brown, A. G., 1B

Cameron, James F., 13, 19
Carcasi, Michael, 0A
Chen, Lawrence, 19
Chevalier, X., 0Z
Cho, Maenghyo, 08
Choi, Sungho, 1D
Chung, Hua, 26
Coley, Suzanne, 19

Cui, Li, 19

Cutler, Charlotte, Ol Dai, Junyan, 1J D'Ambra, Colton, OQ Dawson, G., 1B De Bisschop, Peter, 0A De Simone, Danilo, 09, 0A de Villafranca, Glen, 27

Decoster, S., OL Dei, Satoshi, 25 Delony, Jakin B., 1M Demuynck, S., ON Denbeaux, Greg, 10, 1Q

Derville, A., 0Z DeSisto, Jason, 0l Dinh, Cong Que, 0A Doise, Jan, 0Y Echigo, Masatoshi, 24 Ekinci, Yasin, 0B, 0C Eller, Michael J., 0G Ellison, Christopher J., 0Y Enomoto, Masashi, 1P Enomoto, Satoshi, 0D

Ervin, J., 0N

Fallica, Roberto, 09 Foltz, Benjamin, 19 Foubert, Philippe, 0A Foucher, J., 0Z Gädda, Thomas, 0B Gey, G., 0Z

Giannelis, Emmanuel P., 15, 1R

Gjoka, Alketa, 1V, 1X Goel, V., 17 Greene, Dan, 19 Grzeskowiak, Steven, 1Q Han, Miyeon, 1D Hara, Arisa, 0K, 1N Harumoto, Masahiko, 1A Hasan, Shaheen, 10, 1Q Hawker, Craig J., 0Q

He, Xiaobin, 1J

Heitsch, Andrew T., 0R, 23 Henderson, Clifford L., 1L, 1M

Heo, Yumi, 1D Ho, Victor, 23

Hoarfrost, Megan L., 23

Hopf, T., 0N Horiuchi, Junya, 24 Hou, Xisen, 0G Ide, Hiroyuki, 0A Ido, Yasuyuki, 0W Isono, Takuya, 0U Ito, Kiyohito, 1P Jaber, Jad, 1V, 1X Jain, Vipul, 22 Javey, Ali, 23

Jeong, Changyoung, 08 Jung, Seok-Heon, 12, 15 Kähkönen, Oskari, 0B Kaitz, Joshua, 19, 22 Kamei, Yuya, 0A Kaneko, Fumiya, 1V, 1X Karaste, Kimmo, 0B Kasai, Tatsuya, 25

Katsumata, Reika, 0Q, 0R, 23

Kauppi, Emilia, 0B Kawaguchi, Yukio, 11 Kazazis, Dimitrios, 0B, 0C Ke, Iou-Sheng, 19, 22 Kearns, Kenneth, 19 Kesters, E., 0L Kim, Ji Yeon, 0Y Kim, Kanghyun, 12 Kim, Muyoung, 08

