PROCEEDINGS OF SPIE

SPIDigitalLibrary.org/conference-proceedings-of-spie

Front Matter: Volume 7823

, "Front Matter: Volume 7823," Proc. SPIE 7823, Photomask Technology 2010, 782301 (19 October 2010); doi: 10.1117/12.881306

SPIE.

Event: SPIE Photomask Technology, 2010, Monterey, California, United States

Photomask Technology 2010

**M. Warren Montgomery
Wilhelm Maurer**
Editors

**13–16 September 2010
Monterey, California, United States**

Sponsored by

The international technical group of SPIE dedicated
to the advancement of photomask technology

Published by
SPIE

Volume 7823
Part One of Two Parts

Proceedings of SPIE, 0277-786X, v. 7823

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

The papers included 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. The papers published in these proceedings 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 this book:

Author(s), "Title of Paper," in *Photomask Technology 2010*, edited by M. Warren Montgomery, Wilhelm Maurer, Proceedings of SPIE Vol. 7823 (SPIE, Bellingham, WA, 2010) Article CID Number.

ISSN 0277-786X

ISBN 9780819483379

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 © 2010, 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/10/\$18.00.

Printed in the United States of America.

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

SPIDigitalLibrary.org

Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print and on CD-ROM. Papers are published as they are submitted and meet publication criteria. A unique, consistent, permanent citation identifier (CID) number is assigned to each article at the time of the first publication. Utilization of CIDs allows articles to be fully citable as soon they are published online, and connects the same identifier to all online, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- 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. The complete citation is used on the first page, and an abbreviated version on subsequent pages. Numbers in the index correspond to the last two digits of the six-digit CID number.

Contents

Part One

- xv *Conference Committee*
- xix *EMLC 2010 Best Paper*
e-beam induced EUV photomask repair: a perfect match [7545-11]
M. Waiblinger, Carl Zeiss SMS GmbH (Germany); K. Kornilov, T. Hofmann, K. Edinger, Carl Zeiss SMS NaWoTec GmbH (Germany)

INVITED SESSION

- 7823 03 **Mask Industry Assessment: 2010 [7823-02]**
G. Hughes, D. Y. Chan, SEMATECH (United States)
- 7823 05 **Dry etching technologies for EUV mask (Photomask Japan 2010 Best Paper) [7823-04]**
Y. Iino, M. Karyu, H. Ita, T. Yoshimori, H. Azumano, M. Nonaka, Shibaura Mechatronics Corp. (Japan)
- 7823 06 **Photomask Japan 2010 panel discussion overview [7823-05]**
Y. Nagaoka, KLA-Tencor Japan Ltd. (Japan); H. Mohri, Dai Nippon Printing Co., Ltd. (Japan); S. Akima, Toppan Printing Co., Ltd. (Japan)

PATTERN GENERATION

- 7823 07 **Improvement of mask write time for curvilinear assist features at 22nm (Invited Paper) [7823-06]**
A. Fujimura, I. Bork, D2S Inc. (United States); T. Kiuchi, T. Komagata, Y. Nakagawa, JEOL Ltd. (Japan); K. Hagiwara, D. Hara, D2S, KK (Japan)
- 7823 08 **eMET: 50 keV electron mask exposure tool development based on proven multi-beam projection technology [7823-07]**
E. Platzgummer, S. Cernusca, C. Klein, J. Klikovits, S. Kvasnica, H. Loeschner, IMS Nanofabrication AG (Austria)
- 7823 09 **Multi-shaped e-beam technology for mask writing [7823-08]**
J. Gramss, A. Stoeckel, U. Weidenmueller, H.-J. Doering, Vistec Electron Beam GmbH Jena (Germany); M. Bloecker, M. Sczyrba, M. Finken, T. Wandel, Advanced Mask Technology Ctr. GmbH Co. KG (Germany); D. Melzer, EQUIcon GmbH Jena (Germany)
- 7823 0A **Multiple beam mask writers: an industry solution to the write time crisis [7823-09]**
L. C. Litt, SEMATECH (United States)
- 7823 0B **Resist process windows in electron-beam lithography [7823-10]**
A. T. Jamieson, N. Wilcox, W. Y. Kwok, Y. K. Kim, Intel Corp. (United States)

MASK PROCESS

- 7823 0C **Process window improvement on 45nm technology non volatile memory by CD uniformity improvement** [7823-11]
U. Buttgereit, R. Birkner, Carl Zeiss SMS GmbH (Germany); E. Graitzer, A. Cohen, Carl Zeiss SMS (Israel); B. Triulzi, C. Romeo, Numonyx Italy S.r.l. (Italy)
- 7823 0D **Degradation of pattern quality due to strong electron scattering in EUV mask** [7823-12]
J. Choi, R. W. Lee, S. H. Lee, B. S. Ahn, H. B. Kim, S.-G. Woo, H. K. Cho, SAMSUNG Electronics Co., Ltd. (Korea, Republic of)
- 7823 0E **Reduced basis method for source mask optimization** [7823-116]
J. Pomplun, Zuse Institute Berlin (Germany) and JCMwave GmbH (Germany); L. Zschiedrich, JCMwave GmbH (Germany); S. Burger, F. Schmidt, Zuse Institute Berlin (Germany) and JCMwave GmbH (Germany); J. Tyminski, Nikon Precision Inc. (United States); D. Flagello, Nikon Research Corp. of America (United States); N. Toshiharu, Nikon Corp. (Japan)
- 7823 0F **Plasma monitoring of chrome dry etching for mask making** [7823-14]
S.-W. Kwon, D.-C. Kim, D.-S. Nam, S.-G. Woo, H.-K. Cho, SAMSUNG Electronics Co., Ltd. (Korea, Republic of)
- 7823 0G **Two complementary methods to characterize long range proximity effects due to develop loading** [7823-15]
L. K. Sundberg, G. M. Wallraff, A. M. Friz, B. Davis, IBM Almaden Research Ctr. (United States); A. E. Zweber, IBM Corp. (United States); R. Lovchik, E. Delamarche, IBM Research Zurich (Switzerland); T. Senna, Toppan Photomasks, Inc. (United States); T. Komizo, Toppan Printing Co., Ltd. (Japan); W. D. Hinsberg, IBM Almaden Research Ctr. (United States)
- 7823 0H **New method to determine process window considering pattern failure** [7823-16]
S.-H. Yang, S. Moon, J. Ser, Y.-C. Kim, S.-W. Choi, C.-J. Kang, SAMSUNG Electronics Co., Ltd. (Korea, Republic of)
- 7823 0I **A systematic approach to the determination of SRAF capabilities in high end mask manufacturing** [7823-17]
C. Bürgel, M. Sczyrba, G. R. Cantrell, Advanced Mask Technology Ctr. GmbH Co. KG (Germany)

