2010 International Workshop on EUV Lithography

June 21-25, 2010

Makena Beach Golf Resort ▪ Maui, Hawaii

Workshop Agenda

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Contents

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Welcome

Dear Colleagues;

I will like to welcome you to the 2010 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, 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 in the workshop.

Best Regards

Vivek Bakshi
Organizing Chair, 2010 International Workshop on EUVL

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Workshop Agenda

2010 International Workshop on EUV Lithography

Makena Beach Golf Resort, Maui, Hawaii, USA
June 21-25, 2010

Workshop Agenda Outline

Short Courses (Makena Room, June 21-22, 2010)

EUV Lithography
8:00 AM -5:00 PM, Monday, June 21, 2010

Resist Materials for High Resolution Patterning
6:00 PM-10:00 PM, Monday, June 21, 2010

EUV Physics
8:00 AM – 12:00 PM, Tuesday, June 22, 2010

Introduction to Optical Lithography
1:00 PM – 5:00PM, Tuesday, June 22, 2010

EUVL Workshop (June 22-25, 2010)

Tuesday, June 22, 2010

3:00 PM- 5:00 PM	Registration (Kaeo Ballroom Entry Lanai) Speaker Prep (Wailea Room)
5:00 PM- 7:00 PM	Reception (Pacific Lawn)

Wednesday, June 23, 2010

7:00 AM	–	8:00 AM	Breakfast
8:00 AM	–	12:00 PM	Oral Presentations (Wailea Room)
12:00 PM	–	1:00 PM	Lunch (Holokai Pavilion)
1:00 PM	–	5:00 PM	Oral Presentations (Wailea Room)
5:00 PM	–	6:00 PM	Poster Session and Reception (Makena Room)
7:00 PM			Dinner (Pacific Lawn)

Thursday, June 24, 2010

7:00 AM	–	8:00 AM	Breakfast
8:00 AM	–	12:00 PM	Oral Presentations (Wailea Room)
12:00 PM	–	1:00 PM	Lunch (Holokai Pavilion)
1:00 PM	–	3:00 PM	Oral Presentations (Wailea Room)
3:00 PM			Adjourn

Friday, June 25, 2010

8:30 AM	–	10:00 AM	EUVL Workshop Steering Committee Meeting (Kahili Court Private Room)

2010 International Workshop on EUV Lithography

Makena Beach Golf Resort, Maui, Hawaii, USA
June 21-25, 2010

Workshop Agenda

Monday, June 21, 2010

Short Courses

EUV Lithography
by Vivek Bakshi (EUV Litho, Inc.), Patrick Naulleau (LBNL) and Jinho Ahn (Hanyang University)
8:00 AM -5:00 PM, Monday, June 21, 2010

Resist Materials for High Resolution Patterning
by Cliff Henderson (Georgia Tech University)
6:00 PM-10:00 PM, Monday, June 21, 2010

Tuesday, June 22, 2010

Short Courses

EUV Physics
by David Attwood (LBNL)
8:00 AM – 12:00 PM, Tuesday, June 22, 2010

Introduction to Lithography
by Chris Mack (Lithoguru.com)
1:00 PM – 5:00 PM, Tuesday, June 22, 2010

Registration and Reception

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

Wednesday, June 23, 2010

8:00 AM Welcome and Introduction

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

8:10 AM Session 1: Keynote -1

Session Chair: Sam Sivakumar (Intel)

EUV: Status and Challenges Ahead (Keynote-1)
Jos Benschop
ASML, Eindhoven, Netherlands

EUV Lithography: Approaching Pilot Production (Keynote-2)
Obert Wood
GlobalFoudries, Albany, New York, USA

9: 20 AM Award Ceremony

9:35 AM Break (20 Minutes)

9:55 AM Session 2: High Power EUV Sources

Session Chairs: David Attwood (University of California at Berkeley) and Obert Wood (Global Foundries)

Future of High Power EUV Sources (Source-10, Invited)
Hakaru Mizoguchi
Gigaphoton, Toshigi, Japan

CO_2 Laser-produced Tin Plasmas as EUVL Sources (Source-3)
Thomas Cummins, Gerry O'Sullivan, Emma Sokell, Padraig Dunne, Fergal O'Reilly and Tony Donnelly
University College Dublin, Dublin, Ireland

Improving Efficiency of MOPA Laser System for LPP EUV Source (Source-1, Invited)

Krzysztof M. Nowak, Takashi Suganuma, Toshio Yokotsuka, Koji Fujitaka, Hideo Hoshino, Masato Moriya, Takeshi Ohta, Akira Sumitani, Akira Endo
EUVA (Extreme Ultraviolet Lithography System Development Association), Hiratsuka, Kanagawa, Japan

Modelling of High Intensity EUV Light Sources Based on Laser & Discharge Produced Plasmas (Source-6)
S. V. Zakharov[1,2,3], P. Choi[1,2], V. S. Zakharov[2]
[1] NANO-UV sas, Villebon/Yvette 91140, France
[2] EPPRA sas, Villebon/Yvette 91140, France
[3]also with RRC Kurchatov Institute, Moscow, Russia

Status and Future of High Power EUV Source Technology (Source-11)
Vivek Bakshi
EUVL Litho, Inc., Austin, TX, USA

11:20 Session 3: Next Generation EUV Sources

Session Chair: Jos Benschop (ASML)

Laser-produced terbium & gadolinium Plasmas as EUVL Sources at 6.5 – 6.7 nm (Source-7, Invited)
Padraig Dunne[1], Thomas Cummins[1], John White[1], Deirdre Kilbane[1], Rebekah D'Arcy[1], Emma Sokell[1], Thomas McCormack[1], Imam Kambali[1], Takamitsu Otsuka[2], Colm O'Gorman[1], Enda Scally[1], Fergal O'Reilly[1], Tony Donnelly[1] and Gerry O'Sullivan[1].
[1]University College Dublin, Dublin, Ireland
[2]Utsunomiya University, Tochigi, Japan

Atomic Processes in Plasma EUV Sources at λ=6.5nm (Source-2)
Akira Sasaki
Japan Atomic Energy Agency, Kyoto, Japan

11:55 AM Lunch (Holokai Pavilion)

1:00 PM Session 4: EUV Sources for Metrology

Session Chairs: Padraig Dunne (University College Dublin) and Sergey Zakharov (EPPRA)

EUV Source Development for AIMS and Blank Inspection (Source-4)
Paul A. Blackborow, Matthew J. Partlow, Stephen F. Horne, Matthew M. Besen, Donald K. Smith, Deborah Gustafson
Energetiq Technology, Inc., Woburn, MA, USA

High Brightness EUV Light Source System Development for Actinic Mask Metrology (Source-5)
Sergey V. Zakharov [1,2,5], Peter Choi [1,2], Raul Aliaga-Rossel [1], Adrice Bakouboula [1], Otman Benali [1], Philippe Bove [1], Michele Cau [1], Grainne Duffy [1], Carlo Fanara [2],Wafa Kezzar [1], Blair Lebert [2], Keith Powell [1], Ouassima Sarroukh [2], Luc Tantart [1], Clement Zaepffel [2], Vasily S. Zakharov [2], Alan Michette [3], Edmund Wyndham [4]
[1] *NANO-UV sas, Villebon/Yvette 91140, France*
[2] *EPPRA sas, Villebon/Yvette 91140, France*
[3] *Dept of Physics, King's College, London WC2R 2LS UK*
[4] *Pontificia Universidad Catolica de Chile, Santiago, Chile*
[5] *RRC Kurchatov Institute, Moscow, Russia*

High Brightness EUV Source Using a DC High Voltage Generator (Source-8)
John Madey, Luis Elias and Eric Szarmes
University of Hawai'i at Manoa, Manoa, Hawaii, USA

Status of EUV Sources for Mask Metrology (Source-12)
Vivek Bakshi
EUV Litho, Inc, Austin, TX, USA

2:00 PM Session 5: EUV Optics

Session Chair: Yuriy Platonov (Rigaku Innovative Technologies)

Virtual Sputter Chamber - Multiphysics Simulation of Magnetron Sputter & Deposition of EUV/X-ray Thin Films (Optics-1, Invited)
Chris Walton
Lawrence Livermore National Laboratory, Livermore, CA, USA