Kim, Youngmin, 1D

Kitano, Takahiro, 0W Muramatsu, Makoto, 0W Kobayashi, Shinji, 1P Murphy, Michael, 10, 1Q Koh, Jai Hyun, 0Y Nafus, Kathleen, 0A Kohyama, T., 1V, 1X Nagahara, Seiji, OA Kondo, Yoshihiro, 0A Nakagawa, Hisashi, 18 Kosaka, Terumasa, 11 Nakashima, Hideo, 0A Kosma, Vasiliki, 1R Nakayama, Chisayo, 1A Kozawa, Takahiro, 0D Nannarone, Stefano, 09 Kwok, Amy, 22 Naulleau, Patrick P., 11 LaBeaume, Paul, 19 Nealey, Paul F., 0V Lada, T., 1B Nelson, John, 01 Laukkanen, Markus, OB Neureuther, Andrew R., 11 Lazzarino, F., OL Ngunjiri, Johnpeter, 19 Lee, Byunahoon, 08 Nishi, Takanori, 0W Lee, Choong Bong, Ol Nishino, Tomoki, 21 Lee, Hyungwoo, 08 Novak, Steven, 10 Ober, Christopher K., 15, 1R Lee, Jin-Kyun, 12 Lee, Sangsul, 12 O'Callaghan, G., 0C Li, Haochen, 26 Ogaki, Ryosuke, 11 Li, Jiajing, 0V Oh, Hyuntaek, 12 Li, Mingqi, 0G, 0R, 22, 23 Okada, Soichiro, 1P Lim, Sanghak, 1D Pan, Wenyang, 15 Limary, Ratchana, OR, 23 Park, James, 22 Liu, Cong, 22 Park, Jona, 22 Liu, Weichen, 1G, 1J Park, Soyeon, 1D Long, Luke, 11 Park, Sungwoo, 08 Lopez, Gerald, 27 Petersen, John S., 0A Lorant, C., 0L Pieczulewski, Charles, 1A Lorusso, Gian, 09 Popere, Bhooshan C., OR, 19, 23 Lu, Xinliang, 26 Popescu, C., 0C Ran, Ruicheng, 1J Ludovice, Peter J., 1L, 1M Luong, Nguyen Dang, 0B Rantala, Juha, OB Ma, Shawming, 26 Rena, Rochelle, Ol Rezvani, Seyed Javid, 09 Machida, Kohei, 0D Mack, Chris, Ol Rincon-Delgadillo, Paulina, OV, OY Makinoshima, Takashi, 24 Robinson, Alex P. G., 0C, 1B Roth, J., 0C Mamiya, Hiroaki, 0U Sakai, Kazunori, 15, 1R Mannaert, Geert, 0V, 0Y Sakai, Tatsuya, 25 Mao, Guoping, 1J Sato, Takashi, 24 Martinez, S., OZ Matsuki, Ryota, 11 Satoh, Toshifumi, OU Matsumoto, Yoko, 21 Schweikert, Emile A., 0G McClelland, A. L., OC, 1B Segalman, Rachel A., OQ, OR, 23 Meliorisz, Balint, 0A Sekiguchi, Atsushi, 21 Seko, Tomoaki, 25 Meng, Lingkuan, 1G Miki, Yasushi, 24 Serizawa, Ryuuichi, 25 Milenin, A. P., 0N Shao, Grant, 27 Minami, Hiroko, 21 Shimada, Ryo, 0A Minekawa, Yukie, 0A Shimura, Satoru, 1P Miura, K., 1X Shin, Seungwook, 1D Miyagi, Ken, OU Shiraishi, Gosuke, 0A Mizuno, Takehito, 18 Shiu, Eric, 18 Soussou, A., 0N Montgomery, W., 1B Moon, Junghwan, 08 Stock, Hans-Jürgen, OA Morikita, Shinya, 1P Stokes, Harold, 1A Morita, Kazuyo, 1A Suh, Hyo Seon, OV, OY Motono, Tomohiro, 1A Sung, Jin Wuk, 22 Mun, Jeong-Seok, 12 Takei, Kiniharu, 23

Murakami, Tetsuya, 18

Takeshita, Kazuhiro, OA

Tamaddon, A.-H., 0L

Tanaka, Hiroki, 1A

Tanaka, Yasuaki, 1A

Tanaka, Yuji, 1A

Thackeray, James W., 01, 13

Theis, W., 0C

Thompson, Andrew, 27

Tomono, Masaru, 0A

Trefonas, Peter, OG, OI, OR, 23

Tsuzuki, Shuichi, 18

Ueno, Masayoshi, 24

Umeda, Toru, 18

Vandenberghe, Geert, 09, 0A, 0Y

Vangoidsenhoven, D., 0L

Verkhoturov, Stanislav V., 0G

Vincent, B., 0N

Wang, S., 0N

Weckx, P., 0N

Wei, Yayi, 1J

Weires, Maximilian, 1Q

Willson, C. Grant, 0Y

Wong, Sabrina, 19

Wu, Aiwen, 17, 1U, 1Y

Wu, Janet, 22

Wu, Xin, 1J

Xia, Annie, 1U, 1Y

Xie, Ting, 26

Xu, Cheng Bai, 13

Xu, Hong, 1R

Yaegashi, Hidetami, OK, 1N

Yamada, Koichi, 24

Yamada, Shintaro, 19

Yamamoto, Kimiko, 1A

Yamazaki, Akiyoshi, 0U

Yang, Kou, 1R

Yang, Michael, 26

Yoon, Byeri, 1D

Yoshida, Kohei, 0U

Yoshida, Yuichi, 0A

Yoshihara, Kosuke, 0A

Yoshimura, Shota, 1P

Yoshino, Takumi, OD

You, Gen, 0W

Zhang, Baolin, 1G, 1J

Zhang, Keren, 19

Zhang, Lei, 19

Zhang, Libin, 1J

Zhang, Meiyue, 27

Zhang, Qi, 26

Zhang, Yuanyi, 0Q, 0R, 23

Zhang, Zhengping, 1G

Zhu, Qingjun, 0Y

# **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

Roel Gronheid, KLA-Tencor/ICOS Belgium (Belgium)

