PROCEEDINGS OF SPIE

Photomask Technology 2023

Ted Liang
Editor

2–5 October 2023
Monterey, California, United States

Sponsored by
SPIE.
BACUS
PHOTOMASK TECHNOLOGY GROUP

Co-sponsored by
EUV Tech (United States)
Photronics Inc. (United States)

Published by
SPIE

Volume 12751

Proceedings of SPIE 0277-786X, V. 12750

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

Photomask Technology 2023, edited by Ted Liang, Proc. of SPIE Vol. 12751,
1275101 · © 2023 SPIE · 0277-786X · doi: 10.1117/12.3021569

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 *Photomask Technology 2023*, edited by Ted Liang, Proc. of SPIE 12751, Seven-digit Article CID Number (DD/MM/YYYY); (DOI URL).

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

ISBN: 9781510667501
ISBN: 9781510667518 (electronic)

Published by
SPIE
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time)
SPIE.org
Copyright © 2023 Society of Photo-Optical Instrumentation Engineers (SPIE).

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 fees. To obtain permission to use and share articles in this volume, visit Copyright Clearance Center 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.

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: A unique citation identifier (CID) number is assigned to each article in the Proceedings of SPIE 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 *Conference Committee*

SESSION 1 HIGH-NA EUVL: JOINT SESSION WITH PHOTOMASK AND EUVL CONFERENCES

12751 02 **Actinic pattern mask inspection for high-NA EUV lithography (Invited Paper: BACUS Best paper 1st place)** [12751-1]

SESSION 2 MASK INSPECTION AND REPAIR

12751 03 **Actinic inspection technology enhancement for N3 node and beyond (Invited Paper)** [12751-3]

12751 04 **Photomask contamination standards for defect inspection and review applications (Invited Paper)** [12751-4]

12751 05 **Die-to-database inspections of optical patterned masks** [12751-7]

12751 06 **AFM nanomachining and clean repair of EUV TaBN advanced absorber material** [12751-8]

SESSION 3 CURVILINEAR MASK TECHNOLOGIES

12751 07 **Opportunities, challenges, and applications of native curvilinear data representation in post-tape-out flows** [12751-9]

12751 08 **Leaping into the curvy world with GPU accelerated O(p) computing** [12751-10]

12751 09 **Deep learning-based detection of mask rule check violations in curvilinear mask** [12751-12]

12751 0A **Multibeam fracture flow based on multigon format input** [12751-13]

12751 0B **Novel method for precise curved EUV mask CD characterization by adopting machine learning** [12751-14]

SESSION 4 EMERGING APPLICATIONS: AR/VR & ADVANCED PACKAGING

12751 0C **Displacement Talbot lithography process simulation analysis** [12751-18]

12751 0D **Establishing a nanoimprint lithography ecosystem** [12751-19]

SESSION 5 BLANK TECHNOLOGY

12751 0E **Actinic blank inspection for high-NA EUV lithography (Invited Paper)** [12751-20]

12751 0F **Ion beam deposition for larger form-factor EUV mask blanks (Invited Paper)** [12751-21]

12751 0G **New EUV mask blank for N3 technology node and beyond** [12751-22]

SESSION 6 SPECIAL INVITED TOPICS ON MATURE TECHNOLOGIES

12751 0H **Factors driving merchant photomask growth and shortages (Invited Paper)** [12751-27]

12751 0I **Use of advanced data modeling to introduce and extend mask tools serving mainstream application (Invited Paper)** [12751-28]

12751 0J **Providing solutions for replacement of legacy tools with advanced features (Invited Paper)** [12751-31]

12751 0K **Efficient patterning approaches for non-Manhattan layouts by using variable shaped beam systems (Invited Paper)** [12751-32]

SESSION 7 MASK PATTERNING AND DEFECTS

12751 0L **EUV reticle defectivity: next steps in the EUV scanner and beyond** [12751-34]

12751 0M **EUV mask patterning process to enable opaque SRAFs for bright field EUV mask imaging** [12751-35]

SESSION 8 EUVL EXTENSION (LOW-NA): JOINT SESSION WITH PHOTOMASK AND EUVL CONFERENCES

12751 0N **EUV APSM mask prospects and challenges (Invited Paper: BACUS Best paper 2nd place)** [12751-38]

12751 0O **Development of EUV phase shift mask metrology (Invited Paper)** [12751-40]

SESSION 9 MASK METROLOGY

12751 0P **Realizing EUV photomask defectivity qualification by actinic mask review system (Invited Paper)** [12751-43]

12751 0Q **Towards fast ptychography image reconstruction of EUV masks by deep neural networks** [12751-44]

12751 0R **Optimizing CD-SEM metrology for anamorphic high-NA EUV photomasks** [12751-45]

12751 0S **Innovative applications: extending photomask registration tool for critical dimension measurement to achieve high efficiency** [12751-47]