Growth, Microstructure and Stress Evolution of Sputtered Thin Films for EUV/X-ray Applications (Optics-2, Invited)
Regina Soufli
Lawrence Livermore National Laboratory, Livermore, CA, USA

2:40 PM Break (20 Minutes)

3:00 PM Session 6: Contamination

Session Chairs: Iwao Nishiyama (SELETE) and Greg Denbeaux (University of Albany)

Novel Ozone-based Cleaning Technique for EUV Optics Carbon Contamination (Contamination-2, Invited)
Iwao Nishiyama, Toshihisa Anazawa, Noriaki Takagi, Osamu Suga
MIRAI-Semiconductor Leading Edge Technologies, Inc., Ibaraki, Japan

Carbon Contamination of EUV Masks and its Effect on Imaging (Contamination- 4)
Greg Denbeaux[1], Yu-Jen Fan[1], Leonid Yankulin[1], Petros Thomas[1], Chimaobi Mbanaso[1], Alin Antohe[1], Rashi Garg[1], Andrea Wüest[2], Patrick Naulleau[3], Kenneth Goldberg[3], Iacopo Mochi[3]
[1]College of Nanoscale Science and Engineering, University at Albany, NY
[2]SEMATECH, Albany, NY
[3]CXRO, Lawrence Berkeley National Lab, Berkeley, CA

Analysis of Carbon Contamination on EUV Mask using CSM / ICS (Mask-1)
Jae Uk Lee[1] , Chang Young Jeong[1] , Sangsul Lee[1], Jong Gul Doh[1], , Dong Geun Lee[2], Seong-Sue Kim[2], Han-Ku Cho[2], Seung-yu Rah[3] and Jinho Ahn[1]
[1] Department of Materials Science and Engineering, Hanyang University, Korea
[2] Photomask Team, Memory Division, Semiconductor Business, Samsung Electronics Co., LTD, Korea
[3] Pohang Accelerator Laboratory, Korea

Outgassing and Extreme-ultraviolet Photochemistry of Photoresist and Underlayer Materials (Contaminaion-1)
Grace H. Ho, Fu-H. Kang, Chih-H. Shao, Wei-L. Hung, Chih-B Kao, and Yu-L. Chou
Department of Applied Chemistry, National University of Kaohsiung, Kaohsiung, Taiwan

Nanoparticle Contamination Control and Metrology for the Extreme Ultraviolet Lithography (EUVL) Systems (Contamination-3)
David Y.H. Pui
University of Minnesota, Minneapolis, MN, USA

4:20 PM Break (40 Minutes)

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

5:00 PM Session 7: Poster Session

Session Chair: Ken Goldberg (LBNL)

Chemical Vapor Composite Silicon Carbide (CVC SiC™) Mirror Substrates (Optics-3)
Clifford T. Tanaka
Trex Enterprises Corporation, Kauai, HI, USA

Production of High Purity Functional Water at Point-of-Use for Advanced Mask Cleaning Processes (Mask-3)
Annie Xia
Entegris, Inc., Billerica, MA, USA

EUV Laser for Applications in EUVL Mask Metrology (Source-9)
Davide Bleiner[1], Christoph Imesch[1], Felix Staub[1], Yasin Ekinci[2], Vivek Bakshi[3], and Juerg Balmer[1]
[1]Institute for Applied Physics, University of Berne, Berne, Switzerland
[2]Paul Scherrer Institute, Laboratory for Micro & Nanotechnology, Villigen PSI, Switzerland
[3]EUV Litho, Inc., Austin TX, USA

An Investigation of Flare Value at Pattern Edge Region in EUVL (Resist -5)
Kangyoo Song, Junhwan Lee, Changreol Kim[1], Yongdae Kim[1], Ohyun Kim
Pohang University of Science and Technology, Pohang, Republic of Korea
[1]Hynix Semiconductor Inc, Republic of Korea

Counting outgassing molecules (Contamination-5)
Chih-H. Shao, Chih-B. Kao, Yu-L. Chou, Wei-L. Hung and Grace H. Ho*
Department of Applied Chemistry, National University of Kaohsiung, Nanzih, Kaohsiung 811, Taiwan

Contamination Removal using the Evactron® De-Contaminator (Contamination-6)
Christopher G. Morgan, Ronald Vane, Senajith B. Rekawa[1], Paul E. Denham[1], Brian H. Hoef[1], Michael S. Jones[1], and Patrick P. Naulleau[1]
XEI Scientific, Inc.
1755 E. Bayshore Blvd., Redwood City, CA 94063
[1]Center for X-Ray Optics (CXRO), Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA 94720

A New Resist Evaluation System developed at NewSUBARU (Resist-7)

Hiroo Kinoshita and Takeo Watanabe
Laboratory of Advanced Science and Technology for Industry
University of Hyogo, 1-1-2 Kouto kamigoro Ako-gun Hyogo Pref., Japan 678-1205

7:00 PM Dinner (Pacific Lawn)

Thursday, June 24, 2010

8:00 AM Welcome and Announcements

Vivek Bakshi
EUV Litho, Inc, Austin, TX USA

8:10 AM Session 8: Keynote – 2

EUVL Development in Japan (Keynote-3)
Iwao Nishiyama
SELETE, Japan

8:45 AM Session 9: EUVL R&D Status

Session Chairs: Hiroo Kinoshita (Hyogo University) and David Attwood (University of California at Berkeley)

Panelists:

Greg Denbeaux – USA (University of Albany)

Hiroo Kinoshita –Japan (Hyogo University)

Padraig Dunne – Europe (University College, Dublin)

Chun-Hung Lin – Taiwan (National Cheng Kung University)

Jinho Ahn – Korea (Hanyang University)

10:00 AM Break (15 Minutes)

10:15 AM Session 10: EUVL Mask

Session Chair: Jinho Ahn (Hanyang University)

Development Status of EUVL Blank and Substrate (Mask-6, Invited)
Yoshiaki Ikuta and Toshiyuki Uno
Central Research Center, Asahi Glass Co. Ltd., JAPAN

Defect Detection and Inspection Unmasked: The current state of EUV mask defects (Mask-2, Invited)
Kenneth A. Goldberg, Iacopo Mochi, Sungmin Huh[1], David Chan[1]
Lawrence Berkeley National Laboratory, Berkeley, CA, USA
[1]SEMATECH, Albany, NY, USA

Study of the Minimum Phase Defect Affecting the Exposure Result (Mask-5, Invited)
Hiroo Kinoshita,[1, 3], Kei Takase[1, 3], Toshiyuki Uno[2], Takeo Watanabe[1, 3], and Tetuo Harada[1, 3]
[1]Laboratory of Advanced Science and Technology for Industry, University of Hyogo
1-1-2 Kouto Kamigori, Ako-gun, Hyogo 678-1205, Japan
[2]Asahi Glass Co., Ltd., R&D Center, Yokohama 221-8755, Japan
[3]JST, CREST, Yonban, Chiyoda, Tokyo 102-0081, Japan

11:15 AM Session 11: LER

Session Chair: Patrick Naulleau (LBNL)

Mask Metrology and Pattern Profile Analysis Using the AIT: Down to 64 nm (Mask-4)
Iacopo Mochi, Kenneth A. Goldberg, Tom Wallow[1]
Lawrence Berkeley National Laboratory, Berkeley, CA, USA
[1]Global Foundries, Albany, NY, USA

Stochastic Resist Simulation at EUV (LER-2, Invited)
John J. Biafore, Mark D. Smith
KLA-Tencor, Austin, TX, USA

The Influence of Photoresist Development on Line Edge Roughness (LER-1, Invited)
Chris Mack
Lithoguru.com, Austin, TX, USA

12:10 PM – 1:10 PM Lunch (Holokai Pavilion)

1:10 PM Session 12: EUV Resist

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

Contact Size Variations: Dissecting the Sources (Resist-8, Invited)
Patrick Naulleau
Center for X-ray Optics, Lawrence Berkeley National Laboratory
MS 2-4001 Cyclotron Rd, Berkeley, CA 94720

Flare Mapping and Correction results for EUV Alpha Demo Tool (Resist -4, Invited)
James Moon, Cheol-Kyun Kim, Byoung-Sub Nam, Chang-Moon Lim, Donggyu Yim, and Sung-Ki Park
Hynix Semiconductor Inc., Kyungki-do, Korea

