2008 International Workshop on EUV Lithography

June 10-12, 2008 ▪ Wailea Beach Marriott ▪ Maui, Hawaii

Workshop Agenda and Abstracts

EUV Litho, Inc.

Contents

Organized by:

Co-operating Organization:

We would like to thank our workshop sponsors.

Univesity of Hawai'i at Manoa and JSR

Welcome

Dear Colleagues;

I would like to welcome you to the 2008 International Workshop on EUV Lithography in Maui, Hawaii. We come together at this workshop to outline a detailed R&D roadmap that will guide the EUVL community to address the current EUVL technical challenges and accelerate the introduction of extreme ultraviolet lithography (EUVL) into high-volume semiconductor manufacturing.

I would like to thank the workshop sponsors, steering committee members, workshop support staff, session chairs and presenters for their contributions. I look forward to a successful workshop.

Best Regards,
Vivek Bakshi
Organizing Chair, 2008 International Workshop on EUVL

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Valentino Rigato (Media Lario Technologies)
David Ruzic (University of Illinois at Urbana-Champaign)
Regina Soufli (LLNL)
Serge Tedesco (CEA)
Tony Yen (TSMC)

Workshop Agenda

Day 1: Tuesday, June 10, 2008

5:00 PM- 7:00 PM	*Reception (Kahoolawe Lawn)*
5:00 PM- 7:00 PM	*Registration & Speaker Prep (Maile Room)*

Day 2: Wednesday, June 11, 2008

7:00 AM – 8:00 AM	*Continental Breakfast (Maile Room)*
8:00 AM – 4:30 PM	*Oral Presentations (Maile Room)*
5:00 PM - 6:30 PM	*Poster Session and Reception (Jade/Plumeria)*
7:00 PM	*Dinner (Kahoolawe Lawn)*

8:00 AM Welcome and Introduction

Vivek Bakshi, *EUV Litho, Inc.*

8:05 AM Keynote Speech

Imaging in the EUV Region

E. Spiller
Spiller X-Ray Optics, Livermore, CA

Session 1: EUV Source Technology

Session 1.1 Discharge Produced Plasma (DPP) based EUV Sources

Session Chair: J. Kleinschmidt, Xtreme technologies

Technological Aspects of DPP EUV Source Development for HVM Lithography

V. M. Borisov, G.N. Borisova, A. S. Ivanov, Y. B. Kirukhin, O. B. Khristoforov, V. A. Mishchenko, A. V. Prokofiev, A. Yu. Vinokhodov
The State Research Center of the Russian Federation - Troitsk Institute for Innovation and Fusion Research (SRC RF TRINITI) Moscow Region, Russia

Next Generation EUV Lithography Light Source (Invited)

P. Choi [1,2], S. V. Zakharov [2+], O. Sarroukh [2], R. Aliaga-Rossel [2], O. Benali[2], C. Leblanc[2], V. S. Zakharov [2*], C. Zaepffel [2]
[1] NANO-UV sas, 16-18 av du Québec, SILIC 705, Villebon/Yvette 91140, France, [2] EPPRA sas, 16 av du Québec, SILIC 706, Villebon/Yvette 91140, France , [+] also with RRC Kurchatov Institute, Moscow, Russia, [*] also with KIAM RAS, Moscow, Russia

Session 1.2 High Power Lasers

Session Chair: D. Attwood, LBNL

Multipass Slab CO_2 Amplifiers for Application in EUV lithography (Invited)
V. Sherstobitov*, A. Rodionov**, D. Goryachkin*, N. Romanov*, A. Endo***, K. Nowak***
**JSC "Laser Physics", St. Petersburg, Russia, **Vavilov Optical Institute, St. Petersburg, Russia, ***Gigaphoton Inc., 1200 Manda Hiratsuka, Kanagawa, 254-8567, Japan*

20kW Short Pulse CO_2 Laser System for LPP Sn EUV Source
K. Nowak, H. Hoshino, T. Suganuma, and A. Endo※

EUVA, ※Gigaphoton, Inc., 1200 Manda Hiratsuka, Kanagawa, 254-8567, Japan

High-power Cryogenic Yb:YAG Lasers and Optical Particle Targeting for LPP EUV Sources (Invited)
J. D. Hybl, T. Y. Fan, W. D. Herzog, T. H. Jeys, D. J. Ripin, and A. Sanchez
MIT Lincoln Laboratory, Lexington, MA, United States

10:00 AM Break (15 minutes)

Session 1.3 Laser Produced Plasma (LPP) Based EUV Sources

Session Co-chairs: T. Higashiguchi (Utsunomiya University) and P. Dunne (University College Dublin)

Efficient EUV Source by Use of a Micro-target Containing Tin Nanoparticles (Invited)
T. Higashiguchi, M. Kaku*, M. Katto*, and S. Kubodera*
*Utsunomiya University, Utsunomiya, Japan, *University of Miyazaki, Miyazaki, Japan*

Fundamental Investigation on CO_2 Laser-produced Sn plasma for an EUVL Source (Invited)
Y. Tao, M. S. Tillack, K. L. Sequoia, R. A. Burdt, and S. Yuspeh
Center for Energy Research, University of California, San Diego, CA 9500 Gilman Drive, La Jolla, CA 92093, United States

