2013 International Workshop on EUV Lithography

June 10-14, 2013

Makena Beach & Golf 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 2013 International Workshop on EUV Lithography in Maui, Hawaii. In this leading workshop, with a focus on R&D, researchers from around the world will present the results of their EUVL related research. As we all work 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. I look forward to your participation.

Best Regards

Vivek Bakshi
Chair, 2013 International Workshop on EUVL

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Workshop Agenda

2013 International Workshop on EUV Lithography

Makena Beach & Golf Resort, Maui, Hawaii, USA

June 10-14, 2013

Workshop Agenda Outline

Monday, June 10, 2013

8:30 AM -5:00 PM

EUV Lithography Short Course (Kaeo Ballroom)

Tuesday, June 11, 2013

3:00 PM - 5:00 PM

Registration (Kaeo Ballroom Foyer)
Speaker Prep (Wailea Salon)

6:00 PM - 7:30 PM

Reception (Pacific Lawn)

Wednesday, June 12, 2013

7:30 AM – 8:30 AM	Breakfast (Café Kiowai)
8:30 AM – 11:35 AM	Oral Presentations (Wailea Salon)
11:35 AM – 12:25 PM	Lunch (Molokini Room)
12:25 PM – 3:45 PM	Oral Presentations (Wailea Salon)
3:45 PM	Afternoon off for Networking

Thursday, June 13, 2013

7:30 AM – 8:30 AM Breakfast (Café Kiowai)

8:30 AM – 12:00 PM Oral Presentations (Wailea Salon)

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

1:00 PM – 5:00 PM Oral Presentations (Wailea Salon)

5:00 PM - 6:00 PM Poster Session

6:30 PM – 8:00 PM Dinner (Pacific Lawn)

Friday, June 14, 2013

8:30 AM – 10:00 AM EUVL Workshop Steering Committee Meeting
(Kaeo Ballroom)

2013 International Workshop on EUV Lithography

Makena Beach & Golf Resort, Maui, Hawaii, USA
June 10-14, 2013

Workshop Agenda

Monday, June 10, 2013

Short Courses

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

8:30 AM -5:00 PM

Tuesday, June 11, 2013

Registration and Reception

3:00 PM- 5:00 PM	Registration & Speaker Prep
6:00 PM- 7:30 PM	Reception

Wednesday, June 12, 2013

8:30 AM Welcome and Introduction

Introductions (Intro-1)
Vivek Bakshi
EUV Litho, Inc., Austin, TX, USA

Session 1: Keynote Presentations

EUVL in HVM: Prospects and Challenges (P1)
Sam Sivakumar
Portland Technology Development, Intel Corporation

EUVL Challenges for Next Generation Devices (P2)
Tatsuhiko Higashiki
TOSHIBA Corporation Center for Semiconductor & Storage Products Company
Lithography Process Technology Dept.

Break

Session 2: Panel Discussion: EUVL HVM Insertion and Scaling

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Panelists Presentations:

Sam Sivakumar (P72)
Intel Corporation

Sushil Padiyar (P74)
Applied Materials

Tatsuhiko Higashiki (P71)
TOSHIBA

Pawitter Mangat (P73)
GlobalFoundries

11:35

Group Photograph

Lunch

Session 3: Contamination

Contamination Control in EUV Exposure Tools (P22) (Invited)
Katsuhiko Murakami, Noriaki Kandaka, Takashi Yamaguchi, Atsushi Yamazaki, Tsuneyuki Hagiwara, Tetsuya Oshino, Jiro Inoue and Kazuya Ota
Nikon Corporation

Outgassing, Photoablation and Photoionization of Organic Materials by the Electron-impact and Photon-impact Methods (P23) (Invited)
Grace H. Ho, Yen-H. Huang, Chih-H. Shao, Hung-M. Lin, Jia-J. Sung and Chen-Y. Yeh
Department of Applied Chemistry, National University of Kaohsiung, Nanzih, Kaohsiung 811, Taiwan

Measurements of the Role of Secondary Electrons in EUV Resist Exposures (P29) (Invited)
Greg Denbeaux
College of Nanoscale Science and Engineering, University at Albany, NY

Advancements in Understanding Plasma Cleaning (P27)
E. Kosmowska, D. Varley, R. Vane, and C. Moore
XEI Scientific, Redwood City, CA 94063

Break

Session 4: Optics

Multilayer Mirrors for EUVL: Progress status (P52) (Invited)
Yuriy Platonov, Michael Kriese, Vladimir Martynov, Raymond Crucet, Yang Li, Bodo Ehlers, Jim Rodriguez, Licai Jiang
Rigaku Innovative Technologies, 1900 Taylor Rd., Auburn Hills, MI 48326, USA

EUV related Technology Development at L-3 Integrated Optical Systems (P51) (Invited)
Viswa Velur
Commercial Optical Systems, L-3 Communications

GI Collectors for EUV/BEUV Sources for Metrology (P53) (Invited)
Ladislav Pina
Rigaku Innovative Technologies Europe, 142 21 Prague 4, Czech Republic

A New Design Method for Extreme Ultraviolet Lithographic Objective
Yanqiu Li, Zhen Cao, Fei Liu and Qiuli Mei
School of Optoelectronics, Beijing Institute of Technology, Beijing 100081, China

Adjourn: Time off for Networking

End Day 1

Day 2: Thursday, June 13, 2013

Welcome and Introduction (Intro-2)
Vivek Bakshi
EUV Litho, Inc.

Session 5: Regional Review of EUVL Activities

EUVL Activities in Japan (P61)
Takeo Watanabe
Hyogo University

EUVL Activities in Europe (P62)
Padraig Dunne
University College Dublin, Ireland

EUVL Activities in USA (P63)
Gregory Denbeaux
University of Albany, USA

EUVL Activities in S. Korea (P64)
Jinho Ahn
Hanyang University, S. Korea

EUVL Activities in Taiwan (P65)
Yang-Tung Huang
National Chiao Tung University, Taiwan

EUVL Activities in China (P66)
Yanqui Li
Beijing Institute of Technology, China

Break

Session 6: EUV Sources

Progress in Laser-Plasma Sources – 13.5 nm & Beyond (P12)
Padraig Dunne[1], Takeshi Higashiguchi[2], Takamitsu Otsuka[1,2], Weihua Jiang[3], Akira Endo[4], Bowen Li[1], Colm O'Gorman[1], Thomas Cummings[1], Patrick Hayden[1], Tony Donnelly[1] Fergal O'Reilly[1] and Gerry O'Sullivan[1]
[1]*School of Physics, University College Dublin, Belfield, Dublin 4, Ireland*
[2]*Utsunomiya University, Utsunomiya, Japan*
[3]*Nagaoka University of Technology, Nagaoka, Japan*
[4]*HiLASE Project, Institute of Physics AS, CR, Prague 8, Czech Republic*

Modeling of Laser-plasma Interaction for EUV Sources toward Higher Power and Efficiency (P14)
Akira Sasaki
Quantum Beam Science Directorate, Japan Atomic Energy Agency, 8-1 Umemidai, Kizugawa-shi, Kyoto 619-0215, Japan