MASK MATERIALS

- 7823 0J **Development and characterization of a thinner binary mask absorber for 22-nm node and beyond (Best Paper Award)** [7823-18]
T. Faure, K. Badger, L. Kindt, IBM Corp. (United States); Y. Koderu, T. Komizo, Toppan Printing Co., Ltd. (Japan); S. Kondo, T. Mizoguchi, S. Nemoto, K. Seki, T. Senna, Toppan Photomasks, Inc. (United States); R. Wistrom, A. Zweber, IBM Corp. (United States); K. Nishikawa, Y. Inazuki, H. Yoshikawa, ShinEtsu Chemical Corp. (Japan)
- 7823 0K **Advanced binary film for 193nm lithography extension to sub-32-nm node** [7823-19]
O. Nozawa, H. Shishido, M. Hashimoto, Y. Ohkubo, H. Mitsui, HOYA Corp. (Japan)

7823 OM **Understanding the trade-offs of thinner binary mask absorbers** [7823-21]
J. Tirapu-Azpiroz, IBM Semiconductor Research and Development Ctr. (United States);
G. McIntyre, IBM Advanced Lithography Research (United States); T. Faure, IBM Mask
Development (United States); S. Halle, IBM Advanced Lithography Research (United States);
M. Hibbs, IBM Mask Development (United States); A. Wagner, IBM T.J. Watson Research Ctr.
(United States); K. Lai, IBM Semiconductor Research and Development Ctr. (United States);
E. Gallagher, IBM Mask Development (United States); T. Brunner, IBM Semiconductor
Research and Development Ctr. (United States)

7823 ON **Aging study in advanced photomasks: impact of EFM effects on lithographic performance
with MoSi binary and 6% attenuated PSM masks** [7823-22]
I. Servin, J. Belledent, M. O. Fialeyre, CEA-LETI MINATEC (France); B. Connolly, M. Lamantia,
Toppan Photomasks, Inc. (Germany); M. Szczyba, Advanced Mask Technology Ctr. GmbH
Co. KG (Germany); M. K. Jullian, B. Le Gratiet, STMicroelectronics (France); L. Pain, CEA-LETI
MINATEC (France)

NIL

7823 OO **Development of template and mask replication using jet and flash imprint lithography**
[7823-23]
C. Brooks, K. Selinidis, G. Doyle, L. Brown, D. LaBrake, D. J. Resnick, S. V. Sreenivasan,
Molecular Imprints, Inc. (United States)

7823 OP **6-inch circle template fabrication for patterned media** [7823-24]
K. Itoh, M. Hoga, Dai Nippon Printing Co., Ltd. (Japan); N. Toyama, DNP Corp. USA (United
States)

7823 OQ **Inspection technique for nanoimprint template with mirror electron microscopy** [7823-25]
T. Shimakura, M. Hasegawa, H. Suzuki, H. Ohta, Hitachi, Ltd. (Japan)

MASK DATA PREPARATION

7823 OR **Writing 32nm-hp contacts with curvilinear assist features** [7823-26]
A. Fujimura, D2S Inc. (United States); D. Kim, Luminescent Technologies, Inc. (United States);
I. Bork, D2S Inc. (United States); C. Pierrat, IC Images Technologies, Inc. (United States)

7823 OS **Optimization of MDP, mask writing, and mask inspection for mask manufacturing cost
reduction** [7823-27]
M. Yamabe, Association of Super-Advanced Electronics Technologies (Japan); T. Inoue, SII
NanoTechnology Inc. (Japan); M. Shoji, Nippon Control Systems Corp. (Japan); A. Yamada,
Advantest Corp. (Japan); H. Hoshi, JEOL Ltd. (Japan); K. Takahara, NuFlare Technology, Inc.
(Japan)

7823 OT **Generalization of shot definition for variable shaped e-beam machines for write time
reduction** [7823-118]
E. Sahouria, A. Bowhill, Mentor Graphics Corp. (United States)

SIMULATION

- 7823 0U **Physical resist model calibration for implant level using laser-written photomasks** [7823-28]
D. Shao, B. Zhang, IBM Systems and Technology (United States); S. Marokkey, Infineon Technologies (United States); T. C. Bailey, D. N. Dunn, E. E. Gallagher, Y.-S. Lin, IBM Systems and Technology (United States); T. Murakami, Renesas Electronics Corp. (United States); S. Nakagawa, Toshiba America Electronic Components Inc. (United States); C. Sarma, Infineon Technologies (United States); M. Talbi, IBM Systems and Technology (United States)
- 7823 0V **Compensation methods using a new model for buried defects in extreme ultraviolet lithography masks** [7823-29]
C. H. Clifford, Univ. of California, Berkeley (United States) and Luminescent Technologies, Inc. (United States); T. T. Chan, A. R. Neureuther, Univ. of California, Berkeley (United States); Y. Li, D. Peng, L. Pang, Luminescent Technologies, Inc. (United States)
- 7823 0W **Evaluation of a new model of mask topography effects** [7823-30]
C. Pierrat, IC Images Technologies (United States)
- 7823 0X **An advanced modeling approach for mask and wafer process simulation** [7823-31]
A. Karakas, E. Elsen, I. Torunoglu, C. Andrus, Gauda, Inc. (United States)

OPTICAL PROXIMITY CORRECTION

- 7823 0Z **Model-based double dipole lithography for sub-30nm node device** [7823-33]
A.-Y. Je, SAMSUNG Electronics Co., Ltd. (Korea, Republic of); S.-H. Choi, SAMSUNG Electronics Co., Ltd. (Korea, Republic of) and Korea Univ. (Korea, Republic of); J.-H. Lee, SAMSUNG Electronics Co., Ltd. (Korea, Republic of); J.-Y. Lee, J. Word, Mentor Graphics Corp. (United States); C.-H. Park, S.-H. Lee, M.-H. Yoo, SAMSUNG Electronics Co., Ltd. (Korea, Republic of); G.-T. Kim, Korea Univ. (Korea, Republic of)
- 7823 10 **SMO mask requirements for low k_1 lithography** [7823-34]
S. Nagahara, K. Kawahara, H. Yamazaki, A. Ando, M. Naganuma, K. Yoshimochi, T. Uchiyama, K. Nakashima, Renesas Electronics Corp. (Japan); H. Imai, K. Hayano, H. Migita, E. Tsujimoto, Dai Nippon Printing Co., Ltd. (Japan)
- 7823 11 **Improving model prediction accuracy for ILT with aggressive SRAFs** [7823-35]
S. Jung, W. Sim, M. Jeong, J. Ser, S. Lee, S. Choi, SAMSUNG Electronics Co., Ltd. (Korea, Republic of); X. Zhou, L. Luan, T. Cecil, D. Son, R. Gleason, D. Kim, Luminescent Technologies, Inc. (United States)
- 7823 12 **A systematic study of source error in source mask optimization** [7823-36]
C. Alleaume, E. Yesilada, V. Farys, STMicroelectronics (France); L. Depre, V. Arnoux, Z. Li, Brion Technologies, Inc. (United States); Y. Trouiller, CEA-LETI MINATEC (France); A. Serebriakov, ASML Netherlands B.V. (Netherlands)
- 7823 13 **Impact of model-based fracturing on e-beam proximity effect correction methodology** [7823-37]
C. Pierrat, IC Images Technologies, Inc. (United States); I. Bork, D2S, Inc. (United States)

