2012 International Workshop on EUV Lithography

June 4-8, 2012

Sheraton Maui Resort ▪ Maui, Hawaii

Workshop Abstracts

EUV Litho, Inc.

Contents

Organized by:

EUV Litho, Inc.

Welcome

Dear Colleagues;

I would like to welcome you to the 2012 International Workshop on EUV Lithography in Maui, Hawaii. In this leading workshop, focused entirely on EUVL R&D, researchers from around the world will present the results of their R&D. As we all work to address the remaining technical challenges of EUVL to allow its insertion in high volume computer chip manufacturing as well as the emerging field of Beyond EUV (BEUV), 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. I look forward to your participation.

Best Regards

Vivek Bakshi
Organizing Chair, 2012 International Workshop on EUVL

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Workshop Agenda

2012 International Workshop on EUV Lithography

Sheraton Maui Resort, Maui, Hawaii, USA

June 4-8, 2012

Workshop Agenda Outline

Monday, June 4, 2012

8:30 AM -5:00 PM

EUV Lithography Short Course (Hana Room)

Tuesday, June 5, 2012

3:00 PM- 5:00 PM

Registration (Maui Ballroom Foyer)

Speaker Prep (Wailuku/Kahului Room)

5:30 PM- 7:00 PM

Reception (Ocean Lawn)

Wednesday, June 6, 2012

7:00 AM – 8:00 AM Breakfast

9:00 AM – 12:00 PM Oral Presentations (Wailuku/Kahului Room)

12:00 PM – 1:00 PM Lunch (Kihei /Wailea Room)

1:00 PM – 4:00 PM Oral Presentations (Wailuku/Kahului Room)

4:00 PM Afternoon off for Networking /Sunset Cruise

Thursday, June 7, 2012

7:00 AM – 8:00 AM Breakfast

8:30 AM – 12:00 PM Oral Presentations (Wailuku/Kahului Room)

12:00 PM – 1:00 PM Lunch (Napili Room)

1:00 PM – 4:00 PM Oral Presentations (Wailuku/Kahului Room)

5:00 PM - 6:00 PM Poster Session

6:30 PM – 8:00 PM Dinner (Ocean Lawn)

Friday, June 8, 2012

8:30 AM – 10:00 AM EUVL Workshop Steering Committee Meeting (Hana Room)

2012 International Workshop on EUV Lithography

Sheraton Maui Resort, Maui, Hawaii, USA
June 4-8, 2012

Workshop Agenda

Monday, June 4, 2011

Short Courses

EUV Lithography
by Vivek Bakshi (EUV Litho, Inc.), Patrick Naulleau (LBNL) and Jinho Ahn (Hanyang University)

8:30 AM -5:00 PM, Monday, June 4, 2012

Tuesday, June 5, 2012

Registration and Reception

3:00 PM- 5:00 PM	Registration & Speaker Prep
5:30 PM- 7:00 PM	Reception

Wednesday, June 6, 2012

9:00 AM Welcome and Introduction

Vivek Bakshi
EUV Litho, Inc., Austin, TX, USA

Session 1: Keynote Presentations

EUV Lithography at Insertion and Beyond (P1)

Yan Borodovsky
Portland Technology Development, Intel Corporation

Persistent Efforts to Overcome the Challenge of EUVL (P3)

Soichi Inoue
EUVL Infrastructure Development Center, Inc. (EIDEC)

Break

Session 2: Panel Discussion: EUVL HVM Insertion and Scaling (P4)

Moderator: Sushil Padiyar (AMAT)

Panelists:

Yan Borodovsky (P5)
Intel Corporation

Takashi Kamo (P6)
Toshiba

Additional panelists to be announced

Lunch

Session 3: High Power EUV Sources

Component Technologies of HVM Source for Reliable, High Average Power Operation (Review Paper) (P32)

Akira Endo
Research Institute for Science and Engineering, Waseda University, 3-4-1, Okubo, Shinjuku,Tokyo 169-8555, Japan and
HiLASE Project, Institute of Physics AS, CR, Na Slovance 2, 18221 Prague 8, Czech Republic

Modeling, Benchmarking, and Optimization of EUV Sources for Lithography (P30)

A. Hassanein
Center for Materials under Extreme Environment, School of Nuclear Engineering
Purdue University, West Lafayette, IN, USA

Investigation of Atomic Processes of High-Z ions in Plasmas for EUV Applications (P14)

Akira Sasaki
Quantum Beam Science Directorate, Japan Atomic Energy Agency
8-1 Umemidai, Kizugawa-shi, Kyoto 619-0215, Japan

HEIGHTS Simulation and Optimization of EUV Sources Using Mass-limited Targets (P31)

T. Sizyuk and A. Hassanein
Center for Materials under Extreme Environment, School of Nuclear Engineering
Purdue University, West Lafayette, IN, USA

Break

Session 4: Beyond EUV (BEUV)

Possibility of EUVL system at the Wavelength of 6.8 nm (P34)

Hiroo Kinoshita
University of Hyogo, Center for EUV Lithography
1-1-2 Kouto Kamigouri Ako-gun, Hyogo Pref. 678-1205, Japan

Fundamental Property of 6.X-nm EUV Emission (P23)

Takeshi Higashiguchi[1,2], Takamitsu Otsuka[1], Noboru Yugami[1,2], Thomas Cummins[3], Colm O'Gorman[3], Bowen Li[3], Deirdre Kilbane[3], Padraig Dunne[3], Gerry O'Sullivan[3], Weihua Jiang[4], and Akira Endo[5]
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[5] *HiLASE Project, Institute of Physics AS, CR, Na Slovance 2, 18221 Prague 8, Czech Republic*

Investigating the Effects of Laser Power Density, Pulse Duration and Viewing Angle on a 6.7nm BEUV Source (P15)

Colm O'Gorman[1], Thomas Cummins[1], Takamitsu Otsuka[2], Noboru Yugami[2,3], Weihua Jiang[4], Akira Endo[5], Bowen Li[1], Padraig Dunne[1], Emma Sokell[1], Gerry O'Sullivan[1], and Takeshi Higashiguchi[2,3]
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[2]*Department of Advanced Interdisciplinary Sciences, Center for Optical Research & Education (CORE), and Optical Technology Innovation Center (OpTIC), Utsunomiya University, Yoto 7-1-2, Utsunomiya, Tochigi 321-8585 Japan*
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[5]*Research Institute for Science and Engineering, Waseda University, Okubo 3-4-1, Shinjuku, Tokyo 169-8555 Japan*

End Day 1

Day 2: Thursday, June 7, 2012

Welcome and Introduction (Intro-2)

Vivek Bakshi
EUV Litho, Inc.

Session 6: Contamination

Resist-outgas Testing and EUV Optics Contamination at NIST (P21)

S. B. Hill [1], N. S. Faradzhev [2], L. J. Richter [1], S. Grantham [1], C. Tarrio [1], and T. B. Lucatorto[1]
[1] *National Institute of Standards and Technology, Gaithersburg, MD, USA*
[2] *University of Virginia, Charlottesville, VA, USA*

Nanoparticle/AMC Contamination Control and Metrology for the Extreme Ultraviolet Lithography (EUVL) Systems (P19)

David Y.H. Pui
Mechanical Engineering Department, University of Minnesota, 111 Church Street, SE, Minneapolis, MN 55455, USA

Development of the Novel Evaluation Tool with an In-situ Ellipsometer for the Thickness Measurement of the Contamination Originated by the High Power EUV Irradiation on EUV Resist (P27)

Takeo Watanabe[1], Yukiko Kikuchi[2], Toshiya Takahashi[2], Kazuhiro Katayama[2], Isamu Takagi[2], Norihiko Sugie[2], Hiroyuki Tanaka[2], Eishi Shiobara[2], Soichi Inoue[2]
Testuo Harada[1], and Hiroo Kinoshita[1]
[1]*Center for EUVL, Laboratory of Advanced Science and Technology for Industry, University of Hyogo*
[2]*EUVL Infrastructure Development Center, Inc. (EIDEC)*

Session 7: Mask and Mask Metrology

Development of Actinic Mask Inspection Systems (P33)

Hiroo Kinoshita[a,c], Tetuso Harada[a,c], Yutaka Nagata[b,c], Mitunori Toyoda[d], and Takeo Watanabe[a,c]
[a]*University of Hyogo, Center for EUV Lithograph, 1-1-2 Kouto Kamigouri Ako-gun, Hyogo Pref. 678-1205, Japan*
[b]*Riken, 2-1 Hirosawa, Wako, Saitama Pref. 351-0198, Japan*
[c]*JST CREST, 5-3 Bancho, Chiyoda, Tokyo 102-0075, Japan*
[d]*Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577,Japan*