Investigating the Emission Angle, Charge, and Energy of Ions Produced from Laser Produced Extreme Ultraviolet Sources
A. O'Connor, P. Dunne, P. Hayden, O. Morris, G. O'Sullivan, F. O'Reilly, and E. Sokell
Atomic, Molecular, and Plasma Physics Group, School of Physics, Science Centre North, University College Dublin, Belfield, Dublin 4, Ireland

CO_2 Laser-produced Sn-plasma Source for High-volume Manufacturing EUV Lithography
A. Endo
EUVA, Gigaphoton Inc., 1200 Manda Hiratsuka, Kanagawa, 254-8567, Japan

Session 1.4 Alternate EUV Source Concepts

Session Chair: A. Endo (Gigaphoton)

EUVL Source Based on the Tabletop Storage Ring MIRRORCLE (Invited)
H. Yamada and D. Minkov
Ritsumeikan University, Kusatsu, Shiga Prefecture, Japan

Production of Narrow Band Tunable EUV Radiation Using Optimized High Field Optical Undulators
J. Madey, E. Szarmes and S. Kan
Department of Physics, University of Hawai'i at Manoa, Honolulu, HI 96822,United States

12:00 PM ***Lunch (Haku Room)***

01:00 PM Session 1.5 EUV Source Panel Discussion

Reliable High Power EUV Source Technology for HVM: LPP or DPP?
Panelists: J. Kleinschmidt (Xtreme technologies / Philips Extreme), A. Endo (Gigaphoton), V. Bakshi (EUV Litho, Inc.)

02:00 PM Session 2: EUVL R&D Status Panel Discussion

The Role of Universities and National Laboratories in EUV Lithography
Panelists: D. Attwood (LBNL), H. Kinoshita (University of Hyogo), P. Dunne (University College Dublin)

03:00 PM ***Break (15 minutes)***

3:15 PM Session 3: Contamination

Session Co-chair: I. Nishiyama (Selete) and D. Gustafson (Energetiq)

EUVL Contamination Control: What Research and Development is Needed for HVM? (Invited)
D. N. Ruzic, R. Raju, J. Sporre, H. Shin, W. M. Lytle, S. N. Srivastava[1], V. Bakshi[2]
Center for Plasma Material Interactions at the University of Illinois Urbana-Champaign, Urbana, Illinois 61801, United States, Current affiliation: [1]CYMER Inc, [2] EUV Litho Inc,

Study of the Ionic Outgassing from Photoresist Compositions at 13.5 nm
G. H. Ho, Chih- Jen Liu, Chih- H. Yen, Ming- H. Ho, Shih-Y. Wu, and Yu-H. Shih
Department of Applied Chemistry, National University of Kaohsiung, Kaohsiung 811, Taiwan

EUV-photoresist Outgassing: Characterization Tools and Techniques at NIST

C. Tarrio, [a] B. A. Benner, [a] R. E. Vest, [a] S. Grantham, [a] S. B. Hill, [a] T. B. Lucatorto, [a] J. H. Hendricks, [a] P. Abbott, [a] K-W. Choi[b]
[a] NIST, 100 Bureau Drive, Gaithersburg, MD 2089, [b] Intel Corporation, 255 Fuller Road, Albany, NY 12203, United States

Extreme Ultraviolet Resist Outgassing and Its Effect on Nearby Optics

R. Garg[a], C. Mbanaso[a], J. Waterman[a], L. Yankulin[a], A. Antohe[a], Y. J. Fan[a], W. Montgomery[a], Y. Wei[b], O. Wood[c], Chiew-Seng Koay[d], E. Gullikson[e], A. Aquila[e], C. Tarrio[f], S. Grantham[f], S. Bajt[g], G. Denbeaux[a]
[a]College of Nanoscale Science and Engineering, University at Albany, Albany, NY 12203 UNITED STATES, [b]Qimonda, 255 Fuller Road, Albany, NY 12203 UNITED STATES, [c]AMD, 255 Fuller Road, Albany, NY 12203 UNITED STATES, [d]IBM, 255 Fuller Road, Albany, NY 12203 UNITED STATES, [f]Center for X-ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA 94720 UNITED STATES, [e]NIST, Gaithersburg, MD 20899 UNITED STATES, [g]DESY, Hamburg, Germany

Control technology of EUV Optics Contamination: Modeling, mitigation and cleaning for lifetime extension (Review Paper)

Iwao Nishiyama
MIRAI-Semiconductor Leading Edge Technologies, Inc. (Selete)

05:00 PM Session 4: Poster Session

EUV Radiation from Laser Triggered Tin Target Discharge Produced Plasma

Q. Zhu, J. Yamada, N. Kishi, M. Watanabe, A. Okino, E. Hotta
Department of Energy Sciences, Tokyo Institute of Technology, 4259-J2-35, Nagatsuta, Midori-ku, Yokohama 226-8502, Japan

A Study of Metamorphosis of Discharge Produced Plasma in Tin Vapor as EUV Source

G.N. Borisova, V.M. Borisov, A.S.Ivanov, A.Yu.Vinokhodov
The State Research Center of the Russian Federation - Troitsk Institute for Innovation and Fusion Research (SRC RF TRINITI)

Development at Energetiq, Inc.