OVERVIEW SESSION

- 7823 15 **Design for e-beam: design insights for direct-write maskless lithography (Invited Paper)** [7823-127]
A. Fujimura, D2S, Inc. (United States)
- 7823 16 **Direct write electron beam lithography: a historical overview** [7823-124]
H. C. Pfeiffer, HCP Consulting (United States)
- 7823 18 **Cost/benefit assessment of maskless lithography** [7823-126]
C. N. Berglund, Northwest Technology Group (United States)

USE MODELS AND SPECIAL APPLICATIONS NEEDED I

- 7823 1C **E-beam direct write (EBDW) as complementary lithography** [7823-129]
D. Lam, D. Liu, T. Prescop, Multibeam Corp. (United States)

USE MODELS AND SPECIAL APPLICATIONS NEEDED II

- 7823 1E **Geometrically induced dose correction method for e-beam lithography applications** [7823-131]
R. Galler, EQUIcon Software GmbH Jena (Germany); K.-H. Choi, M. Gutsch, C. Hohle, Fraunhofer Ctr. for Nanoelectronic Technologies (Germany); M. Krueger, EQUIcon Software GmbH Jena (Germany); L. E. Ramos, Vistec Electron Beam GmbH (Germany); M. Suelzle, EQUIcon Software GmbH Jena (Germany); U. Weidenmueller, Vistec Electron Beam GmbH (Germany)

TOOL SUPPLIERS

- 7823 1H **Cell projection use and multi column approach for throughput enhancement of EBDW system** [7823-137]
A. Yamada, Y. Ooae, Advantest Corp. (Japan)
- 7823 1J **Multi-shaped-beam (MSB): an evolutionary approach for high throughput e-beam lithography** [7823-139]
M. Slodowski, H.-J. Döring, I. A. Stolberg, W. Dorl, Vistec Electron Beam GmbH (Germany)

EUV I

- 7823 1L **A lifetime study of EUV masks** [7823-39]
E. Gallagher, IBM Microelectronics (United States); O. Wood, GLOBALFOUNDRIES (United States); L. Kindt, IBM Microelectronics (United States); H. Kato, Toshiba America Electronic Components (United States); U. Okoroanyanwu, GLOBALFOUNDRIES (United States); J. Whang, M. Barrett, IBM Microelectronics (United States); T. Wallow, GLOBALFOUNDRIES (United States)

- 7823 1N **Impact of mask topography and multilayer stack on high NA imaging of EUV masks** [7823-41]
J. Ruoff, Carl Zeiss SMT AG (Germany)
- 7823 1O **EUV mask stack optimization for enhanced imaging performance** [7823-42]
E. van Setten, D. Oorschot, C.-W. Man, ASML Netherlands B.V. (Netherlands); M. Dusa, ASML Belgium BVBA (Belgium); R. de Kruif, N. Davydova, K. Feenstra, C. Wagner, ASML Netherlands B.V. (Netherlands); P. Spies, N. Wiese, M. Waiblinger, Carl Zeiss SMS GmbH (Germany)
- 7823 1Q **Extending a 193nm mask inspector for 22nm HP EUV mask inspection** [7823-44]
G. Inderhees, T.-Y. Fu, Q. Zhang, Y. Xiong, KLA-Tencor Corp. (United States)

EUV II

- 7823 1T **Natural EUV mask blank defects: evidence, timely detection, analysis and outlook** [7823-47]
D. Van den Heuvel, R. Jonckheere, IMEC vzw (Belgium); J. Magana, Intel Corp. (United States); T. Abe, Dai Nippon Printing Co., Ltd. (Japan); T. Bret, Carl Zeiss SMS GmbH (Germany); E. Hendrickx, S. Cheng, K. Ronse, IMEC vzw (Belgium)
- 7823 1U **Printability of EUVL mask defect detected by actinic blank inspection tool and 199-nm pattern inspection tool** [7823-48]
T. Kamo, T. Terasawa, T. Yamane, H. Shigemura, N. Takagi, T. Amano, T. Tanaka, K. Tawarayama, O. Suga, I. Mori, MIRAI-Semiconductor Leading Edge Technologies, Inc. (Japan)
- 7823 1V **Improvement of actinic blank inspection and phase defect analysis** [7823-49]
T. Yamane, T. Tanaka, T. Terasawa, O. Suga, MIRAI-Semiconductor Leading Edge Technologies, Inc. (Japan)
- 7823 1W **Investigation of the influence of resist patterning on absorber LWR for 22-nm-node EUV lithography** [7823-142]
Y. Inazuki, Dai Nippon Printing Co., Ltd. (Japan); T. Shimomura, DNP Corp. USA (United States); T. Abe, T. Ogase, S. Kawashima, T. Takigawa, H. Mohri, N. Hayashi, Dai Nippon Printing Co., Ltd. (Japan)

MASK BUSINESS

- 7823 1X **Mask shop automation: station controllers for photomask manufacturing** [7823-50]
D. Lager, V. Nadamuni, Intel Corp. (United States)
- 7823 1Y **Defect reduction through Lean methodology** [7823-51]
K. Purdy, L. Kindt, J. Densmore, C. Benson, N. Zhou, J. Leonard, C. Whiteside, R. Nolan, D. Shanks, IBM Corp. (United States)
- 7823 1Z **How to match without copying: an approach for APSM mask process matching using aerial imaging** [7823-52]
M. Sczyrba, Advanced Mask Technology Ctr. GmbH Co. KG (Germany); C. Romeo, Numonyx (Italy); F. Schurack, Advanced Mask Technology Ctr. GmbH Co. KG (Germany); T. Castro, Numonyx (United States); B. Connolly, Toppan Photomasks, Inc. (Germany)