Effect of Mask Roughness on Mask Inspection (P35)

Patrick Naulleau
Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720

Optical Design of Absorber Materials for Reduced H-V CD Bias in EUV Lithography (P38)

Seongchul Hong, Sangsul Lee, Jae Uk lee, Inhwan Lee[1], and Jinho Ahn
Department of Materials Science and Engineering, Hanyang University, Seoul 133-791, Korea
[1]*Memory Research & Development Division, Hynix Semiconductor Inc.*

Break

Session 8: EUV Sources for Metrology

Novel EUV Light Sources for Photolithography (P13)

Masami Ohnishi[1], Waheed Hugrass[2] , Yukio Miyake[1], Tatsuya Shimizu[1], Kazuya Hanatani[1] and Hodaka Osawa[1]
[1]*Kansai university, Faculty of Engineering Science, Department of Electrical and Electronic Engineering, 3-3-35 Yamate-cho, Suita-shi, Osaka 564-8680, Japan*
[2]*University of Tasmania, School of Computing and Information Systems, Private Bag, 1359, Newnham, Tasmania 7250, Australia*

Electrodeless Z-Pinch EUV Source for Metrology Applications for Today and the Future (P16)

Deborah Gustafson, Stephen F. Horne, Matthew M. Besen, Donald K. Smith, Matthew J. Partlow, Paul A. Blackborow
Energetiq Technology, Inc., 7 Constitution Way, Woburn, MA 0180, USA

Recent Progress on High Brightness Source Collector Module for EUV Mask Metrology (P17)

Kenneth Fahy[1], Paul Sheridan[1],Padraig Dunne[1,2], and Fergal O'Reilly[1,2]
[1] *NewLambda Technologies Ltd, Science Center North, Belfield, Dublin 4, Ireland*
[2] *UCD School of Physics, UCD, Stillorgan Rd, Dublin 4, Ireland*

Lunch

Session 9: Optics

EUV Multilayer Coatings: Potentials and Limits (Review Paper) (P26)

Sergiy Yulin, Torsten Feigl, Viatcheslav Nesterenko, Mark Schürmann, Marco Perske, Hagen Pauer, Tobias Fiedler, Norbert Kaiser
Fraunhofer-Institut für Angewandte Optik und Feinmechanik, Albert-Einstein-Str. 7, 07745 Jena, Germany

Multilayer Mirrors for EUVL, Status Progress (P22)

Yuriy Platonov, Jim Rodriguez, Michael Kriese, Vladimir Martynov
Rigaku Innovative Technologies, 1900 Taylor Rd., Auburn Hills, MI 48326, USA

Recovery Strategies for Mirrors with Boron Carbide-based Coatings for 6.x nm Lithography (P24)

Regina Soufli[1], Mónica Fernández-Perea[1], Sherry L. Baker[1], Jeff C. Robinson[1], Eric M. Gullikson[2], Nicholas M. Kelez[3], John D. Bozek[3]
[1]*Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550*
[2]*Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720*
[3]*SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025*

Break

Session 10: EUV Resist and Patterning

Status and Challenge of Chemically Amplified Resists for Extreme Ultraviolet Lithography (Review Paper) (P29)

Takahiro Kozawa
The Institute of Scientific and Industrial Research, Osaka University
8-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

Evaluation of Resist Performance with EUV Interference Lithography for 22 to 11 nm HPs (P18)

Yasin Ekinci[a,b,*], Michaela Vockenhuber[a], Bernd Terhalle[a], Mohamad Hojeij[a], Li Wang[a], Jens Gobrecht[a]
[a] *Laboratory for Micro- and Nanotechnology, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland*
[b] *Laboratory of Metal Physics and Technology, Department of Materials, ETH Zürich, 8093 Zürich, Switzerland*

Chemical Reaction Analysis based on the SR Absorption Spectroscopy for the High Sensitive EUV Resist (P28)

Takeo Watanabe[1], Daiju Shiono[2], Yuichi Haruyama[1], Tetsuo Harada[1], and Hiroo Kinoshita[1]
[1] *Center for EUVL, Laboratory of Advanced Science and Technology for Industry, University of Hyogo*
[2] *Tokyo Ohka Kogyo*

EUV Resist Development Status toward sub-20nm Half-Pitch (P36)

Tooru Kimura
JSR Corporation, 100, Kawajiri-cho, Yokkaichi, Mie, Japan

EUVL Workshop Summary (P45)

Vivek Bakshi
EUV Litho, Inc.

Break

Poster Session 5:00 Pm – 6:00 PM

Dinner 6:30PM- 8:00 PM

Adjourn 8:00 PM

Session 12: Poster Session

An Estimation of the Mask Shadow Effect and its Compensation as Flexible Illumination system in EUVL (P11)

Sangheon Lee, Junhwan Lee, Sanghyun Ban, Hye-Keun Oh[1], Byungho Nam[2], Sangpyo Kim[2], Donggyu Yim[2], and Ohyun Kim
Department of Electrical Engineering, Pohang University of Science and Technology, Pohang, Gyeongbuk 790-784, Korea
[1]Department of Applied Physics, Hanyang University, Ansan, Gyeonggi-do, Korea
[2]Hynix Semiconductor, Cheongju, Chungbuk, Korea

Research of the EUV Radiation and CO_2 Laser Produced Tin Plasma (P12)

Wang Xinbing[1], Zuo DouLuo[1], Lu Peixiang[2], Wu Tao[1]
[1]Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan 430074, China
[2] School of Physics, Huazhong University of Science and Technology, Wuhan 430074, China

Spectroscopic Studies of Laser Produced Tin and Tin Alloy Plasmas (P20)

Enda Scally, Paul Sheridan, Tony Donnelly, Thomas Cummins, Imam Kambali, Gerry O'Sullivan and Fergal O'Reilly
School of Physics, University College Dublin, Ireland

Laser Assisted Vacuum Arc (P25)

Isaac Tobin[1], Larissa Juschkin[2], Fergal O’Reilly[2], Paul Sheridan[2], Emma Sokel[2], James G. Lunney[1]
[1] School of Physics, Trinity College Dublin, Dublin 2, Ireland
[2] School of Physics, University College Dublin, Belfield Dublin 4, Ireland

HHG Sources for EUVL Mask Inspection (P41)

Jinho Ahn
Hanyang University, Korea

Friday, June 8, 2012

EUVL Workshop Steering Committee Meeting (Hana Room)

8:30 AM	Breakfast
9:00 -10: 00 AM	EUVL Workshop Steering Committee Meeting

Abstracts

(Listed by Paper number)

P1

EUV Lithography at Insertion and Beyond

Yan Borodovsky

Portland Technology Development, Intel Corporation

Immersion ArF Lithography with Pitch Division enabled IC industry continue Moore's Law without interruption. Extending its historical 2 years/node technology cycle cadence Intel started 22nm node products high volume manufacturing in 2011 and is actively working to enable high volume 14nm node products manufacturing in 2013 and 10nm node products manufacturing in 2015. While technology advancement and innovation in a patterning area for 22 and 14nm nodes came mainly from innovative materials selection and processing steps involved in Pitch division and Computational lithography it will be highly beneficial to our industry to complement mature ArF immersion lithography, advanced Pitch Division technology and highly productive Computational lithography tooling and methods with reliable and cost effective EUV patterning in support of 10nm and beyond nodes technology. As critical features dimensions will enter domain of single nanometer reality of exposing and processing numerous patterning steps on the same layer will result in overlay targets for each exposure that will stretch ArF exposure tooling, mask making, thin films materials processing and metrology requirements for each patterning step to the limit of what one considers reasonable today. And while yet to be matured EUV lithography promise to reduce wafer cost through combining multiple ArF patterning steps on a given layer into one is well recognized and expected its beneficial overlay impact from consolidating several exposure steps in one is often overlooked. Another area of interest to technologists is balancing prospects of high resolution imaging provided by EUV tools against relative immaturity of EUV materials and EUV support infrastructure. Presentation will offer author's opinion regarding most promising options for EUV insertion in Logic HVM manufacturing, its extension beyond 10nm node and key focus areas for research community to contribute to EUV timely insertion and its future advancements.