S. F. Horne, M. J. Partlow, M. M. Besen, D. K. Smith , P. A. Blackborow, D. Gustafson
Energetiq Technology, Inc., 7 Constitution Way Woburn, MA 01801 USA

Measurement of Ionic and Neutral Debris in a DPP EUV Source and Investigation of Reflectivity Degradation of EUV mirrors

R. Raju, J. Sporre, H. Shin, D .N. Ruzic
Center for Plasma Material Interactions, University of Illinois at Urbana- Champaign, Urbana, Illinois, 61801, United States

Liquid Metal Collector Mirrors for EUV Lithography

K. Fahy, G. O'Sullivan, P. Dunne, P. Hayden & F. O'Reilly
UCD School of Physics, University College Dublin, Belfield, Dublin 4, Ireland

Comparison Between Atomic Structure Calculations and Laser Produced Plasma Spectra for Tin

P. Hayden[a,b], G. O'Sullivan[a] and P. Dunne[a]
a School of Physics, University College Dublin, Belfield, Dublin 4, Ireland
b School of Physical Sciences, Dublin City University, Glasnevin, Dublin 9, Ireland

Laser Probing of Tin Based Laser Produced Plasmas

P. Hayden, P. Hough, J. Dardis and J. T. Costello
School of Physical Sciences, Dublin City University, Glasnevin, Dublin 9, Ireland

Optical Particle Targeting for LPP EUV Sources

J. D. Hybl, W. D. Herzog, T. H. Jeys, A. Sanchez, and S. M. Tysk
MIT Lincoln Laboratory, 244 Wood Street, Lexington, MA 02420, United States

Ablation Dynamics of Tin Micro-droplet Target used in LPP-based EUV Light Source

D. Nakamura, T. Akiyama, K. Tamaru, A. Takahashi, T. Okada
Kyushu University, Japan

Beaming of CO_2 Laser-produced Sn plasma along B-field for Efficient Exhaustion

Y. Ueno, T. Suganuma and A. Endo[*]
EUVA, 1200 Manda Hiratsuka, Kanagawa, 254-8567, Japan, [*]Gigaphoton Inc., 1200 Manda Hiratsuka, Kanagawa, 254-8567, Japan

Absolute Characterization of Xenon EUV Radiation Generated by a Compact ECR Plasma Source for Lithographic Applications

R. Bista[a,#], R. Bruch[a], and H. Merabet[b]
[a]*Department of Physics, University of Nevada, Reno, NV 89557 UNITED STATES*
[b]*Mathematics and Sciences Unit, Dhofar University, Salalah 211, Sultanate of Oman*

Effect of Resonant Secondary-electron Emission on Damage Rates of EUV Optics

S. B. Hill[a], N. S. Faradzhev[b], S. Grantham[a], C. Tarrio[a], T. B. Lucatorto[a], T. E. Madey[b], B. V. Yakshinskiy[b], E. Loginova[b] , S. Yulin[c]
a NIST, 100 Bureau Drive, Stop 8411, Gaithersburg, MD 20853-8411, UNITED STATES
b Rutgers University, Department of Physics and Astronomy, Piscataway, NJ 08854-8019,UNITED STATES c Fraunhofer-Institut für Angewandte Optik und Feinmechnik, Jena, Germany

Plasma Assisted Cleaning by Electrostatics (PACE) of Nano-Scale Contaminant Particles from EUV Masks

R. Raju, W. M. Lytle, C. Das, M.J. Neumann, D. N. Ruzic
Center for Plasma Material Interactions at University of Illinois Urbana Champaign, Urbana, Illinois 6180, UNITED STATES

Smoothing Based Model for Images of Buried EUV Multilayer Defects Near Absorber Features

C. H. Clifford and A. R. Neureuther
Electrical Engineering and Computer Sciences, University of California, Berkeley, UNITED STATES

X-Ray Diffraction Microscopy: Reconstruction with Partial Magnitude and Spatial a Priori Information

L. B. Rad, I. Downes, J. Y., P. A. Pianetta, and R. F. W. Pease
Department of Electrical Engineering, Stanford University, Stanford, California 94305, United States

EUV Transmission Grating Spectrometer for Absolute Intensity Measurements from 2 to 250 nm

S. Bergeson[1], N. Grey[1], M. Harrison[1], L. Knight[1], O. Yakushev[2] and A. Shevelko[1,2]
[1] Brigham Young University, Provo, Utah 84602,[2] P.N.Lebedev Physical Institute, Moscow, Russia, 119991

Investigation on Characteristics of W-B-C-N Diffusion Barrier According to Nitrogen Concentration through Applications of Various Thickness Measurement Technique

H. Ju.Sohn[a], D. Kim[a], W. Choi[a], M. Park[a]
[a]Nano Electro-Physics, KSA(Korea Science Academy), 614-100 Busan, Korea