Electrodeless Z-Pinch EUV Source for Metrology Applications (P15) (Invited)
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, USA 01801

High Brightness LPP Light Source for Inspection Applications at High Volume Manufacturing (P16)
Bob Rollinger
ETH Zurich, Switzerland

Lunch

Session 7: EUV Masks

Remaining Challenges for EUV masks for HVM introduction (P33) (Invited)
Pawitter Mangat
Global Foundries

Recent Activities of the Actinic Mask Inspection using the EUV Microscope at Center for EUVL (P32) (Invited)
Takeo Watanabe, Tetsuo Harada, and Hiroo Kinoshita
Center for EUVL, University of Hyogo

Improved Photon Shot Noise Effect on LWR by using attenuated PSM for EUVL

Seejun Jeong[1], SeongChul Hong[2], Jae Uk lee[2], Seung Min Lee[2], Jung Sik Kim[3], and Jinho Ahn[1,2,3]
[1]Department of Convergence NanoScience, [2]Department of Materials Science and Engineering, [3]Department of Nanoscale Semiconductor Engineering, Hanyang University, Seoul 133-791, Korea

Break

Session 8: EUV Resist and Patterning

Development of Novel Molecular Resist Materials based on Ladder-Type Cyclic Oligomers for Extreme Ultraviolet Laser Exposure System (P41) (Invited)

Hiroto Kudo and Shuhei Matsubara
Department of Chemistry and Materials Engineering, Faculty of Chemistry, Materials and Bioengineering, Kansai University, Suita-shi, Osaka, 564-8680, Japan

New Approach for Reducing the Out of Band effect and Outgassing by Applying Top Coat Materials (Outgassing and Out-of Band Protection Layer: OBPL) (P42) (Invited)

Rikimaru Sakamoto, Ryuji Onishi, Noriaki Fujitani, Hiroaki Yaguchi
Nissan Chemical Industries, LTD, Electronic Materials Research La, 635 Sasakura, Fuchu-machi, Toyama, 939-2792, Japan

EUV Resist Development for 16 nm Half Pitch (P43) (Invited)

Yoshi Hishiro
JSR Micro Inc.

Stochastic Effects in Chemically Amplified Resists for Extreme Ultraviolet Lithography (P44) (Invited)

Takahiro Kozawa[1], Julius Joseph Santillan[2], and Toshiro Itani[2]
[1]The Institute of Scientific and Industrial Research, Osaka University
[2]EUVL Infrastructure Development Center, Inc. (EIDEC)
8-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan (Osaka Univ.)

Recent Activities of the EUV Resist Research and Development at Center for EUVL (P45) (Invited)

Takeo Watanabe, Tetsuo Harada, and Hiroo Kinoshita
Center for EUVL, University of Hyogo

Sub-10nm HP Patterning using EUV based Self-Aligned Double Patterning (P46)
Sushil Padiyar
Applied Materials

EUVL Workshop Summary (P90)
Vivek Bakshi
EUV Litho, Inc.

Break

5:00- 6:00 PM Poster Session

Session 10: Poster Session

STAN – A Compact Light Source for EUV and Beyond (P13)
Padraig Dunne[1,2], Fergal O'Reilly[1,2], Paul Sheridan[1,2] and Kenneth Fahy[1,2]
[1]*School of Physics, University College Dublin, Belfield, Dublin 4, Ireland*
[2] *NewLambda Technologies, Science Centre North, Belfield, Dublin 4, Ireland.*

Characteristics of Ion Debris from Laser Produced Tin Plasma in Ambient Gas and Magnetic Field (P11)
Wang Xinbing[1], Zuo DuLuo[1], Lu Peixiang[2]
[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*

Calculation of the Optical Constants Using X-ray Reflectometer for Verifying the Optical Design of the Attenuated Phase Shift Mask (P34)
Seung Min Lee[1], Jae Uk Lee[1], Seongchul Hong[1], Seejun Jeong[2], Jung Sik Kim[3], and Jinho Ahn[1,2,3]
[1]*Department of Materials Science and Engineering,* [2]*Department of Convergence NanoScience,* [3]*Department of Nanoscale Semiconductor Engineering, Hanyang University, Seoul 133-791, Korea*

Experimental Study of EUV Vacuum Material Outgassing (P21)
Xiaobin Wu[1], Caixing Li[2]
[1]*Academy of Opto-Electronics, Chinese Academy of Sciences, Beijing 100094, China*
[2]*Bureau of High-Tech Research and Development, Chinese Academy of Sciences, Beijing, 100864, China*

Electron-impact and Photon-impact Ionization of Organic Solvents in the Threshold-200 eV Range (P24)
Yen-H. Huang, Zin-X. Yang, Grace H. Ho*, Hung-M. Lin, Chia-Y. Chou, Chao-C. Yang, Pei-C. Lo
Department of Applied Chemistry, National University of Kaohsiung, Nanzih, Kaohsiung 811, Taiwan

Optical Properties and Photoablation of Photosensitive Films by 13.5 and 6.7 nm Light (P25)
Chen-Y. Yeh,[1] Jia-J. Sung,[1] Grace H. Ho*,[1] Hsuan-T. Chang,[1] Yi-Y Kuo,[1] Yu-C. Tzeng,[1] Chih-W. Yeh,[1] Hok-S. Fung[2] 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 300, Taiwan*

Quantitative Outgassing Study of Photosensitive Films upon Irradiation at 13.5 and 6.7 nm (P26)

Hung-M. Lin, Yen-H. Huang, Chi-H. Shao, Grace H. Ho,* Chen-Y. Yeh, Chieh Huang, Ho-X. Yen, Yen-H. Huang and Jia-H. Kang
Department of Applied Chemistry, National University of Kaohsiung, Nanzih, Kaohsiung 811, Taiwan

Comparison of O_2-N_2 and H_2 Plasma Cleaning for EUV Applications (P28)

E. Kosmowska, D. Varley, R. Vane, and C. Moore
XEI Scientific, Redwood City, CA 94063

Friday, June 14, 2013

8:30 AM - 10:00 AM

EUVL Workshop Steering Committee Meeting (Kaeo Ballroom)

8:30 AM - 9:00 AM Breakfast

9:00 AM – 10:00 AM Steering Committee Meeting

Abstracts

(Listed by Paper number)

P1

EUVL in HVM: Prospects and Challenges

Sam Sivakumar

Portland Technology Development, Intel Corporation

There are two main paths for improving lithography capability to keep pace with Moore's Law scaling. The historical choices are to increase the numerical aperture (NA) of the exposure tool and to reduce the wavelength of the illumination. ArF immersion lithography which is the mainstay of lithography currently has run out of further increases in NA. This means that the industry faces two choices – continue to stay on ArF immersion with an ever increasing number of masks required for multiple patterning, or switch wavelengths. Due to the cost and complexity of multiple patterning on ArF, EUV lithography is being increasingly counted on to deliver cost-effective performance for next generation lithography. However, the challenges to EUV lithography are formidable – from the source to the scanner hardware to photoresists and reticles, all aspects of lithography has to be re-engineered and this has been the focus of thousands of engineers at supplier and end user companies around the world for several years now. This paper gives an update on the engineering status of EUV lithography, the key focus areas where further improvement is necessary and ongoing, and the key challenges to HVM implementation.