Presenting Author

Yan Borodovsky is Director of Advanced Lithography in Intel's Technology and Manufacturing Group responsible for directing Intel's multi-generational lithography definition. Yan has been involved in the definition and development of advanced patterning techniques, resolution enhancement methods and tooling as well as computational, inverse and complementary lithography since he joined Intel in 1987 as a staff engineer. He was appointed Intel Fellow in 1999 and Intel Senior Fellow in 2003. Yan is author of 22 US patents and many publications.

P3

Persistent Efforts to Overcome the Challenge of EUVL

Soichi Inoue

EUVL Infrastructure Development Center, Inc. (EIDEC)

Decreasing in power consumption of the microelectronics by downscaling of LSIs is one of the key factors in pursuing the ecology of the IT society. Therefore, technologies for downscaling of LSIs such as lithography continue to be the core element for the semiconductor industry, even for nano-scale era. The top runners for this downscaling have already installed the pre-production EUV scanners and have commenced the operation of the pilot lines to fix possible production level issues. However, some key technologies still have fundamental issues. Therefore persistent efforts are necessary to overcome the challenge for realizing EUVL.

This paper reports on the current status, issues and provisions for key technologies of EUVL for sub-20 nm half pitch (hp) generation. The source no doubt needs to increase in power dramatically and reach the set targets with sufficient stability. Fundamental issues also remain in inspection technologies for masks and blanks will also be described. Moreover the primary challenge for resist in concurrently achieving resolution, line width roughness, sensitivity, and outgassing targets will be discussed.

This work was supported by New Energy and Industrial Technology Development Organization (NEDO).

Presenting Author

Soichi Inoue received the B.S. degree in mechanical engineering science, the M.S. degree in information processing, and the D.Eng. degree from the Tokyo Institute of Technology in 1985, 1987, and 2011, respectively.
He joined Toshiba Corporation in 1987 and has been engaging the development of overall lithography technologies for quarter century. Since April 2011, he has been the General Manager with EUVL Infrastructure Development Center, Inc. (EIDEC) on an assignment from Toshiba. He has published more than 90 papers in technical journals and conferences and has been awarded 90 patents. He is the Associate Editor of IEEE Trans. Semiconductor Manufacturing.
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P4

EUVL Readiness and Extension (Panel Discussion)

Sushil Padiyar

Silicon Systems Group (SSG), Applied Materials

Panel Discussion Questions:

1. What would be the timing of EUV HVM Insertion for the industry and would any one device type drive EUV needs specifically over others?
   Discuss Minimum Requirements on Source Power, OPC needs, Mask Defects and Metrology and Resist Diffusion Lengths and Resolution
2. What is your opinion on the impact of TPT on EUV HVM: - minimum TPT needs for full-blown EUV HVM vs. a gradual phase-in of EUVL?
3. What would be practical EUVL scaling paths to meet the ITRS timelines for 5-7nm nodes (2017-2020)?
   Double Patterning to go sub-wavelength or K1 reduction using NA scaling to NA>0.5 (power loss concerns) or 6.7nm wavelength change along with entire infrastructure (optics, resists, power requirements again)

Moderator

Panel Discussion Moderator, Dr. Sushil Padiyar is a Strategic Programs Manager within Applied Material's Silicon Systems Group (SSG).
Sushil is responsible for ensuring alignment of Applied's product portfolio to the ITRS roadmap and requirements and is currently focused on areas of patterning films and metrology.

Previous to Applied Materials, Sushil has worked at Intel Corp and Formfactor Inc and held several technical and management positions in logic and NOR flash memory process development contributing to the development of advanced patterning and design for manufacturing. Sushil has also worked on the transfer of patterning technologies to high-volume manufacturing overcoming process integration and defectivity challenges.

Sushil earned his M.S/PhD in Physics from the University at Albany, State University of New York and received a B.S/M.S degree in Physics from Mumbai University.

P11

An Estimation of the Mask Shadow Effect and its Compensation as Flexible Illumination system in EUVL

Sangheon Lee, Junhwan Lee, Sanghyun Ban, Hye-Keun Oh[1], Byungho Nam[2], Sangpyo Kim[2], Donggyu Yim[2], and Ohyun Kim

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Extreme Ultraviolet Lithography (EUVL) has been considered as the most promising candidate for sub-22 nm half pitch and beyond. One of the critical challenges in EUVL is the mask shadow effect caused by EUV light illumination with oblique incidence angle of 6^{o} due to an asymmetric structure of EUVL scanner. The shadow effect can affect critical dimension (CD) variation and CD shift on wafer. For this reason, the research for the shadow effect while absorber topography is varied is necessary.

This paper reports an estimation of the mask shadow effect caused by absorber sidewall angle, width, and height variation, and we developed flexible illumination system as compensation method to obtain acceptable normalized image log slope (NILS) values with the change of absorber topography using Sentaurus Lithography (Synopsys Inc.). In order to improve NILS values at single pattern of EUV mask, we have changed the illumination setup among conventional, annular, dipole, and quadrupole illumination. NXE:3300B is expected to adopt off-axis illumination (OAI), so the study of the optimal illumination shape and size for certain absorber topography are necessary to obtain high NILS values. Our research gives semiconductor industry a guarantee that EUVL will be closer to mass production.

Presenting Author

Sangheon Lee received his BE in electrical engineering at Kyungpook National University in 2011. He is currently a Master degree candidate in the Department of Electrical Engineering at Pohang University of Science and Technology. His research interest is to inspect EUV mask defects and measure sidewall angles non-destructively for the shadow effect estimation. He had internship at Mask research team of Hynix Semiconductor.

P12

Research of the EUV Radiation and CO_2 Laser Produced Tin Plasma

Wang Xinbing[1], Zuo DouLuo[1], Lu Peixiang[2], Wu Tao[1]

[1]Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan 430074, China
[2] School of Physics, Huazhong University of Science and Technology, Wuhan 430074, China

Experiments of pulse CO_2 laser produced tin plasma had been carried out. Time-integrated extreme ultraviolet spectral measurement showed that the peak of the spectrum was located at 13.5 nm. Plasma parameters of electron temperature and density measurements both in axial and radial direction had been performed from a two-dimensional time and space resolved image spectra analysis. We found that the electron temperature near the plasma plume center slightly varied with the increase of the axial or radial distance, which was related to a collisional decoupling and reheating of the ionized species in the plasma. Space averaged electron temperature and electron density were obtained. Debris speed of laser produced plasma in various buffer gas was quantitatively estimated by means of a fast gated intensified charge coupled device imaging system as well as by visible emission spectroscopy. The stopping power of the hydrogen buffer gas was assessed under ambient pressure ranging from 30 to 10^4 Pa. Time-resolved visible emission spectroscopy showed that thermalizing collisions were responsible for slowing down the fast energetic ions and atoms toward a thermal equilibrium.

Presenting Author

P13

Novel EUV Light Sources for Photolithography

Masami Ohnishi[1], Waheed Hugrass[2],Yukio Miyake[1], Tatsuya Shimizu[1], Kazuya Hanatani[1] and Hodaka Osawa[1]

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[2]University of Tasmania, School of Computing and Information Systems, Private Bag, 1359, Newnham, Tasmania 7250, Australia

Two novel devices to produce Extreme Ultra Violet (EUV) light for lithographic applications are being investigated at the Kansai Plasma Laboratory. The first is a Xe plasma produced discharge using 13.56 MHz rotating magnetic field. The second is a 2.45 GHz microwave plasma produced discharge. Both devices are debris-free and produce about 10 W EUV. The overall efficiency of these devices is 0.8 % and 3 %, respectively. Scaling of the experimental data from the first device shows increasing the input power brings about improvement in the efficiency such that the 100W EUV output needed for commercial applications can be generated for input power of about 3 kW.

Presenting Author

P14

Investigation of Atomic Processes of High-Z ions in Plasmas for EUV Applications

Akira Sasaki

Quantum Beam Science Directorate, Japan Atomic Energy Agency
8-1 Umemidai, Kizugawa-shi, Kyoto 619-0215, Japan

Atomic processes of high-Z ions have been studied for EUV sources. The theoretical model should predict the conversion efficiency taking detailed structure of the emission spectrum into account. The model should also provide accurate estimation of the mean charge and radiative power loss, because as a part of the equation of state (EOS), they have significant effects on the dynamics of the plasmas. In this presentation, a modeling method, which is applicable to Xe, Sn, Gd, Tb, and Kr, which are considered as the fuel for the present and future EUV sources, is presented. The method allows one to construct an atomic model taking the characteristic feature of the energy level structure of each charge state of ions into account. Energy levels with large population including multiply and inner shell excited states, which have significant contribution to the emission are taken into account. The result of calculation is verified by investigating convergence with respect to the size of the model. Another validation through comparisons between different codes at non-LTE kinetics code comparison workshop is also presented. Present method is shown to be also useful for various plasma spectroscopies including those in the fusion research.