Nanoscale Chemical Reaction Induced in Chemically Amplified Resists upon Exposure to Extreme Ultraviolet Radiation (Resist-1, Invited)
Takahiro Kozawa
Osaka University, Osaka, Japan

Novel molecular Materials based on Noria and Double Calixarene for EB and EUV Resist Systems (Resist -2, Invited)
Tadatomi Nishikubo and Hiroto Kudo
Kanagawa University, Japan

Effects of Acid Amplifiers and Polymer Bound Photoacid Generators on EUV Resist Performance: Fundamental Studies and Lithographic Results (Resist-3, Invited)
Gregory M Wallraff, Phillip J. Brock, Young-Hye Na, Mark Sherwood, Hoa D. Truong, William S. A. Swanson, H. C. Kim, W.D. Hinsberg, Masaki Fujiwara* and Kazuhiko Maeda*, Ramakrishnan Ayothi #, Yoshi Hishiro#
IBM Almaden Research Center, San Jose, CA, USA,
** Central Glass Corporation, Ltd., Tokyo, Japan*
 # JSR Micro, Sunnyvale, CA USA

Radiation Chemistry of EUV and EB Resists (Resist-6)
Seiichi Tagawa[1,2]
[1] *The Institute of Scientific and Industrial Research, Osaka University,*
[2] *Japan Science and Technology Agency, CREST, c/o Osaka University, Japan*

2:45 PM WORKSHOP SUMMARY

EUVL Workshop Summary and Announcements

Vivek Bakshi
EUV Litho Inc, Austin, TX, USA

3:00 PM Adjourn

Friday, June 25, 2010

EUVL Workshop Steering Committee Meeting

8:30 AM **Breakfast**

9:00 -10: 00 AM **EUVL Workshop Steering Committee Meeting**

Abstracts

by

Technical Areas

Keynote Talk -1

EUV: Status and Challenges Ahead

Jos Benschop
ASML

EUV has come a long way over the last two decades: full field alpha tool scanners have been installed by ASML in CNSE, Albany, USA and IMEC, Leuven, Belgium. These tools provide invaluable learning to scanner builders as well as EUV end-users.
EUV pre-production tools are being assembled and will be installed this year at multiple customer locations paving the way for EUVL in early production at chip makers and for EUV tools to be shipped in a few years' time.

To make EUV a worthwhile investment it is of critical importance to extend the lifetime of EUV lithography over multiple generations and to do so in a cost effective way, both for EUV suppliers as well as users.

In the presentation a short summary of status of EUV lithography will be followed by a presentation of a potential EUV roadmap down to single digit imaging nodes. Critical issues will be discussed and research challenges will be identified whereby emphasis will be put on >3 year horizon.

Presenting Author

Born in 1960 in Hengelo,The Netherlands. Obtained his MSc (cum laude) in 1984 and PhD in 1989 from physics faculty in Twente University.
From 1984 until 1997 he worked at Philips. Mostly at Philips Research Eindhoven on optical metrology and optical recording. He worked for two years at Philips Research Sunnyvale USA on semiconductor metrology. At last two years in Philips he was responsible for the development of CD-recordable and CD-rewritable.
He joined ASML in 1997. As head of research he was responsible for definition and execution of research programs on Next Generation Lithography which included projects on electron-beam lithography, ion-beam lithography as well as Extreme UltraViolet Lithography. From 2002 until 2007 he was in charge of System Engineering and Research. As Vice President Research he is responsible for definition and execution of research/advanced-development program with international partners (total > 150 fte).
He has published 24 papers and generated 13 patents. He is associate editor of the Journal of Micro/Nanolithography, MEMS and MOEMS (JM3). In 2010 he has been appointed as SPIE fellow.

Keynote Talk -2

EUV lithography: Approaching Pilot Production

Obert Wood
GLOBALFOUNDRIES
257 Fuller Road, Albany, New York 12203, U.S.A.

In 2008, after more than 2 decades of development, the first EUV device integration demonstrations were carried out using standard semiconductor process flows. Only 2 years later, EUV lithography was beginning to be used to pattern the most difficult layers (contact and first interconnect levels) in SRAM device scaling work. Furthermore, the quality of EUV printing at the 22 nm node was considerably higher than the printing produced with double-dipole or double-exposure double-etch 193-nm immersion lithography, particularly for 2-dimensional patterns, and the yield for 80 nm pitch devices fabricated with EUV printing was also higher because the Rayleigh k_1 for 0.25NA EUV lithography is 0.74 and for 1.35NA 193 nm lithography is only 0.28. Once EUV lithography is inserted into production, and higher NA projection optics and enhanced off-axis illumination modes become available, EUV lithography is likely to be used at all of the remaining nodes on the International Technical Roadmap for Semiconductors.

The status of EUV lithography from an end-user perspective will be summarized and the current values of the most important metrics for each of the critical elements of the technology will be compared to the values needed for EUVL pilot production at the 15 nm node.

Presenting Author

Obert Wood is a Principal Member of Technical Staff in the Strategic Lithography Technology Department at GLOBALFOUNDRIES and currently manages the EUV lithography program for the IBM Research Alliance in Albany, New York. He was a Member of Technical Staff at Bell Laboratories for 34 years and has extensive experience in extreme-ultraviolet lithography, ultra-high intensity lasers and laser surgery. Obert received his B.S., M.S. and Ph.D. Degrees from the University of California at Berkeley in Electrical Engineering in 1964, 1965 and 1969. He is author or co-author of 215 technical papers, inventor or co-inventor of 20 patents, and is a fellow of the Optical Society of America, a senior member of IEEE, and a member of the AAAS, the American Physical Society, the American Vacuum Society and the Society of Photo-Optical Instrumentation Engineers.

Contamination -1

Outgassing and Extreme-ultraviolet Photochemistry of Photoresist and Underlayer Materials

Grace H. Ho, Fu-H. Kang, Chih-H. Shao, Wei-L. Hung, Chih-B Kao, and Yu-L. Chou
Department of Applied Chemistry, National University of Kaohsiung, Nanzih, Kaohsiung 811, Taiwan

We characterized neutral and ionic outgassing from photoresist and underlayer materials upon irradiation at 13.5 nm by a quadrupole mass filter, measured absolute ionic outgassing yields by a double-ion chamber, quantified neutral outgassing by a pressure rise method with a well characterized vacuum system, and investigated the exposure kinetics leading to outgassing as a function of the exposure dose. These experiments were conducted at the 08A1BM-LSGM beamline of National Synchrotron Radiation Research Center in Taiwan. We found the amount of outgassing to be EUV photoabsorption and polymeric structure dependent. According to the experimental results, we proposed plausible reaction mechanisms of EUV photochemistry leading to outgassing.

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.

Contamination -2

Novel Ozone-based Cleaning Technique for EUV Optics Carbon Contamination

Iwao Nishiyama, Toshihisa Anazawa, Noriaki Takagi, Osamu Suga
MIRAI-Semiconductor Leadnig Edge Technologies, Inc.;
16-1, Onogawa, Tsukuba, Ibaraki, 305-8569, Japan,

Since contamination on EUV optics, including mirrors and masks, reduces the throughput in EUV lithography, it must be removed. Various cleaning techniques have been developed to do that, such as plasma cleaning, UV and ozone cleaning, hydrogen radical cleaning, in situ EUV cleaning with oxidative gasses, etc. The removal rates of these techniques for carbon contamination are 0.01~1 nm/min under almost ideal conditions; so the actual rates in a production tool will be lower. In HVM, the contamination rate might be dramatically higher, necessitating an even more efficient cleaning technique.

Here we propose a new contamination cleaning technique that uses pure ozone gas. It easily removes simulated carbon contamination film at a rate of over 70 nm/min at room temperature. This rate is two to three orders of magnitude higher than the rates for the techniques mentioned above.

We examined the ability of Si- and Ru-alloy-capped multilayers to withstand our cleaning technique and found that the reflectivity of a Ru-alloy cap decreased while that of a Si cap remained the same. In the presentation, the details of our cleaning technique and the durability of various materials used in EUV masks will be discussed.

This work was supported by NEDO.

Presenting Author

Contamination -3

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

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

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. The protection is made more difficult because the conventional pellicles cannot be used, due to the attenuation of the EUV beam by the pellicles. 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.

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 particles with NIST-traceable sizes of 20 nm, 30 nm, 50 nm, 60 nm, and 70 nm were separately deposited on quartz mask blanks 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.