Presenting Author

Sam Sivakumar is an Intel Fellow and Director of Lithography in Intel's Portland Technology Development Group in Oregon, which he joined in 1990 after graduating from the University of Illinois. He is currently responsible for the definition and development of Intel's next generation lithography processes, resolution enhancement technologies and OPC. He is also responsible for EUV development at Intel and the implementation of EUV into HVM.

P2

EUVL Challenges for Next Generation Devices

Tatsuhiko Higashiki

TOSHIBA Corporation Center for Semiconductor & Storage Products Company
Lithography Process Technology Dept.

The pattern shrinking for lithography has been required for long time. The technologies of next generation lithography are studying for hp 20nm and beyond devices such as Quadra patterning of ArF immersion with spacer process, EUVL, NIL (nano imprint lithography), and DSA (directed self assembly). Each technology has risks in engineering and economical challenges. Quadra patterning problems are opportunity cost loss from optimization of process condition and the difficulty of CD control.

In future, some of devices will need sub-10nm node lithography. We have to prepare next EUVL technology such as high NA EUVL or EUV+DSA complementary lithography. In this paper, challenges of innovative next generation EUVL technologies and expectation of infrastructures will be discussed.

Presenting Author

Tatsuhiko Higashiki is a senior manager of advanced lithography and mask process department in TOSHIBA Semiconductor & Storage Product Company. He joined Toshiba in 1985. He worked on the development of exposure tools such as i-line, KrF, X-ray and EB steppers. Moreover, he has been working all of lithography and mask technologies, such as exposure tools, OPC, DFM, resist, mask and metrology and inspection. His current research interests are advanced lithography and mask technologies such as EUVL, Nano imprint, DSA (directed self assembly), and desktop lithography. He received his Doctor of Engineering (1994) in advanced alignment technologies from the National University of National Electro-Communications.

P11

Characteristics of Ion Debris from Laser Produced Tin Plasma in Ambient Gas and Magnetic Field

Wang Xinbing[1], Zuo DuLuo[1], Lu Peixiang[2]

[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

In this paper the ion debris measurements were carried out in the presence and absence of magnetic field using Faraday cup (FC) array. A TEA CO_2 laser was used to produce the plasma, the tin target was mounted and rotated in a vacuum chamber, an IRD photodiode was used for EUV detection. The ambient magnetic field is supplied by an assembly of 2 permanent magnets creating a nearly uniform field configuration to cover the plasma plume expansion. To measure ion debris distribution, 5 Faraday cups were placed at a distance of 12 cm from the target surface, equally placed at angle of 18^o with respect to the surface normal. Our initial experimental results indicated that the ion kinetic energy and ions yield can be reduced by H_2 buffer gas from the pressure of 10 to 1000 Pa, while magnetic field (~ 0.8 T) will deflect propagation direction of ions, and reduced the FC signal perpendicular to the target. Our results show that buffer gas combined with the magnetic field is an effective way to reduce the ion debris.

Presenting Author

P12

Progress in Laser-Plasma Sources – 13.5 nm & Beyond

Padraig Dunne[1], Takeshi Higashiguchi[2], Takamitsu Otsuka[1,2], Weihua Jiang[3], Akira Endo[4], Bowen Li[1], Colm O'Gorman[1], Thomas Cummings[1], Patrick Hayden[1], Tony Donnelly[1] Fergal O'Reilly[1] and Gerry O'Sullivan[1]

[1]School of Physics, University College Dublin, Belfield, Dublin 4, Ireland
[2]Utsunomiya University, Utsunomiya, Japan
[3]Nagaoka University of Technology, Nagaoka, Japan
[4]HiLASE Project, Institute of Physics AS, CR, Prague 8, Czech Republic

We report recent progress on UTA (unresolved transition array) and strong line emission with high efficiency emission from highly ionized high-*Z* materials, such as Sn, Gd and Tb. This emission can be optimized for conversion efficiencies greater than 1% in the extreme ultraviolet (EUV) spectral region [1, 2]. Plasmas of the high-*Z* elements Sn and Gd produce strong resonant emission due to 4*d*–4*f* and 4*p*–4*d* transitions at 13.5 nm and 6.7 nm, respectively, which overlap in adjacent ion stages to yield an intense unresolved transition array in their spectra [1]. The in-band high-energy emission is thus attributable to hundreds of thousands of near-degenerate resonance lines lying within a narrow wavelength range. The UTA is scalable to shorter wavelengths, and Gd is shown to have a similar overall conversion efficiency to Sn (13.5 nm) though at a higher plasma temperature, with a narrow spectrum centered at 6.7 nm, where a 70% reflectivity mirror is anticipated. Because it moves to shorter wavelength with increasing the atomic number, *Z*, the $n = 4$–$n = 4$ UTA can be used for other applications, such as transmission x-ray microscopy for biological imaging in the water window. An alternative source is provided by the $n = 3$–$n = 4$ emission from third row elements, for example zirconium. We demonstrate a table-top broadband emission water window source based on laser-produced plasmas with a reasonably low-power laser [3].

[1] S.S. Churilov and A.N. Ryabtsev, *Phys. Scr.* **73**, 614 (2006)
[2] T. Cummins *et al*. *Appl. Phys. Letts*, **100**, 3684242-1 (2012)
[3] B. W. Li et al., Appl. Phys. Lett, 102, 041117 (2013)

Presenting Author

Padraig Dunne received his PhD from University College Dublin in experimental atomic physics in 1994. His research interests include Laser Produced Plasmas (LPP) 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.

P13

STAN – A Compact Light Source for EUV and Beyond

Padraig Dunne[1,2], Fergal O'Reilly[1,2], Paul Sheridan[1,2] and Kenneth Fahy[1,2]

[1]*School of Physics, University College Dublin, Belfield, Dublin 4, Ireland*
[2] *NewLambda Technologies, Science Centre North, Belfield, Dublin 4, Ireland.*

We report recent progress on the compact, high-power laser produced plasma source developed at NewLambda technologies.

NewLambda Technology's STAN™ is the culmination of 30 years of research into incoherent EUV/soft x-ray light sources. For end users who wish to have a lab based high brightness source of soft x-rays in the 10-eV to 500-eV range STAN™ represents a compelling choice. The STAN™ system consists of a laser plasma soft x-ray source, brought to a debris free focus by our plasma robust self-healing liquid metal coated optics. The laser optics are protected by our simple and effective Permanent Clarity™ technology, which allows us to produce tiny laser plasmas continuously on bulk liquid materials, for turnkey simplicity and low cost operation.