Part Two

MASK REPAIR

- 7823 20 **Advanced laser mask repair in the current wafer foundry environment** [7823-53]
T. Robinson, D. Yi, J. LeClaire, R. White, R. Bozak, M. Archuleta, RAVE LLC (United States)
- 7823 21 **Impact of new MoSi mask compositions on processing and repair** [7823-54]
A. Garetto, Carl Zeiss SMT Inc. (United States); J. Stuckey, D. Butler, MP Mask Technology Ctr. LLC (United States)
- 7823 22 **Prospect of EUV mask repair technology using e-beam tool** [7823-55]
S. Kanamitsu, T. Hirano, Toshiba Corp. (Japan); O. Suga, Semiconductor Leading Edge Technologies, Inc. (Japan)
- 7823 23 **Study of EUV mask defect repair using FIB method** [7823-56]
T. Amano, N. Takagi, H. Shigemura, T. Terasawa, O. Suga, MIRAI-Semiconductor Leading Edge Technologies, Inc. (Japan); K. Shiina, F. Aramaki, A. Yasaka, SII NanoTechnology Inc. (Japan); Y. Inazuki, N. Hayashi, Dai Nippon Printing Co., Ltd. (Japan)

MASK CLEANING

- 7823 24 **Study and improvement approach to 193-nm radiation damage of attenuated phase-shift mask** [7823-57]
Y. Sakamoto, T. Hirose, H. Tsukuda, T. Yamazaki, Y. Kojima, H. Ida, T. Haraguchi, T. Tanaka, Toppan Printing Co., Ltd. (Japan); R. Koitabashi, Y. Inazuki, H. Yoshikawa, Shin-Etsu Chemical Co., Ltd. (Japan)
- 7823 25 **Fundamental study of droplet spray characteristics in photomask cleaning for advanced lithography** [7823-58]
C. L. Lu, C. H. Yu, W. H. Liu, L. Hsu, A. Chin, S. C. Lee, A. Yen, Taiwan Semiconductor Manufacturing Co. Ltd. (Taiwan); G. Lee, HamaTech APE GmbH & Co. KG (Taiwan); P. Dress, HamaTech APE GmbH & Co. KG (Germany); S. Singh, U. Dietze, HamaTech APE USA, Inc. (United States)
- 7823 26 **Qualification of BitClean technology in photomask production** [7823-59]
T. Robinson, R. White, R. Bozak, M. Archuleta, D. Brinkley, D. Yi, RAVE LLC (United States)
- 7823 27 **Evaluation of the contamination removal capability and multilayer degradation in various cleaning methods** [7823-60]
N. Takagi, T. Anazawa, I. Nishiyama, O. Suga, MIRAI-Semiconductor Leading Edge Technologies, Inc. (Japan)
- 7823 28 **Study of the airborne SO₂ and NH₃ contamination on Cr, MoSi, and quartz surfaces of photomasks** [7823-61]
H. Fontaine, G. Demenet, V. Enyedi, S. Cetre, CEA-LETI MINATEC (France)

INSPECTION I

- 7823 2B **Native pattern defect inspection of EUV mask using advanced electron beam inspection system** [7823-64]
T. Shimomura, DNP Corp. USA (United States); Y. Inazuki, T. Abe, T. Takikawa, H. Mohri, N. Hayashi, Dai Nippon Printing Co., Ltd. (Japan); F. Wang, L. Ma, Y. Zhao, C. Kuan, H. Xiao, J. Jau, Hermes-Microvision, Inc. (United States)
- 7823 2C **Development of EB inspection system EBeyeM for EUV mask** [7823-65]
T. Hirano, S. Yamaguchi, M. Naka, M. Itoh, M. Kadowaki, T. Koike, Y. Yamazaki, Toshiba Corp. (Japan); K. Terao, M. Hatakeyama, H. Sobukawa, T. Murakami, K. Tsukamoto, T. Hayashi, K. Watanabe, N. Kimura, Ebara Corp. (Japan); N. Hayashi, Dai Nippon Printing Co., Ltd. (Japan)

INSPECTION II

- 7823 2D **Study of shape evaluation for mask and silicon using large field of view** [7823-66]
R. Matsuoka, H. Mito, Hitachi High-Technologies Corp. (Japan); S. Shinoda, Y. Toyoda, Hitachi Ltd. (Japan)
- 7823 2F **Inspection of advanced computational lithography logic reticles using a 193-nm inspection system** [7823-68]
C.-F. Yu, M.-C. Lin, M.-T. Lai, L. T. H. Hsu, A. Chin, S. C. Lee, A. Yen, Taiwan Semiconductor Manufacturing Co. Ltd. (Taiwan); J. Wang, E. Chen, D. Wu, KLA-Tencor Corp. Taiwan (Taiwan); W. H. Broadbent, W. Huang, Z. Zhu, KLA-Tencor Corp. (United States)
- 7823 2G **Lithographic plane review (LPR) for sub-32nm mask defect disposition** [7823-70]
V. Tolani, D. Peng, L. He, G. Hwa, H.-M. Chang, G. Dai, N. Corcoran, T. Dam, L. Pang, Luminescent Technologies, Inc. (United States); L. C. Tuo, C. J. Chen, R. Lai, Taiwan Semiconductor Manufacturing Co. Ltd. (Taiwan)
- 7823 2H **Computational lithography and inspection (CLI) and its applications in mask inspection, metrology, review, and repair** [7823-71]
L. Pang, D. Peng, L. He, D. Chen, V. Tolani, Luminescent Technologies, Inc. (United States)

METROLOGY I

- 7823 2I **Detecting measurement outliers: remeasure efficiently** [7823-72]
A. Ullrich, Advanced Mask Technology Ctr. GmbH Co. KG (Germany)
- 7823 2J **Advanced mask CD MTT correction technique through improvement of CD measurement repeatability of CD SEM** [7823-73]
C. H. Ryu, H. Y. Jung, J. Y. Jun, T. J. Ha, C. R. Kim, O. Han, Hynix Semiconductor Inc. (Korea, Republic of)
- 7823 2K **Improving registration measurement capability by defining a 2D grid standard using multiple registration measurement tools** [7823-74]
O. Loeffler, G. Antesberger, A. Ullrich, J. Richter, A. Wiswesser, Advanced Mask Technology Ctr. GmbH Co. KG (Germany); M. Higuchi, T. Kamibayashi, Toppan Printing Co., Ltd. (Japan); F. Laske, D. Adam, M. Ferber, K.-D. Roeth, KLA-Tencor MIE GmbH (Germany)

- 7823 2L **CD inspection by Nuflare NPI 6000 tool** [7823-75]
J. Richter, C. Utzny, J. Heumann, Advanced Mask Technology Ctr. GmbH Co. KG (Germany); S. Tamamushi, N. Takamatsu, NuFlare Technology, Inc. (Japan)
- 7823 2M **In-Die registration metrology: design data preparation solution** [7823-76]
F. Laske, L. Ho, M. Ferber, K.-D. Roeth, D. Adam, KLA-Tencor MIE GmbH (Germany); S. Kim, S. Chou, Synopsys, Inc. (United States)