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 over 200 journal papers and 17 patents. He has developed/co-developed several widely used commercial aerosol instruments. Dr. Pui is a fellow of the American Society of Mechanical Engineers (ASME), 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 is currently serving as the President of the International Aerosol Research Assembly (IARA) consisting of 13 international aerosol associations.

Contamination -4

Carbon Contamination of EUV Masks and its Effect on Imaging

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The impact of carbon contamination on extreme ultraviolet (EUV) masks is significant due to throughput loss and potential effects on imaging performance. Current carbon contamination research primarily focuses on the lifetime of the multilayer surfaces, determined by reflectivity loss and reduced throughput in EUV exposure tools. However, contamination on patterned EUV masks can cause additional effects on absorbing features and the printed images, as well as impacting the efficiency of cleaning process. In this work, several different techniques were used to determine the contamination topography. Lithographic simulations were also performed and the results compared with the experimental data.

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.

Contamination -5

Counting outgassing molecules

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We measure neutral outgassing from photoresists upon irradiation at 13.5 nm in the extreme ultraviolet (EUV) region by a pressure rise method. In order to determine the amount of outgassing in absolute numbers, we measure the pumping speed of the vacuum system as a function of particle masses, and also calibrate the pressure ion gauge (IG) into absolute pressure. Taking the pumping speed and IG correction factors for different kinds of gases into account, the pressure rises arise from various amounts of the gases consist with the theoretically predicted values within ±20% with no observable dependency on masses nor gas identities. The pressure rise method derives the amount of outgassing from the round-robin resist, and scales it to 2.8×10^{15} molecules cm^{-2} s^{-1} upon 0.4 W/cm^2 EUV irradiation. This amount of outgassing is about the medium number among those reported in the outgassing benchmarking project [K.R. Dean et al., Proc. SPIE 6519 (2007) 65191P]. We use a quadrupole mass spectrometer (QMS) to characterize the identities of outgassed species and to determine the amounts of outgassing of these individual species. To count the outgassed species in quantity, we apply a correction, the transmission function of QMS as a function of m/z, to the measured mass spectra. The characterization and quantitative analysis on outgassed species from PMMA, RRR and photoresists will be presented.

Presenting Author

Contamination -6

Contamination Removal using the Evactron® De-Contaminator

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The issue of contamination on extreme ultraviolet (EUV) optics needs to be addressed in order to allow EUV lithography to become commercially feasible. Image quality in scanning electron microscopes (SEMs) can also be degraded by hydrocarbon contamination. In both systems, hydrocarbon contamination is cracked and then polymerized by either a photon beam in the case of EUV optics or an electron beam for SEMs.

The use of the Evactron® De-Contaminator, a low power downstream plasma cleaner, has been shown to be effective in removing carbon contamination from SEMs. This commercially available product has been installed on over 900 SEMs worldwide. The Evactron De-Contaminator typically uses room air to clean in a downstream process. Oxygen radicals chemically etch the surface to be cleaned; there is no sputter etch by ions. Pure oxygen can also be used. The cleaning plasma can also be created using hydrogen gas, which opens the possibility of cleaning through reduction chemistry.

The effectiveness of the downstream plasma cleaning process has also been tested on EUV mirrors at the Center for X-Ray Optics at Lawrence Berkeley National Laboratory. It has been shown that the downstream plasma is effective at removing hydrocarbons from EUV mirrors without damaging them.

Presenting Author

LER-1

The Influence of Photoresist Development on Line Edge Roughness

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Most theoretical descriptions of lithography make an extremely fundamental and mostly unstated assumption about the physical world being described: the so-called *continuum approximation*. Even though light energy is quantized into photons and chemical concentrations are quantized into spatially distributed molecules, the descriptions of aerial images and latent images ignore the discrete nature of these fundamental units and use instead continuous mathematical functions. For example, the very idea of chemical concentration assumes that the volume one is interested in is large enough to contain many, many molecules so that an average number of molecules per unit volume can be used. While we can mathematically discuss the idea of the concentration of some chemical species at a point in space, in reality this concentration must be an average extended over a large enough region. While in most cases the volumes of interest are large enough not to worry about this distinction, when trying to understand lithography down to the nanometer level the continuum approximation begins to break down.

When describing lithographic behavior at the nanometer level, an alternate approach, and in a very real sense a more fundamental approach, is to build the quantization of light as photons and matter as atoms and molecules directly into the models used. Such an approach is called *stochastic modeling*, and involves the use of random variables and probability density functions to describe the statistical fluctuations that are expected. Of course, such a probabilistic description will not make deterministic predictions – instead, quantities of interest will be described by their probability distributions, which in turn are characterized by their moments, such as the mean and variance.

While stochastic modeling has been successfully applied to photoresist exposure and post-exposure bake processes in recent years, the stochastic behavior of resist dissolution is much less understood. Dissolution rate variance comes from both the variance in the polymer solubility itself and the resulting variation in the development path required to bypass randomly insoluble polymer molecules. Percolation theory, where the percolation probability is equal to the probability that a polymer molecule will become soluble, has the potential for providing the theoretical framework required to solve this problem, and will be applied to the problem of photoresist development in order to predict line-edge roughness. In particular, fractal surface growth/etching models [1] will be applied to photoresist dissolution to predict the difference in dissolution rates between the stochastic and continuum models, and to predict the resulting surface roughness.

1. Barabasi A. L. and Stanley H. E., *Fractal Concepts in Surface Growth* Cambridge University Press, Cambridge (1995).

Presenting Author

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

LER-2

Stochastic Resist Simulation at EUV

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Accurate and flexible simulation methods may be used to help a researcher's understanding of how complex resist effects influence the patterning of nanoscale structures. Historically, modeling strategies for optical lithography have applied the continuum approximation to the physics being simulated. However, the real world is discrete: light energy is made up of photons; chemical concentration has no meaning at a point. Stochastic simulation allows the user to predict responses that naturally arise from random fluctuations in lithography, such as LER, LWR, and CD variability. In this work, we attempt to gain insight into the behavior of a state-of-the-art EUV resist through the use of stochastic resist simulation. The statistics of photon and molecule counting are discussed. A discrete, probabilistic ionization and electron scattering simulator for acid generation at EUV is discussed. The effect of simulated photoelectron blur upon resist performance is discussed. The model's parameterized fit to experimental data of average resist CD and LWR is discussed.

Presenting Author

Mask-1

Analysis of carbon contamination on EUV mask using CSM/ ICS

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Extreme ultra violet lithography (EUVL) is considered to be the solution of mass production process for 22nm half pitch and below. EUVL has several challenges, and one of the most important issues is a carbon contamination on EUV mask which can deteriorate critical dimension (CD) uniformity and EUV mask life time.

The impact of carbon contamination on the mask performance were analyzed by the in-situ contamination system (ICS) combined with coherent scattering microscopy (CSM) which has been installed at Pohang Light Source. Optical design and system performance will be introduced including the results on EUV mask contamination analyses through carbon thickness and EUV reflectivity survey. The influence of carbon contamination on the imaging properties including image contrast and CD changes measured by CSM will be presented. In addition, strategies for carbon contamination mitigation and cleaning process will be discussed.

Presenting Author

Jae-uk Lee is a graduate student under Professor Jinho Ahn. He received bachelor degrees in Materials Science and Engineering from Hanyang university, Seoul, Korea. His current research interests are removal of contamination and inspection technique for EUV mask.

Mask-2

Defect Detection and Inspection Unmasked: The current state of EUV mask defects

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Notwithstanding the laws of thermodynamics, researchers in EUV lithography strive to create defect-free reticles. Following a long period of slow development in this area, our understanding of defect detectability and printability has grown substantially in the last two years, thanks to careful defect inspection and cross-correlation experiments undertaken by groups worldwide.

DUV tools have steadily improved their sensitivity and are currently viewed as essential for mask blank inspection. Yet the wavelength-specific response of EUV multilayers, mask patterns, and defects skews the predictive capabilities of non-actinic imaging in ways that are challenging to unravel. Actinic mask inspection data (i.e. recorded with EUV light) is now limited to the output of a small number of working tools--and printing tests--but there is finally enough data to draw early conclusions.

I will review the current state of the art in EUV defect inspection, exploring what is known about the various type of defects, their printability and detectability, the status of defect-free mask blank preparation, and the development of a new crop of defect-detection tools.= No virus found in this incoming message.

