2009 International Workshop On EUV Lithography

July 13-17, 2009

Sheraton Waikiki Beach ▪ Honolulu, Hawaii

Abstract Book

EUV Litho, Inc.

Contents

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EUV Litho, Inc.

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Welcome

Dear Colleagues;

Welcome to the 2009 International Workshop on EUV Lithography in Oahu, Hawaii. Leading researchers from around the world will present the results of their R&D to address the remaining technical challenges of EUVL to allow its insertion in high volume computer chip manufacturing. We look forward to a productive interaction among colleagues to brainstorm technical solutions.

This workshop has been made possible by the support of workshop sponsors, steering committee members, workshop support staff, session chairs and presenters. I would like to thank them for their contributions and making this workshop a success.

Best Regards

Vivek Bakshi
Organizing Chair, 2009 International Workshop on EUVL

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2009 International Workshop on EUV Lithography
Sheraton Waikiki Beach, Honolulu, Hawaii, USA
July 13-17, 2009

Workshop Agenda

(A) Lithography Education Series (July 13-14, 2009)

EUV Lithography
Kona Room, 8:00 AM -5:00 PM, Monday, July 13, 2009

Resist Materials for High Resolution Patterning
Kona Room, 6:00 PM-10:00 PM, Monday, July 13, 2009

EUV Physics
Kona Room, 8:00 AM – 12:00 PM, Tuesday, July 14, 2009

Introduction to Lithography
Kona Room, 1:00 PM – 5:00PM, Tuesday, July 14, 2009

(B) EUVL Workshop (July 14-17, 2009)

Tuesday, July 14, 2009

4:00 PM- 6:00 PM	Registration & Speaker Prep (Lanai Room)
5:00 PM- 7:00 PM	Reception (Helumoa Playground)

Wednesday, July 15, 2009

7:00 AM	–	8:00 AM	Continental Breakfast (Lanai Foyer)
8:00 AM	–	12:00 PM	Oral Presentations (Lanai Room)
12:00 PM	–	1:00 PM	Lunch (Honolulu Suite)
1:00 PM	–	4:30 PM	Oral Presentations (Lanai Room)
5:00 PM	–	6:30 PM	Poster Session and Reception (Honolulu Suite)
7:00 PM			Dinner (Rum Fire)

Thursday, July 16, 2009

7:00 AM	–	8:00 AM	Continental Breakfast (Lanai Foyer)
8:00 AM	–	12:00 PM	Oral Presentations and Panel Discussions (Maui Room)
12:00 PM	–	1:00 PM	Lunch (Honolulu Suite)
1:00 PM	–	4:00 PM	Oral Presentations (Maui Room)
4:00 PM			Adjourn

Friday, July 17, 2009

8:30 AM	–	10:30 AM	Breakfast and Steering Committee Meeting (Honolulu Suite)

2009 International Workshop on EUV Lithography
Sheraton Waikiki Beach, Honolulu, Hawaii, USA
July 13-17, 2009

Workshop Agenda

Monday, July 13, 2009

Lithography Education Series

EUV Lithography
by Vivek Bakshi (EUV Litho, Inc.), Patrick Naulleau (LBNL) and Jinho Ahn (Hanyang University)
Kona Room, 8:00 AM -5:00 PM, Monday, July 13, 2009

Resist Materials for High Resolution Patterning
by Cliff Henderson (Georgia Tech University)
Kona Room, 6:00 PM-10:00 PM, Monday, July 13, 2009

Tuesday, July 14, 2009

Lithography Education Series

EUV Physics
by David Attwood (LBNL)
Kona Room, 8:00 AM – 12:00 PM, Tuesday, July 14, 2009

Introduction to Lithography
by Chris Mack (Lithoguru.com)
Kona Room, 1:00 PM – 5:00 PM, Tuesday, July 14, 2009

Registration and Reception

4:00 PM- 6:00 PM	Registration & Speaker Prep (Lanai Room)
5:00 PM- 7:00 PM	Reception (Helumoa Playground)

Wednesday, July 15, 2009

8:00 AM Welcome and Introduction
Vivek Bakshi, EUV Litho, Inc.

8:10 AM Session 1: Keynote Presentations

Session Chair: David Attwood (LBNL / UC Berkeley)

R&D Status and Key Technical and Implementation Challenges for HVM Application of EUVL (KEY-1)
Sam Sivakumar
Intel Corporation

Readiness and Challenges in EUV Mask Technology for 32nm-HP Node and Beyond (KEY-2)
Han-Ku Cho and Seong-Sue Kim
Semiconductor R&D Center, Samsung Electronics Co., LTD.

9:10 AM Session 2: EUV Source Technology

Session Co-Chairs: Ndaona Chokani (ETHZ) and Padraig Dunne (UCD)

High Brightness Next Generation EUV Lithography Light Source (SOURCE-1, Invited)
Peter CHOI [1,2], Sergey V. ZAKHAROV [2+], Raul ALIAGA-ROSSEL [1], Aldrice BAKOUBOULA [1], Otman BENALI [1,2], Philippe BOVE [1], Michèle CAU [1], Grainne DUFFY [1], Sebastian FANT [2], Blair LEBERT [2], Ouassima SARROUKH [2], Edmund WYNDHAM [3], Clement ZAEPFFEL [2], Vasily S. ZAKHAROV [2*]
[1] *NANO-UV sas, 16-18 av du Québec, SILIC 705, Villebon/Yvette 91140, France*
[2] *EPPRA sas, 16 av du Québec, SILIC 706, Villebon/Yvette 91140, France*
[3] *Pontificia Universidad Catolica de Chile, Santiago, Chile*
[+] *RRC Kurchatov Institute, Moscow, Russia*
[*] *KIAM RAS, Moscow, Russia*

Angular Distribution of the Ion Emission from a Tin-based Laser Produced Plasma Extreme Ultraviolet Source (SOURCE-2)
Oran Morris, Aodh O'Connor, Emma Sokell and Padraig Dunne
School of Physics, University College Dublin, Belfield, Dublin 4, Ireland

Molecular Dynamics Investigation on Tin (Source-7)
M. Masnavi, M. Nakajima and K. Horioka
Department of Energy Sciences, Tokyo Institute of Technology, Nagatsuta, Midori-ku, Yokohama 226-8502, Japan

Fiber Lasers for EUV Lithography (SOURCE-6, Invited)
Almantas Galvanauskas
University of Michigan, Ann Arbor, MI, USA

LPP EUV Source Development at ETHZ (SOURCE-4)
B. Rollinger, A. Giovannini, D. Bleiner, N. Chokani, and R. S. Abhari
Laboratory for Energy Conversion, ETH Zurich, Sonneggstrasse 3, 8092 Zurich, Switzerland

EUV Source Technology Status (SOURCE-5)
Vivek Bakshi
EUVL Litho, Inc., Austin, TX 78748, USA

10:50 AM **Break (15 minutes)**

11:05 AM **Session 3: EUV Optics**

Session Chair: Patrick Naulleau (LBNL)

Multilayer Optics for Next-generation EUVL Systems (OP-1, Invited)
Regina Soufli
Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

Non-rotationally Symmetric Projection Systems for EUVL *(OP-2, Invited)*
R. Hudyma
Hyperion Development LLC, 358 South Overlook Dr., San Ramon, CA 94582, USA

Technology Readiness for HVM Source Collector (OP-3)
Roland Geyl, Renaud Mercier Ythier
Sagem, Avenue de la Tour Maury, 911280 Saint Pierre du Perray FRANCE

12:00 PM **Lunch (Honolulu Suite)**

1:00 PM Session 4: METROLOGY

Session Co-Chairs: Regina Soufli (LLNL) and Charles Tario (NIST)

High Accuracy EUV Reflectometry and Scattering at the ALS (MET-8, Invited)
Eric M. Gullikson
Center for X-Ray Optics, Lawrence Berkeley National Laboratory, One Cyclotron Road, Berkeley, CA 94720

At-wavelength EUV metrology at NIST (MET-4)
C. Tarrio, S. Grantham, R. E. Vest, P-S. Shaw T. B. Lucatorto
National Institute of Standards and Technology, *100 Bureau Drive, Gaithersburg, MD*

EUV Reflectometry for Determining the Optical Properties of Photoresists and Underlayer Materials upon Irradiation at 13.5 nm (MET-7)
Grace H. Ho,[1] Fu-H. Kang,[1] Yu-H. Shih,[1] Hok-S. Fung,[2] Hwang-W. Fu,[2] Rikimaru Sakamoto,[3] Takafumi Endo,[3] Bang-C. Ho,[3] Yang-T. Huang,[4] and Bor-Y. Shew[2]
[1]*Department of Applied Chemistry, National University of Kaohsiung, Nanzih, Kaohsiung 811, Taiwan*
[2]*National Synchrotron Radiation Research Center, Hsinchu 311, Taiwan.*
[3]*Electronic Materials Research Laboratories, Nissan Chemical Industries, Ltd., Tayama 937-2792, Japan*
[4]*Department of Electronics Engineering, National Chiao Tung University, Hsinchu300, Taiwan*

ZnO Scintillator for Single-shot EUV Laser Focal Spot Imaging with sub-100 Picosecond Response Time (MET-1, Invited)
T. Shimizu[a,d], K. Yamamoi[a], E. Estacio[a], T. Nakazato[a,d], N. Sarukura[a,d],Y. Kagamitani[b], D. Ehrentraut[b], T. Fukuda[b,c],
[a] *Institute of Laser Engineering, Osaka Univ., 2-6 Yamadaoka, Suita, Osaka 565-0871, Japan*
[b] *Institute of Multidisciplinary Research for Advanced Materials, Tohoku Univ.*
[c] *WPI Advanced Institute for Materials Research Tohoku University*

Development of X-ray Tool for Critical-Dimension Metrology (MET-2)
Boris Yokhin[1 *], Alexander Krokhmal[1], Alexander Dikopoltsev[1], David Berman[1], Isaac Mazor[1], Byoung-Ho Lee[2], Dong-Chul Ihm[2] and Kwang Hoon Kim[2]
[1]*Jordan Valley Semiconductors Ltd., Ramat Gabriel Ind. Zone, Migdal Haemek, Israel, 23100*
[2]*Samsung Electronics, San#16 Banwol-dong, Hwasung-City, Gyeonggi-Do, Korea 445-701*

Development of ultra-fine structure metrology system using coherent EUV source (MET-5)

Hiroo Kinoshita[1,3], Nagata Yutaka[2,3], Tetsuo Harada[1,3], and Takeo Watanabe[1,3]
[1]*LASTI, University of Hyogo, 3-1-2, Koto, Kamigori, Ako, Hyogo, Japan 678-1205*
[2]*RIKEN Wakou*
[3] *JST CREST*

2:40 PM Break (20 Minutes)

3:00 PM Session 4: Contamination

Session Co-chairs: David Ruzic (UIUC) and Grace Ho (NUK)

An Investigation of Debris Production by Various EUV Sources (CONT-1, Invited)

D.N. Ruzic, J. Sporre, V. Surla, M.J. Neumann
Center for Plasma Material Interactions, Department of Nuclear Plasma and Radiological Engineering, University of Illinois at Urbana-Champaign, IL, USA

Modification of Ru Surfaces during Simultaneous Irradiation of Thermalized and Energetic Sn particles at Grazing Incidence (CONT-2, Invited)

V. Rigato
INFN Laboratori Nazionali di Legnaro, Italy

Predicting Optics Damage Potential from Resist Outgassing Components (CONT-3)

C. Tarrio,[1] S. B. Hill,[1] N. Faradzhev,[2] R. E. Vest,[1] R. Garg,[3] T. B. Lucatorto[1]
[1]*National Institute of Standards and Technology*
[2]*Rutgers University*
[3]*University at Albany*

Absolute Total Ion Yield and the Relative Extent of Ionic Outgassing of Photoresists and Underlayer Materials upon Irradiation at 13.5 nm (CONT-4)

Grace H. Ho, Yu-H. Shih, and Fu-H. Kang
Department of Applied Chemistry, National University of Kaohsiung, Nanzih, Kaohsiung 811, Taiwan

Mask and Optics Contamination from outgassing, in-band, and out-of-band exposures (CONT-5)
G. Denbeaux, Leonid Yankulin,Yu-Jen Fan, R. Garg, Chimaobi Mbanaso, Petros Thomas, Alin Antohe
College of Nanoscale Science and Engineering, University at Albany, NY, USA

4:30 PM BREAK (30 Minutes)

5:00 PM – 6:30 PM Poster Session and Reception

5:00 PM Session 5: Poster Session

Session Chair: Ken Goldberg (LBNL)

1-D Plasma Modeling with Radiation Transport (Source-3)
J. White, A. Cummings, P. Dunne, and G. O'Sullivan,
School of Physics, University College Dublin, Ireland

Tabletop Synchrotron for Actinic Defect Inspection of EUVL Mask (Source-9)
H. Yamada, Y. Shimura, D. Minkov, S. Narita, and K. Igarashi
Ritsumeikan University, Kusatsu, Shiga Prefecture, Japan

Resist Transmission Measurement using EUV Light (MET-3)
Takeo Watanabe, Yasuyuki Fukushima, Tetsuo Harada, and Hiroo Kinoshita
Laboratory of advanced Science and Technology for Industry, University of Hyogo, Hyogo 678-1205, Japan.