METROLOGY II

- 7823 2N **Improving registration metrology by correlation methods based on alias-free image simulation** [7823-77]
D. Seidel, Carl Zeiss SMS GmbH (Germany); M. Arnz, Carl Zeiss SMT AG (Germany); D. Beyer, Carl Zeiss SMS GmbH (Germany)
- 7823 2O **Using principal component analysis for photomask CD signature investigations** [7823-78]
G. R. Cantrell, C. Bürgel, A. Feicke, M. Sczyrba, C. Utzny, Advanced Mask Technology Ctr. GmbH Co. KG (Germany)
- 7823 2P **Performance evaluation results on 2Xnm node enabler for mask registration metrology** [7823-79]
O. Loeffler, J. Richter, A. Wiswesser, Advanced Mask Technology Ctr. GmbH Co. KG (Germany); F. Laske, D. Adam, M. Ferber, K.-D. Roeth, KLA-Tencor MIE GmbH (Germany)

HDD TECHNOLOGY DIRECTIONS

- 7823 2T **Advanced cleaning of nano-imprint lithography template in patterned media applications** [7823-81]
S. Singh, S. Chen, HamaTech USA, Inc. (United States); P. Dress, HamaTech APE GmbH & Co. KG (Germany); N. Kurataka, G. Gauzner, Seagate Technology (United States); U. Dietze, HamaTech USA, Inc. (United States)
- 7823 2U **Challenges and promises in the fabrication of bit patterned media** [7823-148]
M. T. Moneck, J.-G. Zhu, Carnegie Mellon Univ. (United States)

POSTER SESSION: MASK BLANKS

- 7823 2W **High performance photomask technology with the advanced binary film** [7823-80]
K. Murano, K. Takai, K. Ugajin, M. Suenaga, T. Motokawa, M. Saito, T. Higaki, O. Ikenaga, H. Watanabe, Toshiba Corp. (Japan)

POSTER SESSION: CLEAN

- 7823 2X **Advanced photomask cleaning for 32nm and beyond** [7823-82]
J.-M. Kim, Y.-J. An, D.-S. Lee, H.-J. Ahn, H.-J. Jung, J.-C. Lee, D.-H. Lee, S.-S. Choi, PKL Co., Ltd. (Korea, Republic of)

- 7823 2Y **Fundamentals and applications of dry CO₂ cryogenic aerosol for photomask cleaning** [7823-150]
I. Varghese, M. Balooch, C. W. Bowers, Eco-Snow Systems (United States)
- 7823 2Z **Damage/organic free ozonated DI water cleaning on EUVL Ru capping layer** [7823-153]
S. Lee, B. Kang, H. Kim, M. Kim, Hanyang Univ. (Korea, Republic of); H. Cho, C. Jeon, H. Ko, H. Lee, SAMSUNG Electronics Co., Ltd. (Korea, Republic of); J. Ahn, J.-G. Park, Hanyang Univ. (Korea, Republic of)

POSTER SESSION: EUV

- 7823 31 **Mask process correction (MPC) modeling and its application to EUV mask for electron beam mask writer EBM-7000 (First Place Best Poster Award)** [7823-84]
T. Kamikubo, T. Ohnishi, S. Hara, H. Anze, Y. Hattori, S. Tamamushi, NuFlare Technology, Inc. (Japan); S. Bai, J.-S. Wang, R. Howell, G. Chen, J. Li, J. Tao, J. Wiley, Brion Technologies, Inc. (United States); T. Kurosawa, Y. Saito, T. Takigawa, Brion Technologies KK (Japan)

POSTER SESSION: INSPECTION

- 7823 34 **An analysis of correlation between scanning direction and defect detection at ultra high resolution** [7823-69]
K. Lim, SAMSUNG Electronics Co., Ltd. (Korea, Republic of); S. Choi, Sungkyunkwan Univ. (Korea, Republic of); W. Cho, D. H. Chung, C.-U. Jeon, H. Cho, SAMSUNG Electronics Co., Ltd. (Korea, Republic of)
- 7823 38 **28N foundry reticle real challenges and solutions for IC fabs** [7823-90]
M. Yeh, D. Wu, KLA-Tencor Corp. (Taiwan); B. Mu, B. Reese, KLA-Tencor Corp. (United States)
- 7823 39 **Study of EUV mask inspection technique using DUV light source for hp22nm and beyond** [7823-91]
R. Hirano, N. Kikuri, H. Hashimoto, K. Takahara, M. Hirono, NuFlare Technology, Inc. (Japan); H. Shigemura, Semiconductor Leading Edge Technologies, Inc. (Japan)

POSTER SESSION: MASK DATA PREPARATION

- 7823 3C **Study of data I/O performance on distributed disk system in mask data preparation** [7823-94]
S. Ohara, Nippon Control System Corp. (United States); H. Odaira, T. Chikanaga, M. Hamaji, Y. Yoshioka, Nippon Control System Corp. (Japan)
- 7823 3D **Proximity effect correction concerning forward scattering** [7823-95]
D. Tsunoda, M. Shoji, H. Tsunoe, Nippon Control System Corp. (Japan)
- 7823 3E **An optimized OPC and MDP flow for reducing mask write time and mask cost** [7823-96]
E. Yang, C. H. Li, S. J. Park, Semiconductor Manufacturing International Corp. (China); Y. Zhu, Mentor Graphics Corp. (China); E. Guo, Semiconductor Manufacturing International Corp. (China)

POSTER SESSION: METROLOGY

- 7823 3H **A new CDSEM metrology method for thin film hardmask patterns using multiple detectors (Third Place Best Poster Award)** [7823-99]
S. Harada, Y. Chihara, M. Hirano, T. Iwai, M. Kuribara, I. Iko, M. Seyama, J. Matsumoto, T. Nakamura, Advantest Corp. (Japan)
- 7823 3J **Optimized reticle alignment structures for minimizing aberration sensitivities and pattern shifts** [7823-101]
B. Moest, M. van de Kerkhof, H. Kok, ASML Netherlands B.V. (Netherlands)

POSTER SESSION: NIL

- 7823 3L **Duplicated templates for discrete track media** [7823-103]
A. Tatsugawa, N. Yamashita, T. Oomatsu, K. Saitou, T. Katou, T. Ishioka, K. Usuki, FUJIFILM Corp. (Japan)