Metrology by a Tabletop Synchrotron MIRRORCLE

H. Yamada, N. Toyosugi, M. Morita, D. Minkov, and K. Igarashi
Ritsumeikan University, Kusatsu, Shiga Prefecture, Japan

Resist Process Development for the EUV Alpha Demo Tool at IMEC

Anne-Marie Goethals[1], A. Niroomand[2], F. Van Roey[1], J. Hermans[1], G. F. Lorusso[1], B. Baudemprez[1], I. Pollentier[1], Jean-Francois de Marneffe[1], R. Jonckheere[1] and K. Ronse[1]
1 IMEC, Kapeldreef 75, B-3001 Leuven, Belgium 2, on assignment from Micron Technology

EUV Interference Lithography Employing 11-m Long Undulator as a Light Source

T. Watanabe[1], T. Geun Kim[1], 2, S. Suzuki[1], M. Osugi[1], Y. Fukushima[1], H. Kinoshita[1], and T. Mochizuki[1]
1 Laboratory of advanced Science and Technology for Industry, University of Hyogo, Hyogo 678-1205, Japan. 2 Division of Advanced Materials Science and Engineering, Hanyang University, Seoul 133-791, Republic of Korea.

Day 3: Thursday June 12, 2008

8:00 AM – 04:25 PM *Oral Presentations (Maile Room)*

7:00 PM *Dinner (Haku Room)*

8:00 AM Session 5: Mask

Session Co-chairs: K. Ota (Selete) and J. Ahn (Hanyang University)

Overview of EUV Reticle Protection Technology: Progress and Current Status (Invited Review Paper)
K. Ota, M. Amemiya, T. Taguchi and O. Suga
MIRAI-Semiconductor Leading Edge Technologies, Inc. (MIRAI-Selete)
16-1, Onogawa, Tsukuba, Ibaraki 305-8569, Japan

Nanoparticle Contamination Control in EUVL Systems: Carrier, Scanner and Metrology (Review Paper)
D. Y. H. Pui[1], J. Wang[1], C. Asbach[2] and H. Fissan[2]
[1]Particle Technology Laboratory, University of Minnesota, Minneapolis, MN 55455 UNITED STATES,[2]Institute of Energy and Environmental Technology (IUTA), 47229 Duisburg, Germany

EUV Mask Inspection system
H. Kinoshita[1, 4], T. Yoshizumi[1, 4], M. Osugi[1,4] J. Kishimoto[1,4], T. Sugiyama[3], N. Sakaya[2,3] K. Hamamoto[2,3] and T. Watanabe[1,4]
1 Laboratory of Advanced Science and Technology for Industry, University of Hyogo 3-1-2 Koto, Kamigori-cho, Ako-gun, Hyogo 678-1205, Japan, 2 HOYA Corporation R&D Center, 3 Asahi Glass Co., LTD, R & D Center, 4 CREST-JST

OPC Flare and Optical Modeling Requirements
L. Zavyalova, B. Ward*, P. Brooker, K. Lucas
*Synopsys, 1301 South Mopac Expressway, Austin, TX 78746, *Synopsys assignee to IMEC, Leuven, Belgium B3001*

A Study of Attenuated PSM Structure for EUVL to Minimize Mask Shadowing Effect
S. Lee[1], C. Y. Jeong[1], T. G. Kim[1], Hyun-Duck Shin[1], E. J. Kim[2],
Hye-Keun Oh[2] and J. Ahn[1]
[1] Division of Advanced Materials Science and Engineering, Hanyang University, [2] Department of Applied Physics, Hanyang University, Korea

Mask Panel Discussion

Will Defects be the Last Issue Standing in the Way of EUVL?
Moderator: David Pui (University of Minnesota), H. Kinoshita (University of Hyogo), K. Goldberg (LBNL)

10:20 AM ***Break***

10:35 AM Session 6: ML Optics and Optics Design

Session Chair: R. Soufli (LLNL)

High-NA Optical Systems for EUV lithography (Production and Development) (Invited)
R. Hudyma
Hyperion Development LLC, 358 South Overlook Dr., San Ramon, CA 94582, United States

Diffractive Optical Elements and Their Potential Role in High Efficiency Illuminators
P. Naulleau
Lawrence Berkeley National Lab, MS 2-400, 1 Cyclotron Rd, Berkeley, CA 94720, United States

Multilayer Mirrors for EUV Lithography – Pushing Technological Limits (Invited)
T. Feigl, S. Yulin, M. Perske, M. Schürmann, N. Kaiser, A. Tünnermann
Fraunhofer-Institut für Angewandte Optik und Feinmechanik, Albert-Einstein-Str. 7, 07745 Jena, Germany

11:30 AM ***Break***

12:00 PM ***Lunch (Haku Room)***

01:00 PM Session 7: Metrology

Session Co-Chairs: K. Goldberg (LBNL) and H. Kinoshita (University of Hyogo)

A Survey of EUV At-Wavelength Optical Testing (Invited Review Paper)
K. A. Goldberg and P. Naulleau
Lawrence Berkeley National Lab, MS 2-400, 1 Cyclotron Rd, Berkeley, CA 94720

New Prospects in Short Wavelength Materials Science and Spectroscopy using various EUV Sources (Invited)
N. Sarukura
Inst. for Laser Engineering, Osaka University, Japan