A Compact and Ultrahigh-vacuum Reflectometer for EUV Applications (MET-6)
Hwang-W. Fu,[1] Grace H. Ho,[2] Liang-J. Huang,[1] Chia-F. Chang,[1] Shang-W. Lin,[1] Shiang-W. Luo,[1] Fu-H. Kang,[2] Yuh-H. Shih,[2] Hok-S. Fung,[1] and Bor-Y. Shew[1]
[1]National Synchrotron Radiation Research Center, Hsinchu 311, Taiwan.
[2]Department of Applied Chemistry, National University of Kaohsiung, Nanzih, Kaohsiung 811, Taiwan

An Investigation of the Impact of Mask Shadowing Effect on Flare in Extreme Ultraviolet Lithography (MASK-1)
Jun-Hwan Lee, O-Hyun Kim
Department of Electronic and Electrical Engineering,
Pohang University of Science and Technology, South Korea

Development of Mask Contamination/Inspection System for EUV Lithography (MASK-2)

Sangsul Lee[1 2], Chang Young Jeong[1], Dong Geun Lee[3], Seong-Sue Kim[3], Han-Ku Cho[3], Seung-yu Rah[4], Ohyun Kim[5], Moonsuk Yi[6] and Jinho Ahn[1]
[1] Department of Materials Science and Engineering, Hanyang University
[2]Information Display Research Institute, Hanyang University
[3] Photomask Team, Memory Division, Semiconductor Business, Samsung Electronics Co., LTD
[4] Pohang Accelerator Laboratory
[5] Department of Electrical Engineering, Pohang University of Science and Technology
[6] School of Electrical and Computer Engineering, Pusan National University

Optimizing Structure of Attenuated Phase Shift Mask for Minimizing Shadowing Effect (MASK-7)

Hyun-Duck Shin[1], Chang Young Jeong[2], Sangsul Lee[2], Tae Geun Kim[2], and Jinho Ahn[2]
[1]Department of Nanoscale Semiconductor Engineering, Hanyang University, Korea
[2]Department of Material Science and Engineering, Hanyang University, Korea

Dependence of Acid Yield on Polymer Structure in EUV Chemically Amplified Resist (RESIST-5)

Hiroki Yamamoto[1], Takahiro Kozawa[1], Seiichi Tagawa[1],Takeshi Iwai[2], and Junichi Onodera[2]
[1]The Institute of Scientific and Industrial Research, Osaka University (ISIR), Japan
[2]Tokyo Ohka Kogyo Co., Ltd. (TOK), Japan

Line Width Roughness Investigation through Resist Molecular Structure in Extreme Ultra-violet Lithography (Resist-3)

Hyunsu Kim
Lithography Laboratory, Department of Applied Physics, Hanyang University, Ansan, 426-791, S. Korea

7:00 PM **Dinner (Rum Fire)**

Thursday, July 16, 2009

8:00 AM Session 7: Panel Discussion

Panel Discussion Moderator: David Attwood (LBNL)

Topic: EUVL R&D Status

Panelists:
David Attwood – USA (University of California at Berkley)
Hiroo Kinoshita –Japan (Hyogo University)
Padraig Dunne – Europe (University College, Dublin)
Grace Ho – Taiwan (National University of Kaohsiung)
Jinho Ahn – Korea (Hanyang University)

9:00 AM Session 8: EUV Mask

Session Co-Chairs: Hiroo Kinoshita (Hyogo University) and Jinho Ahn (Hanyang University)

Optimizing the Mask Structure for Extreme Ultraviolet Lithography (MASK-6, Invited)
Chang Young Jeong, Sangsul Lee, Hyun-Duck Shin, Tae Geun Kim, and Jinho Ahn
Department of Materials Science and Engineering, Hanyang University, 17 Haengdang-Dong, Seoul, 133-791, Korea

Wavelength-Specific Reflections: A Decade of EUV Mask Inspection Research (MASK-4, Invited)
Kenneth A. Goldberg[1], Iacopo Mochi[1], Sungmin Huh[2]
[1]Lawrence Berkeley National Laboratory
[2]SEMATECH

Study of Critical Dimensions of Printable Phase Defects Using an Extreme Ultraviolet microscope (MASK-3, Invited)
Hiroo Kinoshita[1, 3]Yoshito Kamaji[1, 3], Kei Takase[1, 3], Takashi Sugiyama[2], Toshiyuki Uno[2] Tetsuo Harada[1] and Takeo Watanabe[1, 3]
[1]Laboratory of Advanced Science and Technology for Industry, University of Hyogokamigori, Ako-gun, Hyogo 678-1205, Japan
[2]Asahi Glass Co., Ltd., R&D Center, Yokohama 221-8755, Japan
[3]JST, CREST, Yonban, Chiyoda, Tokyo 102-0081, Japan

Zoneplate lenses for EUV microscopy (MASK-5)

Iacopo Mochi[1], Kenneth A. Goldberg[1], Erik H. Anderson[1], Sungmin Huh[2]
[1] Lawrence Berkeley National Laboratory
[2] SEMATECH

10: 15 AM Break (15 Minutes)

10:30 AM Session 9: Panel Discussion

Panel Discussion Moderator: Vivek Bakshi (EUV Litho, Inc.)

Topic: Actinic Defect Inspection Technology for EUVL Masks

Panelists:
Hiroo Kinoshita (Hyogo University)
Debbie Gustafson (Energetiq)
Sergey Zakharov (Nano UV)
John Madey (University of Hawaii)
Hironari Yamada (Ritsumeikan University)
Vivek Bakshi (EUV Litho, Inc.)

12:00 PM – 1:00 PM Lunch

1:00 PM Session 10: EUV Resist

Session Co-Chairs: Takahiro Kozawa (Osaka University) and Chris Mack (Lithoguru.com)

Development Status and Future Prospect of Extreme Ultraviolet Resists
(Resist -9, Invited)

Takahiro Kozawa
The Institute of Scientific and Industrial Research, Osaka University (ISIR), Japan

Improvement of EUV Resist Materials (RESIST-1, Invited)

Jeongsik KIM, Jungyoul LEE, Jae-Woo LEE, Deog- Bae KIM, Jaehyun KIM
Dongjin Semichem CO., Ltd, 625-3 Yodang-Ri, Yanggam-Myun, Hwasung-Si, Gyeonggi-Do, 445-931 KOREA

Molecular Resist Materials for EUVL Lithography: What Might Be Possible and How Do We Get There? (RESIST-11, Invited)
Clifford L. Henderson[1], Richard A. Lawson[1], Laren M. Tolbert[2]
[1] *School of Chemical & Biomolecular Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0100, USA*
[2] *School of Chemistry and Biochemistry, Georgia Institute of Technology, Atlanta, GA 30332, USA*

EUV Interference Lithography (RESIST-10, Invited)
Harun H. Solak[1,2], V. Auzelyte[1], A. Langner[1], S. S. Sarkar[1], A. Weber[1], H. Pruchova[1], M. Kropf[1], C. David[1], J. Gobrecht[1]
[1] *Paul Scherrer Institut, Lab for Micro and Nanotechnology, Villigen 5232, Switzerland*
[2] *EULITHA AG, 5232 Villigen PSI, Switzerland*

EUV Interference Lithography in New SUBARU (RESIST-6)
Takeo Watanabe[1], Tae Geun Kim[1, 2], Tetsuo Harada[1], Yasuyuki Fukushima[1], and Hiroo Kinoshita[1]
[1] *Laboratory of advanced Science and Technology for Industry, University of Hyogo, Hyogo 678-1205, Japan*
[2] *Division of Advanced Materials Science and Engineering, Hanyang University, Seoul 133-791, Korea*

Monte Carlo Simulation of Chemical Intermediates in CARs (RESIST-4)
A. Saeki, T. Kozawa, and S. Tagawa
The Institute of Scientific and Industrial Research, Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

2:50 PM Break (15 minutes)

3:05 PM Session 11: LER

Session Chair: Cliff Henderson (Georgia Tech)

Stochastic Approach to Modeling Line Edge Roughness in Photolithography (Resist-8, Invited)
Chris Mack
Lithoguru.com, 1605 Watchhill Rd., Austin, TX 78703

How Will Wafer Plane Line-edge Roughness Requirements Impact Mask Specifications? (RESIST-7, Invited)

Patrick P. Naulleau and Simi A. George
Center for X-Ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA 94720

Sub-22 nm Line and Space patterning using Resist Reflow Process for Extreme Ultra-Violet Lithography (RESIST-2)

In Wook Cho, Hyunsu Kim, Jee-Hye You, Hye-Keun Oh
Lithography Laboratory, Department of Applied Physics, Hanyang University, Ansan, 426-791, S. Korea

4:00 PM WORKSHOP SUMMARY

Vivek Bakshi, EUV Litho Inc.

4:10 PM Adjourn

Friday, July 17, 2009

8:30 AM - 10:30 AM (Honolulu Suite)

8:30 AM	**Breakfast**
9:00 AM	**EUVL Workshop Steering Committee Meeting**

Abstracts

by

Technical Areas

Keynote Talk -1

R&D Status and Key Technical and Implementation Challenges for HVM Application of EUVL

S. Sivakumar
Intel Corporation

The number of options available for extending the litho roadmap beyond the 22nm node is limited. Intel has EUV lithography as a key element in its patterning roadmap and plans to insert the technology as soon as all the critical capabilities are available and affordable. However several critical infrastructure gaps and challenges remain. The current state of Intel EUV capability and accessible state of the art will be summarized including EUV mask capability, recent results on available EUV exposure tools, and current photoresist capability. Infrastructure gaps include integrated in-fab reticle storage, inspection, cleans, and repair capability and definition and agreement on how such capability will be integrated within or compatible with the available scanner platforms in a manufacturable way. The current EUV mask blank defect inspection capability roadmap does not extend below 40nm, AIMS capability does not exist, and the EUV patterned mask inspection roadmap is also not clear.