Presenting Author

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

Mask-3

Production of High Purity Functional Water at Point-of-Use for Advanced Mask Cleaning Processes

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Mask cleaning remains as one of the major challenges in EUV lithography. Without the use of traditional pellicles, EUV masks demand high purity and effective but mild cleaning techniques for protection from defects. Recently, trends towards dilute chemistries and progress in megasonic cleaning have brought renewed interest in gasified DI water. In this paper, we describe the design and development of a point-of-use functional water treatment system, specifically for advanced mask cleaning applications. The system is comprised of two modules – the purification module and the gasification module. The purification module provides treatment features including TOC reduction, sub-micron particle retention, degassing, as well as thermal and pressure control. The gasification module employs micro-porous PFA membrane contacting technology to deliver ultra clean bubble-free DI water with various gases (O_3, N_2, H_2, CO_2, NH_3, etc.) over a wide concentration range. A novel direct injection design achieves precisely controlled low dissolved gas concentration without relying on either gas or liquid dilution. The treatment system is also equipped with closed loop process control to maintain and regulate process temperature, pressure and dissolved gas concentration. This active control feature allows precise control and minimal process variations.

Presenting Author

Annie Xia joined Entegris in 2005 and is currently a Program Manager in Liquid Filtration Business Unit at Entegris Corporation. Prior to Entegris, Annie was an etch process engineer for Tokyo Electron Ltd. She obtained her B.S. and Masters in Chemical Engineering from the Massachusetts Institute of Technology.

Mask-4

Mask metrology and Pattern Profile Analysis using the AIT: Down to 64 nm

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Accurately measuring the characteristics of EUV masks is an essential step in the lithography process. The reticle surface properties are usually assessed with SEM inspection and they are required to meet ever more stringent specifications with shrinking lithography deign rules. However, the mask surface properties by themselves are not sufficient to predict the quality of the printed pattern. Through-focus images on printed wafers are inspected under the SEM to extract aerial image parameters like LWR, NILS and the size of the process window.

The Sematech Berkeley Actinic Inspection Tool (AIT) provides a complementary capability and is routinely used to perform aerial image metrology analysis at wavelength. It is the highest performing EUV mask microscope now in operation, several years ahead of commercial tools. AIT data can be used to study the light field that actually reaches the photoresist, taking into account the wavelength-dependent complete mask pattern architecture, plus subtle phase effects that may originate under the multilayer, like the inherent mask phase roughness.

We have characterized a GlobalFoundries mask investigating the dependence of observed line edge roughness, contrast, and NILS dependence on line width and numerical aperture (NA). The data also serves to benchmark the performance of the AIT. We show a direct evaluation of the LER Transfer Function (LTF) for different NA values comparing the LER of real lines and their aerial images.

Presenting Author

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

Mask-5

Study of the Minimum Phase Defect Affecting the Exposure Result

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We constructed an extreme ultraviolet microscopy (EUVM) system for actinic mask inspection that consists of Schwarzschild optics and an X-ray zooming tube. This system was used to inspect extreme ultraviolet lithography (EUVL) finished masks and Mo/Si coated substrates on Ultra Low Expansion (ULE) glass. We also have fabricated programmed phase defects on the blanks used for inspection. In that study, we fabricated some mask blanks with the programmed hole-pit defects with different width and depth by a new process and carried out actinic inspection using EUVM.. As results, 4.0 nm-deep hole-pit defects with widths ranging from 35 to 180 nm were clearly resolving. However, 20-nm-wide and 25-nm-wide hole-pit defects were not resolved. Also, 3.0 nm and 2.0 nm-deep hole-pit defects with widths ranging from 60 to 180 nm were resolved. However, hole-pit defects with widths ranging from 20 nm to 40 nm were not resolved. Additionally, 1.0 nm-deep hole-pit defects with widths ranging from 70 to 180 nm were clearly resolving. However, hole-pit defects with widths ranging from 20 nm to 60 nm were not resolved. From these results, we have identified of printability in programmed phase defects with all kinds of width and depth on mask blanks with EUVM.

Presenting Author:

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

Mask-6

Development Status of EUVL Blank and Substrate

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Asahi Glass has been developing of the EUVL (extreme ultra violet lithography) mask blank and polished substrate since 2003, including the developments of all essential materials and processes: the low thermal expansion material (LTEM), the material developments of the reflective, capping and absorber films, the process developments of the substrate polishing, the cleaning, the film deposition and the resist film coating processes. In this paper, we present the current development status of the full-stack EUV mask blank and polished substrate which are the most suitable for the EUV lithography process development with EUV pre-production exposure tools. We are going to update the major performances of the reflective multilayer-coated LTEM substrate such as the substrate flatness, the EUV optical properties of the Mo/Si reflective layers and the defect of LTEM substrate and reflective layer. The performances of the Ta-based absorber and the resist films will be reported as well to show the readiness of the EUV mask blank suitable for any kinds of process developments of the EUV lithography.

Presenting Author

Toshiyuki Uno obtained the master degree in Material Science and Engineering from Tokyo Institute of Technology in 1995 and joined Asahi Glass in 1995. He has been involved in the development and manufacturing of functional glasses with dry coating for electronics applications since 1995, and has been joined the EUV mask blank development program at AGC since 2003. He is currently working as a senior researcher of EUV mask blank development at central research center.

Optics-1

Virtual Sputter Chamber - Multiphysics Simulation of Magnetron Sputter & Deposition of EUV/X-ray Thin Films

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Lack of detailed knowledge of process conditions remains a key challenge in magnetron sputtering, both for chamber design and for process development. Fundamental information such as the pressure and temperature distribution of the sputter gas, and the energies and arrival angles of the sputtered atoms and other energetic species is often missing, or is only estimated from general formulas. However, open-source or low-cost tools are available for modeling all the physics of the sputter process, which can give more accurate data from desktop computations than traditional empirical approaches. Knowledge of the fundamental physics can give new understanding of thin film growth, and new control of roughness, intermixing, and stress evolution that affect applications to EUVL, astronomy, and free-electron lasers.

To get a better understanding of magnetron sputtering, we have collected existing models for the 4 main physics steps: 1) dynamics of the plasma using Particle In Cell-Monte Carlo Collision (PIC-MCC), 2) impact of ions on the target using molecular dynamics (MD), 3) transport of sputtered atoms to the substrate using Direct Simulation Monte Carlo (DSMC), and 4) growth of the film using hybrid Kinetic Monte Carlo (KMC) and MD methods. All the models have been tested against experimental measurements. The spatial distribution and electron temperature T_e of the plasma have been reproduced within ~25% for a scaled model of an example magnetron system. The rarefaction of the neutral gas in front of a magnetron observed by Rossnagel[1]and others has been reproduced, and it is associated with a local pressure increase of ~50% which may strongly influence film properties such as stress and film density. Results on energies and arrival angles of sputtered atoms and reflected gas neutrals are applied to the Kinetic Monte Carlo simulation of film growth. Arrival energies have also been applied to predict substrate heating, and to finite-element thermal modeling of the substrate surroundings for thermal management. Model results and applications to growth of Cu, Zr and Be films will be presented. Work underway on increasing computation speed with parallelization will also be discussed.

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1. Rossnagel, S.M., *Gas density reduction effects in magnetrons.* Journal of Vacuum Science & Technology A-Vacuum Surfaces & Films, 1988. **6**(1): p. 19-24.

Presenting Author

Optics -2

Growth, microstructure and stress evolution of sputtered thin films for EUV/x-ray applications

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Boron carbide and silicon carbide are important reflective materials for single layer and multilayer optics operating in the extreme ultraviolet / x-ray range, in applications such as EUV lithography, solar physics, astrophysics and plasma diagnostics. They have also recently emerged as coating materials for grazing incidence x-ray mirrors designed for free-electron laser (FEL) facilities such as the Linear Coherent Light Source (LCLS), the first x-ray FEL in the world. This first-of-a-kind x-ray source produces ultra-short (~100 femtosecond) monochromatic X-ray pulses of unprecedented brightness (10^{32} photons/pulse) in the first harmonic ranging between 0.8 and 8 keV. The revolutionary capabilities of the LCLS will generate a wealth of new research in the fields of physics, biology and materials science. A study and optimization of DC-magnetron sputtered boron carbide and silicon carbide films with thicknesses ranging from 20 nm to 1 micron are presented in this manuscript. Film characterization techniques employed in this study include Atomic Force Microscopy, extreme ultraviolet/x-ray reflectance, large-angle x-ray diffraction, x-ray photoemission spectroscopy (XPS) and Rutherford backscattering (RBS). The high compressive stress of these coatings is mitigated by modifying the sputtering gas pressure. The evolution of the film morphology and stress as a function of thickness and sputtering pressure are presented, and the film growth parameters are fitted to a stochastic growth model [1-4]. The damage threshold properties of the reflective coatings developed for the LCLS will also be discussed [5-6].