Development of Coherent EUV Scattering Microscopy
J. Kishimoto , T. Watanabe and H. Kinoshita, Dong gun Lee*, Seong-Sue Kim*, and Han-Ku Cho*
*Laboratory of Science and Technology for Industry, University of Hyogo, Japan, *Samsung Electronics Co., Ltd., Korea*

Characterization of Performance and Lifetime of EUV Source Collectors with a Full Size EUV Collector Reflectometer
U. Hinze [1], B. N. Chichkov [1],T. Feigl [2], U. D. Zeitner [2], C. Damm [2], D. Bolshukhin [3], J. Kleinschmidt [3], G. Schriever [3], Max-C. Schürmann [3]
[1] Laser Zentrum Hannover e.V. (LZH), Hannover, Germany, [2] Fraunhofer IOF Jena (IOF), Germany, [3] XTREME technologies GmbH (XTREME), Germany

Process Control of Lithography and CMP by Innovative Optical Methods
L. Pfitzner, A. Nutsch, and G. Roeder
Fraunhofer Institute of Integrated Systems and Device Technology (Fraunhofer-IISB) Schottkystrasse 10, 91058 Erlangen, Germany (email to: lothar.pfitzner@iisb.fraunhofer.de)

02:25 PM **Break**

02:40 PM Session 8: Resist and Patterning

Session Co-Chairs: M. Goethals (IMEC) and T. Kozawa (Osaka University)

Sensitization Mechanisms of Chemically Amplified Resists and Resist Design for 22 nm node (Invited)
T. Kozawa and S. Tagawa
The Institute of Scientific and Industrial Research, Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

Harnessing EUV photons to Design Fast and High Resolution Resists (Invited)
J. W. Thackeray, E. Aqad, M. F. Cronin, K. Spear-Alfonso
Rohm and Hass, Inc., United States

Progress in EUV Resist Development (Invited)
T. Kai, D. Shimizu, K. Maruyama, A. Saitou, T. Shimokawa, Y. Hishiro†,
Semiconductor Materials Laboratory, JSR Corporation, Yokkaichi Plant, 100, Kawajiri-cho, Yokkaichi Mie 510-8552 Japan, †JSR Micro, INC., 1280 N. Mathilda Ave., Sunnyvale, CA 94089, United States

Stochastic Approach to Modeling Line Edge Roughness in Photolithography
C. Mack
Lithoguru.com, 1605 Watchhill Rd., Austin, TX 78703, United States

Our Approaches to EUV Resist Materials
N. Ohshima
Fujifilm, Japan

Influences of Polymer Protection Groups on EUV Resist Performances
J. Lee, J. Kim, Hyun-Jin KIM, Jae-Woo Lee, Deog- Bae Kim, J. Kim
Dongjin Semichem Co., Ltd., 625-3 Yodang-Ri, Yanggam-Myun, Hwasung-Si Gyeonggi-Do, 445-931 Korea

04:25 PM	***Break***
7:00 PM	***Dinner and Adjourn (Haku Room)***

Keynote Speech

Imaging in the EUV region

E. Spiller

Spiller X-Ray Optics, Livermore, Ca 94550

Progress during the last decades is slowly reducing the gap between imaging methods for the visible and for x rays. Röntgen's shadowgraphs are still used for most medical applications. X-ray diffraction has achieved atomic resolution already in 1912 but is restricted to crystallized specimen. The fact that the refractive index of all materials is close to one eliminates scattering and makes medical x-ray images possible, but makes it difficult to produce the elements used in the visible: lenses and mirrors. Enhancement of the small interaction between radiation and matter is possible with multi-component element where the amplitudes generated from each component are added coherently and in phase. Multilayer mirrors and zone plates are examples; these elements are now used in telescopes, microscopes and cameras. Cameras for EUV lithography with diffraction limited resolution are now available, and the future of EUV lithography is not limited by the performance of the optic but by cost. The talk will summarize the progress of the last decades, discuss the present status and challenges for the future, for example obtaining atomic resolution for general, non-crystalline specimen and achieving phase contrast in medical imaging.

Presenting Author

Eberhard Spiller, SPILLER X-RAY OPTICS, obtained his Ph.D in physics from the University of Frankfurt/Germany in 1964 and stayed with the faculty until 1968, when he joined the IBM T.J. Watson Research Center in Yorktown Heights as staff member. He retired from IBM as IBM Emeritus in 1993 and started SPILLER X-RAY OPTICS in 1995. His early research interest included lasers, holography, coherence, and speckle statistics, the broadening of picosecond pulses in laser mirrors and the characteristics of bistable optical resonators. In 1971 he discovered that multilayer mirrors with useful reflectivities for optical instruments should be possible in the vacuum ultraviolet and soft x-ray region and started to work on their realization. He pioneered the use of synchrotron radiation for x-ray lithography and x-ray microscopy in 1975 and has initiated the development of normal incidence soft x-ray optics for astronomy. He has used multilayer mirrors for high-resolution soft x-ray imaging and has built several x-ray telescopes for the Smithsonian Astrophysical Observatory. These instruments have produced x-ray images of the solar corona with the highest resolution obtained up to that time. He is continuing work in soft x-ray optics for applications in microscopy and lithography.