STAN™ is extremely flexible, and can be driven by low cost 10-W laser input where brightness and etendue are the drivers, or coupled to kW class lasers where flux is the key requirement. STAN™ can be coupled to applications directly or through one of our monochromator systems providing photons from the VUV into the 'Water Window'.

The core technology behind STAN™ is the liquid metal coated collector optic. This optic is coated with the same metal material as the plasma fuel, meaning that debris from the plasma becomes absorbed into the liquid mix, thus maintaining a clean, efficiently reflecting surface over many thousands of hours. The robust nature of the optic means it can be placed within millimetres of the plasma source, delivering more photons to your application than would be possible with conventional solid optics.

Presenting Author

Padraig Dunne received his PhD from University College Dublin in experimental atomic physics in 1994. His research interests include Laser Produced Plasmas (LPP) 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.

P14

Modeling of Laser-plasma Interaction for EUV Sources toward Higher Power and Efficiency

Akira Sasaki

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

Despite long intensive research and development, still considerable improvement of power and efficiency of the EUV source is demanded to realize the EUV lithography and its future extension. Studies of the atomic processes have successfully explained the emission from laser produced Xe, Sn and rare earth plasmas. On the other hand, recently improvement of the conversion efficiency (CE) above 5% has been shown in a new experimental condition, using double pulse laser irradiation to produce and pump Sn mist target, which is composed of micro Sn clusters. We investigate a modeling method which is capable of reproducing production of Sn clusters by the first pulse and their interaction with second pulse to produce high temperature plasmas. Methods to calculate complex multi-dimensional radiation transfer, which has a critical effect to the dynamics of the Sn plasmas, are also discussed.

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

Electrodeless Z-Pinch EUV Source for Metrology Applications

Deborah Gustafson, Stephen F. Horne, Matthew M. Besen, Donald K. Smith, Matthew J. Partlow, Paul A. Blackborow

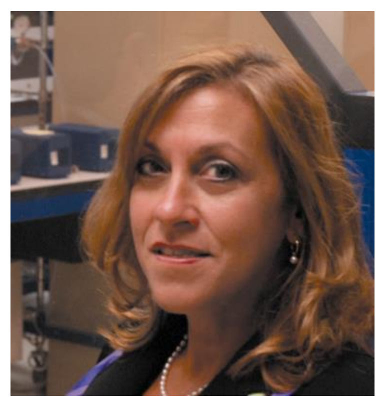
Energetiq Technology, Inc., 7 Constitution Way, Woburn, MA, USA 01801

Energetiq's EQ-10HB has been selected as the source for pre-production actinic mask inspection tools. This talk will review initial integration of the Energetiq source into an actinic mask inspection tool. We will review the critical aspects of the source performance to the integration of these tools.

In order for the production mask inspection tools to be cost effective, however, much brighter source will be required by 2015. Energetiq will present new source technology ideas that have been modeled 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.

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.

P21

Experimental Study of EUV Vacuum Material Outgassing

Xiaobin Wu[1], Caixing Li[2]

[1]Academy of Opto-Electronics, Chinese Academy of Sciences, Beijing 100094,China
[2]Bureau of High-Tech Research and Development, Chinese Academy of Sciences,Beijing,100864,China

In this paper, a setup used to measure the EUV induced outgassing of vacuum material has been built. Integrated with constant volume method, orifice conductance method and double channels method, the deflation of stainless steel (316, 304), brass H62, aluminum 2A12, and other representative material has been measured. A QSM is used to analyze the component of gas. A lamp is used to heat up the material, and the temperature range is 23℃～300℃. The rule of outgassing rate at different temperature has been studied.

Presenting Author

Xiaobin Wu earned his PhD in optical engineering from Tsinghua University, China in 2008. He joined in the Academy of Opto-Electronics, Chinese Academy of Sciences, and performed research on EUV technology.

P22

Contamination Control in EUV Exposure Tools

Katsuhiko Murakami, Noriaki Kandaka, Takashi Yamaguchi, Atsushi Yamazaki, Tsuneyuki Hagiwara, Tetsuya Oshino, Jiro Inoue and Kazuya Ota

Nikon Corporation

Contamination control in EUV exposure tools will be reviewed. The optics of EUV exposure tools are composed of multilayer mirrors. Photoelectrons occur when a multilayer mirror is irradiated with EUV radiation. If there is adsorbed hydrocarbon on the mirror surface, it will be reduced by the photoelectron and carbon contamination will grow. If there is adsorbed water on the mirror surface, it will be reduced by the photoelectron and the mirror surface will be oxidized. Both phenomena degrade reflectivity of the multilayer mirror. Improvement of the cleanliness of vacuum environment where mirrors are placed is the most promising solution. However, it is difficult to stop the degradation completely. Therefore, some kind of mitigation means is required. Oxygen flow during EUV exposure is an effective means for carbon contamination mitigation. Deposited carbon contamination can easily be cleaned with UV exposure under oxide atmosphere. Capping layer on top of multilayer coatings is an effective means against oxidation. Ru was widely used for such a capping layer coating. We have developed oxide capping layers which have much improved oxidation durability than Ru capping layer. And also we have developed multilayer mirror oxidation model which can estimate oxidation impact on EUVL optics.

Because practical pellicle material which can be used in EUV exposure tools is not yet developed, protection of a mask against particle adhesion is a crucial issue. In vacuum where drag force due to air does not exist, particles have ballistic motion. We have demonstrated that silica aerogels is useful to capture such flying particles in vacuum.

A part of this work was supported by NEDO.

Presenting Author

P23

Outgassing, Photoablation and Photoionization of Organic Materials by the Electron-impact and Photon-impact Methods

Grace H. Ho, Yen-H. Huang, Chih-H. Shao, Hung-M. Lin, Jia-J. Sung and Chen-Y. Yeh

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We measured the absolute outgassing rates of polymethylmethacrylate (PMMA) and four extreme ultraviolet (EUV) R&D samples upon EUV irradiation, and benchmarked our results with reported values. The successfulness of the benchmarking test has demonstrated that the Taiwanese facility is capable of evaluating absolute resist outgassing rates, making it one of a limited number of EUV resist evaluation sites worldwide. In this talk, we will further show the latest results on BEUV outgassing from PMMA and DuPont's EUV model resists of various thicknesses, and correlate the outgassing results to resist photoablation rates that we determined by specular reflectivity spectrometry and profilometry. To understand the fundamental of energy disposal into organic materials, we measured ion products by photon-impact and electron-impact ionization (PI and EI) of twelve organic solvents in the 15-200 eV energy range. Results of the study reveal a similarity of EI and PI reaction pathways as a function of impact energies, and demonstrate that dissociative or molecular ionization pathways are strongly structure and thermodynamic dependent. From the results, the implication of using EI or PI to study EUV and beyond EUV resist outgassing will be discussed.

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.