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Presenting Author

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

Resist-1

Nanoscale Chemical Reaction Induced in Chemically Amplified Resists upon Exposure to Extreme Ultraviolet Radiation

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In lithography, the normalized image log slope (NILS) is an important metric that describes the quality of an aerial image of incident photons. The aerial image is converted to a latent image through lithographic processes in the resist. The quality of latent image is known to correlate to line edge roughness (LER). The chemical gradient is also an important metric that describes the quality of a latent image. The relationship between NILS and chemical gradient is discussed on the basis of chemical reactions induced in nanoscale regions of chemically amplified resists upon exposure to extreme ultraviolet radiation. Understanding of chemical reactions induced in resist materials is essential to the development of resist materials used in the 22 nm node and beyond. The material design on the basis of reaction mechanisms is important to reduce line edge roughness (LER) without sacrificing sensitivity and resolution. The chemical reactions are discussed from the EUV-material interaction during the energy deposition, to the catalytic chain reactions during postexposure baking, to the formation of line edge roughness. In particular, the effect of effective reaction radius for catalytic chain reactions on the relationship between NILS and chemical gradient is discussed.

Presenting Author:

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

Resist-2

Novel Molecular Materials Based on Noria and Double Calixarene for EB and EUV Resist Systems

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The synthesis and physical properties of the ladder cyclic oligomer Noria (water wheel in Latin) and double-calixarene-like cyclic oligomer (DC) derivatives with pendant adamantate and oxetanyl groups were examined. Noria was synthesized by the condensation reaction of resorcinol and 1,5-pentanedial in the presence of HCl as a catalyst in high yield. i.e., only noria could be obtained based on dynamic covalent chemistry (DCC) system. In the case of resorcinol and 2,5-dihydroxybenzaldehyde, double-calixarene-like cyclic oligomer (DC) could be synthesized in high selectively. Although Noria and DC had excellent thermal stability, they had not good solubility. The properties of noria and DC derivatives with pendant adamantate and oxetanyl groups were also examined, and it was found that these derivatives had excellent physical properties such as good solubility in common organic solvents, good film-forming ability, and high thermal stability, for the applicable as EB and EUV resist materials. Furthermore, their patterning properties were examined and 22 ~ 26 nm patterns could be obtained.

Presenting Author

Tadatomi Nishikubo received Bachelor degree in Applied Chemistry in Kanagawa University, Japan, in 1967. He joined NOK. Co,, Ltd, Japan in 1967-1978. He received Doctorate degree in Electronic Chemistry from Tokyo Institute of Technology, Japan, in 1976. His carrier at Kanagawa University has included being Lecturer (1978), Associate Professor (1980), Full Professor (1986), Dean (2000-2005) and Vice-President (2006-2007). He worked with Dr. R. W. Lenz as a visiting faculty at the University of Massachusetts, USA, in 1981-1982. Since 2006, he is Trustee of Kanagawa University. His research interest covers synthesis and reactions of new photo-functional polymers.

Resist-3

Effects of Acid Amplifiers and Polymer Bound Photoacid Generators on EUV resist Performance : Fundamental Studies and Lithographic Results

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In the drive to improve the photospeed and resolution of EUV resists, the use of acid amplifiers and polymer bound Photoacid generators are subjects of significant current interest. Acid amplifiers (AA's) operate by increasing acid concentration via thermal reactions catalyzed by photogenerated acid, thereby increasing the effective quantum yield. Bonding the PAG anion to the polymer backbone in principle should result in reduced acid diffusion, lower image blur and ultimately higher resolution. Both of these approaches can lead to better EUV photoresists, however the performance tradeoffs and the ultimate improvement to resolution are not clear at this time. We have prepared several types of resists containing AA's and have investigated the additives' effects on resist sensitivity in EUV and DUV exposures. UV-VIS and FT-IR spectroscopic techniques were employed to measure, respectively, the yield of acid formation and the extent of deprotection in resists containing these additives. We will describe the results of our studies aimed at understanding the reasons for observed differences in resist performance, acid yield formation and extent of deprotection for ArF and EUV chemically amplified resist systems containing either acid amplifiers or sensitizers as additives. Recently we reported PAG-bound resist polymers based on a new triphenyl sulfonium fluoroalkyl sulfonate incorporated into a methacrylate monomer. In this report we describe in detail the characterization of this and other polymers prepared with bound PAGs. We will present measurements of acid diffusion, deprotection chemistry and photoacid volatilization and contrast these results with those obtained from conventional PAG's. We will also present results from 193 nm immersion, EUV and electron beam lithography.

Presenting Author

Resist-4

Flare Mapping and Correction results for EUV Alpha Demo Tool

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One of the major concerns developing EUVL technology is high flare effect introduced by short wavelength of the source and difference in optics used for the tool. Compared to conventional lithography, source wavelength is 14 times smaller and this coupled with change in the optics from lens to mirror may show significant rise in flare level. In our previous study, ADT tool at IMEC showed 16% flare level compared to 2~3% of conventional ArF scanner. Measurement from the wafer showed that high flare level of EUV tool limited the minimum resolution of printable feature size as well as degraded the output image on the wafer. Therefore flare correction is very crucial and prior to correction, prediction of flare effect is inevitable in order to acquire high resolution wafer result in EUVL technology.

In this study, in order acquire high resolution wafer result in EUVL technology, we mapped and corrected the EUV flare effect on real layer of DRAM. We investigated many aspect of flare correction such as flare mapping, data handling of flare corrected data, mask creation of flare corrected data and wafer result of corrected and uncorrected data. First, flare distribution of the EUV Alpha Demo tool was measured and was used in simulation tool to simulate several test case wafer result. Next, using the measured flare distribution result, flare mapping was performed on contact layer of DRAM. With acquired flare map, correction of the flare effect on layout was performed. In house EUV mask was then created using flare corrected and uncorrected data and wafer measurement was performed to verify the flare correction scheme. Currently, measurement of the corrected and uncorrected data is under way and comparison result will be presented at the conference.

Presenting Author

Resist-5

An Investigation of Flare Value at Pattern Edge Region in EUVL

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Extreme Ultraviolet Lithography (EUVL) is one of the leading candidates for the next generation lithography of 32nm half pitch technology and beyond. But there are still many problems to be solved before its introduction to mass production. One of the critical issues in EUVL is flare effect, which is related to the unwanted scattering light. It degrades the contrast of aerial images and the control of the critical dimension (CD) across the exposure field. Therefore, it is necessary to predict accurate flare value and compensate it at OPC level.

Mathematically, flare is obtained by convolution of the flare point spread function (PSF) with a clear-field mask. Once the flare PSF is determined, flare level depends on the absorber density of clear-field mask.

In this paper, we investigated a smart way to obtain an accurate flare map especially at the edge area of pattern where the gradient of flare value is high. The flare PSF of Alpha demo tool (ADT) was fractal model provided by Hynix semiconductor Inc. Because the region of PSF expends several millimeters, there exists a trade-off between resolution and computer resources when a flare map is extracted. To circumvent this problem, we defined PSF1 and PSF2 with small and large grid size respectively. Then, we convoluted the PSF1 with edge of each pattern where the gradient of pattern density was high and the PSF2 with central region of each pattern where the gradient was low.

Presenting Author

Resist-6

Radiation Chemistry of EUV and EB Resists

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The increasing density of semiconductor devices has required the development of high resolution exposure techniques. The miniaturization of feature sizes has been achieved mainly by shortening the wavelength of exposure tools. The shortening of wavelength means the increase in the photon energy of exposure tools such as extreme ultraviolet (EUV, 13.5 nm) lithography, where ionization is a main process. Recently, high sensitive resists are required for EUV and electron beam (EB) resists. Nowadays chemically amplified resist (CAR) is only one high sensitive resist and the situation will not change in the near future. Another important ionizing radiation for lithography is EB. EB lithography is an indispensable technology for the fabrication of photomasks. The present paper reviews radiation chemistry of EUV and EB resists, especially the detaled mechanisms of nanospace and acid generation reactions in EUV and EB resists.