Presenting Author

Akira Sasaki received the Dr. Eng. degree in energy science from Tokyo Institute of Technology, Tokyo, Japan in 1991. He joined Japan Atomic Energy Agency in 1996. He has been studying modeling and simulation of atomic processes of Xe and Sn plasmas of the EUV source for lithographic applications since 2002.

P15

Investigating the Effects of Laser Power Density, Pulse Duration and Viewing Angle on a 6.7nm BEUV Source

Colm O'Gorman[1], Thomas Cummins[1], Takamitsu Otsuka[2], Noboru Yugami[2,3], Weihua Jiang[4], Akira Endo[5], Bowen Li[1], Padraig Dunne[1], Emma Sokell[1], Gerry O'Sullivan[1], and Takeshi Higashiguchi[2,3]

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EUV emission at 6.7nm may be coupled with a La/B_4C mirror to produce a source for EUVL at that wavelength. Emission from 4d – 4f and 4p – 4d transitions in Gd ions have been shown to be a possible source at this wavelength region [1,2]. Theoretical modeling [3] has predicted that a plasma temperature greater than 100 eV will be required to produce the ionization stages necessary for the emission of an unresolved transition array (UTA) around 6.5 - 6.7 nm in the spectrum of Gadolinium (Gd).

In this work we will present results on the influence of laser pulse duration, irradiating laser power density and viewing angle on the conversion efficiency (CE) and on the EUV emission spectra of the Gadolinium unresolved transition array centered at 6.7nm. The experiment is carried out using a variety of power densities, laser pulse durations and target densities.

The detected spectra are shown to have a strong dependence on viewing angle when produced with the 10 ns pulse duration attributed to absorption by low ion stages of Gd [4]. This absorption is less pronounced when using the 150 ps laser due to plasma expansion effects.

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Presenting Author

Colm O' Gorman is a PhD student with the Atomic, Molecular and Plasma Physics group in UCD. He received his B.Sc in Physics from University College Dublin in 2009. His research activities have focused on EUV emission spectroscopy and ion spectroscopy of laser produced plasmas.

P16

Electrodeless Z-Pinch EUV Source for Metrology Applications for Today and the Future

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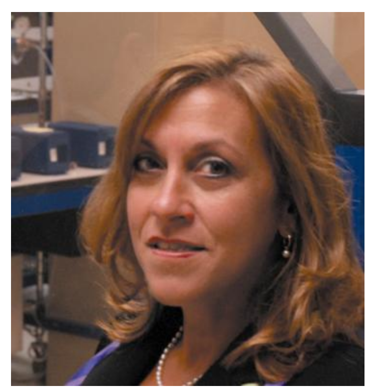
Energetiq's EQ-10HB has been selected as the source for pre-production actinic mask inspection tools. This improved source enables the mask inspection tool suppliers to build prototype tools with capabilities of defect detection and review down to 16nm design rules. In order for the production mask inspection tools to be cost effective, however, much brighter source will be required by 2013-2015.

In this presentation we will present new source technology being developed at Energetiq to address the critical source brightness issue. The new technology will be shown to be capable of delivering brightness levels sufficient to meet the HVM requirements of AIMS and ABI and potentially API tools.

We will also address the need for the next generation source requirements of 6.xnm. We will present results utilizing a higher power electrodeless Z-pinch source to enable research and development of resists and optics at 6.7nm.

Presenting Author



Debbie Gustafson is an industry veteran for over 20 years and has held various management positions in technical Sales and Marketing in the Semiconductor Equipment Industry. Her focus has been on component and subsystem equipment and service. Ms. Gustafson's is a senior manager at Energetiq Technology, Inc. in Woburn, Massachusetts as their Vice President of Marketing and Sales. Her responsibility also includes marketing and the management of manufacturing and finance. She has successfully driven the company to become the leading supplier of EUV sources globally. Ms. Gustafson has vast knowledge in the international markets with a focus on Asia. She has managed the opening of a subsidiary in Japan and a joint venture sales and service organization in Korea. She also has extensive experience in negotiating multimillion dollar contracts and supplier agreements.

Currently Ms. Gustafson is the past chairperson of the SEMI New England Committee. She holds a BS in Mechanical Engineering and an MBA in Management from Bentley College.

P17

Recent Progress on High Brightness Source Collector Module for EUV Mask Metrology

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NewLambda Technologies (www.NewLambda.com) are developing a high brightness source collector module for EUV mask metrology applications. The collector optic is a liquid metal coated ellipsoid section. The optic rotates slowly to maintain a uniform and stable thickness of liquid metal over the interior surface. The source is a laser produced plasma which uses the same liquid metal as the plasma fuel. This allows close proximity of the collector to the source without need for debris mitigation before the collector. Thus the module is being designed to deliver a clean, debris-free, high-brightness source of 13.5 nm photons to match industry demands. We report on recent progress and we present new results from our prototype system.

Presenting Author

Fergal O'Reilly is a member of the Atomic, Molecular and Plasma Physics Group in UCD, where he works on commercialization of research in application areas including EUV Sources, soft x-ray microscopy and laser development. He led research developing the concept of a liquid mirror as a means to deliver EUV photons simply and cheaply to applications and is also a founder of Newlambda Technologies. He has a PhD in EUV/soft X-ray spectroscopy of laser plasmas and ion beams, and has over 10 years of research experience in the area. His previous industrial research and product development experience was in two separate start-up companies, in the areas of atmospheric pressure surface treatment of textiles, plastics and metals, and the development of novel electronic ink display systems based on nanomaterial deposition.

P18

Evaluation of Resist Performance with EUV Interference Lithography for 22 to 11 nm HPs

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The performance of EUV resists is one of the key factors for the cost-effective introduction of EUVL. In the last years, the EUV interference lithography tool at Paul Scherrer Institute, with its high-resolution down to 8 nm HP and HP-independent areal image, has been successfully employed for resist performance testing. In this paper, we present performances (dose, CD, LER) of various CARs and inorganic resists. The comparative study of the resists shows that the current status of the EUV resist development is very promising. CAR platforms are available down to 18 nm HP with a sensitivity of about 10 mJ/cm^2 and for 16 nm HP with a sensitivity of about 30 mJ/cm^2. For 11 nm HP and below, inorganic resist platform of Inpria, offers the highest sensitivity. The general trend in the transition from 22 nm to 16 nm, and to 11 nm HP is the slower and thinner resists. The measure of progress in resist development for 16 nm and 11 nm nodes is set by the sensitivities of these available platforms. Future development for 16 nm HP should be towards faster CAR than the available materials. With decreasing HP, pattern collapse becomes the limiting factor. Moreover, patterning with 6.5 nm wavelength will be presented.

Presenting Author

Yasin Ekinci was born in 1976 and received his Bachelor degree in Physics at Middle East Techical University, Ankara, Turkey, in 1997; his Masters degree in Engineering Sciences in University of De Montfort, Leicester, UK, in 1999. He obtained his Ph.D in Max-Planck Institute for Dynamics and Self-Organization, Goettingen, Germany in 2003. In 2004 he joined Paul Scherrer Institute as a postdoc and carried out researched on EUV-IL and nanooptics. Between 2006-2009 he worked as a lecturer in Department of Materials at ETH Zurich. Since 2009, along with his position at ETH Zurich, he is at Paul Scherrer Institute and leading the EUV-IL research. He is author/co-author of 47 papers and more than 75 conference contributions.

P19

Nanoparticle/AMC Contamination Control and Metrology for the Extreme Ultraviolet Lithography (EUVL) Systems

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Extreme Ultraviolet Lithography (EUVL) is a leading lithography technology for the next generation semiconductor chips. Photomasks, in a mask carrier or inside a vacuum scanner, need to be protected from nanoparticle contamination larger than 20 nm diameter, the minimum feature size expected from this technology. We have developed models and performed experiments in atmospheric-pressure carriers and in vacuum tools down to 20 mTorr. Nanoparticles between 60 nm and 250 nm were injected into the vacuum chamber with controlled speed and concentration to validate the analytical and numerical models. Also, methods and models were developed to evaluate nanoparticle generation, transport and deposition on photomasks in carriers. Various protection schemes have been developed and evaluated using these experimental and modeling tools. Recent research has extended to the study of Airborne Molecular Contamination (AMC) detection and control.