Among his publications are the book "Soft X-Ray Optics" (ISBN 0-8194-1655-X), published by SPIE Engineering Press in 1994 and book chapters on "X-Ray Lithography" (Topics in Applied Physics, Vol. 22, Springer-Verlag, 1977), "Soft X-Ray Optics and Microscopy" (Handbook on Synchrotron Radiation, North-Holland, 1983) and several reviews in Handbooks and Encyclopedias. He has served as chairman and cochairman at many conferences and taught courses on X-Ray Optics at many locations. He is a fellow of the Optical Society of America, the American Association for the Advancements of Science and SPIE and a member of the Deutsche Physikalische Gesellschaft.

He has received Outstanding Contribution and Invention Awards from IBM for the invention of an electron-beam/x-ray resist, for contribution to x-ray lithography, and for contributions to x-ray optics and astronomy and has won R&D 100 awards in 1999, 2002 and 2003.

Contamination Abstracts

Contamination Abstracts Cont.

Contamination 1

Study of the Ionic Outgassing from Photoresist Compositions at 13.5 nm

G.H. Ho*, Chih-Jen Liu, Chih-H. Yen, Ming-H. Ho, Shih-Y. Wu, and Yu-H. Shih

Department of Applied Chemistry, National University of Kaohsiung, Kaohsiung 811, Taiwan

Light at 13.5 nm is well above the ionization energy of all materials. Yet, up to date no outgassing study has addressed on studying ionic outgassed species from EUV photoresists exposed to the 13.5 nm radiation. Noting that ions are typically more reactive and adhesive on surfaces than their respective atoms or radicals, it is thus important to study the ionic outgassing for a further understanding of its role in the EUV optics contamination. The work conducted the ionic outgassing study at National Synchrotron Radiation Research Center by a quadrupole mass spectrometer without turning on the ionizer. Outgassed ions from eighteen photoacid generators (PAGs) and polymethyl methacrylate (PMMA) were identified. The amounts of these outgassed species were determined in a relative quantity. The F+ outgassing was found to be the major channels for all PAGs containing CF3 or C4F9 moiety, and it can be well correlated with the extent of F photoabsorption of each PAG. The photoabsorption, photoionization and partial photoionization cross sections of PGME, EL, MAK, and PGMEA at 13.5 nm were measured; the results showed that PGME gives off the least amount of ionic products. The ionic products of PMMA are CH_3^+, $C_2H_3,5^+$, and $C_3H_{3,5,7}^+$ ions.

Presenting Author

Grace Hsiuying Ho received her B.S. degree in 1983 from the department of chemistry, national Cheng-kung university, Taiwan, and obtained her Ph. D. degree in 1990 from the department of chemistry, university of Pittsburgh, PA, USA. Prof. Ho was an associate scientist of national synchrotron radiation research center, Taiwan in 1991 - 1998. In 1998 - 2001, she joined ASML Taiwan as an application engineer, participated in 193 nm ArF photoresist development, supported the introduction of the scanner technology to Taiwan. In 2001- 2004, she worked for the micropatterning technology development department, Taiwan semiconductor manufacturing company Ltd., Taiwan, joined the development of the 0.13 um BEOL low-k and 90 nm lithographic processes, and was responsible for new tool evaluation. From 2004 to present, she is an associate professor of Department of Applied Chemistry, national university of Kaohsiung (NUK), and works on the ionic outgassing study of photoresist materials. Besides her research work, she organizes a course program of semiconductor manufacturing technology at NUK for undergraduate and graduate students. Prof. Ho is a member of SPIE and a life Member of the Chinese Chemical Society, Taiwan, R. O. C.

Contamination 2

EUV-photoresist Outgassing: Characterization Tools and Techniques at NIST

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Extreme-ultraviolet lithography (EUVL) has several hurdles that must be overcome in order for it to be implemented as a high-volume manufacturing process. Currently, a significant amount of effort is being spent on the development of a photoresist that meets the lithographic and contamination requirements for EUVL. Outgassing from a photoresist caused by EUV illumination poses a risk to optics lifetime and overall tool efficiency because the organic outgassing products can create conditions that lead to carbon growth on EUV irradiated optics. At NIST we have recently begun a program for the characterization of EUV photoresists under EUV illumination. For these tasks we have constructed a compact, portable exposure chamber in order to accurately determine the pressure rise from an illuminated photoresist. In addition, we have also developed a method to perform compositional analysis on the vacuum contaminants produced by an illuminated photoresist or vacuum background pressure. In this paper we will describe the technique and present results. In addition, we shall present additional resist characterization facilities under development at NIST including EUV interference lithography and EUV resist sensitivity measurement facilities.

Presenting Author

Steve Grantham received his doctorate from the University of Central Florida's Center for Research and Education in Optics and Lasers (CREOL). His research there involved the study and application of short pulse laser produced plasmas. Since 1999 he has worked at NIST with a recent emphasis on EUV metrology for EUVL source evaluation. In 2004 he received the Department of Commerce silver medal for the development of NIST's EUV metrology program. In 2007 he and four other members of NIST's photon physics group were awarded the William P. Slichter Award for outstanding achievement in strengthening ties between NIST and industry.