P24

Electron-impact and Photon-impact Ionization of Organic Solvents in the Threshold-200 eV Range

Yen-H. Huang, Zin-X. Yang, Grace H. Ho*, Hung-M. Lin, Chia-Y. Chou, Chao-C. Yang, Pei-C. Lo

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The electron-impact ionization (EI) and photon-impact ionization (PI) of organic solvents in the ultraviolet and extreme ultraviolet (EUV) energy range are not only of fundamental interests, their underlying PI and EI chemistry are important for industrial applications, for example, in EUV lithography for IC manufacturing. The PI and EI spectra of 12 organic solvents were examined in the threshold-200 eV range with a quadrupole mass spectrometer (QMS). The EI measurements were carried out by operating QMS under an "RGA" mode using different electron- impact energy up to 150 eV, whereas the PI measurements were conducted under a "+ION" mode at BL04B1-Seya and BL08A1-LSGM beamlines at National Synchrotron Radiation Research Center in Taiwan. To demonstrate the accountability of our measurements the EI spectra at 70 eV were benchmarked to those reported by National Institute of Standards and Technology (NIST). The similarity of EI and PI pathways at the same impact energy will be presented: Solvents containing a carboxylate moiety will undergo mainly through the C(O)-OR bond breakage, whereas those containing no carboxylate moiety will have molecular ion as one of its major EI and PI products through the extensive threshold-200 eV range. The dissociative ionization reaction mechanisms and thus its implication to the choice of using EI or PI for EUV and beyond EUV resist outgassing studies will be discussed.

Presenting Author

Yen-Hsiang Huang is a graduate student of Department of Applied Chemistry, National University of Kaohsiung (NUK), Taiwan. He received his bachelor degree in NUK. His current research interests include photoionization and photoemission of small organic compounds in the VUV and EUV energy range. He is supervised by Professor Grace H. Ho of NUK.

P25

Optical Properties and Photoablation of Photosensitive Films by 13.5 and 6.7 nm Light

Chen-Y. Yeh,[1] Jia-J. Sung,[1] Grace H. Ho*,[1] Hsuan-T. Chang,[1] Yi-Y Kuo,[1] Yu-C. Tzeng,[1] Chih-W. Yeh,[1] Hok-S. Fung[2] and Bor-Y. Shew[2]

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Extreme ultraviolet (EUV) light at 13.5 nm is the most likely light source for EUV lithography (EUVL) beyond the 16 nm technology node, whereas beyond EUV (BEUV) light at 6.X nm is a candidate light source for the emerging lithography. Optical properties of photosensitive thin-films, including the refractive index (n), photoabsorption coefficient (k) and thin-film thickness (T), are needed parameters for optimizing resist performance at the lithographic step. A vacuum-compatible specular reflectometer was used to measure nkT values of polymethylmethacrylate, DuPont's copolymer and terpolymer films at 13.5 and 6.7 nm, following by *in situ* exposure and actinic investigation on photoablation of the samples against EUV and BEUV irradiation, the light source which was delivered from the BL08A1-LSGM beamline at National Synchrotron Radiation Research Center in Taiwan. The resistance of the photosensitive films against EUV and BEUV irradiation was crossed-examined by a profilometer to determine thickness losses of the films as a function of the EUV and BEUV exposure dose.

Presenting Author

Chen-Yu Yeh a graduate student of Department of Applied Chemistry, National University of Kaohsiung (NUK), Taiwan. He received his bachelor degree in NUK. His study focuses on photoabsorption and photoablation of photosensitive film by EUV and BEUV light. He is supervised by Professor Grace H. Ho of NUK.

P26

Quantitative Outgassing Study of Photosensitive Films upon Irradiation at 13.5 and 6.7 nm

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We characterized outgassed species and quantify the amount of outgassing from photosensitive films upon irradiation at 13.5 and 6.7 nm with a quadrupole mass spectrometer (QMS). A benchmark comparison revealed that absolute outgassing rates of polymethylmethacrylate (PMMA) and four EUV R&D samples upon EUV irradiation determined by this work were consistent with values provided by CNSE or IMEC groups. Thus, we have effectively demonstrated that the Taiwanese facility is capable of evaluating absolute resist outgassing rates, making it one of a limited number of EUV resist evaluation sites worldwide. Furthermore, we measured the dependence of outgassing on film thicknesses and polymeric structures with PMMA and two DuPont's EUV model resists at 13.5 and 6.7 nm. This work was conducted at the 08A1BM-LSGM beamline of National Synchrotron Radiation Research Center in Taiwan.

Presenting Author

Hung-Miao Lin is a graduate student of Department of Applied Chemistry, National University of Kaohsiung (NUK), Taiwan. She received her bachelor degree in NUK. Her current research focuses on outgassing and photochemistry of photosensitive films upon irradiation by EUV and BEUV light. She is supervised by Professor Grace H. Ho of NUK.

P27

Advancements in Understanding Plasma Cleaning

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Abstract to be published.

Presenting Author

P28

Comparison of O_2-N_2 and H_2 Plasma Cleaning for EUV Applications

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We report results from plasma cleaning of hydrocarbons from vacuum chambers with a focus on comparing efficacy of air (O_2-N_2) versus hydrogen (H_2). In both cases we varied discharge gas pressures of the upstream remote plasma from 5 to 200 mTorr and RF plasma power from 20 to 50 W, in addition to examining the effect of distance from the plasma. It was found for both gases that gas pressure selection is key for maximizing cleaning rates: lower pressures result in reduced reactant generation while higher pressures cause increased scattering by the gas, thus an optimal pressure is indicated for a given system. We also present technical details of a new plasma cleaning product designed with features appropriate for meeting the requirements of EUV Lithography including low-particle and ultra-clean construction using SS316L, an elastomer-free gas manifold using all-metal seal valves, in-line 3 nm filter/purifier, and clean-room assembly.

Presenting Author

P29

Measurements of the Role of Secondary Electrons in EUV Resist Exposures

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Abstract to be published

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.

P30

Critical Issues in Photoresist Outgas Witness-plate Testing

C. Tarrio, S. B. Hill, R. F. Berg, N. S. Faradzhev, S. Grantham, and T. B. Lucatorto

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Several criteria have been set out for photoresist witness-plate tests, not all of which can be met at all of the facilities doing this testing. Carbon growth must be mass limited, that is, each molecule adsorbed on the sample must react with the extreme ultraviolet light. Exposure must be done in one hour and on an area equivalent to at least 90 % of a 200 mm wafer at a maximum pumping speed of 270 L/s. We have done a series of experiments examining the relationship between carbon growth and the specified controlled parameters. We find that the reduction in carbon growth resulting from a sub mass-limited test can be estimated by a simple model. Once this estimate is applied, our experiments thus far show that the "corrected" carbon growth is linear with exposed area, dose, and inverse pumping speed, as expected. The relationship between carbon growth and total exposure time is not easily modeled because the outgassing can persist for more than one hour after the exposure is completed.

Presenting Author

Dr. Tarrio 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.