EUVL mask surface inspection tools, operated at low pressure, are used not only for mask contamination control/monitoring but also for mask surface cleaning studies. It is desirable to characterize the EUVL mask surface inspection tools with contaminants commonly seen in vacuum processes. The conventional latex spheres are known to evaporate under the intense EUV beam. We have developed a method to deposit particles of known material and NIST-traceable sizes on the mask surface. Our method can produce particles with 98% size-uniformity. SiO_2 and other process generated particles with NIST-traceable sizes of 20 nm to 800 nm were separately deposited on quartz blank and coated masks with a controlled deposition spot size and number density. The technique enables the sizing and counting accuracies of the mask surface scanners to be determined. Some of the recent studies on mask deposition, AMC detection and control, and particle transport in low-pressure environment will be addressed in this presentation.

Presenting Author

David Y. H. Pui, a Distinguished McKnight University Professor, is the L.M. Fingerson/TSI Inc Chair in Mechanical Engineering and the Director of the Particle Technology Laboratory and of the Center for Filtration Research, University of Minnesota. He has a broad range of research experience in aerosol science and technology and has over 220 journal papers and 20 patents. He has developed/co-developed several widely used commercial aerosol instruments. He organized several successful international nanoparticle symposia to promote research cooperation especially among young scientists. Dr. Pui is a fellow of the American Society of Mechanical Engineers (ASME) and a fellow of the American Association for Aerosol Research (AAAR), and is a recipient of the Smoluchowski Award (1992), the Max Planck Research Award (1993), the International Aerosol Fellow Award (1998), the Humboldt Research Award for Senior U.S. Scientists (2000), and the David Sinclair Award (2002). He received the Fuchs Memorial Award at the International Aerosol Conference (IAC-2010) in Helsinki, conferred jointly by the American, German and Japanese aerosol associations.

P20

Comparison of Temporal Evolution of the EUV emission in Gadolinium and Tin Laser-Produced Plasmas

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We have developed a spectrometer consisting of a modified ISAN spectrometer, fitted with a short emission lifetime phosphor detector and gated intensified CCD camera, which is capable of tracking the temporal evolution of photon emission from plasmas with approximately 1 ns resolution, in the wavelength range 5 nm to 60 nm. In this paper we report our preliminary results for the time-resolved spectroscopic measurements of gadolinium and tin laser-produced plasmas gated for 2 ns and 5 ns with a 1 ns step. The plasmas were produced using a Nd:YAG laser at different power densities of 5.2×10^{11} W/cm^2 and 5.5×10^{12} W/cm^2 with laser spot diameters of approximately 140 μm and 40 μm respectively. In general, Sn 13.5 nm 2% in-band emission lasts longer than Gd 6.7 nm 0.6% in-band emission, with the Sn plasma emitting at over half its maximum intensity for approximately 9 ns and the Gd plasma emitting at over half its maximum intensity for approximately 2.5 ns.

P21

Resist-outgas Testing and EUV Optics Contamination at NIST

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I will summarize our ongoing studies of EUV-induced optics contamination and resist outgassing at the NIST synchrotron. I will discuss general trends and correlations observed during operation of our resist-outgas testing facility which uses only EUV photons rather than electrons. To identify any potential differences between electron- and photon-based outgas-testing systems, we plan to compare the atomic-H cleaning rates for deposits formed by electrons and photons. Results of a new effort to study the efficacy of atomic-H cleaning of non-carbon contaminants will also be presented. We have extended our work on general optics contamination, which previously revealed highly non-linear intensity and pressure scaling laws, to include studies of the wavelength dependence of EUV-induced contamination rates for several species at various pressures and intensities. We have found that between 50 nm and 80 nm the rates are all nearly an order of magnitude larger than the in-band rates at 13.5 nm, which themselves are roughly five times larger than rates for broad-band exposures centered at 10 nm. Recent, preliminary broad-band exposures at wavelengths spanning (120 to 200) nm suggest that the contamination rates decrease back towards the in-band rates beyond 80 nm.

This work is supported in part by Intel Corporation.

P22

Multilayer Mirrors for EUV: Status and Progress

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RIT continues to conduct research on improving performance of multilayer coatings for EUVL applications. During the last year we have been working on a capping layer development for collector optics, on enhancing reflectivity of multilayer mirrors for 13.5nm and 6.X nm wavelengths and improving thermal stability of our coatings. Progress on these new developments will be reported. Also we will present results on deposition of multilayers for 45 degrees illuminator optics, grazing and normal incidence optics designed for 13.5nm and 6.Xnm.

Presenting Author

Yuriy Platonov received MS degree in physics in 1977 from Moscow State University and PhD degree from Nizhny Novgorod State University in 1989. From 1978 to 1991 he worked at the Institute of Applied Physics of Russian Academy of Sciences (RAS) and his activities were focused on laser produced plasma diagnostics, pulsed laser deposition technology and multilayer X-ray optics. From 1991 to 1995 he ran the X-ray Optics Laboratory at the Institute for Physics of Microstructures of RAS. Since 1995 he is Director, Coatings and Senior Science Adviser at Rigaku Innovative Technologies, formerly Osmic. His field of scientific interests includes physics of artificial thin film structures, design and deposition of x-ray multilayer optical elements, X-ray analytical instrumentation, and multilayer neutron optics.

P23

Fundamental Property of 6.X-nm EUV Emission

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We have demonstrated a laser-produced plasma beyond extreme ultraviolet (BEUV) source with peak emission around 6.X nm, which was attributed to hundreds of thousands of near-degenerate resonance lines in an unresolved transition array (UTA) [1]. We have observed the variation of the spectral behavior and the conversion efficiency in Gd and/or Tb plasmas [2-7], and we would focus on the fundamental property for next generation lithography efficient BEUV sources.

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Presenting Author

Takeshi Higashiguchi is an associate professor. He received his Ph.D. in engineering from Utsunomiya University. His research activities have focused on short-wavelength light sources, laser-plasma interaction, and plasma photonics devices.

P24

Recovery Strategies for Mirrors with Boron Carbide-based Coatings for 6.x nm Lithography

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The introduction of 6.x nm lithography has established the need for boron carbide (B4C)- or boron (B)-based reflective multilayer coatings to be used in the mirrors and masks of the 6.x nm lithography systems. Inevitably, at some point during the operation of an EUV lithography tool, its multilayer-coated reflective components will have to be replaced after damage and/or contamination has occurred that prevents their efficient operation. It would be tremendously cost-efficient if, instead of manufacturing brand new optics as replacements, the multilayer optics could be repaired or their super-polished substrates recovered. This talk will present a survey of strategies for recovery of mirrors that have been coated with B4C-based thin films and will discuss the first experimental results from implementation of such strategies. Mirror recovery techniques include the options to (i) repair and preserve the damaged coating, or (ii) completely remove the damaged coating followed by recovery and re-coating of the super-polished mirror substrate. The experimental results that will be presented refer to grazing-incidence mirrors with single-layer B4C coatings for the Linac Coherent Light Source (LCLS) x-ray free electron laser (FEL)1. Degradation in LCLS mirrors is exhibited as carbon-containing deposits on top of the B4C coating surface, likely induced by interaction of the powerful FEL beam with residual hydrocarbons present in the mirror environment. The relevance and extendibility of these results to mirrors coated with B4C- or B-based multilayer coatings will be discussed.

1 R. Soufli, M. Fernández-Perea, S. P. Hau-Riege, S. L. Baker, J. C. Robinson, E. M. Gullikson, J. D. Bozek, N. M. Kelez, S. Boutet, "Lifetime and damage threshold properties of reflective x-ray coatings for the LCLS free-electron laser", Proc. SPIE **8077**, 807702 (2011).

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and by the University of California Lawrence Berkeley National Laboratory under Contract No. DE-AC03-76F00098. Funding was provided by SLAC National Accelerator Laboratory under DOE Contract DE-AC02-76SF00515.

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.

P25

Laser Assisted Vacuum Arc

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The use of tin discharge produced plasmas as a source of extreme ultraviolet (EUV) emission has been studied for many years and the issues it presents are well known. By utilizing a novel material like galinstan for EUV emission could yield solutions to some of these.

In this contribution we compare the EUV emission, fast ion yield and angular debris characteristics of both tin and galinstan using the Laser Assisted Vacuum Arc (LAVA-lamp) discharge. In this system a high-current discharge between two rotating electrodes covered with a thin liquid metal film is triggered by local laser ablation of this surface coating.