Conference Co-chair

**Daniel P. Sanders**, IBM Research - Almaden (United States)

Conference Program Committee

Robert Allen, IBM Research - Almaden (United States)

**Gilles R. Amblard**, SAMSUNG Austin Semiconductor LLC (United States)

Ramakrishnan Ayothi, JSR Micro, Inc. (United States)

**Ryan Callahan**, FUJIFILM Electronic Materials U.S.A., Inc. (United States)

**Joy Y. Cheng**, Taiwan Semiconductor Manufacturing Company Ltd. (Taiwan)

**Ralph R. Dammel**, EMD Performance Materials Corporation (United States)

**Anuja De Silva**, IBM Corporation (United States)

Danilo De Simone, IMEC (Belgium)

**Douglas J. Guerrero**, Brewer Science, Inc. (United States)

**Clifford L. Henderson**, University of South Florida (United States)

Craig D. Higgins, GLOBALFOUNDRIES Inc. (United States)

**Christoph K. Hohle**, Fraunhofer-Institut für Photonische Mikrosysteme (Germany)

Scott W. Jessen, Texas Instruments Inc. (United States)

Yoshio Kawai, Shin-Etsu Chemical Company, Ltd. (Japan)

Qinghuang Lin, ASML US, Inc. (United States)

Nobuyuki N. Matsuzawa, Panasonic Corporation (Japan)

**Steve S. Putna**, Intel Corporation (United States)

Mark H. Somervell, Tokyo Electron America, Inc. (United States)

Jason K. Stowers, Inpria (United States)

James W. Thackeray, Dow Electronic Materials (United States)

Raluca Tiron, CEA-LETI (France)
Rick Uchida, Tokyo Ohka Kogyo America, Inc. (United States)
Thomas I. Wallow, ASML Brion Technologies (United States)

#### Session Chairs

Opening Remarks and Award Announcements

Roel Gronheid, KLA-Tencor/ICOS Belgium (Belgium)

Daniel P. Sanders, IBM Research - Almaden (United States)

1 Keynote Session

Roel Gronheid, KLA-Tencor/ICOS Belgium (Belgium)

Daniel P. Sanders, IBM Research - Almaden (United States)

- 2 Inorganic Resists: Joint Session with Conferences 10960 and 10957 Robert L. Brainard, SUNY CNSE/SUNYIT (United States) Jason K. Stowers, Inpria Corporation (United States)
- Stochastics and Exposure Mechanisms: Joint Session with Conferences 10960 and 10957
   Marie Krysak, Intel Corporation (United States)
   Thomas I. Wallow, ASML San Jose (United States)
- 4 EUV Resists

**Danilo De Simone**, IMEC (Belgium) **Anuja De Silva**, IBM Corporation (United States)

5 Resist Fundamentals

**Nobuyuki N. Matsuzawa**, Panasonic Corporation (Japan) **Douglas J. Guerrero**, Brewer Science, Inc. (Belgium)

6 Integration

Yoshio Kawai, Shin-Etsu Chemical Co., Ltd. (Japan) Ryan Callahan, FUJIFILM Electronic Materials U.S.A., Inc. (United States)

7 Monolayer Materials in Device Fabrication

**Ralph R. Dammel**, EMD Performance Materials Corporation (United States)

**James W. Thackeray**, Dow Electronic Materials (United States)

8 Directed Self-assembly 1: Joint Session with Conferences 10960 and 10958

Raluca Tiron, CEA-LETI (France)
Ricardo Ruiz, HGST, Inc. (United States)

9 Directed Self-assembly II: Defectivity Mark H. Somervell, Tokyo Electron America, Inc. (United States) Douglas J. Guerrero, Brewer Science, Inc. (United States)

#### 10 Student Session

**Scott W. Jessen**, Texas Instruments Inc. (United States) **Robert D. Allen**, IBM Research - Almaden (United States)

Poster Preview Speed Talks

**Scott W. Jessen**, Texas Instruments Inc. (United States) **Robert D. Allen**, IBM Research - Almaden (United States)

#### 11 Material Supplier

**Christoph K. Hohle**, Fraunhofer-Institut für Photonische Mikrosysteme (Germany)

**Gilles R. Amblard**, SAMSUNG Austin Semiconductor LLC (United States)

### 12 Underlayers

**Ryusuke Uchida**, Tokyo Ohka Kogyo America, Inc. (United States) **Ramakrishnan Ayothi**, JSR Micro, Inc. (United States)

Tribute to C. Grant Willson (retiring in 2019) **Qinghuang Lin**, ASML US, Inc. (United States) **Roel Gronheid**, KLA-Tencor/ICOS Belgium (Belgium)