P31

Improved Photon Shot Noise Effect on LWR by using attenuated PSM for EUVL

Seejun Jeong[1], SeongChul Hong[2], Jae Uk lee[2], Seung Min Lee[2], Jung Sik Kim[3], and Jinho Ahn[1,2,3]

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EUVL currently faces numerous challenges including mask shadowing effect and photon shot noise effect. Photon shot noise effect is the statistical fluctuations between photon and photo resist (PR) and this effect results in degradation of imaging performance. It has been understood that photon shot noise is a significant concern for EUVL due to its energetic photons. EUV light has 14.3 times higher energy than that of ArF light. Because of EUV light's energetic photons, smaller number of photons that react with photo resist is required for the same amount of dose, thus resulting in greater photon shot noise effect. In order to alleviate this effect, photo resist with higher reactivity or method to transfer more photons onto wafer (e.g., photomask) is necessary.

In this paper, a 6% attenuated phase shift mask (PSM) is proposed to mitigate photon shot noise effect. Instead of single thick absorber layer, two-layer thin stack with absorber layer and phase shift layer is used in this PSM, which can be easily fabricated with standard EUV mask process. 26.5 nm of Tantalum nitride (TaN) has been used as an absorber material due to its high absorption at EUV wavelength region. We selected 14 nm of molybdenum (Mo) as a phase shifter which has a similar refractive index (n) but an attenuated absorption coefficient (k) as compared to the tantalum nitride (TaN) absorber on 2.5 nm thick Ru capped 40 pairs of Mo/Si multilayers. This structure has ~6% reflectivity at the absorber stack and 180° phase shift.

The improved photon shot noise effect on LWR of PSM were compared with those of conventional BIM with a 70 nm-thick TaN absorber for the 14 ~ 22 nm line and space (L/S) 1:1 dense pattern. Exposure conditions of ASML NXE:3300 were applied in the simulation : a numerical aperture (NA) of 0.33, a partial coherence (σ) of 0.2 - 0.9, off-axis illumination (circular, annular, dipole) and incident angle of 6° with 4X system. LWR were evaluated by using lithography simulation tool, PROLITH X4 of KLA-Tencor. We have used a 70 nm EUV generic resist model which was offered by KLA-Tencor, and the optical constants of materials were obtained from PROLITH X4 and the index of refraction database in CXRO.

Presenting Author

P32

Recent Activities of the Actinic Mask Inspection using the EUV Microscope at Center for EUVL

Takeo Watanabe, Tetsuo Harada, and Hiroo Kinoshita

Center for EUVL, University of Hyogo

The EUV microscope (EUVM) was developed for the actinic mask inspection at BL3 beamline at NewSUBARU synchrotron radiation facility. The light source of the EUVM is a bending magnet. This EUVM was consisted of 30X Schwarzschild optics and 10-200X x-ray zooming tube. The EUV mask image was transferred the electron image by the CsI thin film, this electron image was magnified by X-ray zooming tube, this electron image change to the photon image by the micro channel plate (MCP), and the photon images capture by CCD camera. The defect repaired EUV actinic mask was observed using the EUVM to confirm the effectiveness of the repairing method.

However, since the grain size of CsI is large, the image of the mask becomes noisy. Thus, we developed a full-field EUV microscope based on a multilayer-mirror objective. Recently, Toyoda of Tohoku University has proposed an innovative objective design enhancing a magnification over 1000, which is suitable for using EUV-CCD camera as a detector.[1, 2] Besides, this novel design corrected for off-axis aberrations, i.e., coma, astigmatism, and field curvature, can be configured to have a large field of view in a few hundred micron scale with a diffraction-limited resolution, which allows us a rapid whole mask inspection within a practical observation time. The performance of the actinic mask inspection is discussed.

Reference
1) M. Toyoda, T. Jinno, M. Yanagihara, Aplanatic Three-Mirror Objective for High-Magnification Soft X-Ray Microscopy, *AIP Conference Proceedings*, 1365,176-179 (2011.9).
2) M. Toyoda: Japan Patent JP-A-2010-79257 (2010).

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).

P33

Remaining Challenges for EUV masks for HVM introduction

Pawitter Mangat

Global Foundries

Abstract to be published

Presenting Author

P34

Calculation of the Optical Constants Using X-ray Reflectometer for Verifying the Optical Design of the Attenuated Phase Shift Mask

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[3]Department of Nanoscale Semiconductor Engineering
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We proposed attenuated phase shift mask (PSM) structure that consists of 16.5nm TaN absorber layer and 24nm Mo phase shifter layer on 2nm Ru capped 40 pairs of Mo/Si multilayer. This PSM was designed to satisfy 12% EUV reflectivity at pattern stack and 180 degrees phase difference of light reflected from pattern stack and multilayer mirror. To design the optical performance of PSM, we used optical constants obtained from the index of refraction database in CXRO. The optical constants depend on the density of materials and the properties of thin film materials including density are different from bulk materials. If the PSM is manufactured, its optical properties should be different from that of designed one because most of optical constants in CXRO refraction index database are calculated value using density of bulk materials. So we performed this study to verify reflectivity and phase different of manufactured PSM and to modify the design of PSM when it is needed.

We deposited TaN and Mo, the phase shifting absorber stack materials, on Si substrates and measured their density with the x-ray reflectometer and calculated the optical constants of the mask stack materials by substituting this density into the equation of complex optical constants at EUV region. The results were compared with database in CXRO and were used for reflectivity and phase different simulation to confirm optical design change of the PSM. To verify the design, we fabricated the PSM blank and measured the reflectivity directly by using EUV reflectometer. As a result, the measured reflectivity was similar to designed value and we confirmed that fabricated PSM had improved optical performance as designed.

The simulation of reflectivity and phase difference were performed using the EM-suite provided by Panoramic Technology Inc. and incident angle was 6 degrees. We obtained atomic scattering factor from the database in CXRO.

Presenting Author

P41

Development of Novel Molecular Resist Materials based on Ladder-Type Cyclic Oligomers for Extreme Ultraviolet Laser Exposure System

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A new dynamic covalent chemistry (DCC) system in the reaction of resorcinol and 1,5-pentanedial could be achieved, yielding an only soluble oligomer noria (noria means water wheel in Latin) in high yield, resembling a water-wheel in appearance. Application of the noria derivatives with pendant photo-reactive groups were examined for extreme ultraviolet laser (EUVL) resist materials. The obtained noria derivatives had good solubility, good film-forming ability, high thermal stability, and high photo-chemical reactivity. Furthermore, certain new ladder cyclic oligomers could be synthesized using a similar approach to that employed for the synthesis of noria and their application as next generation resist materials was also investigated. As the results, noria derivatives with pendant adamantyl ester groups had high sensitivity under EUVL exposure system and could offer a line and space pattern with a resolution of 15 nm.

Presenting Author

Hiroto Kudo is an Associate Prpfessor at Kansai University, Japan. He received his Doctor of Engineering from Tokyo Institute of Technology in 2000. He has been with Kanagawa University from 2001- 2009 and has been with Kansai university since 2011. His research interests are on the topic of synthesis, properties and application of photo-functional polymer.