Encouraging progress has been made in EUV lithography on a number of fronts but each of the remaining infrastructure challenges will need to be recognized, funded, and addressed by the collection of EUV industrial stakeholders before a positive return on our investment is achievable.

Presenting Author

Sam Sivakumar is an Intel Fellow and Director of Lithography in Intel's Portland Technology Development Group in Oregon. He is responsible for the definition, development and deployment of Intel's next generation lithography processes.

After graduating from the University of Illinois at Urbana-Champaign, Sivakumar joined Intel in 1990 and throughout his career with the company has worked in the lithography area on photoresists, patterning equipment and process development. He has contributed to lithography development, characterization and transfer to high-volume manufacturing of every submicron process technology generation at Intel since 1990.

He has published over 25 papers on semiconductor processing and holds 20 patents on lithography and patterning with another 17 patents pending.

Keynote Talk-2

Readiness and Challenges in EUV Mask Technology for 32nm-HP Node and Beyond

Han-Ku Cho and Seong-Sue Kim

Semiconductor R&D Center, Samsung Electronics Co., LTD.,
San#16 Banwol-Dong, Hwasung-City, Gyeonggi-Do, Korea, 445-701

Recent progress in key technologies of EUV lithography takes a step forward to its commercialization in near future. It is reported that source, regarded as the number one showstopper, has come closer to the goal of pre-production tool requirement and resist has shown excellent resolution by EUV ADT. In the meantime, reduction of EUV mask blank defect density and mask infrastructure such as blank inspection tool and defect review tool still remain challenging.

The phase defect of EUV mask is the root of all the anxieties regarding blank defect and infrastructure. Substrate defect smoothing and its effect on inspection and printability are shown, where in-house programmed defect masks with phase defect are utilized. Based upon this result the strategy for blank infrastructure is discussed. The current status of EUV mask defectivity is also addressed by the patterned mask with the up-to-date blank. The application of EUV ADT to Samsung's DRAM device is finally presented for confirming the technical viability.

Presenting Author

Han-Ku Cho received the B.S.(1982) and M.S.(1984) degrees from Seoul National University in EE Department, and the Ph.D.(1995) from University of Arizona in ECE Department. He has joined at Semiconductor Business in Samsung Electronics since 1995. After 14-year experience in lithography and photomask area, currently, as a Vice President and Director, he is in charge of production, management, and technology development at Photomask Team, Semiconductor R&D Center.

Contamination -1

An Investigation of Debris Production by Various EUV Sources

D.N. Ruzic, J. Sporre, V. Surla, M.J. Neumann

University of Illinois at Urbana Champaign

As industry seeks to provide a viable extreme ultraviolet light (EUV) source for the future of lithography, it is still clear that source debris is a major concern to the cost effectiveness of these sources. The Center for Plasma Material Interactions (CPMI) at the University of Illinois at Urbana-Champaign has the capability to address these concerns with various debris diagnostics. CPMI is equipped with an energetic ion energy spectrum analyzer, an energetic neutral species analyzer, a calibrated EUV photodiode, as well as an intermediate focus diagnostic; each of these devices allows for the investigation of current debris mitigation methods, and their effects on various lithographic processes. CPMI is furthermore equipped with the capability to mimic each of the various EUV sources: discharge produced plasmas (DPP), laser produced plasmas (LPP), as well as laser assisted DPP (LADPP). With these devices, CPMI is well equipped to handle the future requirements of fuel mixture analysis and the consequent effects on debris production, EUV output, as well as industry viability analysis.

Presenting Author

Dr. David N. Ruzic is the Director of the Center for Plasma Material Interactions at the University of Illinois at Urbana-Champaign. He is a full professor in the Department of Nuclear, Plasma, and Radiological Engineering and affiliated with the Department of Electrical and Computer Engineering and the Department of Physics, having joined the faculty in 1984. His current research interests center on plasma processing for the microelectronics industry (deposition, etching, EUV lithography and particle removal) and on fusion energy research. Prof. Ruzic is a Micron Professor at Illinois and a Fellow of the American Nuclear Society and of the American Vacuum Society. He is the author of the AVS monograph, *Electric Probes for Low Temperature Plasmas*, numerous book chapters, patents, and over 100 refereed journal articles. He obtained his PhD and MS in Physics from Princeton University, and his BS degree in Physics and Applied Math from Purdue University. He really enjoys teaching and tries to blow something up during every lecture.

Contamination-2

Modification of Ru surfaces during simultaneous irradiation of thermalized and energetic Sn particles at grazing incidence

V. Rigato

INFN Laboratori Nazionali di Legnaro (Italy)

The modification of ruthenium surfaces exposed to the simultaneous irradiation of thermalized and fast Sn particles with flux ratios (Γ_{ion}/Γ_{th}) in the range $1x10^{-2}$-1.0 is investigated with the Monte Carlo codes TRIDYN and TRIM.SP. Grazing incidence angles and fast-ion energies (E_{ion}) are varied in the range 5.0°-20.0° and 300eV-30keV respectively. The physical and chemical model assumptions are discussed.

The study of the interaction of Sn with Ru at grazing incidence is crucial to understand mirrors' degradation and to tune the working parameters of both the Sn-fueled EUV sources and of the debris suppression systems used in EUV Lithography test-stands. In this study we analyze principally the evolution of sputtering yields, reflection coefficients, growth rates and depth profiles as a function of the incident fluence, to determine the essential physical parameters related to mirrors' lifetime definition. The transition from the stable Sn self-assisted deposition regime to the regime of steady Ru sputter-erosion is determined as a function of Γ_{ion}/Γ_{th}, E_{ion} and incidence angle.

Sn surface incorporation and surface swelling are also presented in the transition regime where neither the sputtering yields or the surface depth profiles are stable.
Steady state contamination establishment is reviewed. The in-band EUV reflectivity of the surfaces modified by Sn irradiation is correlated to mirror's performance and lifetime.

Presenting Author

Valentino Rigato has been working for more than 15 years at the National Institute of Nuclear Physics - National Laboratories of Legnaro (INFN-LNL, Italy), where he is responsible for interdisciplinary research projects on advanced materials preparation and characterization. He is the coordinator of the Van de Graaff AN2000 ion accelerator since 1997. In the period 2006-2008 worked in Media Lario Technologies s.r.l. (Italy) as chief scientist officer on advanced thin films and EUV reflective coatings. His experience ranges from surface characterization and ion surface interaction studies to thin films processes for the synthesis of nano-structured materials and multi-layers for mechanical, optical and X-ray applications.

Contamination-3

Predicting optics damage potential from resist outgassing components

C. Tarrio,[1] S. B. Hill,[1] N. Faradzhev,[2] R. E. Vest,[1] R. Garg,[3] T. B. Lucatorto[1]

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An effort is underway to complement the resist witness-plate test with a method to estimate the damage potential of a given resist from knowledge of the components in the resist outgas coupled with data on optics degradation in the presence of those individual outgas components. In addition to the possibility that this method could be used to screen a large number of resists preliminary to performing a witness plate test, it can also provide important information on the damage rates of specific molecules that resist manufacturers would use to tailor resist designs. We have examined the behavior of samples under EUV illumination during exposure to several common resist-outgas molecules. We find that the scaling of the damage rate with pressure is much closer to logarithmic than linear with partial pressure, making prediction of damage rates difficult in real-world circumstances. We will discuss strategies for making improved measurements and predictions of optics damage at the low partial pressures expected in a stepper environment.

Presenting Author

Dr. Tario has been at NIST since 1991 working on at-wavelength EUV metrology. He received his BS in Physics and math from Bates College in 1982 and PhD in Physics from University of Virginia in 1991.

Contamination-4

Absolute total ion yield and the relative extent of ionic outgassing of photoresists and underlayer materials upon irradiation at 13.5-nm

G. H. Ho, Yu-H. Shih, and Fu-H. Kang

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This study determines the absolute total ion yield and the relative extent of ionic outgassing from photoresists and underlayer materials upon irradiation at 13.5-nm using the double-ion (DI) chamber method and quadrupole mass spectrometry (QMS), respectively. Test samples include PMMA, the round-robin resist, and different types of underlayer materials.* Measurements were conducted at the 08A1BM - LSGM beamline of National Synchrotron Radiation Research Center. The resulting absolute total ionic yield can be correlated satisfactorily to the absorbance values of the sample. The extent of F^+ outgassing is linearly dependent on the ratio of F photoabsorption to the overall EUV photoabsorption of the sample. However, the extent of $C_nH_m^+$ outgassing shows no dependency on the hydrocarbon portion of photoabsorption. This study derives the Dill's parameter C of reactions leading to ionic outgassing by monitoring ion intensities as a function of the exposure dose using the DI chamber and QMS methods.

*The authors would like to thank Nissan Chemical Industries, Ltd. of Japan for providing samples.

Presenting author

Yu-Hsien Shih received her B.S. degree in 2007 from the Department of Applied Chemistry, National University of Kaohsiung (NUK), Taiwan, where she continues to work forward the master's degree and works on the ionic outgassing from photoresist compositions upon irradiation by extreme ultraviolet light. She'll finish her master's study in July 2009, and expects to continue the researches in the related fields.

Contamination -5

Mask and Optics Contamination from outgassing, in-band, and out-of-band exposures

G. Denbeaux, L. Yankulin, Yu-Jen Fan, R. Garg, C.Mbanaso, P, Thomas, A. Antohe

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One of the remaining challenges for the commercialization of EUV lithography is the lifetime of the Mo/Si multilayer optics and masks. The lifetime is predominantly determined by the carbon contamination on the surfaces of the optics, which is caused by residual hydrocarbons in the vacuum chamber when the optics are exposed to EUV radiation sources.

Recent results have shown an influence of the illumination wavelength on the contamination rate, with longer wavelengths in the vacuum ultraviolet range providing faster contamination than EUV radiation near 13.5 nm. This is a concern for illumination optics in exposure systems since the currently used Sn and Xe EUV plasma sources emit radiation in the vacuum ultraviolet. To help understand this effect and work toward a more complete understanding of the contamination mechanisms, an Energetiq EQ-10M xenon plasma source was equipped with a filters and a spectrometer to measure the rate of contamination on EUV optics due to illumination between 13 nm and 100 nm.

The topography of patterned masks causes larger effects of the carbon contamination than from optics. The carbon contamination on the sidewalls of the absorber causes the effective feature size to increase requiring more dose to print than would be predicted simply by the absorption of the carbon. Results will be shown of a series of EUV exposures into resist from a contaminated mask, along with comparisons to scanning electron microscope images of the mask and optical simulations of the predicted effect of the contamination on the wafer plane intensity.

Presenting Author

Professor Gregory Denbeaux's research focuses on high-resolution microscopy for lithography and magnetic materials, as well as high-resolution optical techniques. His research on magnetic materials focuses on nanometer-scale magnetism and magnetic recording. Denbeaux, who also serves as a staff scientist at the Center for X-Ray Optics at Lawrence Berkeley National Laboratory, received his bachelor's degree in physics from Wesleyan University and master's and doctorate from Duke University.

Mask-1

An Investigation of the Impact of Mask Shadowing Effect on Flare in Extreme Ultraviolet Lithography

Jun-Hwan Lee, O-Hyun Kim

Department of Electronic and Electrical Engineering,
Pohang University of Science and Technology

Extreme Ultraviolet Lithography (EUVL) is a hot candidate for 22nm line and space (L/S) pattern. One of the critical issues in EUVL is Flare, which is integrated light scattering from surface roughness in an optical system. It degrades the control of critical dimension (CD) across the exposure field. Also, it generates more CD changes as half pitch size decreases. Therefore, it is important to predict accurate flare map based on fine-grid size for Flare variation compensation.