SESSION 10 MASK DESIGN AND CORRECTIONS

12751 0T **Curvilinear OPC mask synthesis flow (Invited Paper)** [12751-48]

12751 0U **Improvements on pattern fidelity at high curvature region of curvilinear mask with a novel method of MPC (Invited Paper: BACUS Best paper 3rd place)** [12751-49]

12751 0V **PEC-aware MPC for CD quality improvement** [12751-50]

12751 0W **Machine learning assisted effective OPC verification hotspot capture** [12751-52]

SESSION 11 MASK WRITERS

12751 0X **Multi-beam mask writer MBM-3000 for next generation EUV mask production (Invited Paper)** [12751-54]

12751 0Y **Integration of e-beam mask writer corrections in MPC applications** [12751-58]

POSTER SESSION

12751 0Z **An advanced 2D feature transmitted algorithm for mask defect detection** [12751-60]

12751 10 **Research and optimization of electronic charge phenomena on CDSEM imaging of binary photomask** [12751-61]

12751 11 **Programmable photomask for photolithography systems** [12751-62]

12751 12 **How to improve intra-field CDU of contact hole patterns in both X-Y directions with CDC technology** [12751-63]

12751 13 **Optimized test pattern selection with machine learning method** [12751-64]

12751 14 **SEM image contour extraction with deep learning method** [12751-66]

12751 15 **Rounded-corner aware OPC for convergency and lithography performance improving** [12751-67]

12751 16 **High-brightness and compact LPP EUV source for inspection system** [12751-68]

12751 17 **Quantitative study of local MEEF of 2D mask corrected by inverse lithography technology** [12751-72]

12751 18 **Identifying new absorber materials for EUV photomasks (BACUS Best poster)** [12751-73]

12751 19 **Research of mask photoresist sensitivity for local critical dimension uniformity improvement in ArF lithography** [12751-74]

12751 1A **Dense mask registration fingerprint characterization to better understand and mitigate the metrology to device offset** [12751-76]

12751 1B **A study on the imaging characteristics of phase shift mask for EUV technology with novel material** [12751-78]

12751 1C **Efficient representation of full mask density maps in advanced mask data preparation flows** [12751-79]

12751 1D **A formulation of mask optimization into QUBO model for Ising machines** [12751-81]

12751 1E **A simulation-based methodology to analyze the impact of edge-length on curvilinear mask accuracy** [12751-82]

12751 1F **A study of applying mask process correction to constant width curvilinear SRAFs** [12751-83]

12751 1G **Improving overlay performance through enhanced stage positioning accuracy** [12751-84]

12751 1H **Mask optimization approach for wafer LCDU improvement in ArF lithography** [12751-86]

12751 1I **Renewing i-line laser mask writers with reduced power consumption and increased productivity** [12751-87]

Conference Committee

Conference Chair

Ted Liang, Intel Corporation (United States)

Conference Co-chair

Seong-Sue Kim, Seoul National University (Korea, Republic of)

Conference Program Committee

Frank E. Abboud, Intel Corporation (United States)
Uwe F.W. Behringer, UBC Microelectronics (Germany)
Ingo Bork, Siemens EDA (United States)
Brian Cha, Entegris, Inc. (United States)
Jin Choi, SAMSUNG Electronics Co., Ltd. (Korea, Republic of)
Aki Fujimura, D2S, Inc. (United States)
Emily E. Gallagher, imec (Belgium)
Arosha W. Goonesekera, Lasertec USA, Inc. (United States)
Naoya Hayashi, Dai Nippon Printing Co., Ltd. (Japan)
Henry H. Kamberian, Photronics, Inc. (United States)
Bryan S. Kasprowicz, HOYA Corporation (United States)
Byung Gook Kim, ESOL, Inc. (Korea, Republic of)
Romain Lallement, IBM Thomas J. Watson Research Center (United States)
Lawrence S. Melvin III, Synopsys, Inc. (United States)
Nihar Mohanty, Meta (United States)
Kent H. Nakagawa, Toppan Photomasks, Inc. (United States)
Dong-Seok Nam, ASML (United States)
Takahiro Onoue, HOYA Corporation (Japan)
Danping Peng, TSMC North America (United States)
Jed H. Rankin, IBM Corporation (United States)
Douglas J. Resnick, Canon Nanotechnologies, Inc. (United States)
Thomas Franz Karl Scheruebl, Carl Zeiss SMS Ltd. (Israel)
Ray Shi, KLA Corporation (United States)
JaeSik Son, SK Hynix System IC Inc. (Korea, Republic of)
Claire van Lare, ASML Netherlands B.V. (Netherlands)
Yongan Xu, Applied Materials, Inc. (United States)
Kei Yamamoto, FUJIFILM Corporation (Japan)
Seung-Hune Yang, SAMSUNG Electronics Co., Ltd. (Korea, Republic of)
Shusuke Yoshitake, NuFlare Technology, Inc. (Japan)
Larry S. Zurbrick, Keysight Technologies, Inc. (United States)