The comparison is made using the following techniques:

- absolutely calibrated time integrated EUV spectroscopy
- 2 µm spatially resolved time integrated in-band EUV imaging of plasma pinch region
- temporal characterisation of in-band EUV emission with a filtered fast photodiode
- time of flight diagnostic of ions with a Faraday cup
- characterisation of plasma constituent material by deposition analysis.

The obtained knowledge can be used for further optimisation of galinstan as a source e.g. conversion efficiency, source brightness, or total in-band EUV output.

Presenting Author

P26

EUV Multilayer Coatings: Potentials and Limits (Review Paper)

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High-reflective Mo/Si interference coatings are a key component for extreme ultraviolet lithography (EUVL) enabling the mass production of integrated circuits with nodes below 22 nm. Mo/Si multilayer coatings must meet stringent requirements in terms of maximum reflective performance and sufficient functional stability in order to be applicable in production EUVL systems. Recent advances in multilayer technology have enabled normal-incidence Mo/Si multilayers with over 70% reflectivity at 13.5 nm. This paper covers some theoretical considerations, prospects of modern interface-engineered strategy (interface barriers and capping layers) and deposition techniques for controlled fabrication of:

- high-reflective Mo/Si multilayers with R > 69% @ 13.5 nm,
- high-temperature Si-based multilayers operated up to 600°C,
- TiO_2- and Nb_2O_5-capped Mo/Si multilayers with enhanced radiation stability,
- broadband multilayer coatings with maximum integral reflectivity and
- B-based multilayers for future generation of EUVL (λ = 6.x nm).

The paper summarizes recent progress and the present knowledge in preparation of high-reflective multilayer coatings for EUVL with regard to minimum structure imperfections, enhanced thermal and radiation stabilities and different possibilities in broadening of the angular reflective response.

Presenting Author

Sergiy Yulin received MS degree in physics in 1989 from Kharkov State Polytechnic University and PhD degree from Kharkov State University in 1998. From 1989 to 1999 he worked at the Kharkov State Polytechnic University and his activities were focused on research and development of EUV/Soft X-ray optics on the base of artificial multilayer coatings. From 1999 to 2003 he ran the Soft-X-Ray and EUV-Coatings group at the Fraunhofer Institute for Applied Optics and Precision Engineering (IOF) in Jena. His field of interests includes physics of multilayer thin film structures, design and deposition of Soft-X-Ray and EUV multilayer optical elements. He has published over 40 scientific papers and patents.

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P27

Development of the Novel Evaluation Tool with an In-situ Ellipsometer for the Thickness Measurement of the Contamination Originated by the High Power EUV Irradiation on EUV Resist

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Extreme ultraviolet lithographic exposure requires the vacuum environment. The carbon is contaminated on a Mo/Si multilayer, which is originated by the outgassing species of the hydrocarbons decomposed from the resist material during EUV exposure. Thus the carbon contamination reduces the total reflectivity of the imaging optics and the mask to affect the lithographic performance such as the throughput and the resolution of the resist pattern replication. Since the carbon contamination should be reduced to maintain the lithographic performance, the relationship between the carbon contamination and the outgassing species from the resist material should be clarified. Therefore, the novel in-situ contamination thickness evaluation tool is developed and installed at the 10.8-m-long undulator BL9C beamline of NewSUBARU synchrotron radiation facility. Utilizing this tool, starting adhesion point was observed and the carbon contamination thickness can be evaluated using the same EUV light intensity level which is required in high volume manufacturing (HVM). The ion counting type QMS is attached to the novel contamination tool. The relationship between the carbon contamination and the outgassing species during the exposure of the high power EUV light can be clarified to reduce the contamination adhesion. In addition, the contamination adhesion by EUV light and e-beam should be compared.

Presenting Author

Takeo Watanabe received his Ph.D from Osaka City University in 1990. He is associate professor in the Center for EUV, Laboratory of Advanced Science and Technology for Industry, University of Hyogo. He is an expert of the EUV lithographic technology, including optics, exposure tool, mask and resist technologies. And his current work is focused on the research and development of EUV resist material and process. He has authored over 150 technical papers, and he is the EUVL session chair, the organizing committee member, and the program committee member of the International Conference of Photopolymer Science and Technology (ICPST).

P28

Chemical Reaction Analysis based on the SR Absorption Spectroscopy for the High Sensitive EUV Resist

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The top issue of EUV lithography is to achieve a high power and a long stability EUV source for high volume manufacturing. To relax the specification of the EUV power and maintain the high-lithographic throughput, high sensitive EUV resist is required. And to keep the electric performance of the electronic devices, low LER of EUV resist is also required. To satisfy these requirements the acid-production yield should increase. The dominant chemical reaction is proposed to be the ionization reaction to produce the secondary electron. However, the acid-production yield is limited when taking account of only this reaction mechanism. Thus other reaction mechanism should be taken account. The chemical reaction analysis by the SR absorption spectroscopy was carried out utilizing BL07B beamline at NewSUBARU synchrotron radiation facility. The direct excitation might be occurred in the PAG system to produce acid during EUV exposure and multiple reactions were seemed to be occurred to produce the acid from the PAG of TPS-imidate type during EUV exposure. To achieve high sensitivity of EUV resist, ionization and direct excitation should be taken into account.

Presenting Author

Takeo Watanabe received his Ph.D. from Osaka City University in 1990. He is associate professor in the Center for EUV, Laboratory of Advanced Science and Technology for Industry, University of Hyogo. He is an expert of the EUV lithographic technology, including optics, exposure tool, mask and resist technologies. And his current work is focused on the research and development of EUV resist material and process. He has authored over 150 technical papers, and he is the EUVL session chair, the organizing committee member, and the program committee member of the International Conference of Photopolymer Science and Technology (ICPST).

P29

Status and Challenge of Chemically Amplified Resists for Extreme Ultraviolet Lithography (Review Paper)

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The development status of extreme ultraviolet (EUV) lithography approaches the requirements for the high volume production of semiconductor devices with the minimum line width of 22 nm. For the development of resist materials toward 16 and 11 nm nodes, the trade-off relationships between resolution, line edge roughness (LER), and sensitivity is the most serious problem. In particular, the reduction of LER is a difficult task. In this paper, the status and challenge of resist technology are discussed from the viewpoint of the feasibility of 16 and 11 nm fabrication. In addition to the overall review of EUV resist technology, the acid generator, the anion of which is bound to the polymer through a covalent bond, and the short wavelength EUV lithography are discussed. The potential of anion-bound resists is discussed on the basis of its reaction mechanism. The challenge in the development of resist materials for the short wavelength EUV is discussed from the viewpoint of sensitivity and resolution blur caused by secondary electrons.

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.

P30

Modeling, Benchmarking, and Optimization of EUV Sources for Lithography

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Laser- and discharge-produced plasmas (LPP, DPP) are currently the promising sources of an efficient EUV output for advanced lithography. Optimization of source parameters is very important to enhance conversion efficiency, minimize plasma debris, and increase overall device lifetime. For example, in LPP devices, optimum laser pulse parameters with adjusted wavelength/energy/duration ablating simple planar or spherical tin target can provide 2-3 % coefficient efficiency (CE) in laboratory experiments and in agreement with simulation results. Additional effects such as ablation of target with complicated geometry or tin-doped targets including pre-pulsing technique can also significantly increase CE. Recent investigations showed that such LPP system improvements allow reducing laser energy loses by decreasing photons transmission (third or higher harmonics of Nd:YAG laser) or photons reflection (for CO_2 laser). Also optimization of target heating using pre-pulses or ablating low-density and porous tin oxide can improve LLP source by creating efficient plasma plume and as a result increase CE. Second important challenge in the developing LPP devices is decreasing fast ions and target debris to protect the collecting system and increase its lifetime. Mass-limited targets such as small tin droplets are considered among the best choices for cleaner operation of the optical system because of lower mass of atomic debris produced by the laser beam. The small diameter of droplets, however, can decrease the conversion efficiency (CE) of EUV photons emission, especially in the case of CO_2 laser, where laser wavelength has high reflectivity from the tin surface. We studied ways of improving CE in mass-limited targets. We considered in our modeling various possible target phases and lasers configurations: from solid/liquid droplets subjected to laser beam energy with different intensities and laser wavelength to dual-beam lasers, i.e., a pre-pulse followed by a main pulse with adjusted delay time in between. We studied the dependence of vapor expansion rate, which can be produced as a result of droplet heating by pre-pulse laser energy, on target configuration, size, and laser beam parameters. For better understanding and more accurate modeling of all physical processes occurred during various phases of discharge/laser beam/target interactions, plasma plume formation and evolution, EUV photons emission and collection, we have implemented in our HEIGHTS package state-of-the art models and methods, verified, and benchmarked against laboratory experiments in our CMUXE center as well as various worldwide experimental results.