Computationally, Flare is defined as a convolution of the flare point spread function (PSF) with the clear-field mask. Once the flare PSF is determined, flare level depends on the absorber density of clear-field mask. However, in view of shadowing effect caused by surface topography of multilayer mask and oblique illumination, the effective absorber density of clear-field mask changes from the original absorber density of clear-field. Accordingly, off-axis angle, half pitch size, azimuthal angle, and absorber thickness not only affect shadowing effect but also change flare level.

In this paper, we investigated the influence of these parameters on flare in EUVL. Flare based on an approximation model of the scaled flare PSF for POB2 of the engineering test stand has been simulated.

Mask-2

Development of Mask Contamination / Inspection System for EUV Lithography

S Lee[1 2], C. Y. Jeong[1], D.G. Lee[3], Seong-Sue Kim[3], Han-Ku Cho[3], Seung-yu Rah[4], O. Kim[5], M. Yi[6] and J. Ahn[1]

[1] Department of Materials Science and Engineering, Hanyang University
[2]Information Display Research Institute, Hanyang University
[3] Photomask Team, Memory Division, Semiconductor Business, Samsung
[4] Pohang Accelerator Laboratory
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Mask contamination is one of the critical issues for lithography process using short wavelength light source. (*e.g.*, haze in ArF lithography and carbon contamination in EUV lithography) And the actinic mask inspection is another critical issue in EUVL due to its extremely low throughput. Coherent scattering microscopy (CSM) has been proposed as an actinic inspection technique, which records the coherent diffraction pattern from the EUV mask and reconstructs its aerial image using a phase retrieval algorithm. Accelerated contamination system combined with CSM has been installed at Pohang Accelerator Laboratory for in-situ mask contamination and inspection study, which can trace the change of mask performance (CD, DOF, MEEF, HV-bias) as well as defect generation according to the EUV exposure.

In this presentation, we will report the structure of this system and the first experimental results of reconstructed aerial image of coherent diffraction pattern from the EUV mask by using synchrotron EUV beam. In addition, we will introduce the results about EUV mask contamination by combining EUV reflectivity and ellipsometry. This system is expected to play an important role in inspection technique emulating actual lithography process.

Mask -3

Study of Critical Dimensions of Printable Phase Defects Using an Extreme Ultraviolet microscope

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We constructed an extreme ultraviolet microscopy (EUVM) system for actinic mask inspection that consists of Schwarzschild optics and an X-ray zooming tube. This system was used to inspect completed extreme ultraviolet lithography (EUVL) masks and Mo/Si coated substrates on Ultra Low Expansion (ULE) glass. We also have fabricated programmed phase defects on the blanks used for inspection. The EUVM system was capable of resolving a programmed line-pit defect with a width of 40 nm and a depth of 10 nm and also that with a width of 70 nm and a depth of 2 nm. However, a 75-nm-wide, 1.5-nm-deep pit defect was not resolved. The EUVM system was also capable of resolving programmed hole-pit defects with widths ranging from 35 to 170 nm and depths ranging from 2.2 to 2.5 nm. However, 20-nm-wide, 1.5-nm-deep hole-pit defects were not resolved. These results agree with the simulation results perfectly. Thus, in this study, critical dimensions of a pit defects on mask blanks were determined to be a width of 20 nm and a depth of 2 nm.

Presenting Author

Hiroo Kinoshita received Bachelor and Master of engineering degree in Mechanical Engineering from KEIO University in 1972 and1974, respectively. After that, he worked for NTT. He had developed a X-ray Proximity Lithography, Mask inspection tool using EB and Extreme Ultraviolet Lithography. In 1995 he moved to Himeji Institute of Technology
(Now it called University of Hyogo). He received a doctor degree from KEIO university in 2004.

Mask-4

Wavelength-Specific Reflections: A Decade of EUV Mask Inspection Research

K. A. Goldberg[1], I. Mochi[1], S. Huh[2]

[1]Lawrence Berkeley National Laboratory
[2]SEMATECH

Mask inspection is essential for the success of any pattern-transfer lithography technology. Yet EUV Lithography faces such unique challenges that numerous ideas and solutions have emerged. Resonant-reflective multilayer coatings have a wavelength-specific response that dramatically affects the way that defects appear--or disappear--at various illuminating wavelengths.Ranging from basic research and demonstration experiments to commercial inspection tool prototypes, this presentation will survey the recent history of work in this area. During the past decade, many groups have dedicated their research efforts toward the inspection of EUV masks, trying different configurations and geometries, but all with similar goals. Compounding the challenges, the differences between blank and patterned mask inspection are significant enough to warrant separate approaches. From scanning beams to microscopy, dark field imaging to confocal microscopy, many techniques have been put into practice. I will review the challenges, many of the methods, and their best results.

Presenting Author

Kenneth A. Goldberg (A.B. in Physics and Applied Math; M.A. and Ph.D. in Physics, University of California, Berkeley) is a staff physicist at Lawrence Berkeley National Laboratory's Center for X-Ray Optics. He specializes in the development of technologies for EUV wavelengths, including lithography, interferometry, mask inspection, and synchrotron radiation beamlines. He has published over 100 papers on science and technology for EUV wavelengths and has 12 patents.

Mask-5

Zoneplate lenses for EUV microscopy

I. Mochi , K. A. Goldberg, E. H. Anderson
Lawrence Berkeley National Laboratory

S. Huh
SEMATECH

While EUV lithography is a leading choice for reach the next nodes in microchip fabrication, EUV light is not very easy to deal with.

We operate the Sematech Berkeley Actinic Inspection Tool (AIT), a synchrotron based zoneplate-lens microscope for EUV mask inspection. This microscope is equipped with a set of zoneplates with different magnifications and numerical apertures. Each zoneplate is an off-axis holographic lens with hundreds zones made of gold patterned on a silicon nitride membrane. The AIT achieves high contrast imaging down to 88-nm mask patterns and smaller.

Like every kind of lens, zoneplates have advantages and limitations. We will describe our insights, methods, and real-world experience operating the AIT and optimizing its performance. We will cover the detailed zoneplates design considerations, order sorting, field of view, aberration compensation and minimization techniques, illumination, and stability; image degradation from scattering and stray light generated by mask patterns. We will also present new techniques to acquire stable through-focus series.

Presenting Author

Iacopo Mochi graduated in physics at the University of Florence (Italy) and obtained a PhD degree with a thesis on the optical design of a fluorescence LIDAR for the remote sensing of the sea surface. He worked for three years at the Italian National Institute for Astrophysics (INAF) for the development of astronomical instrumentation. Iacopo Mochi is currently employed at the Lawrence Berkeley National Laboratory working as a Post-Doc at the Actinic Inspection Tool project for EUV mask inspection.

Mask-6

Optimizing the Mask Structure for Extreme Ultraviolet Lithography

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and J. Ahn

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Extreme ultra violet lithography (EUVL) using 13.5nm wavelength is expected to be the mainstream of production process for 22nm half pitch and below. Mask shadowing is a unique phenomenon caused by using of multilayer mirror-based mask with oblique incident angle of light. This results in a horizontal-vertical (HV) biasing effect and ellipticity in contact hole pattern. To meet the reflectivity requirement (< 0.5%) of the SEMI standard, the required absorber thickness should be at least 70nm. Thick absorber stack is not desirable, because it induces many practical problems such as shadowing effect and difficulties in manufacturing.

In the presentation, the technical review on mask issues will be given. And also we will suggest an optimal mask structure for EUVL to minimize mask shadowing effect without a loss of image contrast. Phase shift concept would be a possible solution to improve image contrast with thinner absorber stack. The effect of phase shift and reflectivity depending on the mask structure were studied using aerial image simulation. The influence of phase shift on the imaging property including image contrast, mask error enhancement factor (MEEF), and process window was also calculated using EM-SUITE simulation tool. In addition, the impact of mask shadowing and strategies for shadowing effect mitigation will be discussed.

Presenting Author

Jinho Ahn received his B.S. (1986) and M.S. (1988) degrees from Seoul National University, and Ph.D. (1992) degree from the University of Texas at Austin all in MSE department. He worked for NEC, Japan (1993 – 1995), and joined Hanyang University in 1995 as a professor at MSE department. He also works as a director of New Growth Engine Semiconductor Research Center of the Ministry of Commerce, Industry and Energy. Currently, he is a leader of national projects for "EUV lithography technology" and "Stepper development for displays."

Mask-7

Optimizing structure of Attenuated Phase Shift Mask for minimizing shadowing effect

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We suggest an optimal attenuated phase shift mask (att-PSM) structure for minimizing shadowing effect in EUV lithography. Shadowing effect is a critical issue caused by the unique oblique illumination optics in extreme ultraviolet (EUV) lithography. When the incident ray is parallel to the mask pattern, there is no difference between designed pattern and printed pattern. However, if the incident ray is perpendicular to the mask pattern, the printed pattern is biased. The att-PSM is an available option to minimize shadowing effect.

All the simulations were carried out with EM-Suite simulation tool to confirm the application possibility of att-PSM in 22 nm line-and-space pattern under the condition of alpha demo tool (ADT). Etching is done to trench 1~6 pairs of multilayer (ML) and then the trench is refilled Mo. And TaN pattern is placed on top of Mo area to obtain 180°±6° phase shift effect with EUV reflectivity of 5~13% and minimized shadowing effect. The optimized att-PSM consists of etched Mo/Si ML, TaN attenuator (15.5 nm), Mo phase shifter (34.5 nm) and Ru capping layer (2 nm). This att-PSM shows EUV reflectivity of 12.6% and phase shift effect of 174°. This results in a higher image contrast, a larger process window, and a lower horizontal-vertical CD bias than a binary image mask.

Mask-8

Optical Performance of Absorber Materials for Extreme Ultraviolet Lithography Masks

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In extreme ultraviolet (EUV) lithography the correct choice of the absorber materials affects the mask quality, lithographic performance, and optical inspection contrast. The requirements of EUV absorber are high EUV absorption, good CD control, high chemical stability in cleaning process, good etch selectivity to buffer layer, low defects and stress, and deposition and etching via low temperature process.

In this study we propose new absorber materials for EUV binary masks. The optical constants of ZnO, Ag doped ZnO, and ITO at 13.5-nm were calculated and measured by using Rutherford Backscattering Spectrometry and X-Ray Reflectivity. It is found that the optical constants of them show lower refractive index and higher extinction coefficient than that of TaN layer, a typical absorber material. The binary masks with ZnO, Ag doped ZnO, and ITO absorber materials of various thicknesses were fabricated and the optical performance of them was measured. The result shows that the height difference between high reflecting mirror stack and the absorbing stack can be reduced using these absorber materials, indicating that the geometric shadow effect can be significantly reduced.

Metrology -1

ZnO Scintillator for Single-shot EUV Laser Focal Spot Imaging with sub-100 Picosecond Response Time

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Next-generation lithography applications will require the development of scintillator devices as optical components capable of efficient and fast imaging. As was demonstrated recently, zinc oxide (ZnO) is a prominent candidate. In this talk, we will present our newest results on the investigation of the scintillator properties of ZnO crystal. The imaging capabilities of the ZnO scintillator is demonstrated by imaging the beam focal spot of an EUV laser emitting at 13.9 nm wavelength. The fluorescence image of the ZnO crystal was taken and compared with a high-resolution target as reference. The system's resolving power was determined to be ~5.5 μm/pixel. These results present a feasible method to perform single-shot beam diagnostics for EUV laser sources using a ZnO crystal scintillator. Additionally, the temporal response of a ZnO has been further improved by modifying the crystal growth scheme. The ultraviolet fluorescence lifetime at 380-nm has been shortened to less than 100 ps for 290 nm pulsed excitation. Using the 51-nm excitation pulse of the X-Ray Free Electron Laser prototype at the SPring-8 research facility, a response time of ~70 picoseconds was confirmed. These results suggest that the hydrothermal-method grown ZnO is currently the fastest scintillator in the 50-60 nm wavelength region.