POSTER SESSION: OPTICAL PROXIMITY CORRECTION

- 7823 3M **Optimize the OPC control recipe with cost function** [7823-104]
Q. Liu, Semiconductor Manufacturing International Corp. (China); L. Zhang, Mentor Graphics Corp. (China)
- 7823 3N **OPC recipe optimization using simulated annealing** [7823-105]
T. Desouky, Mentor Graphics (Egypt)
- 7823 3P **NP-completeness result for positive line-by-fill SADP process** [7823-107]
Q. Li, Mentor Graphics Corp. (United States)
- 7823 3Q **A full chip MB-SRAF placement using the SRAF guidance map** [7823-108]
M.-C. Tsai, ASML Brion Technologies (United States); S. Nojima, M. Miyairi, Toshiba Corp. (Japan); T. Nishibe, ASML Brion Technologies (Japan); B.-D. Chen, H. Feng, W. Wong, Z. Zhu, Y.-W. Lu, ASML Brion Technologies (United States)
- 7823 3R **Optical proximity correction challenges with highly elliptical contacts** [7823-109]
C. Cork, Synopsys SARL (France); L. Barnes, Y. Ping, X. Li, S. Jang, Synopsys, Inc. (United States)
- 7823 3T **Affordable and process window increasing full chip ILT masks** [7823-111]
G. Xiao, D. Irby, T. Cecil, D. Kim, Luminescent Technologies, Inc. (United States); S. Ohara, I. Aburatani, Nippon Control System Corp. (Japan)
- 7823 3U **Substrate aware OPC rules for edge effect in block levels** [7823-112]
D. Shao, T. C. Bailey, I. Stobert, I. Popova, C. S. Chang, IBM Corp. (United States)

- 7823 3V **Multi-layer model vs. single-layer model for N and P doped poly layers in etch bias modeling** [7823-113]
J. Li, Synopsys, Inc. (United States); E. Vidal-Russell, Micron Technology, Inc. (United States); D. Beale, Beale Innovations, Inc. (United States); C. Wang, L. S. Melvin III, Synopsys, Inc. (United States)
- 7823 3X **Simultaneous source-mask optimization: a numerical combining method** [7823-115]
T. Mülders, Synopsys GmbH (Germany); V. Domnenko, Synopsys, Inc. (Russian Federation); B. Küchler, T. Klimpel, H.-J. Stock, Synopsys GmbH (Germany); A. A. Poonawala, K. N. Taravade, W. A. Stanton, Synopsys, Inc. (United States)
- 7823 3Y **Optimization of double patterning split by analyzing diffractive orders in the pupil plane** [7823-149]
N. Zeggaoui, STMicroelectronics (France) and CNRS-LTM (France); V. Farys, STMicroelectronics (France); Y. Trouiller, CEA-LETI MINATEC (France); E. Yesilada, F. Robert, STMicroelectronics (France); M. Besacier, CNRS-LTM (France)

POSTER SESSION: PATTERNING

- 7823 40 **EUV mask defect mitigation through pattern placement (Second Place Best Poster Award)** [7823-120]
J. Burns, M. Abbas, Synopsys, Inc. (United States)

POSTER SESSION: SIMULATION

- 7823 41 **Integrated mask and optics simulations for mask corner rounding effect in OPC modeling** [7823-122]
J. Xue, Z. Deng, Synopsys, Inc. (United States); K. Koo, Synopsys Korea Inc. (Korea, Republic of); J. Shiely, Synopsys, Inc. (United States); S. Lee, Synopsys Korea Inc. (Korea, Republic of); Y. Zhang, Y. Fan, Synopsys, Inc. (United States); T. Schmoeller, Synopsys GmbH (Germany)

Author Index

Conference Committee

Conference Chair

M. Warren Montgomery, CNSE/SEMATECH (United States)

Conference Cochair

Wilhelm Maurer, Infineon Technologies AG (Germany)

Program Committee

Ki-Ho Baik, ASML Netherlands B.V. (Netherlands)
Ronald R. Bozak, RAVE LLC (United States)
William H. Broadbent, KLA-Tencor Corporation (United States)
David Y. Chan, SEMATECH North (United States)
Han-Ku Cho, SAMSUNG Electronics Company, Ltd. (Korea, Republic of)
Roxann L. Engelstad, University of Wisconsin-Madison (United States)
Emily E. Gallagher, IBM Corporation (United States)
Rik M. Jonckheere, IMEC (Belgium)
Chin-Hsiang John Lin, Taiwan Semiconductor Manufacturing Company Ltd. (Taiwan)
Thomas H. Newman, Micronic Laser Systems Inc. (United States)
Hiroshi Nozue, NuFlare Technology, Inc. (Japan)
James E. Potzick, National Institute of Standards and Technology (United States)
Frank M. Schellenberg, Consultant (United States)
Thomas Scheruebl, Carl Zeiss SMS GmbH (Germany)
Robert J. Socha, ASML US, Inc. (United States)
Anna Tchikoulaeva, GLOBALFOUNDRIES Dresden Module Two, GmbH & Company KG (Germany)

Session Chairs

- 1 Invited Session
M. Warren Montgomery, CNSE/SEMATECH (United States)
Wilhelm Maurer, Infineon Technologies AG (Germany)
- 2 Pattern Generation
Hiroshi Nozue, NuFlare Technology, Inc. (Japan)
M. Warren Montgomery, CNSE/SEMATECH (United States)
- 3 Mask Process
Emmanuel Rausa, Plasma-Therm LLC (United States)
M. Warren Montgomery, CNSE/SEMATECH (United States)

- 4 Mask Materials
Mark T. Jee, HOYA Corporation USA (United States)
Thomas B. Faure, IBM Corporation (United States)
- 5 NIL
Naoya Hayashi, Dai Nippon Printing Company, Ltd. (Japan)
Douglas J. Resnick, Molecular Imprints, Inc. (United States)
- 6 Mask Data Preparation
Thomas H. Newman, Micronic Laser Systems Inc. (United States)
Wilhelm Maurer, Infineon Technologies AG (Germany)
- 7 Simulation
Ki-Ho Baik, ASML Netherlands B.V. (Netherlands)
Banqiu Wu, Applied Materials, Inc. (United States)
- 8 Optical Proximity Correction
Robert J. Socha, ASML US, Inc. (United States)
Steffen F. Schulze, Mentor Graphics Corporation (United States)
- 9A Overview Session
Brian J. Grenon, Grenon Consulting, Inc. (United States)
Wolf Staud, Applied Materials, Inc. (United States)
- 9B Use Models and Special Applications Needed I
Wolf Staud, Applied Materials, Inc. (United States)
Brian J. Grenon, Grenon Consulting, Inc. (United States)
- 9C Use Models and Special Applications Needed II
Wolf Staud, Applied Materials, Inc. (United States)
Brian J. Grenon, Grenon Consulting, Inc. (United States)
- 9D Tool Suppliers
Brian J. Grenon, Grenon Consulting, Inc. (United States)
Wolf Staud, Applied Materials, Inc. (United States)
- 10 EUV I
Emily E. Gallagher, IBM Corporation (United States)
Frank E. Abboud, Intel Corporation (United States)
- 11 EUV II
Chan-Uk Jeon, SAMSUNG Electronics Company, Ltd. (Korea, Republic of)
Paul W. Ackmann, GLOBALFOUNDRIES Inc. (United States)