Presenting Author

Prof. Seiichi Tagawa is currently the Director of Beam Application Frontier Laboratory at the Institute of Scientific and Industrial Research, Osaka University. He is also the Head of Nanofabrication Function, Handai-Functional Nanofoundry, Osaka University and the Distinguished Professor/ Emeritus Professor of Osaka University. He received his Ph.D. in Nuclear Engineering, University of Tokyo in 1973.

Resist-7

A New Resist Evaluation System developed at NewSUBARU

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We have developed a new resist evaluation system at NewSUBARU. This system consists of Mo/Si multilayer mirror , resist coated on the wafer, Q-mass and in-situ ellipsometory. SR light illuminates a Mo/Si mirror at first, and reflected light irradiates the resist. Outgases from resist will evaporate in the vacuum chamber. Species of outgas will be detected by Q-mass. The hydrocarbon will attach to the Mo/Si mirror and the thickness of hydrocarbon is measured by in-situ ellipsometry. Using this system, we can evaluate which resist is available for the exposure tools.

Presenting Author

Resist-8

Contact Size Variations: Dissecting the Sources

Patrick Naulleau

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The large k1 factor afforded by EUV lithography has significant benefits in terms of printing contacts. Truly understanding the limitations of EUV lithography in this regime, however, requires an understanding of the dominant sources of contact size variation. Sources and aggravating factors include, mask roughness, shot noise, optical error enhancement factor, resist error enhancement factor, etc. Here we describe these terms and their relative importance in detail. The results show that although the optical error enhancement factor is quite low at EUV, resist is a significant aggravating term reducing the tolerance to error terms such as mask roughness.

Presenting Author

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

EUVL R&D Status

Panelists

Greg Denbeaux – USA (University of Albany)
Hiroo Kinoshita –Japan (Hyogo University)
Padraig Dunne – Europe (University College, Dublin)
Chun-Hung Lin – Taiwan (National Cheng Kung University)
Jinho Ahn – Korea (Hanyang University)

Presenting Author

Dr. Chun-Hung Lin received his B.S. degree in 1995 from Department of Physics in National Taiwan University, M.S. and Ph.D degrees in 1997 and 2002 from Graduate Institute of Electro-Optical Engineering in National Taiwan University. He was a principle engineer in Advanced Lithography Technology Department of Taiwan semiconductor manufacturing company, Ltd. in 2002-2003, a postdoctoral researcher of National Center for High Performance Computing in 2003-2004 and an associate researcher of National Nano Device Laboratories in 2004-2007. From 2007 to present, he is an assistant professor of Institute of Electro-Optical Science and Engineering, National Cheng Kung University (NCKU). His interests are in EUV interferometric lithography, nanoimprint lithography, optical simulation and nano-photonics.

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

Source -1

Improving efficiency of CO_2 laser system for LPP Sn EUV source

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Recent years have witnessed the commercial deployment of EUV Laser-Produced-Plasma source technology, a testament to a successful solution of numerous technological challenges. The development of the LPP source is far from over however. The EUV collector mirror lifetime, spectral purity of the generated radiation and the efficiency and the reliability of high power laser driver are still the issues awaiting better solutions.

This talk addresses some of the pressing technical challenges of the LPP laser driver, such as efficiency, footprint and stability of operation. The current approach taken in the industry is a MOPA system based on a small average power pulsed master oscillator (<100W, 20-50ns pulse, 50-100kHz pulse repetition frequency) and a chain of power amplifiers.

The amplifiers are usually based on commercial multi-kilowatt fast flow laser units. The limitations of this approach in terms of efficiency and beam stability are explained with an aid of numerical modeling of the gain medium and thermal distortions in the optical components of the system. The model results are supported by experimental data of our 10kW laser system.

Experiments have shown that such MOPA system cannot provide more than 25% overall operation efficiency. The main reason is an insufficient power level at initial amplifier stages. An approach taken at EUVA Japan was to develop a master oscillator system capable of >2kW average power in order to drive the power amplifiers into saturation. A pre-amplifier system based on a novel configuration of a RF-excited CO2 laser is the key to high efficiency. Over 40% energy efficiency was predicted from 100W input, opening the avenue to efficient pre-amplification.

The multi-kW output predictions were verified in our experimental pre-amplifier. Over 2kW of output power was obtained from 100W input at near-diffraction limited beam.

Presenting Author

Source-2

Atomic Processes in Plasma EUV Sources at λ=6.5nm

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Atomic processes of elements with Z=60-70 are investigated for the application to the future light source for the lithography at a wavelength of 6.5nm. Properties of emission lines of 4p-4d and 4d-4f transition arrays, including the wavelength, spectral width, and transition probability are investigated for open 4d shell ions, based on the atomic data calculated using the HULLAC code. Emission lines in the λ=6.5nm region and corresponding charge state are identified. Using a collisional radiative model, coefficients of radiative transfer are calculated, which is used to estimate the output power and emission spectrum using a simple model on the basis of local thermodynamic equilibrium (LTE), and the requirement of pumping conditions for the laser produced plasma sources, such as the intensity and wavelength, 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.

Source-3

CO_2 Laser-produced Tin Plasmas as EUVL Sources

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Research to date surrounding EUV emitting tin plasmas for lithography has mainly concentrated on using pulsed lasers operating at 1064 nm but theoretical modelling [1] and recent experiments [2] have shown that a move to CO_2 lasers operating at 10.6 μm will have more intense in-band EUV emission at lower power densities, thus improving the EUV conversion efficiency. One of the key factors is the reduced plasma density, and hence opacity, that is observed in CO_2 laser-generated plasmas. Consequently, we have measured the in-band (centred on 13.5 nm) and broadband EUV emission of a CO_2 laser produced tin plasma using a 0.25-m, absolutely calibrated spectrometer operating in the 9 – 17 nm spectral region. We have done this for a range of laser power densities, pulse energies and pulse durations, and the EUV conversion efficiency has been measured at both 45° and normal to the target surface.

This research is supported by Science Foundation Ireland, grant no. 07/IN.1/I1771.

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Presenting Author

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

Source-4

EUV Source Development for AIMS and Blank Inspection

Paul A. Blackborow, Matthew J. Partlow, Stephen F. Horne, Matthew M. Besen, Donald K. Smith, Deborah Gustafson
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With EUV Lithography readying for production, the need for commercially available actinic mask inspection tools is critical. A key to developing a successful tool is a reliable high brightness EUV light source. The Energetiq EQ-10 is a commercially available EUV light source, with demonstrated reliability of over 15 sources in the field. It is being used today for laboratory based actinic mask blank inspection at Selete. Results will be presented from a program to optimize the EQ-10 for higher brightness. The platform used for this work is a new version of the EQ-10. The redesigned source demonstrates increased EUV power and brightness compared to the standard EQ-10. The program aims to optimize source operating conditions and pinch geometries of the new source to maximize brightness.

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 and has worked at ASTeX, Mykrolis and Helix. Ms. Gustafson's is a senior manager at Energetiq Technology, Inc. in Woburn, Massachusetts as their Vice President of Sales and Service. Her responsibility also includes marketing and the management of manufacturing and finance.
Currently Ms. Gustafson is the chairperson of the SEMI New England Committee. She holds a BS in Mechanical Engineering and an MBA in Management from Bentley College.