Presenting Author

Professor Nobuhiko Sarukura received his B.S., MS, and Ph.D. degrees from the University of Tokyo. He has previously worked at NTT Corporation, the Institute of Physical and Chemical Research (RIKEN), and as Associate Professor at the Institute of Molecular Science. He was also a visiting associate professor at Tohoku University and University of Tokyo. At present, he is a professor at the Institute of Laser Engineering, Osaka University, working on vacuum ultraviolet and extreme ultraviolet light sources. Professor Sarukura has been a head editor of the Japanese Journal of Applied Physics since 2000.

Metrology-2

Development of X-ray Tool for Critical-Dimension Metrology

B. Yokhin[1 *], A. Krokhmal[1], A. Dikopoltsev[1], D. Berman[1], I. Mazor[1], Byoung-Ho Lee[2], Dong-Chul Ihm[2] and K. H. Kim[2]

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In the era of technology nodes 32 nm and below, lithography control becomes a great challenge. Extendibility of existing methods like CD-SEM and OCD for measurements of CD profiles, overlays, and lines roughness becomes more and more limited. Small Angle X-ray Scattering (SAXS) is a possible candidate to complement and, in a longer term, to replace them. Previously reported CD-SAXS results were promising; however as obtained using bulky sources as synchrotron, they are most often restricted to research rather than production control.

We have designed a pilot set-up (XCD™) around a commonly available μ-focus X-tube, high-luminosity focusing mirror-monochromator and pixilated detector, having in mind that after further optimization of the components, the tool will have a suitable footprint and acceptable throughput. The system operates on MoKα (17.4 keV) beam shining through the wafer, from below. The angular resolution allows to measure structures with a pitch 100 nm and below. A software package was developed to simulate and process XCD spectra, taking into account all the components contributing to the instrumental function of the system.

For the purpose of the feasibility study a special CD structure was prepared. It consists of Si trenches with 50 nm pitch. It was found that in a relatively short time, pitch and width can be extracted with a precision on the level 1% RSD. In the paper we will present quantitative data obtained on the pilot unit, and the projected performance of the future tool.

Presenting Author

Boris Yokhin holds an M.S. degree in nuclear physics from Leningrad University and a Ph.D. in physics from the Radium Institute, Leningrad, Russia. He is the author of more than 30 patents and over 30 published scientific papers.
He has served with Jordan Valley, Israel, since 1990, first as Senior Physicist, and starting year 2000 as Chief Technology Officer.
Prior to his tenure at Jordan Valley Semiconductor, Dr. Yokhin accrued more than 20 years of research and development experience in nuclear physics and X-ray technologies. He held the position of Senior Scientific Fellow at the Radium Institute in Leningrad, Russia.

Metrology-3

Resist transmission measurement using EUV light

T. Watanabe, Y. Fukushima, T. Harada, and H. Kinoshita

Laboratory of advanced Science and Technology for Industry, University of Hyogo

The EUV resist transmission measurement with a high accuracy using a wavelength of 13.5 nm was installed in BL10 beamline in NewSUBARU synchrotron facility. It was measured that the transmittance of the resist by the extreme ultraviolet (EUV) light, and it was evaluated that the relation between the E_0 sensitivity of the resist and transmittance of the resist under EUV exposure. The measured-transmittance value was almost same as that of a calculated value obtained by a table of Henke atomic scattering factor. Furthermore, it is confirmed that there is a correlation between the photo-absorption coefficient of the anion of PAG and the E_0 sensitivity and under the EUV exposure at wavelength of 13.5 nm. However, there is no correlation between the photo-absorption coefficient of the cation of PAG and the E_0 sensitivity. Thus, increasing of the atomic photoabsorption cross section of the anion of PAG is effective to increase the sensitivity of the chemically amplified resist in EUVL.

Metrology-4

At-wavelength EUV metrology at NIST

C. Tarrio, S. Grantham, R. E. Vest, P-S. Shaw T. B. Lucatorto

National Institute of Standards and Technology

The National Institute of Standards and Technology has been making at-wavelength measurements in support of EUVL for two decades now. We will discuss changes that have been made in our metrological capabilities over the past several years in response to an increasing number of demands from our industrial collaborators. These include improvements in the accuracy of our detector calibrations and reflectivity measurements, extensions to allow characterization of large scale optics, and the development of instrumentation to characterize spatially resolved EUV detection schemes including a novel wafer-plane dosimeter based on imaging plates that is absolute, two-dimensional, and linear in response over at least four orders of magnitude in flux.

Metrology-5

Development of ultra-fine structure metrology system using coherent EUV source

H. Kinoshita[1,3], N. Yutaka[2,3], T. Harada[1,3], and T. Watanabe[1,3]

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A new metrology system has been developed that is based on X-ray diffraction microscopy in the EUV region and is capable of measuring CD value and inspecting pattern defects with a high accuracy. The integration of a coherent EUV source employing a high-harmonic laser system and EUV scatterometric microscopy has enabled the construction of a practical system for CD measurement and the inspection pattern defects with subnanometer accuracy.

Metrology-6

A compact and ultrahigh-vacuum reflectometer for EUV applications

Hwang-W. Fu,[1,*] G. H. Ho,[2] Liang-J. Huang,[1] Chia-F. Chang,[1] Shang-W. Lin,[1] Shiang-W. Luo,[1] Fu-H. Kang,[2] Yuh-H. Shih,[2] Hok-S. Fung,[1] and Bor-Y. Shew[1]

[1]National Synchrotron Radiation Research Center, Taiwan [2]Department of Applied Chemistry, National University of Kaohsiung

A newly-built, vacuum-compatible reflectometer has been successfully operated at the National Synchrotron Radiation Research Center (NSRRC) for extreme ultraviolet and X-ray applications. This paper presents detailed information on this reflectometer, including the overall design, its mechanical precision, and a magnetic sample-holder assembly for quick sample replacement and fixed sample surface plane. Reflectivity measurements at 13.5-nm were conducted at the 08A1BM - LSGM beamline of NSRRC. The results of the measurements on bare-silicon, Sc/Mo multilayer, EUV photoresist and underlayer samples demonstrate that the EUV reflectometer is able to determine the refractive index, absorbance, and thickness properties of EUV materials with ±10% experimental uncertainty.

Presenting Author

Dr. Grace H. Ho received her B.S. degree in 1983 from the department of chemistry, National Cheng-Kung University, Taiwan and Ph. D. degree in 1990 from the department of chemistry, University of Pittsburgh, PA, USA. She was an associate scientist of National Synchrotron Radiation Research Center in 1991 – 1998, an application engineer of ASML in 1998 – 2001, and a section manager of Taiwan semiconductor manufacturing company, Ltd. in 2001- 2004. From 2004 to present, she is an associate professor of Department of Applied Chemistry, National University of Kaohsiung (NUK), and works on the EUV photochemistry of photoresist materials.

Metrology-7

EUV reflectometry for determining the optical properties of photoresists and underlayer materials upon irradiation at 13.5nm

G. H. Ho,[1] Fu-H. Kang,[1] Yu-H. Shih,[1] Hok-S. Fung,[2] Hwang-W. Fu,[2] R. Sakamoto,[3] T. Endo,[3] Bang-C. Ho,[3] Yang-T. Huang,[4] and Bor-Y. Shew[2]

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This study uses a newly-built EUV reflectometer to measure the specular reflectivity curves of EUV photoresists and underlayer materials at 13.5-nm. In addition to identifying the refractive index, absorbance, and thickness of the EUV thin-film materials, this study demonstrates that EUV reflectometry is a powerful technique to monitor the evolution of resist thickness and the refractive index of photoresists and underlayer materials upon EUV irradiation. This *in situ* and actinic technique is unique in that it can achieve what X-ray reflectivity measurement cannot: This work will show the evolution of the reflectivity curves as a function of the exposure dose for the round-robin resist and underlayer materials, and further demonstrate the usage of the technique to tract the structural integrity and thickness loss of the samples.

Presenting Author

Fu-Hsiu Kang received the Bachelor degree form the Dept. of Applied Chemistry, National University of Kaohsiung(NUK), Taiwan in 2007. Now, he is a master student of the Dept. of Applied Chemistry, NUK. He is interested in studying the optical properties of photoresist and underlayer materials upon extreme ultraviolet radiation at 13.5-nm by the EUV reflectometer method.

Metrology-8

High Accuracy EUV Reflectometry and Scattering at the ALS

E. M. Gullikson

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High accuracy EUV reflectometry is required for the metrology of the multilayer coatings of both the EUVL mask and optics. The requirements for precision and accuracy of both the wavelength and reflectance are driven by the error budget for added figure error of the optics and by the illumination uniformity budget of the mask. Accelerated lifetime testing of the coatings requires high precision measurements in order to detect small changes in reflectivity. EUV scattering can be used to provide direct quantitative measurements of the surface roughness which leads to flare in a lithographic camera or line edge roughness in the case of the mask. High accuracy measurements of the EUV optical constants of materials are made available through the CXRO web site.

Presenting Author

Eric M. Gullikson received his BS in physics from the University of Hawaii in 1977 and PhD in physics from the University of California, San Diego in 1984. After a post-doc at AT&T Bell Labs he joined the Center for X-Ray Optics at Lawrence Berkeley National Laboratory in 1987. He has worked on the development of high-accuracy reflectometry and scattering measurement techniques for EUV and soft x-ray radiation. He is author or coauthor of over 200 publications.

Optics-1

Multilayer optics for next-generation EUVL systems

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The advance of highly reflective and precise multilayer optics has enabled imaging at EUV / x-ray wavelengths at near-normal angles of incidence. This presentation will discuss basic principles and experimental results on the development of state-of-the-art multilayer optics for EUVL. Such optics need to satisfy Angstrom-scale specifications for the figure, mid- and high-spatial frequency roughness in order to meet requirements for high imaging resolution, low flare, and high reflectivity. Precision surface metrology (atomic force microscopy, optical profilometry, full-aperture interferometry), x-ray diffraction, EUV reflectance and scattering, transmission electron microscopy and other techniques are employed to optimize the substrate and multilayer film properties at each stage of development. A velocity modulation method is applied for film thickness control during multilayer deposition, resulting in sub-diffraction limited performance. Highlights will be presented from four- and two-mirror EUVL cameras including the Micro-Exposure Tool (MET), which to date remains the highest resolution EUV micro-field camera. Other examples will include EUV multilayer optics for solar physics and space weather satellites, next-generation high-NA EUVL systems, and novel approaches for EUVL collector optics.

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Presenting Author

Regina Soufli received her Ph.D. in Electrical Engineering from the University of California, Berkeley, and was staff scientist at the Harvard-Smithsonian Center for Astrophysics working for NASA’s Chandra X-ray Observatory. At Lawrence Livermore National Lab she has been principal investigator on EUV/x-ray optics programs for EUV lithography, solar physics, synchrotron and free-electron lasers, and high-energy physics. She has recently been working on x-ray optics for the Linac Coherent Light Source (LCLS), the world's first x-ray free electron laser, and on EUV multilayer optics for NASA/NOAA's space weather satellites and NASA's Solar Dynamics Observatory. Her interests are in EUV/x-ray interactions with matter, surface science, thin films, roughness and scattering. She is author of over 60 publications and a book chapter, and has received two “R&D 100” awards.