Presenting Author

Prof. Ahmed Hassanein is the Paul L. Wattelet Prof. and Head of the School of Nuclear Engineering at Purdue University. He holds five engineering degrees (B.Sc., 3 M.Sc., and Ph.D.) in nuclear engineering and physics from Alexandria University and the University of Wisconsin. He has more than 30 years of experience in research and development in the fields of nuclear and plasma physics, engineering, and material science. Nationally and internationally recognized as one of the world's foremost leaders in the area of modeling and benchmarking material responses to different radiation and plasma sources. Developed unique models and comprehensive computer packages as well as state-of-the art experimental facilities to predict material behavior, lifetime issues, plasma evolution, and fluid hydrodynamics under various irradiation conditions. These models and results are being used in several national and international research fields.

He authored more than 400 journal publications and technical reports in more than 30 different Journals in many fundamental science areas including radiation damage and materials' lifetime, laser and discharge produced plasmas, hydrodynamics, heat transfer, particle diffusion and transport, atomic and plasma physics, photon and radiation transport, thermal hydraulics, molecular dynamics, and biomedical. He was the General Chair of the 38th IEEE International Conference on Plasma Science (ICOPS-2011). He is currently Fellows of SPIE, IEEE, and AAAS.

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HEIGHTS Simulation and Optimization of EUV Sources Using Mass-limited Targets

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Current challenges in the development of efficient laser produced plasma (LPP) sources for EUV lithography are the demand for higher EUV power at IF and maximizing the lifetime of source components. Hence, further development of LPP devices for EUVL should be based on mass-limited targets such as tin droplets with 10-100 μm diameters illuminated using CO_2 lasers. However, smaller sizes of target and high reflectivity of the 10 μm laser from solid/liquid tin are main reasons of the low EUV intensity source and the reduced volume of EUV emitting area created by such wavelength that also results in low conversion efficiency. Pre-plasma created by shorter pre-pulse laser wavelength extends the suitable absorption area for the main CO_2 pulse wavelength. Optimization of EUV sources from small droplet targets using dual laser pulses depends on many parameters and requires detailed analyses of pre-plasma conditions. Mainly lasers with shorter wavelengths (harmonics of Nd:YAG) can be used for creation of the pre-plasma since they have better absorption in solid and liquid matter. The CO_2 laser can then be the best choice for the second stage, i.e., EUV production stage, since the evolving plasma plumes are more suitable for the absorption of such longer laser wavelength.

We investigated ways of improving CE from mass-limited targets. We studied in details the combined effects of pre-pulsing with various parameters and different sizes of tin droplets on EUV conversion efficiency using our full 3D integrated multi-physics HEIGHTS package.

Presenting Author

P32

Component Technologies of HVM Source for Reliable, High Average Power Operation (Review Paper)

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Basic architecture of 13.5nm HVM source is well established in laboratory in 10Hz operation mode. Two distinguished characteristics are short pulse CO_2 laser irradiation of dispersed Sn clusters in guiding magnetic field for full evacuation. This method is scalable to the next stage of the wavelength (6.7nm), namely Gd as the active media, which is to be fully recycled for low cost operation. High repetition rate operation needs upgrade of component technologies in laser technologies. The first one is high duty gas isolator for high average power CO_2 laser and the second one is picosecond pre-pulse solid state laser. It is shown that picosecond plasma generates lower energy ions for equivalent droplet dispersion, and easier to control the vapor to guide in the magnetic field to particle traps positioned outside the active region. Thin disc laser technology is explained for this specific application.

Presenting Author

Akira Endo received his doctoral degree from Tokyo Institute of Technology in 1981 by an experimental study of high pulse energy, short pulse gas lasers. He worked in Institute of Solid State Physics, University of Tokyo, Max Planck Institute for Biophysical Chemistry in Gottingen, Germany, and appointed as a research leaders in "Femtosecond Technology" project under MITI, and "EUV Lithography" under METI. His research covers from high pulse energy, short pulse lasers to EUV/X-ray generation by plasma and laser Compton scheme. He is now a research manager in "HiLase" project in Czech Republic, and contributing to establish architecture of high beam quality, high pulse energy solid state laser based on thin disc configuration.

P33

Development of Actinic Mask Inspection Systems

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Actinic mask inspection systems for EUVL is being developed. One is EUV Microscope on which a magnification mirror was additionally attached. Up to now, 88 nm-width patterns were clearly observed on X-ray CCD camera. The other is coherent scatterometry microscope with high harmonic generated fs laser source. Recently, full coherent 13.5nm source with a power of 1μW and the divergence of 0.17 mrad has been completed. Using this source, defects less than 2 nm and CD measurements with a 3σ accuracy of 0.13 nm has been observed.

Presenting Author

Hiroo Kinoshita is an expert with over 35 years' experience in lithography. He worked for NTT, where he developed the step and repeat x-ray lithography system and an EUVL experimental system. He moved to the Himeji Institute of Technology (now the University of Hyogo) in 1995, and since then he has been responsible for the industrial application of EUVL. He has authored over 150 technical papers. He is a fellow of the Japan Society of Applied Physics.

P34

Possibility of EUVL system at the Wavelength of 6.8 nm

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From the reasons of the delay of development of a light source etc., introduction of EUVL is set to the pattern line width to 22nm or subsequent ones. Fabrication of 11nm generation is difficult also considering NA of 0.4 on the wavelength of 13.5nm. For this reason, there is a proposal which sets a wavelength to 6.8nm.
However, the material system consisting multilayer which has high reflectance with a wavelength of 6.8nm is not found. Although the multilayer made of B4C as a light element is advancing, the report which exceeded 40% during recent 20 years is not made. Moreover, the FWHM of the multilayer reflectivity is less than half of Mo/Si and the integrated reflectivity which contributes to exposure decreases to 1/5. Although the transmission of resist becomes high, sensitivity becomes about 1/5 of the present 13.5 nm condition. Consideration of the multilayer reflectance and sensitivity of resist the efficiency reduces to 1/25 with a wavelength of 13.5nm.

Considering the present light source power, I think that the exposure system set to 6.8 nm is very difficult.

Presenting Author

Hiroo Kinoshita is an expert with over 35 years' experience in lithography. He worked for NTT, where he developed the step and repeat x-ray lithography system and an EUVL experimental system. He moved to the Himeji Institute of Technology (now the University of Hyogo) in 1995, and since then he has been responsible for the industrial application of EUVL. He has authored over 150 technical papers. He is a fellow of the Japan Society of Applied Physics.

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EUV Resist Development Status Toward sub-20nm Half-Pitch

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As semiconductor technologies are proceeding, industry is requiring sub-20nm half pitch lithography for device manufacturing. ArF immersion lithography is still at leading edge, however multiple process to extend ArF immersion lithography causes several limitation, such as cost of ownership increase, limitation of process margin so on. Extreme-Ultra-Violet (EUV) lithography as high volume device production is long-awaiting technology to solve a number of conflicts. Many technical barriers of EUVL have been overcome. Resist is also one of the difficulties of EUVL. We already reported 16nm half pitch resolution at SPIE in 2011. However, the performance was not enough, such as line-edge-roughness, sensitivity and process margin. In this workshop, we report the progress of EUV resist development and its concept of chemical design. Polymer dissolution contrast, PAG acid diffusion length suppression and additional process are items to step-up the lithographic performance.

Presenting Author

Toru Kimura obtained master of engineering at Tokyo Institute of Technology in 1997. Then he joined Japan Synthetic Rubber Co., Ltd. (Change name to JSR Corporation in 1997). In 1997, he was assigned to Tsukuba Laboratories to study photo-sensitive polymers.

He started photo resist study in 2003 in JSR Yokkaichi Research Center and then moved to JSR Micro NV in Belgium in 2004. At IMEC he developed ArF immersion materials. He returned to Japan in 2009 and started EUV materials development as technical manager at JSR Yokkaichi Research Center.