- 12 Mask Business
Wilhelm Maurer, Infineon Technologies AG (Germany)
Artur P. Balasinski, Cypress Semiconductor Corporation (United States)
- 13 Mask Repair
Ronald R. Bozak, RAVE LLC (United States)
Peter D. Buck, Toppan Photomasks, Inc. (United States)
- 14 Mask Cleaning
Anna Tchikoulaeva, GLOBALFOUNDRIES Dresden Module Two, GmbH
& Company KG (Germany)
Ronald R. Bozak, RAVE LLC (United States)
- 15 Inspection I
William H. Broadbent, KLA-Tencor Corporation (United States)
Emily E. Gallagher, IBM Corporation (United States)
- 16 Inspection II
James E. Potzick, National Institute of Standards and Technology
(United States)
Larry S. Zurbrick, Agilent Technologies, Inc. (United States)
- 17 Metrology I
John M. Whittey, KLA-Tencor Corporation (United States)
David Y. Chan, SEMATECH North (United States)
- 18 Metrology II
Thomas Scheruebl, Carl Zeiss SMS GmbH (Germany)
Uwe F. W. Behringer, UBC Microelectronics (Germany)
- 19 HDD Technology Directions
Peter R. Goglia, Xyratex International Inc. (United States)
Kong Son, Xyratex International Inc. (United States)

e-beam induced EUV photomask repair – a perfect match

M. Waiblinger^a, K. Kornilov^b, T. Hofmann^b, K. Edinger^b

^aCarl Zeiss SMS GmbH - Carl-Zeiss-Promenade 10, 07745 Jena, Germany

^bCarl Zeiss SMS (NaWoTec GmbH) Industriestr. 1, D-64380 Rossdorf, Germany

1. ABSTRACT

Due to the updated ITRS roadmap EUV might enter the market as a productive solution for the 32 nm node¹. Since the EUV-photomask is used as mirror and no longer as transmissive device the severity of different defect types has changed significantly. Furthermore the EUV-photomask material stack is much more complex than the conventional 193nm photomask materials which expand the field of critical defect types even further. In this paper we will show, that “classical” 193 mask repair processes cannot be applied to EUV material. We will show the performance of a new repair process based on the novel ebeam repair tool MeRiT[®] HR 32. Furthermore this process will be applied on real EUV mask defects and the success of these repairs confirmed by wafer prints.

2. KEYWORDS

MeRiT MG 45, MeRiT HR 32, mask repair, defect repair, absorber defect, multilayer defect, electron beam repair, spontaneous etching, passivation

3. INTRODUCTION

The cost involved in the production of photolithographic masks makes up an increasingly larger portion of the semiconductor industry as the technology node decreases. EUV has been discussed to be key for next-generation production techniques for several years. Issues like the EUV source, EUV resists and mask-defects have kept engineers and researchers busy for some time now. Remarkable progress was achieved for the EUV sources, whereas defect free masks are still a major challenge. It can be expected, that the first EUV pilot lines will go online 2-3 years from now.

From a mask maker point of view mask defects are not a new topic but the requirements for EUV are much different than for 193 nm mask types. Since the EUV-photomask is used as a mirror and no longer as a transmission device the severity of different defect types has changed significantly. Furthermore the EUV-photomask material stack is much more complex than the conventional 193nm photomask materials which expand the field of defect types even further. For the transition phase from 193 nm to EUV it is extremely helpful to have a defect repair tool which can be used for the classical 193 nm and EUV technology.

Over the last years photomask defect repair by focused electron beam induced processing using the Zeiss MeRiT[®] MG 45 tool has become standard in practically all high end mask manufacturing processes. This technology employs a high resolution electron beam to induce a local chemical reaction on the mask surface. A suitable precursor gas is dispensed through a nozzle in close vicinity to the incident beam (Figure 1). Depending on the precursor chemistry, a reaction is induced by the electrons, leading to either a deposition caused by fragmentation of precursor molecules or to a reaction between the adsorbed molecules and the substrate material, resulting in volatile products and thus etching of the substrate material. The reaction is confined to the area exposed by the electron beam, so this technique allows high resolution nanostructuring.

The MeRiT[®] electron beam mask repair tool provides many benefits over other mask repair techniques. These benefits have been addressed in previous papers and include the lack of irradiation damage that arises with FIB based tools, including physical sputtering and ion implantation, as well as the ability to perform

repairs without creating debris, as is the case with AFM based repair techniques^{2,3,4}. The MeRiT[®] ebeam repair tool is the only repair tool that can perform both clear and opaque repair on a wide variety on masks⁵.

Figure 1: Basic principle for photomask repair: First the precursor molecules are adsorbed on the mask. The exposure with a focused electron beam can either start a reaction which immobilize the precursor (deposition) or reacts with the substrate to a volatile product (etching)

For the upcoming technology nodes the required accuracy for an ebeam based mask repair tool is quite high. Furthermore it can be expected that new mask materials will enter the market which might require new processes and new chemistry. To serve these needs a new tool has been developed called MeRiT[®] HR 32 (Figure 2). The MeRiT[®] HR 32 is a completely redesigned tool. Due to the reduced mechanical and electronic noise, reduced drift and a small beam diameter the tool can perform high resolution repairs. The new developed precursor management allows handling “exotic” materials and enables even very complex sequences.

Figure 2: To enable mask repair for the upcoming nodes a new ebeam based mask repair tool was developed called MeRiT[®] HR 32

4. Experimental

E-beam based mask repair is well established in any state of the art mask making technology for 193 nm photomasks. The first obvious test to apply 193 nm etches process on EUV material was not successful (figure 3). Once the absorber material is etched parasitic degradation is induced. This process continued over hours until the pattern fidelity is no longer sufficient.

Figure 3: Basic 193 nm etch technology applied on EUV material shows strong and uncontrolled degradation of the absorber material

Investigation with a tilted SEM showed, that the absorber dissolves between the capping layer and the anti reflective layer forming a cavity as depicted in figure 4. It is obvious, that this kind of repair technology cannot be used for any productive process.

Figure 4: Basically all EUV absorber materials show parasitic degradation if etched with established etch chemistry for 193 nm photomasks.