Optics-2

Non-rotationally Symmetric Projection Systems for EUVL

R. Hudyma

Hyperion Development LLC

Presenting Author

Russell M. Hudyma received his B.S. and M.S. degrees in Optics from the University of Rochester. He specializes in the field of optical design, analysis and simulation, for a wide range of applications including remote sensing, surveillance and defense systems, microlithography and semiconductor process. Over 100 of his designs have been built and implemented into commercial systems. He holds 83 US and international patents, most of which are related to optical systems for semiconductor applications. He is the co-founder and managing partner of Hyperion Development, LLC.

Optics-3

TECHNOLOGY READINESS FOR HVM SOURCE COLLECTOR

R. GEYL, R. M. Ythier

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In the frame of the European program Eagle, Sagem has investigated the advantages and drawbacks of the various potential collector designs for EUV sources. New designs have been investigated and an innovative type of collector has been designed and patented for DPP sources. This two-mirror design uses a logarithmic spiral for the primary mirror and offers very good performances. With a two-stage design, it is possible to collect 60 % of 2 Pi sr with a total efficiency in the range of 25 - 30%. Other main advantages are a good far-field uniformity, a thermal shielding of the litho tool thanks to the ML coating, a compact design and a low cost of ownership.

Manufacturability is currently under development at Sagem, with the goal to manufacture a first HVM compatible collector in 2010. Since a large power will be absorbed, Sagem has validated the implementation of cooling channels inside the mirror, in order to keep the collector at ambient temperature. Performances have been tested on prototypes, demonstrating the high potential of this solution. The feasibility of polishing of large aspheres, with a very low roughness and a very large departure from the best sphere (several mm) has been demonstrated on samples and prototypes. Lastly, first coating validations on a logarithm spiral have been performed with success.

Presenting Author

Roland GEYL holds the position of VP Sale. He graduated from Ecole Supérieure d'Optique Orsay in 1979. He has more than 25 years experience in precision optics design, manufacturing and testing in the field of high performance optics for Astronomy, Space, Laser. He is the initiator of Sagem's development in semiconductor DUV and EUV optics and more specifically leader for the EUV Collector development.

Resist-1

Improvement of EUV Resist Materials

J. KIM, J.LEE, Jae-Woo LEE, Deog- Bae KIM, J. KIM

Dongjin Semichem CO. KOREA

Extreme Ultraviolet Lithography is one of the leading technologies for fabrication of sub 32 nm next generation patterning. EUVL has many challenges to overcome in the improvement of EUV source and photomask along with the development of new resist materials. The critical issues of EUV resist are told in 3 point of views, LWR, resolution and sensitivity, which are related by trade-off triangle.

Our approaching concept to make smaller trade-off triangle is film-uniformity. We have modified resist component structures in order to interact equally in every point of resist film vertically as well as horizontally. In this paper, we will introduce our experimental approaches to improve resist performances, analytical methods and real patterning data, including polymer PAG, polymer Quencher, sequentially random polymer structures.

Resist-2

Sub-22 nm Line and Space patterning using Resist Reflow Process for Extreme Ultra-Violet Lithography

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Extreme Ultra-Violet Lithography (EUVL) has been developed and studied for sub-22nm semiconductor device. It is too difficult to get a smooth sub-22nm pattern because line edge roughness (LER) and width roughness (LWR) could not been controlled well. According to 2008 ITRS roadmap, LER has to be below 1.7 nm to get a 22 nm node for EUVL. In our previous work, resist reflow process (RRP), which bakes the resist over the glass transition temperature, is very helpful to reduce LER and LWR for EUVL. LER and LWR could be shrunken from ~ 6 nm to ~ 1 nm. As RRP time goes by, however, critical dimension could be wider because the developed resist can flow easier when the temperature is over the glass transition temperature. So another method is suggested to solve this problem. The developed resist, which is intentionally designed by a 1:3 line and space (L/S) (11 nm : 33 nm) pattern, is baked over glass transition temperature. As a result, LER and LWR can be smoothed by RRP and we could get a 22 nm 1:1 L/S pattern.

Presenting Author

In Wook Cho received B.S. degree of Department of Applied Physics from Hanyang University, South Korea in 2008. He has been doing the research about effect of LER and LWR for EUV since 2008. His work is not only LER & LWR, but also molecular resist material which is the work using variations of molecular weight and the molecular size of molecular resist for EUV.

Resist-3

Line width roughness investigation through resist molecular structure in extreme ultra-violet lithography

H. Kim

Hanyang University

A chemically amplified resist is composed of several materials such as polymer, photo acid generator (PAG), quencher, and so on. After lithography process, disposition of the materials makes the final shape of the pattern. Up to now, the conventional lithography simulation tools have not included any minute structure difference inside the resist molecules. People assumed uniform distribution of PAG, protected polymer site, and molecular structure. However, they are not uniformly distributed and are dependent on any given position and structure inside the resist. For example, the size of one molecular structure would be ~ 5 nm if five polymers having a molecular weight (M_W) of 1200 g/mol form one protected polymer for the molecular type resist. This molecular size makes a large line width roughness. Therefore, we supposed different composition of materials that could get smaller roughness at edge of the pattern. For example, a compound of large size polymer with small size that. And this line width roughness is investigated by looking at the molecular dispersion and structures including other resist parameters.

Presenting Author

Hyunsu Kim received bachelor's degree in physics in 2007 from Kyung-won Univ. Korea. Since 2008, he is a MS student in the nano-science at Hanyang University's lithography laboratory. He is studying about LER reduction technology of the photoresist in EUVL by Monte-Carlo simulation.

Resist-4

Monte Carlo Simulation of chemical intermediates in CARs

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As feature sizes shrink, line edge roughness (LER) has emerged as one of the most serious problems in the performance of transistors. Considerable efforts have been devoted to experimental and computational investigations from the viewpoints of physical and chemical properties of resist polymers, process factors, and quality of aerial images. Post-optical lithography such as an extremely ultraviolet (EUV) and an electron beam (EB) has been expected as a next generation lithographic tool in < 22 nm technical node. In chemically-amplified photoresists (CARs), photo acid generators (PAGs) are directly excited, giving rise to acids which promote acid-catalyzed reaction during post exposure bake (PEB). On the other hand, because EUV and EB have more than one order of magnitude higher energy than ionization potential of resist resin, homogeneous ionization of resist dominates the energy deposition process.

Here, in order to elucidate the origin of LER in the CARs for post-optical lithographies, we investigated the effects of proton dynamics during acid formation process and acid diffusion during PEB on the LER of latent image. The dynamics and diffusion were calculated by a Monte Carlo technique based on diffusion under Coulomb potential induced by many-body charged species. The final pattern formation after development process is also discussed.

Presenting Author

Akinori Saeki received BS and MS degrees in nuclear engineering from Osaka University in 1999 and 2001, respectively. He received Dr of engineering in applied chemistry from Osaka University in 2007. His research interest is in nanometer-scale dynamics of chemical intermediates in condensed matters such as resist, organic semiconductors, and organic liquids. He is an assistant professor at Osaka University.

Resist-5

Dependence of Acid Yield on Polymer Structure in EUV Chemically Amplified Resist

H. Yamamoto[1], T. Kozawa[1], S. Tagawa[1],
T. Iwai[2], and J. Onodera[2]

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[2]Tokyo Ohka Kogyo Co., Ltd. (TOK)

The trade-off relationships between sensitivity, resolution and line edge roughness is the most serious problems in EUV lithography. In order to overcome them, a fundamental understanding of the reactions in resist materials has become essential for the EUV resist design. In chemically amplified resists for ionizing radiation such as an electron beam (EB) and EUV, protons of acids are mainly generated through the deprotonation of polymers. In this work, the polymer structure dependence of acid yield was investigated in EUV and EB resist using an acid-sensitive dye as indicator to evaluate acid yields. These results clearly showed the dependence of acid generation efficiencies on polymer structure. Both results showed similar trend. However, the energy deposition process is different between them. The depth profile of acid concentration in EUV resist films is strongly affected by the absorption coefficient. We investigated the dependence of acid generation on polymer structure in terms of acid generation efficiency and absorption coefficient. The dependence of acid distribution on polymer structure is discussed.

Resist-6

EUV interference lithography in NewSUBARU

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In the development of EUV resist, simultaneous achievement of high sensitivity and low line-edge-roughness (LER) is strongly required. Considering the EUV resist evaluation system, since a mirror-optics for the exposure system has abberation and flare, low LER cannot be achieved by using this kind of optics. Thus EUV interference lithography (IL) which has no flare is a promising method to evaluate the sensitivity, LER, and the resolution limit of EUV lithography. The EUV-IL system for both 22 nm node and 16 nm node was constructed at the BL9 beamline in NewSUBARU synchrotron radiation facility. A world largest 11-m-long undulator was used for a light source, which can produce excellent coherence light for the EUV-IL. It is confirmed the coherence length of more than 500 □m using Young's double slit method. Futhermore, a specific configuration of the EUV-IL system and its results will be discussed.

Resist-7

How will wafer plane line-edge roughness requirements impact mask specifications?

P. Naulleau and S. A. George

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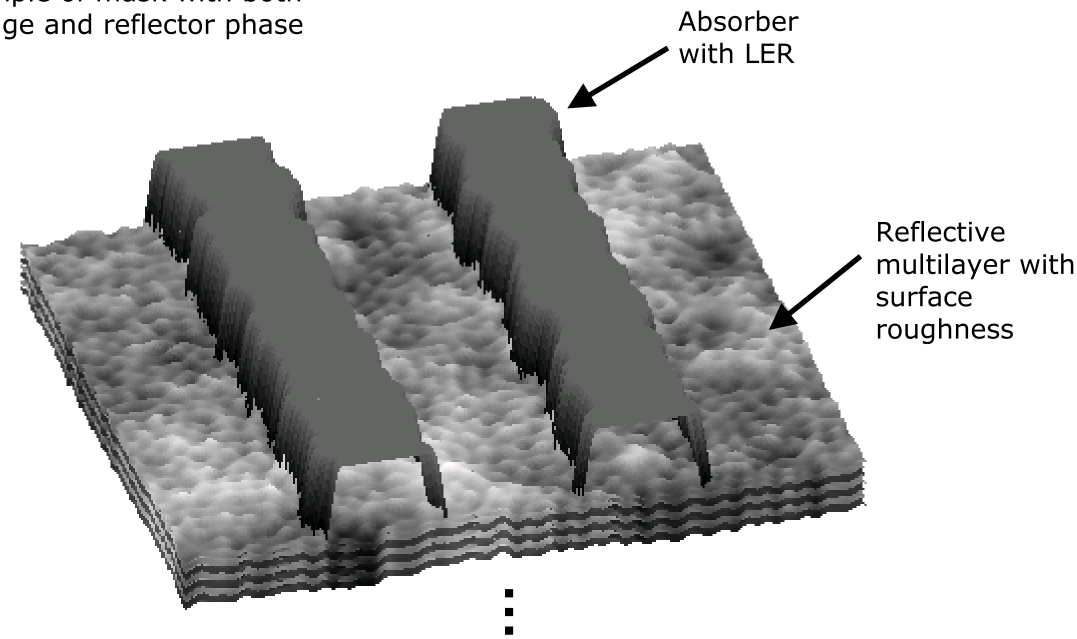
Line-edge roughness (LER) and the related effect of contact size variation remain as significant challenges facing the commercialization of extreme ultraviolet (EUV) lithography. LER is typically viewed as a resist problem; however, recent simulation results have shown that the mask can indeed be an important contributor. Problems arise from both mask absorber LER as well as mask multilayer roughness leading to random phase variations in the reflected beam (see Fig. 1). The latter effect is especially important as higher coherence off-axis illumination conditions are used and defocus is considered.