P42

New Approach for Reducing the Out of Band effect and Outgassing by Applying Top Coat Materials (Outgassing and Out-of Band Protection Layer: OBPL)

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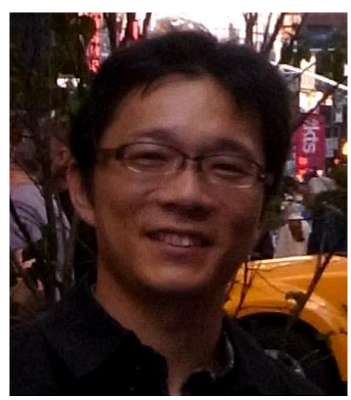
EUV lithography is one of the next generation lithography candidates for hp22nm and beyond. However the light source, tools, masks and resists are still the key issues for the EUV lithography. For the development of the EUV light source, the low power is one of the critical issues that will make the low throughput. Another one is the Out of Band (OoB) light existing in the EUV source. OoB is concerned to be the cause of deterioration of the lithography performance. The outgassing from resist is another big issue for the EUV lithography, and how to prevent and keep the cleanness of exposure tool is very important topic. The OoB effect and outgassing from resist issues must be resolved toward the high volume manufacturing.

In order to resolve these critical issues, applying top coat material can be the promising candidate process. The key characteristics for top coat material are reducing the OoB effect, preventing the outgassing from resists as barrier layer, and controlling the resist profile and process window. The material is called OBPL (**O**utgass and Oo**B** **P**rotection **L**ayer). This paper describes the material design having the high absorption in OoB range and high transmittance for 13.5nm wavelength, and having the outgassing barrier performance to reduce the outgassing from resist. Regarding the OoB protection property, we investigated with the pre OoB exposure method of inline MET system in LBNL. Finally, we discuss the EUV lithography performance with OBPL in PTI and NTI process.

Presenting Author



Rikimaru Sakamoto is R & D Manager and Chief research Chemist for Nissan Chemical Industries, LTD in the department of Electronic Materials Research Laboratories. In 2000, he joined Nissan Chemical, R&D for Semiconductor material research group. Since 2000, he has been researching Lithography related materials, especially, resist underlayer materials (BARCs and spin on hard mask), and Top coat for EB/EUVL.

P43

EUV Resist Development for 16 nm Half Pitch

Yoshi Hishiro

JSR Micro Inc.

In order to pattern high quality 16nm half pitch with good RLS balance, we developed a package solution with new resist, under layer, and topcoat materials specific to EUVL. High Tg resin and high absorption resin were incorporated into EUV resist. High Tg resin showed good LWR and local CD uniformity (LCDU). High absorption resin showed higher resist sensitivity. New silicon type under-layer materials with different hydrophobicity were developed for further patterning performance improvement. Silicon type under-layer material with higher hydrophobic surface property improved line collapse margin which in turn improved resist resolution. EUV top-coat material was developed and examined for EUV resist sensitivity to out of band (OOB) radiation. EUV top-coat suppressed OOB influence and improved lithographic performance. JSR system resolved 15 nm half pitch lines and spaces and 20 nm contact hole patterns.

Presenting Author

Yoshi Hishiro is a Director R& for JSR Micro Inc. Previously, he worked for Sumitomo Chemical as product manager for electronic materials and Micron Technology as advanced lithography group supervisor.
He has been in the semiconductor industry for more than 20 years. He is currently responsible for Litho and CMP R&D, including advanced patterning like EUV and DSA. He holds various patents in the US and Japan.

P44

Stochastic Effects in Chemically Amplified Resists for Extreme Ultraviolet Lithography

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Extreme ultraviolet (EUV) lithography is promising for the high-volume production of semiconductor devices for the 16nm node and below. However, the stochastic effect is a significant concern in lithography using high-energy (92.5 eV) photons and highly sensitive resists. In this study, we investigated the stochastic effects induced in a chemically amplified resist. Resist patterns fabricated by an EUV exposure tool were analyzed using a Monte Carlo simulation on the basis of the sensitization and reaction mechanisms of chemically amplified EUV resists. The contribution of protected unit fluctuation to line edge roughness (LER) and defects (bridge, shrinkage, and line break) is discussed on the basis of the results of analysis.

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.

P45

Recent Activities of the EUV Resist Research and Development at Center for EUVL

Takeo Watanabe, Tetsuo Harada, and Hiroo Kinoshita

Center for EUVL, University of Hyogo

The EUV interference lithographic tool (BL9B), and the contamination thickness measurement using in-situ ellipsometry (BL9C) have been developed at Center for EUVL to develop and evaluate 1X nm EUV resist, which has high sensitivity, low line edge roughness (LER), high resolution, and low contaminating characteristics. The development of these instruments and that of EUV resist evaluation results will be reported for various kind of resist platforms. In addition, EUV resist chemical reaction analysis using SR absorption spectroscopy (BL7B) will be also reported. Using this method, multiple-acid generation is discussed for the solution of the trade-off between high sensitivity and low LER.

As describes above, for developing 1X nm EUV resist, entire resist characteristics such as resolution, sensitivity, LER, carbon contamination and outgassing of EUV resist can be totally evaluated using four beamlines at NewSUBARU at Center for EUVL. These systems might be helpful for processing the EUV resist R&D to toward the practical use of EUVL in high volume manufacturing.

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).

P46

Sub-10nm HP Patterning using EUV based Self-Aligned Double Patterning

Sushil Padiyar

Applied Materials

EUV lithography source power and resist properties have recently shown steady progress towards device manufacturing requirements. With 55W LPP source power in lab and 14nm resist HP data demonstrations (chemically amplified resists), IC device makers are evaluating the appropriate HVM insertion node for EUV lithography. This paper is an early feasibility check for sub-10nm HP patterning using EUV based Self-Aligned double patterning. While sub-wavelength 13.5nm lithography using low k1 resolution enhancement techniques (like done with 193nm sources) and newer, lower 6.xnm EUV wavelength sources are possible alternatives for sub-10nm HP solutions, 13.5nm EUV based double patterning provides an early learning vehicle and a viable alternative for device manufacturing at competitive costs. This work is a joint effort between ASML, IMEC and Applied Materials and has current potential to scale down to <7nm HP at 1:1 duty cycle.

Presenting Author

Sushil Padiyar is a Strategic Programs Manager within Applied Material's Silicon Systems Group (SSG).Sushil is responsible for ensuring alignment of Applied Material'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. / Ph.D. 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.

P51

EUV related Technology Development at L-3 Integrated Optical Systems

Viswa Velur

Commercial Optical Systems, L-3 Communications

L-3 IOS has been involved with technology development in various aspects of design, manufacture and building of optical systems. L-3 IOS has been involved in making optics for EUVL since 1996. This talk will showcase technology development at L-3 IOS WRT metal optics manufacturing and its application in EUVL.