Contamination 3

EUVL Contamination Control: What Research and Development is Needed for HVM?

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This paper will describe the research and development needs in the area of EUVL (extreme ultra- violet lithography) contamination control to achieve HMV (high volume manufacturing) requirements. The entire integrated EUVL scanner system will be considered: source, collector, spectral purity filter, projection optics, mask, illuminator optics and wafer. Energetic atom and macro-particle emission are unavoidable when plasmas are used to generate photons in both DPP and LPP based EUV sources. These emitted particles interact first with the collection optics for the EUV radiation. Then low energy atoms from sputtered collector material and condensable fuel such as Sn can exit at the intermediate focus. The very EUV photons that the system is designed to create can have an effect on the projection and illumination optics causing a reduction of mirror reflectivity. Particle contamination is problematic at the mask, and resist issues on the wafers themselves have an effect on the masks and optic elements. The origin of debris and efficiency of mitigation schemes will be discussed. We will also present progress on studies from our recent experiments, including cleaning of collector optics using reactive ion etching plasma, particle contamination removal from the mask blanks and degradation of mirror reflectivity.

Presenting Author

Professor D. N. Ruzic received the Ph.D. degree in physics from Princeton University, Princeton, NJ, in 1984. He is presently the director of the Center for Plasma Material Interactions (CPMI) and professor of Nuclear, Plasma and Radiological Engineering at the University of Illinois at Urbana-Champaign. His research areas are experimental fusion research, modeling of edge-plasma atomic physics, atomic properties of potential first-wall materials, plasma processing of semiconductors, extreme ultraviolet (EUV) sources for lithography, and physical vapor deposition. He served as a member of the Editorial Board of J. Vac. Sci. and Technology from 1994 to 2000. He is currently a fellow of American Vacuum Society and the American Nuclear Society. He is also a member of American Physical Society, Institute of Electrical and Electronics Engineers, Society of Photographic Instrumentation Engineers and a member of the Technical Working Group on EUV Collector Optics. Prof. D. N. Ruzic has published more than 100 papers in refereed journals, 3 book chapters, and 2 books.

Contamination 4

Effect of Resonant Secondary-electron Emission on Damage Rates of EUV Optics

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Low energy secondary electrons (~0-20 eV) generated by EUV photons (~92 eV) incident on multilayer mirrors (MLMs) are thought to activate a range of surface reactions that can damage the optic by deposition of a carbonaceous overlayer or by chemical transformation of the top-most layers of the mirror. The particular damage mechanism depends on the composition of background gases that adsorb and react on the surface and on the properties of the capping layer terminating mirror surface. This study shows that the mirror degradation rate may also depend critically on the MLM structure and the illumination conditions. The constructive interference that yields the high reflectivity of MLMs creates a standing wave that can vary dramatically in intensity above and below the surface of the optic. This could result in significant variation in the MLM damage rate depending on the exact resonance condition and resulting surface intensity. In this paper we investigate these resonant effects by discussing reflectivities, contamination rates and secondary electron yields (SEYs) for mirrors designed to have different EUV intensities at the vacuum/surface interface. We also compare SEYs calculated as a function of photon energy with experimentally measured yields and show that narrow- and broad-band irradiation can produce significantly different secondary electron fluxes and hence potentially different damage rates.

Presenting Author

Steve Grantham received his doctorate from the University of Central Florida's Center for Research and Education in Optics and Lasers (CREOL). His research there involved the study and application of short pulse laser produced plasmas. Since 1999 he has worked at NIST with a recent emphasis on EUV metrology for EUVL source evaluation. In 2004 he received the Department of Commerce silver medal for the development of NIST's EUV metrology program. In 2007 he and four other members of NIST's photon physics group were awarded the William P. Slichter Award for outstanding achievement in strengthening ties between NIST and industry.

Contamination 5

Extreme Ultraviolet Resist Outgassing and its Effect on Nearby Optics

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One of the remaining challenges for the commercialization of EUV lithography is the lifetime of the Mo/Si multilayer optics and masks. The lifetime is dominated by carbon contamination on the surfaces of the optics, which is caused by residual hydrocarbons in the vacuum chamber when optics are exposed to EUV radiation. One of the possible sources of the hydrocarbons in the chamber is photoresist. Extreme ultraviolet (EUV) photoresists are known to outgas during exposure to EUV radiation in the vacuum environment. Due to this issue, work has been performed to measure the species and quantities that outgas from EUV resists. Additionally, since the goal of these measurements is to determine the relative safety of various resists near EUV optics, work has been performed to measure the deposition rate of the outgassed molecules on Mo/Si-coated witness plate samples. The results for various species and tests show little measurable effect from resist components on optics contamination with modest EUV exposure doses. Therefore, to be able to understand which type of hydrocarbons are harmful to EUV mirror reflectivity, three hydrocarbon species – benzene, tert-butanol and diphenyl sulfide – which are thought to be representative of commonly outgassed species from EUV photoresist were injected in to the system at elevated pressure. The goal of this work was to measure the contamination rate from these three species and to be able to draw conclusions about other species. The results of the experiments showed that after 8 hours of exposure there was not enough contamination to be significantly measurable. In addition to these hydrocarbon species, we also used vacuum grease and carbon tape as an outgassing source for hydrocarbons. Comparatively, high contamination rates were achieved with vacuum grease and carbon tape.