Here we describe these effects in detail and explore how they will impact EUV mask requirements for the 22-nm half-pitch node and beyond. Figure 2 shows modeling results for 22-nm lines printed in a 0.32-numerical aperture system with 100-nm defocus assuming a mask with 0.24-nm rms multilayer roughness and no absorber edge roughness (unlike the example in Fig. 1). The impact of the phase roughness on the printed line-edge roughness is clearly evident and demonstrates the basic problem with mask roughness.

Experimental results demonstrating this effect will be presented. We will also describe both rigorous and simplified modeling approaches. Finally modeling-based process-window analysis will be used to determine mask multilayer roughness specifications for the 22 and 16-nm half-pitch nodes.

Fig. 1. Example of mask with both absorber edge and reflector phase roughness



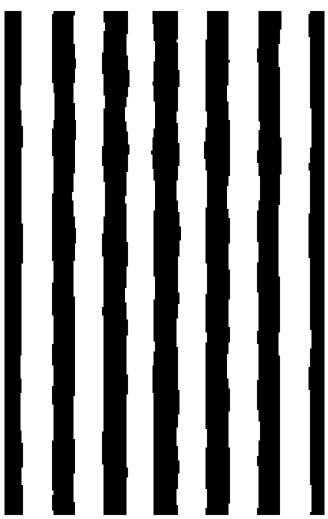


Fig. 2. Example of the effect of mask multilayer roughness on printed 22-nm lines. The modeling results assume an aberration free optic with a numerical aperture of 0.32 and a defocus of 100 nm. Moreover, the mask multilayer roughness is assumed to be 0.24 –nm rms and the absorber lines are assumed to be perfectly smooth (unlike the example in Fig. 1 which also includes absorber line edge

Presenting Author

Dr. Patrick P. Naulleau has been involved in EUV lithography since 1997 when he joined Lawrence Berkeley National Laboratory (LBNL) to work in the area of actinic interferometric alignment. Since 2001 he has lead LBNL's EUV Patterning project starting with the 0.1-NA ETS optics and now the 0.3-NA MET optic. He is internationally recognized for leading EUV patterning studies and his contributions to EUV System designs. He is the lead author of chapter on EUV Patterning in the book EUV Lithography.

Resist-8

Stochastic Approach to Modeling Line Edge Roughness in Photolithography

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In contrast to continuum modeling, a stochastic approach to modeling chemical events treats each fundamental microscopic event as a probabilistic event, typically represented by a binary random variable. By using the continuum (mean field) result as the probability function for this random variable, the properties of complex chemical reactions can be derived. In this paper, a stochastic modeling approach is used to predict the results of a reaction-diffusion system governing the exposure and post-exposure bake of a chemically amplified photoresist used in semiconductor lithography. Unlike continuum approaches, the stochastic modeling approach allows the prediction of both the mean value and the standard deviation of the resulting chemical concentrations within the resist at the end of the post-exposure bake. In this way, basic predictions can be made concerning line edge roughness based on the fundamental stochastic mechanisms at work.

In particular, the statistics of chemical concentration, photon shot noise, exposure, diffusion, amplification, and full reaction-diffusion for a chemically amplified resist are derived. The result is a prediction of the probability distribution, mean and standard deviation, of the final concentration of blocked and deblocked polymer in the resist using simple, analytical expressions. Combining this result with a prediction of the gradient of blocked polymer concentration at the resist line edge provides a function proportional to the line edge roughness of a resist feature.

Presenting Author

Chris A. Mack received Bachelor of Science degrees in physics, chemistry, electrical engineering, and chemical engineering from Rose-Hulman Institute of Technology in 1982, a Master of Science degree in electrical engineering from the University of Maryland in 1989, and a Ph.D. in chemical engineering from the University of Texas at Austin in 1998. Mr. Mack founded FINLE Technologies, the developer of the lithography simulation software PROLITH, in 1990, serving as President and Chief Technical Officer until the acquisition of FINLE by KLA-Tencor in 2000. For the next five years he served as Vice President of Lithography Technology for KLA-Tencor. In 2003 he received the SEMI Award for North America for his efforts in lithography simulation and education, and he became a fellow of SPIE in 2006. He is also an adjunct faculty member at the University of Texas at Austin and spent the Fall 2006 semester as a visiting professor at the University of Notre Dame. He has recently completed a comprehensive graduate-level textbook on optical lithography, Fundamental Principles of Optical Lithography, published in late 2007. Currently, he writes, teaches, and consults on the field of semiconductor microlithography in Austin, Texas, where he lives with his wife Susan and their daughters Sarah and Anna.

Resist-9

Development status and future prospect of extreme ultraviolet resists

T. Kozawa

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The development of extreme ultraviolet (EUV) resists has been intensively pursued. Owing to the intensive development, the resolution of EUV lithography has reached well below 30 nm using chemically amplified resists. The delineation of line-and-space patterns with 11 nm half pitch has also been reported using EUV interference lithography with a non-chemically amplified resist. The sensitivity of chemically amplified resists has been getting close to the targeted sensitivity of 10 mJ cm^{-2}. However, the surface roughness of patterned resists, referred to as line edge roughness (LER) or line width roughness (LWR), is still far from the targeted value at 22 nm node. In this presentation, the development status of EUV resists is reviewed in terms of material design. The future prospects of EUV resists are discussed on the basis of reaction mechanisms of chemically amplified EUV resists.

Presenting Author

Takahiro Kozawa is an associate professor of the Institute of Scientific and Industrial Research (ISIR), Osaka University. He received his BS and MS degrees in nuclear engineering from the University of Tokyo, and PhD degree in chemical engineering from Osaka University in 1990, 1992, and 2003, respectively. His work is mainly focused on beam-material interaction and beam-induced reactions in resist materials.

Resist-10

EUV Interference Lithography

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EUV interference lithography has emerged as a useful tool in the last decade for exposing periodic nanostructures with resolution not available yet from conventional projection tools. Due to the need for coherent illumination EUV-IL tools have been set up at synchrotron radiation facilities. One of the major applications of this technology has been characterization of new photoresist materials that are being developed for EUV lithography. The PSI EUV-IL tool has been serving the academic and industrial research communities for about five years during which time hundreds of resists have been tested and significant progress in resist performance, especially in terms of resolution, has been observed. Dense line/space and contact-hole type patterns are available through two-beam and multiple-beam interference respectively. The aerial image is well defined and the contrast can be varied through flood exposures. The recent achievement of 11 nm half-pitch line structures at PSI is a new resolution record in photon lithography and proves the absence of physical processes that could block EUV lithography before this important resolution node. More recently we have seen indications of substrate effects in EUV exposure of photoresists which can have important implications for the industrialization of EUV lithography.

Presenting Author

Harun H. Solak received Ms. and Ph.D. from the University of Wisconsin-Madison in Electrical Engineering for his work on EUV and x-ray microscopy. As a postdoctoral researcher at the same university he set up the first EUV interference lithography system for research on EUV resists. He later joined the Paul Scherer Institute in Switzerland where he has been leading EUV interference lithography group as a senior scientist. He recently founded the startup firm EULITHA AG to commercialize nanostructuring capabilities of EUV-IL. His research interests include nanolithography, x-ray optics and plasmonic nanostructures.

Resist-11

Molecular Resist Materials for EUVL Lithography: What Might Be Possible and How Do We Get There?

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High resolution patterning for the 32-nm node and beyond require a combination of resolution, sensitivity, and line edge roughness (LER) that is difficult to meet in any known resist system due to the now well known RLS tradeoff. Furthermore, even if imaging is acceptable, pattern collapse may be itself be a significant limiter for these future patterning nodes. Our group has undertaken a comprehensive program designed to elucidate possible resist material and process solutions to these problems, understand their performance and what controls their performance at a fundamental level, and use that fundamental information to design improved generations of resist materials and processes. First a review of our progress in negative tone molecular resists for EUVL where capability down to 20 nm scale patterning has been demonstrated. Next, a review of our progress in positive tone molecular resists will be given. Both types of systems will be discussed in terms of their fundamental limits as explored through detailed mesoscale simulations. Finally, a summary of our recent work to characterize and develop methods for circumventing pattern collapse problems will be presented.

Presenting Author

Professor Clifford L. Henderson is currently an Associate Professor and the Robert C. "Bud" Moeller Faculty Fellow in the School of Chemical & Biomolecular Engineering at Georgia Tech. He received his B.S. in Chemical Engineering from Georgia Tech, and his M.S. and Ph.D. degrees in Chemical Engineering from The University of Texas at Austin. After completing a short period of work with Motorola in their Advanced Products Research and Development Laboratory (APRDL), he returned to join the faculty at Georgia Tech in 1998. His research group focuses on: (1) the behavior of organic materials in confined geometries, (2) developing new materials and processes for micro- and nanofabrication, (3) developing a fundamental understanding of the physiochemical processes that occur in such materials and processes, and (4) developing models that can be used to describe, control, and design such systems. He has authored or coauthored more than 140 papers and holds 7 patents in areas related to polymeric materials, lithography, and materials and methods for micro- and nanofabrication.

Source-1

High Brightness Next Generation EUV Lithography Light Source

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G. DUFFY [1], S. FANT [2], B. LEBERT [2], O. SARROUKH [2], E. WYNDHAM [3], C. ZAEPFFEL [2], V. S. ZAKHAROV [2*]

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[2] EPPRA sas, *France*
[3] Pontificia Universidad Catolica de Chile, *Chile*
[+] RRC Kurchatov Institute, *Moscow*, *Russia*
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Power (for HVM), brightness (for AIM) and reliability specifications for EUV light sources are pre-eminent barriers impeding the adoption of EUV lithography in manufacturing. The detailed analysis identified that self-absorption and etendue constraints limit the usable power of a conventional single unit EUV source. The required irradiance can be achieved by spatial multiplexing, using multiple sources. Detailed parametric scans have provided basic numbers to select the optimal regime for tin and xenon based source operation. The in-band emission from Xe XX and Xe XXII ions produced in the plasma by fast electrons may exceed the emiision from Xe XI ions of conventional xenon based EUV source. NANO-UV presents CYCLOPS™, a new generation commercial EUV light source unit, incorporating the i-SoCoMo™ technology, together with early experiences of operating 12 separate sources in a multiplexed configuration, the HYDRA™-12 design. This novel source is based on a nanosecond, ultra fast micro-plasma capillary discharge with an in-built plasma structure (PlasmaLens™) for photon collection and projection, induced by an intense electron beam generated due to the transient hollow cathode effect. Higher irradiance required is obtained by spatial and temporal multiplexing of multiple sources, due to the very low etendue and compact form factor of each i-SoCoMo™ unit. The HYDRA™-12 source can satisfy the source power and brightness requirement for an at-line AIM tool for mask inspection.

Presenting Author

Dr. Sergey V. Zakharov graduated from the Moscow Physical-Technical Institute. He received the doctor degree in physical-mathematical sciences from Kurchatov Institute of Atomic Energy, Moscow, Russia, in 1984. He joined Troitsk Institute of Innovation and Fusion Research (TRINITI), Russia, in 1981, where he is currently Head of the theoretical laboratory. His works concern plasma turbulence theory, nonlinear waves, charged particle beams, radiation-magnetohydrodynamics and non-equilibrium plasma theory in HEDP and ICF. For works on interaction of high power electron beams with dense gas he was rewarded the State Prize for young scientists and engineers in 1987. For researches on high energy density physics and radiating multicharged ion plasma he was rewarded the Great Government Reward in 1997. Since 1999 he joined EPPRA SAS, France, as a Principal Scientist. He works on the theory of non-equilibrium heavy-ion plasmas and modeling of discharge and laser produced plasma radiation sources. Under his leadership the radiation-magnetohydrodynamic codes ZETA and Z* were created and are being developed.