Presenting Author

Viswa Velur is the Product Line Manager for Commercial Optical Systems at L-3 Communications, Integrated Optical Systems (IOS). He has spent most of his career in the optics industry involved in optical, systems & mechanical engineering and program management. He has hands on experience with high resolution imaging systems, laser source development, non-linear optics, adaptive optics, interferometry, cryogenics, detectors, instrumentation and spectroscopy. He worked at the California Institute of Technology, The Fermi Institute at the University of Chicago and KLA-Tencor prior to joining L-3 communications. He has authored or co-authored numerous technical articles in journals ranging from SPIE to Nature magazine and he has been part of major press releases. Viswa Velur has a Bachelor of Engineering degree in Mechanical Engineering from The University of Madras, India, a Master of Science in Mechanical Engineering from Texas A&M University and an MBA in Finance from The UCLA Anderson School of Management.

P52

Multilayer Mirrors for EUVL: Progress status

Yuriy Platonov, Michael Kriese, Vladimir Martynov, Raymond Crucet,
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RIT continues to conduct research on improving the performance of multilayer coatings for EUVL. During the last year we have worked on the deposition of large area collectors, illumination system optics and imaging optics for applications in EUV Lithography. We have also engaged in the development of refurbishment techniques for multilayer optics and the further improvement of multilayer reflectivity at 6.X nm. Progress on these new developments will be reported.

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.

P53

GI Collectors for EUV/BEUV Sources for Metrology

Ladislav Pina

Rigaku Innovative Technologies Europe, 142 21 Prague 4, Czech Republic

Grazing incidence (GI) collectors for EUV sources for metrology, EUV lithography studies and EUV microscopy are of increasing interest. GI collectors can be used for LPP, DPP, electron impact, synchrotron and FEL sources of EUV, BEUV, WW and SXR radiation.
Reported GI collectors in combination with laboratory EUV lithography LPP and DPP sources have been developed and tested within collaboration of hot plasma and optical laboratories in Prague and Warsaw. Currently no suitable sources are available for production level mask defect inspection tools, so high brightness EUV sources to support mask metrology remain a topic with high application potential.

Presenting Author

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A New Design Method for Extreme Ultraviolet Lithographic Objective

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Choosing an adequate initial configuration for optimization plays an important role in obtaining high quality Extreme Ultraviolet lithographic objectives. The optical system of this presentation is divided into object side group, middle group and image side group. We present a new method for both acquiring spherical initial configurations of individual group and connecting three groups based on real ray calculations. The parameters of object side group and image side group are calculated with the non-obstruction and pupil-stop constraints. Then the parameters of middle group are calculated with the conjugate constraints of matching pupils of three groups. Finally the three groups are connected into a feasible system. The method is effective for designing initial configurations suited for further optimization and manufacture process because the incident angles of imaging beam and the mirror figures can be wholly controlled in each design phase. We design a NA 0.33 EUV lithographic objective of six aspherical mirrors using this method. This objective's mean wavefront error (RMS) is reached 0.023λ through gradual optimization process.

Presenting Author

Yanqiu Li is currently a professor of Beijing Institute of Technology of China. She holds over 30 Chinese patents and has published 150 articles on Optics. She received her MS and PhD degrees in optics from Harbin Institute of Technology of China. She worked as a director of the micro& nano fabrication division at IEECAS, as an associate professor at Harbin Institute of Technology of China, as a Senior Engineer at Nikon, as an invited professor of Hemeiji Institute of Technology and Tohoku University of Japan, as a frontier researcher at RIKEN of Japan.

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Status of EUVL Activities in Taiwan

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In the past two years, the EUVL activities are more and more concrete in Taiwan. TSMC (Taiwan Semiconductor Manufacturing Company) started to invest big money into research targeting the development of EUVL tools. Some companies tried to provide EUVL-related materials and parts. A 3-year national project was granted again, and a dedicated EUV beamline will be constructed at NSRRC (National Synchrotron Radiation Research Center) to serve academic researches. In this report, the EUVL activities, especially the R&D woks, will be summarized to give an overall picture of EUVL development in Taiwan.

Presenting Author

Yang-Tung Huang (M'90) was born in Taiwan, Republic of China, in 1955. He received the B.S. degree in electrophysics, the M.S. degree in electronics from National Chiao Tung University, R.O.C., in 1978 and 1982 respectively, and the Ph.D degree in electrical and computer engineering (minor in optical sciences) from the University of Arizona, U.S.A., in 1990. He is a Distinguished Professor of the Department of Electronics Engineering and the Institute of Electronics, the Director of EECS (Electrical Engineering and Computer Science) Undergraduate Honors Program, and a joint professor of the Department of Biological Science and Technology, National Chiao Tung University. He is also the Program Convener of Nanoelectronics and Nanophotonics for National Program on Nano Technology (NPNT). He has been the Director of the Institute of Electronics for three years, the Director of Semiconductor Research Center for two years, the Director of Nano Facility Center for four years, and the Chairman of the Department of Electronics Engineering and the Institute of Electronics for three years. He received the Outstanding Research Award from the National Science Council in 1997. His current researches include integrated optics, Si nano-photonics, and bio-optoelectronics. He has been leading a team to run a national project for investigation on EUVL-related technologies.

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EUVL Readiness and Extension (Panel Discussion)

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Background

With fast-growing demand in mobility and big data related fields, the semiconductor industry has entered an exciting phase with major technology inflections expected in the areas of devices, materials, miniaturization and fast chipset to chipset communications. The choice of next generation lithography, beyond current 193 nm based lithography, is a critical decision for the industry.

The 450 mm wafer size transition, along with high volume manufacturing (HVM) EUV lithography insertion, are expected to impact the industry dynamics and cost of ownership for lithography. The panelists for this discussion are the leading lithography researchers from major semiconductor companies, who will cover topics that will include roadmaps, technical and cost requirements, and the overlap between these two major technology changes.

List of questions for panelists

1. EUVL HVM Timelines
    a. HVM Lithography roadmaps for the next 10 years for your company
        i. Choice of Lithography techniques for various ITRS nodes and device types
        ii. EUVL and 450 mm insertions for HVM
        iii. Lithography requirements for 300 mm and 450 mm scanners
    b. At what node do you expect EUVL to be competitive with 193 nm immersion (193i) lithography, and for what throughput of EUVL and 193i scanners? How will this comparison differ for 300 mm and 450 mm wafers?

2. What are the EUV source requirements as a function of NA, resolution, throughput for 300 mm and 450 mm EUVL scanners?

3. 450 mm and 193i Contingencies
    A. What are your perspectives on whether 300 mm EUVL HVM will precede 450 mm wafer transition, or whether 450 mm transition will start with 193i multi-patterning and then migrate to 450 mm EUVL HVM?
    B. What are your opinions about selections of multi-patterning EUV (13.5 nm) vs. BEUV (6.x nm) for future nodes?

Agenda

1. Panel Question Introduction, Review of inputs on EUVL HVM Insertion from last year's panelists, Summary of progress and new developments since last year.

   Sushil Padiyar (P75)

2. Presentations from panelists:

   Sam Sivakumar – Intel Corporation (P72)

   TBA – Applied Materials (P74)

   Tatsuhiko Higashiki - Toshiba (P71)

   Pawitter Mangat - GlobalFoundries (P73)

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 Material'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. /Ph.D. 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.

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