Source-5

High Brightness EUV Light Source System Development for Actinic Mask Metrology

Sergey V. Zakharov [1,2]+, Peter Choi [1,2], Raul Aliaga-Rossel [1], Adrice Bakouboula [1], Otman Benali [1], Philippe Bove [1], Michele Cau [1], Grainne Duffy [1], Carlo Fanara [2],Wafa Kezzar [1], Blair Lebert [2], Keith Powell [1], Ouassima Sarroukh [2], Luc Tantart [1], Clement Zaepffel [2], Vasily S. Zakharov [2], Alan Michette [3], Edmund Wyndham [4]
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[+] RRC Kurchatov Institute, *Moscow, Russia*

EUV lithography deployment is critically dependent on the availability of mask infra structure, including all metrology modalities. EUV sources for actinic mask metrology, particularly for defect inspection, require extremely high brightness. The self-absorption of radiation limits the in-band EUV radiance of the source plasma and makes it difficult to attain the necessary brightness and power from a conventional single unit EUV source. One possible solution is through multiplexing of multiple low etendue sources. NANO-UV is delivering a new generation of EUV light source with an intrinsic photon collector, the i-SoCoMo™ concept, where a micro plasma pulsed discharge source is integrated to a photon collector based on an in situ active plasma structure. The source is characterized by high brightness, low etendue and very high irradiance, at moderate output power, without the use of external physical optics. Such a source could form the basic building block, through multiplexing of several units, to satisfy the very high brightness and moderate power requirement of the EUV sources required for actinic mask metrology. Based upon this multiplexing concept, a family of specially configured multiplexed source structures, the HYDRA™ design, is being introduced to address the mask metrology needs. The design of the 3 sources for AIMS, ABI and APMI is presented. Upgrade of the source unit and preliminary experience in the operation of HYDRA™ is discussed.

Presenting Author

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

Source-6

Modelling of High Intensity EUV Light Sources Based on Laser & Discharge Produced Plasmas

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

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

Presenting Author

Source-7

Laser-produced terbium & gadolinium Plasmas as EUVL Sources at 6.5 – 6.7 nm

Padraig Dunne[1], Thomas Cummins[1], John White[1], Deirdre Kilbane[1], Rebekah D'Arcy[1], Emma Sokell[1], Thomas McCormack[1], Imam Kambali[1], Takamitsu Otsuka[2], Colm O'Gorman[1], Enda Scally[1], Fergal O'Reilly[1], Tony Donnelly[1] and Gerry O'Sullivan[1].
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What's next? is a natural question in terms of Moore's Law [1], which has dictated the fabrication of ever smaller features in silicon over the last 40 years. Moving from 13.5-nm sources to 6.7-nm extreme ultraviolet sources would seem to be a logical step along this route, holding out the potential to further shrink features beyond the 11-nm node. Recent work by Churilov et al. [2], and earlier work by O'Sullivan [3] show that gadolinium (Gd, Z = 64) and terbium (Tb, Z = 65) emit strongly in the 6.5 – 6.7 nm band, due mainly to unresolved transition arrays (UTAs), hugely complex spectral features that arise from transitions between mixed atomic configurations where the active electrons typically have a principal quantum number, n = 4, 5 or 6.

We have investigated the spectra of laser produced plasmas, formed on targets containing Gd and Tb, using Nd:YAG and CO_2 lasers operating at 1064 nm and 10.6 µm respectively. The spectra were recorded on a 2-m grazing incidence spectrograph in time integrated mode and a 0.25-m grazing incidence spectrograph in time resolved mode, with time resolution down to 5 ns. We have done this for a range of laser power densities, pulse energies and pulse durations, and the spectra have been measured at both 45° and normal to the target surface.

We have analysed the spectra using the Cowan suite of codes and modelled the plasmas using both collisional-radiative and local thermodynamic equilibrium models in order to aid optimisation of the laser parameters.

This research is supported by Science Foundation Ireland, grant no. 07/IN.1/I1771.

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Presenting Author

Source-8

High Brightness EUV Source Using a DC High Voltage Generator

John Madey, Luis Elias and Eric Szarmes
University of Hawai'i at Manoa

The low energy, high current and small focused ebeam spot sizes needed for operation of high brightness inverse Compton and optical undulator EUV light sources have represented a challenge to the designers of the accelerator and ebeam transport systems for these devices due to the strong self-forces of these low energy beams. We describe a compact system capable of operation at a wavelength of 13.5 nm using a 2 MeV electrostatic accelerator, gas focusing and a optical storage cavity pumped by a phase coherent high rep rate laser source to achieve the micron-scale focal spot sizes for operation at the high brightnesses required for EUV metrology.

Presenting Author

John Madey is a Professor of Physics at the University of Hawai'i at Manoa. His research team developed the first free electron laser at Stanford University in 1975 and the first compact infrared FEL for use in quantum optics and high field quantum electrodynamics, spectroscopy, remote sensing, and materials science in 1983. His efforts in the years since has focused on the research made possible by the broad tunability, extraordinary coherence, and high peak power of free electron lasers.

Source-9

EUV Laser for Applications in EUVL Mask Metrology

Davide Bleiner[1], Christoph Imesch[1], Felix Staub[1], Yasin Ekinci[2], Vivek Bakshi[3], and Juerg Balmer[1]
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Extreme ultraviolet lithography (EUVL) is the leading patterning technology for integrated circuit fabrication at the 22 nm half-pitch node, whose implementation relies on EUVL masks that are free of printable defects. While plasma-based spontaneous emission EUV sources are still not meeting the industry specifications for mask metrology tools to measure these mask defects, the alternative EUV sources deserve the attention for characterizing EUVL masks defects. The University of Berne's EUV laser is a high brilliance ($>10^{26}$ ph s^{-1} mm^{-2} $mrad^{-2}$ 0.1%BW) and narrow linewidth ($\Delta\lambda/\lambda = 10^{-4}$) source that delivers up to 1 MW EUV pulses within 2mrad. Due to its extremely high brilliance, masks with nano-sized defects can be imaged with a single shot on a field of view of 10x10 μm. Our exposure chamber has been originally equipped with Y/Mo multilayer optics coupled to *Ni*-like Sn laser emission at 11.9 nm, which has provided reliable performance, in terms of projection characteristics and lifetime. No damage was produced to the multilayer optics for exposures up to 200 shots. The current footprint of the system is dictated by the pulse stretching/compression extension to a 10 m^2 layout, yet it is compactable to a size suitable for commercial platforms. Such a facility equipped with Fresnel nano-optics can provide capability to measure the defects on EUVL masks and it is ready to take the EUV mask defect metrology challenge. In this paper the experimental data are complemented with simulations.

Presenting Author

Dr Davide Bleiner is XUV Laser Scientist at the Institute for Applied Physics of the University of Berne. He obtained his PhD in 2002 from the Swiss Federal Institute of Technology (ETH) in Zurich, working on laser ablation for inductively coupled plasma (ICP) mass spectrometry. He has earned research research fellowships from the Flemish Science Foundation for computational investigation of laser plasma, from the Swiss Science Foundation for instrumental design and the Italian Research Council for laser plasma ion implantation. He was awarded the Elsevier Atomic Spectrometry Award in 2005. His activity is mostly focused on the design and implementation of instrumentation for improved laser plasma sources, either ion or photon-based. Lately he is focused on EUV laser for actinic nano-imaging and photoelectron spectroscopy. He acts as a reviewer for a number of international journals in atomic spectrometry and laser science.

Source-10

Future of High Power EUV Sources

Katsuhiko Wakana*, Tamotsu Abe**, Yukio Watanabe**, Takanobu Ishihara**, Tsukasa Hori**, Takeshi Ohta**, Akihiko Kurosu**, Hiroshi Komori**, Hiroaki Nakarai*, Kohji Kakizaki**, Akira Sumitani**, Junichi Fujimoto* and Hakaru Mizoguchi*

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We succeeded in the development of the LPP EUV light source with high power and low debris. Our major achievement is shown at power improvement, due to two technologies. One is the CO_2 laser improvement with fine focusing quality. 7.9 kW CO_2 laser power was focused on small spot size less than 300 μ. The other is introduction of pre-pulse laser which can expand Tin droplet into micro mist, so that following CO_2 laser power is efficiently absorbed. As the result, 200 W EUV light was radiated from plasma point and 104 W EUV light was focused on IF point. Pulse energy in the burst behaves with 10 to 20 % stability around 1 mJ at 100 kHz operation. We have already introduced super conductivity magnet system for high speed ion guiding. We verified the high speed ionized Tin can perfectly guided into ion trap across the magnet field. Magnet system can contribute to reduce the amount of debris flying to the collector mirror.

Presenting Author

Katsuhiko Wakana received Bachelor and Master of engineering degree in Materials Science and Engineering from KYUSHU University in 1997 and 1999, respectively. After that, he joined USHIO Inc. In 2000 he moved to Gigaphoton Inc. He had developed KrF/ArF excimer lasers as Light Source System for Photo Lithography there. He has been developing a EUV light source system since 2009.

EUV

Litho, Inc.