Source-2

Angular distribution of the ion emission from a tin-based laser produced plasma extreme ultraviolet source

O. Morris, A. O'Connor, E. Sokell and P. Dunne

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In-band emission from Laser Produced Plasmas (LPPs) is maximized at power densities in a range around 10^{11} W/cm^2. At these power densities fast ion emission may cause significant damage to components in a real world projection lithography system. Fast ions, impinging on multilayer optics, can lead to the sputtering of mirror layers and debris can be deposited on multilayer optics and hence LPPs can degrade in-band reflectivity. In order to effectively mitigate this damage it is necessary to know the energy and direction of the emitted ions.

The charge state and energy distributions of ions emitted from a Sn-based LPP extreme ultraviolet source, formed at a power density of ≈ 4 x 10^{11} W/cm^2, have been recorded as a function of angle. At all angles investigated, very few highly charged ions (above Sn^{9+}) were detected. For each individual ion stage detected, more energetic ions showed preferential emission close to target normal whereas the less energetic ions exhibited peak emission at larger angles. At all angles, with increasing ion stage, peak ion emission occurred at greater energies. The sum of the emission, for each ion stage recorded, at each observed kinetic energy, decreased with increasing angle from target normal.

Presenting Author

Padraig Dunne received his PhD from University College Dublin in experimental atomic physics in 1994. His research interests include Laser Produced Plasmas (LPPs) as sources of ions and continuum radiation for photoabsorption spectroscopy, as sources of EUV radiation for next generation photolithography and microscopy/imaging. He has co-authored over 40 peer-reviewed journal articles and a similar number of conference papers. He is currently Graduate School Director in the UCD College of Engineering, Mathematical and Physical Sciences and an associate professor in the UCD School of Physics. He is a member of SPIE and of the Institute of Physics.

Source-3

1-D plasma modeling with radiation transport

J. White, A. Cummings, P. Dunne, and G. O'Sullivan

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Next generation lithography schemes for the semiconductor industry are based on a 13.5-nm tin plasma light source [1], where hundreds of thousands of near degenerate 4d-4f, 4p-4d, and 4d-5p transitions from Sn^{5+}–Sn^{13+} ions overlap to form an unresolved transition array [2]. Such plasmas are optically thick, and radiation transport must be included to calculate spatially-resolved, time-dependent spectra.

To aid computation, UTAs can be treated statistically for 4d-4f and 4p-4d transitions [3, 4] using the Cowan code [5] and *nl* splitting for $\Delta n = 0$ (and 4d-5p) transitions determined using an energy functional method [6]. The atomic results can then be coupled to a 1-D Lagrangian plasma hydrodynamics code [7], to calculate spectra versus laser power and pulse width at normal incidence. The theoretical results are compared to experiment, and conversion efficiency determined to quantify optimum laser parameters within the 2% bandwidth. Absorption from neutral and lower tin ion discrete transitions (Sn I–Sn IV)[8] is not included in the opacity calculations, since such absorption at normal incidence is considerably lower.

Source-4

LPP EUV Source Development at ETHZ

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In order to be applied in high volume manufacturing processes, an extreme ultraviolet lithography (EUVL) source must provide the required power, as well as yield long lifetimes of the components. One approach for a source employs the use of a laser produced plasma (LPP) EUV source, whereby a target is irradiated by a laser. At ETH Zurich, a program has recently been initiated to develop & characterize suitable laser-target configurations that have low cost-of-ownership, and to realize debris mitigation techniques that prolong the component lifetimes. For this purpose, at ETH Zurich, a plasma science facility has been constructed to measure the spatial & temporal distributions of radiation & particle fluxes over 4π sr, the in-band & full-band emissions, as well as the heat load on collection optics. This facility is complemented by multi-scale computational tools that are used to simulate the LPP from the target length scales (μm) up to the optics length scales (m). We will, in this paper, describe the techniques of this multi-scale computational tool set, and present results for laser-target configurations in which we have examined issues of collector lifetime, debris load and radiation. In synergy with the companion experiments, this computational tool set shall accelerate the development of a EUV light source.

Presenting Author

Ndaona Chokani received his B.A. in engineering science from Oxford University in 1984 and his Ph.D. in engineering from Cambridge University in 1988. He is at the Swiss Federal Institute of Technology Zürich; previously he served on the faculty at North Carolina State University and then on the faculty at Duke University, where he was a Professor of mechanical engineering and materials science. His current research activities focus on energy conversion in renewable energy and in plasma light sources, the development and application of novel instrumentation, and the development of digital signal processing techniques. His previous research, supported by the U.S. Air Force Office of Scientific Research, the U.S. Air Force Research Laboratory, NASA, and the National Science Foundation, has focused on hydrodynamic stability of compressible flows and shockwave/boundary-layer interactions. He has previously served on the National Academies' Air Force Science and Technology Board, as an Associate Editor of the Journal of Aircraft, and as a Member of the AIAA's Transition Study Group, the AIAA's Aerodynamics Measurement Technology Technical Committee, and the AIAA's Thermophysics Technical Committee. He is a co-recipient of a 2008 award for a best paper presented at the 2007 IGTI Turbo Expo. He is an Associate Editor of the AIAA Journal, an Associate Fellow of the AIAA, and member of ASME and SPIE.

Source-5

EUV Source Technology Status

V. Bakshi

EUV Litho, Inc.

Summary of current performance status of high power discharge produced plasma (DPP) and laser produced plasma (LPP) based EUV sources will be presented. In addition, leading technical challenges for high power EUV Sources that can support high volume computer chip manufacturing will discussed.

Presenting Author

Dr. Vivek Bakshi is the president of EUV Litho, Inc., an organization that he formed to promote EUV Lithography via workshops and education courses. Previously, he was a senior member of the technical staff in SEMATECH's Lithography Division. Dr. Bakshi has authored/co-authored over 125 technical publications, including book chapters and articles in peer-reviewed journals and trade publications. He has edited two books on EUV Lithography: *EUV Sources for Lithography* (SPIE Press, 2006) and *EUV Lithography* (SPIE Press, 2008).

Source-6

Fiber Lasers for EUV Lithography

A. Galvanauskas

University of Michigan

Extreme ultraviolet lithography (EUVL) is currently a primary technology for extending optical lithography below 32 nm half pitch. However, development of production-worthy EUV radiation sources has been one of the key challenges of implementing EUVL. EUV radiation is generated by hot plasma produced by high-intensity laser light. For high throughput lithography systems at least 200W of 13.4nm radiation at intermediate focus is required. Due to the inherently low efficiency of EUV radiation from hot plasmas this translates to very high laser-driver average power, which can be as high as 25kW.

Fiber lasers have been demonstrated as a viable solution to a laser-driver problem. This laser technology is power scalable, highly efficient, compact and very reliable. Indeed, commercial cw fiber laser systems are available with average powers in the 20kW to 50kW range and with 25% to 30% overall plug-to-optical efficiencies. The main technological trade-off that fiber laser architecture has to overcome is between a limited pulse energy achievable from a single fiber and a limited highest droplet frequency attainable in practical Sn-based LPP sources of EUV radiation. We have shown that this trade-off is resolved through a suitable spectral combining architecture of multiple pulsed fiber-laser modules using existing technologies. In this talk we will review fiber laser technology for implementing 25kW power EUVL laser drivers.

Presenting Author

Almantas Galvanauskas received Ph.D. degree in physics from the Royal Institute of Technology, Stockholm, Sweden, in 1993.

From 1993 to 2001, he was with IMRA America Inc., Ann Arbor, MI, where he was leading research and development efforts on high-energy and high-power femtosecond fiber amplifier technology. Since 2002, he has been at the University of Michigan, Ann Arbor, where he is currently a professor in the Electrical Engineering and Computer Science Department. His current research interests are in high power fiber laser technology, ultrashort pulse, and high-intensity fiber lasers and their use for a variety of laser plasma applications in particular. He is an author and co-author of over 200 papers, conference contributions, and over 30 inventions.

Source-7

Molecular Dynamics Investigation on Tin

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Laser-produced tin (Sn) plasma has been considered as one of main candidates for extreme ultraviolet (EUV) light source used in EUV lithography due to its high conversion efficiency and scalability to high EUV power. The Sn target could be either solid or liquid droplet. In order to increase conversion efficiency and to mitigate energetic ions and neutral from laser-produced Sn plasma, fundamental investigation is necessary. Theoretical study by means of hydrodynamic simulation is expected to guide us to optimize Sn target and pumping conditions. Equation of state of materials is an inevitable ingredient of all hydrodynamic simulations. However, the early stages of the laser-matter interaction process, equation of state at phase transition, for example, liquid-vapor transition, and the ejection of particles are remain unexplored. Investigations of these early stages are essential in order to understand the dynamics of fundamental mechanisms. Although theoretical models in this regard exist, they are mostly based on questionable thermodynamic equilibrium concepts and have been insufficiently verified by measurements. The question of the behavior of Sn properties under either rapid heating/cooling is still open.

The aim of this research is to investigate the properties of Sn over wide physical conditions by means of molecular dynamics simulations. In particular, we are interested to investigate the behavior of physical parameters of Sn in transient situation relevant to conditions in laser-produced EUV sources.

This research is supported by Gigaphoton Inc.

Presenting Author

Majid Masnavi, obtained his Ph.D in energy sciences from the Tokyo Institute of Technology in 2003 for research and education in optics and x-ray lasers. He is staying with the faculty as a researcher and his research focuses on the atomic physics, high density plasmas, magnetohydrodynamics, and molecular dynamics.

Source-8

External Debris Mitigation System for LPP Sources

W. L. Bear, X. Xiong

Wynnbear Parallel EUV Lithography (PEUVL) Corporation

Currently in the debris mitigation systems of source suppliers, e.g., Cymer, the ene of Sn+ ions are reduced from 3keV to 300eV, however, the ions still damage the m layer mirrors (MLM) coating via accumulation and there is a need to reduce the energy from 300 eV to 0 eV. Therefore, we provide the last step of the debris mitigat for the LPP sources to fully eliminate ions' damage to MLM via an External Deb Mitigation System. Our debris mitigation method and system uses an intense elec field on the entire MLM. We build a strong electric field on the surface of MLM to prev any low-energy ions from contacting the MLM coating. The existing debris mitigat systems usually employ a rotating shutter, lamellas, or a magnetic source generating a magnetic field to deflect the ions into a foil plate surface or an electrost grid, etc. Our approach allows any existing technology to be continued to be used a at the same time provide an additional layer of debris mitigation via ring lamellas t are placed between MLM and the intermediate focus.

Source-9

Tabletop Synchrotron for Actinic Defect Inspection of EUVL Mask

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Use of MIRRORCLE synchrotron for actinic defect inspection of EUVL is highlighted in this poster. Small emitter size in micron order will realize accurate and quick mask inspection with 10 to hundred mW 2% bandwidth EUV radiation. The focal point shape can be either micron order spot or 1micron x 2 cm long. About 10mW total power in 2% band width is generated from a single target which corresponds to the photon density of about 3mW/um^2(or 3kW/mm^2) by 20MeV machine. The beam divergence is also as small as +/- 5 mrad. Specific optics will be discussed to make 1-micron order spot or 2cm long line image. Suggestion of proper optics is quite welcome for collaboration.

In order to generate 100W EUV we place 1000 of multiple targets along the exact circular beam orbit of MIRRORCLE. Radiation from all targets can be superposed and focused into one spot by using quasi-ellipsoidal mirror.

EUV

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