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Optical Design of Absorber Materials for Reduced H-V CD Bias in EUV Lithography

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Shadowing effect is a unique phenomenon caused by using mirror-based mask with oblique incident angle of light, and this results in a horizontal-vertical (H-V) critical dimension (CD) bias. Acoording to the previous reports, H-V CD bias increses abruptly with decreasing pattern size and the current Ta-based absorber with ~70nm thickness is inappropriate for 16nm printing with 0.32 NA system. Some group reported thin absorber stack with phase shift layer to reduce H-V CD bias, but simultaneous variation of phase and reflectivity caused limitation of its application. But we reported improved mask performance of enhanced image contrast as well as reduced H-V CD bias with attenuated PSM by using Mo phase shifter which has similar reflractive index with TaN absorber layer. During the optimization of our PSM, it was observed that the absorber stack is required to have higher reflectivity when the pattern size becomes smaller.

In this paper, we report the effect of thickness and optical constant of the absorber stack on the variation of H-V CD bias. The analysis of aerial image was performed by using EM-suite simulation tool. We applied the illumination conditions of the PPT (ASML NXE:3100, NA=0.25, σ=0.8) and the HVM (ASML NXE:3300, NA=0.33, σ=0.9) with a conventional circular illumination.

We have concluded that the H-V CD bias originates from the asymmetry of the near field intensities between left and right sides of the absorber pattern. And we have found that the thick absorber stack should have lower reflectivity while thin absorber stack should have higher reflectivity for reduced H-V CD bias. The detailed simulation process and results will be presented during the presentation.

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Presenting Author

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Strategies for Cleaning EUV Optics, Masks and Vacuum Systems with Downstream Plasma Cleaning.

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One cause of reduction in reflectivity on extreme ultraviolet (EUV) optics and masks is carbon contamination. This reduction will decrease the throughput of an EUV lithography tool. Removing carbon contamination from EUV optics and masks can be accomplished by using downstream plasma cleaning with a variety of gases such as oxygen gas mixtures and hydrogen. The carbon contamination is removed by radicals created by the downstream plasma.

In this paper two strategies are discussed which can be used to decontaminate EUV optics, masks and vacuum systems. The first strategy cleans the EUV entire chamber, optics and masks included, by operating the downstream plasma cleaner from a port on the chamber. The drawback to this strategy is that slower cleaning will occur in regions of the tool further away from the cleaner. The second strategy is to bring the plasma close to the EUV optic or mask to be cleaned. This strategy has been demonstrated with plasma cleaners used to remove contamination from Transmission Electron Microscopes (TEMs), in which the cleaner is inserted into the TEM like a sample holder and the plasma is created near the pole pieces of a TEM where cleaning action will be most effective.

Presenting Author

Dr. Gabe Morgan received his B.S. in Chemistry from Humboldt State University in 1991 and his Ph.D. in Chemistry from the University of California, Santa Barbara in 1997. After postdoctoral work at Caltech and SRI International, he joined XEI Scientific, Inc. in 2007. At XEI he has been researching solutions to the problem of contamination in vacuum chambers, including systems used in EUV lithography.

P43

Recent Developments in Construction of Metrology, Calibration, and Resist Testing Tools for the Successful HVM Implementation of EUV Lithography

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EUV Technology has pioneered the development of several of stand-alone inspection, metrology, calibration, and resist outgassing testing tools for EUV lithographic applications that can be operated in a clean room environment on the floor of a fab. EUV Technology is the world's leading manufacturer of EUV metrology and testing tools. One of the principal challenges in the ongoing EUVL research effort is the development of necessary at wavelength metrology tools and resist outgassing and testing tools.

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With the recent development of a resist out-gassing testing system equipped with both an in-band EUV photon excitation source and an e-beam exposure capability, a direct comparison of resist outgassing for two modes of excitations was obtained. Measurements were performed in an ultra-clean measuring chamber equipped with a high sensitive residual gas analyzer (RGA), so as not to add background (non-resist related) contamination and a separate electron gun illuminates the witness sample for cracking hydrocarbons during exposure.

Due to practical limitations, very little published results are available verifying that the electron induced resist outgassing is equivalent to the EUV induced resist outgassing. Recent RGA and optics contamination results from several EUV sensitive resists using in-band EUV photon excitation and an e-beam excitation under same measurement conditions will be presented.

In addition, an overview of our planed development activities HVM metrology tools for EUV Lithography will be presented along with the challenges in developing these HVM tools in order to support the successful implementation of EUV Lithography.

Presenting Author

P44

Inverse Compton Source for EUVL Metrology

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RadiaBeam Technologies has been actively involved in the development of high repetition rate Inverse Compton Scattering (ICS) X-ray sources since 2008, and is currently conducting a pilot experiment on an ICS system scalable to Extreme Ultraviolet Lithography (EUVL) wavelength range, in collaboration with the Accelerator Test Facility at Brookhaven National Laboratory. Here we describe a novel technical approach towards increasing EUVL ICS average power by utilizing a high repetition rate normal conducting RF photoinjector and an active CO2 laser cavity, which compensates the laser re-circulation optical losses via re-amplification. The end use EUVL ICS dedicated system would be a relatively inexpensive and compact source with brightness of ~ 100 W/mm^2-sr-0.1% at 6.7 nm wavelength, suitable for EUVL metrology applications.

Presenting Author

Pedro Frigola received his B.S. and M.S. in Physics from the University of California, Los Angeles (UCLA) in 2000. He served as a Staff Research Associate at UCLA's Particle Beam Physics Laboratory (PBPL) where he was central to the design, construction, and measurement efforts for undulator magnets and photoinjector fabrication projects. In 2004 he co-founded RadiaBeam Technologies, a company that manufactures particle accelerator components, diagnostics and turnkey accelerator systems, where he is currently leading the development of several RF photoinjector projects.

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High CE Technology for HVM EUV Source

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Since 1989, EUV microlithography technology has been developed for future lithography. In this paper we look back at the history outline and report the latest development activities of EUV light source. We have been developing CO_2-Sn-LPP EUV light source which is the most promising solution as the 13.5nm high power light source for HVM EUVL. Unique original technologies such as; combination of pulsed CO_2 laser and Sn droplets, double laser pulse shooting and mitigation with magnetic field have been developed in Gigaphoton Inc. The theoretical and experimental data have clearly showed the advantage of our proposed strategy. We reported engineering data from our test tools such as 20W average clean power, CE=2.5%, 7 hours operation. We have also demonstrated the maximum 4.7% CE with 20 μm droplet, 93% Sn ionization rate by double laser shooting scheme and 98.5% Sn debris mitigation by magnetic field using small size 10 Hz experimental device. Based on these data we are developing first practical source for HVM; "GL200E". The latest data and the overview of EUV light source for the HVM EUVL will also be reported.

Presenting Author

Dr. Hakaru Mizoguchi is the Director and Chief Technology Officer of Gigaphoton Inc. and member of The International Society of Optical Engineering, The Laser Society of Japan and The Japan Society of Applied Physics.
Mizoguchi received a diplomat degree in plasma diagnostics field from the Kyushu university, Fukuoka, Japan in 1982 and join Komatsu ltd.. He joined CO_2 laser development program in Komatsu for 6 years. After that he was guest scientist of Max-Plank Institute Bio-Physikalish-Chemie in Goettingen in Germany two years, from 1988 to 1990. Since 1990 he concentrated on KrF, ArF excimer laser and F_2 laser research and development for lithography application. He was general manager of research division in Komatsu Ltd. until 1999. He got Dr. degree in high power excimer laser field from Kyushu university in 1994. In 2000 Gigaphoton Inc. was founded. He was one of the founders of Gigaphoton Inc.. From 2002 to 2010 he organized EUV research group in EUVA program. Now he is promoting EUV light source product development with present position.

Shinji Okazaki received his BS and PhD degrees in electrical engineering from Tokyo Institute of Technology. He joined Central Research Laboratory, Hitachi Ltd., in 1970. From 1970 to 1976, he involved in the development of compound semiconductor devices. During this period, he worked on the development of electron beam direct writing (EBDW) technology and mask writing technology. He stayed at Rensselaer Polytechnic Institute from 1980 to 1981 as a visiting researcher where he worked on the fine patterning technology. After coming back to Hitachi in 1981, he continued the development of EBDW technology. He also involved in the development of resolution enhancement technologies for optical lithography from 1983. July in 1998, he was assigned as a research manager of EUV laboratory at ASET. Since April in 2002 to March 2007, he was a director of EUV Process Technology Research Department of ASET. After finishing ASET EUVL program, he returned to Hitachi Central Research. In April 2009, he moved to Gigaphoton Inc.(GPI) and assigned as a chief researcher and a director of general affairs at EUVA. After finishing EUVA Project at the end of March 2011, he returned to GPI. Currently he is an advisor to general manager in EUV development division of GPI

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