There have been attempts to suppress spontaneous etching behavior by executing a two step process. First the defect is repaired then the surface is passivated. For passivation the repaired area is flooded with a passivation precursor and exposed by the electron beam again. This technology works does not work in a production environment. The reason is that the spontaneous etching modifies the sidewall on a minute

timescale. For realistic repairs it is not unusual, that a repair takes longer than unwanted side effects need to affect the mask integrity. If the absorber degenerates faster than the repair itself it is impossible to perform a successful repair. Assuming very small and fast repairs still have the problem, that the most important area which needs passivation is the sidewall. In best case the ebeam comes parallel to the sidewall. So at the sidewall, where passivation is most critical the passivation process has the lowest efficiency. Last but not least the passivation layer can be effected by the etch process itself. In mask production it is likely that there is more than one defect on the mask. Even if a repair was performed successfully and the defect area was passivated successfully the repair of a second defect can destroy the passivation.

This is depicted in the upper part of figure 5. In this row a large contact hole was etched into the absorber and then passivated. This process was repeated 3 times at different position from left to right. It can be observed clearly, that the first contact hole has a big “aura” which is also visible in the middle contact hole. This “aura” is due to a growing cavity below the antireflective layer. This very basic experiment shows the limitation of the two step etch / passivation process.

To get to a process which is more applicable in a productive environment Carl Zeiss developed a new etch process which has no spontaneous etching. Therefore passivation with all the implications is no longer required. In the lower section of figure 5 the same etch sequence was performed with the new process. None of these etched contact holes shows an “aura”. Since the SEM image in was taken after all 6 contact holes have been etched it shows that the new process is soft enough not to damage the passivation of the first row.

Figure 5: Two etch series have been performed. The SEM image was taken after all six boxes have been etched. The upper part was etched 1 by 1 and each hole was etched than passivated from left to right. A clear degradation can be observed. On the lower part the same experiment was repeated with the new etch chemistry. No absorber degradation could be observed in the lower part.

To quantify the process the etch selectivity was derived. Therefore a series was etched into the EUV mask material where the etch time was varied in a laboratory environment. The depth of the etched area was than measured using AFM (see figure 6). It can clearly be seen, how first the antireflective layer is etched then the absorber itself before the etch speed slows down on the Ru-capping layer. To derive the etch selectivity the different slopes are fitted assuming a linear behavior. The so derived etch selectivity is better than 75:1.

Figure 6: The etch selectivity is derived from the etch speed in the different layer. The red lines are linear fits of the etch speed in the absorber layer and on the Ruthenium capping layer. The etch selectivity is better than 75:1

An example for a successful EUV mask repair is depicted in figure 7. The upper left image shows a SEM image from a mask with a particle defect embedded in a sidewall line. From a repair point of view a particle defect is much more complicate than a standard absorber defect. This mask was printed and measured again on the wafer using SEM depicted in the lower left image. It can be clearly observed that the particle defect prints on the wafer. Then the mask was repaired and measured again with SEM. This is shown in the upper right image. The defect was removed almost completely. Furthermore no damage of the capping layer is visible. This so repaired mask was again printed on wafer and measured with SEM (lower right image). The wafer print confirmed that the defect was removed successfully. Furthermore no negative impact of the surrounding of the repair area could be observed.

Figure 7: Example for a particle defect on a EUV mask. In the wafer print before repair shows that this defect is transferred to the wafer during the printing process. After repair the particle is removed and is no longer visible on the wafer print result

The second example shows a deposition⁶ (Figure 8). The upper left picture shows an SEM image of an absorber defect. This defect looks not so critical but in AFM (upper middle picture) it can be seen, that the absorber is thinned. In the lower left image you see an SEM image of the area as printed on the wafer. It shows that this defect is transferred during the printing process. Reason might be that the absorber material is too thin to absorb the EUV light sufficiently. This defect was repaired using a deposition process (upper right image). After repair the corresponding wafer print shows that this defect is no longer transferred to the wafer. Again no negative interference of the repair process can be observed in the surrounding of the repaired area can be observed.

Figure 8: Example for deposition. Where the defect is almost invisible in SEM, AFM shows that the absorber is too thin which is confirmed in the wafer print. After deposition the defect is no longer transferred to the wafer.

5. CONCLUSION

The novel MeRiT[®] HR 32 mask repair tool has been specifically developed for electron beam induced photomask repair for 32nm and below for 193nm and EUV lithography. The significantly improved tool stability together with a new gas management system allows the development of new repair processes especially for EUV masks.

It was shown, that the well established repair processes for 193 nm masks of the previous MeRiT[®] MR 45 tool generation cannot be applied to EUV mask material due to parasitic degradation. The new MeRiT[®] HR 32 allowed the development of new EUV repair process avoiding this effect. It was shown, that this process has a very broad process window. Furthermore this process can be controlled in a way that the capping layer between the absorber material and the reflective multilayer is not damaged. The ebeam based MeRiT[®] HR 32 mask repair tool enables accurate, stable and damage free repairs for 193 nm and EUV mask types, both . for the repair of clear and dark defects.

6. ACKNOWLEDGEMENT

Thanks a lot for the hard work and effort of Ted Liang, Sang Lee and Michael Leeson from Intel Corporation

7. REFERENCES

- [1] "International Technology Roadmap for Semiconductors 2009 – Litho edition", http://www.itrs.net/Links/2009ITRS/2009Chapters_2009Tables/2009_Litho.pdf

- [2] C. Ehrlich, K. Edinger, V. Boegli, and P. Kuschnerus, "Application data of the electron beam based photomask repair tool Merit MG", Proc. SPIE Vol. 5835, 145 (2005).
- [3] T. Liang, A. Stivers, M. Penn, D. Bald, and C. Sethi, "Demonstration of damage-free mask repair using electron beam-induced processes", Proc. SPIE Vol. 5446, 291 (2004).
- [4] A. Garetto, C. Baur, J. Oster, M. Waiblinger, and K. Edinger, "Advanced process capabilities for electron beam based photomask repair in a production environment", Proc. SPIE Vol. 7122, (2008).
- [5] A. Garetto, J. Oster, M. Waiblinger, and K. Edinger, "Challenging defect repair techniques for maximizing mask repair yield", Proc. SPIE Vol., (2009).
- [6] T. Liang, G. Zhang, S. Son, R. Chen, S. Lee, M. Leeson, P. Yan, A. Ma, L. He, G.V.F. Ghadiali, B. Olson, X. Liu, C. Ma, E. Lanzendorf, B. Lieberman; "Strategy and Feasibility of Defect-free Mask Fabrication to Enable EUVL", presented on EUV Symposium 2009 (Prag)