Presenting Author

Rashi Garg received her B. Tech. degree in Material Science from the Indian Institute of Technology, Kanpur, India, in 2003. She completed her MS in Material Science from College of Nanoscale Science and Engineering, State University of New York, Albany in 2004. She is currently working towards her Ph.D. degree in Nanoengineering at the College of Nanoscale Science and Engineering, State University of New York, Albany. Her current research interests include EUVL, EUV photoresist outgassing and EUV optics contamination studies.

Contamination 6

Control Technology of EUV Optics Contamination: Modeling, Mitigation and Cleaning for Lifetime Extension

I. Nishiyama

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Contamination control is a key issue in EUV lithography because the projection optics require a very long reflectivity lifetime under strong EUV irradiation in a partial vacuum. The author reviews current knowledge for optics contamination control from following points of view; modeling, mitigation and cleaning.

Modeling: Degradation of EUV mirror was caused by two type of chemical reactions; one is carbon deposition from residual organic molecules, and the other is oxidation by residual water. There are many experimental works to estimate the lifetime of mirrors under accelerating conditions both of pressure and EUV intensity. Theoretical models have been proposed for lifetime scaling.

Mitigation: Methods to extend the optics lifetime are classified to two categories; one is vacuum environmental control such as suppression of contaminant and artificial blending of mitigating gases. The other is development capping layer which has high tolerance for mirror degradation.

Cleaning: Extreme difficulty of completely preventing any degradation in mirror reflectivity makes it necessary to develop cleaning technology. There are two type of cleaning technologies: One is oxidative removal of contamination, which is applicable to carbon contamination. The other is reductive removal of contamination, which is potentially applicable to both the carbon contamination and oxidation.

Mask Abstracts

Mask 1

Nanoparticle Contamination Control in EUVL Systems: Carrier, Scanner and Metrology

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Extreme Ultraviolet Lithography (EUVL) is a leading lithography technology for the sub-32 nm chip manufacturing technology. Photomasks, in a mask carrier or inside a vacuum scanner, need to be protected from contamination by nanoparticles larger than the minimum feature size expected from this technology. The protection is made more difficult because pellicle cannot be used, due to the attenuation of the EUV beam by the pellicle. Under a 3-yr program funded by Intel, we have developed models and performed experiments in atmospheric-pressure carriers and in vacuum system down to 20 mTorr. Nanoparticles between 60 nm and 250 nm were injected into the vacuum chamber with controlled speed and concentration to validate the analytical and numerical models. Also, methods and models were developed to evaluate nanoparticle generation, transport and deposition on photomasks in carriers. Various protection schemes have been developed and evaluated using these experimental and modeling tools. For metrology studies, we have developed a method to deposit NIST traceable standard nanoparticles of selected materials, e.g., PSL, SiO2 and Au on photomasks for scanner calibration and cleaning studies. A review of these topics, which were published in 14 refereed papers, will be presented in this talk.

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, University of Minnesota. He has a broad range of research experience in aerosol science and technology with 175 refereed journal papers, and has developed/co-developed several widely used commercial aerosol instruments. Dr. Pui is a fellow of the American Society of Mechanical Engineers (ASME) and is a recipient of the Max Planck Research Award (with Prof. H. Fissan), the International Aerosol Fellow Award, the David Sinclair Award, and the Humboldt Research Award for Senior U.S. Scientists. TSI Incorporated recently endowed a Fissan-Pui-TSI Award for International Collaboration for presentation at the International Aerosol Conference once every four years. Dr. Pui's recent professional activities include serving as the President of the International Aerosol Research Assembly (IARA) and organizing several international nanoparticle symposia to promote research cooperation especially among young scientists. He was a co-chair of the International Aerosol Conference held in Minnesota, September 2006, attended by the largest group of aerosol researchers ever.

Mask 2

Plasma Assisted Cleaning by Electrostatics (PACE) of Nano-Scale Contaminant Particles from EUV Masks

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Removal of nano-scale contaminant particles from EUV photomasks is of critical importance to the implementation of EUV lithography. Plasma Assisted Cleaning by Electrostatics (PACE) is a dry and non-contact technique developed within the Center for Plasma Material Interactions (CPMI) at the University of Illinois Urbana Champaign, and has several advantages over other conventional wet cleaning techniques. There is no theoretical limitation to the size of particles removed, no damage is observed on the mask, and the entire mask can be cleaned at once in minutes. Removal of polystyrene latex (PSL) particles of different sizes (30-220 nm) have been investigated and recent results show that PACE technique is able to achieve a particle removal efficiency (PRE) of 100% on Si wafers. Parameters investigated are: input plasma power 1-3 kW, He plasma, current density to the sample surface of 0.5 ~50 mA/cm2, and bias frequency to the substrate is 0.01 Hz - 200 Hz. Preliminary results of PSL particle removal from a chromium coated mask blank show complete particle removal (PRE = 100 %). Recent results of particle removal from a variety of 6 inch EUV masks as well as various particle types will be presented. Damages to the EUV mask blank which result in a loss of reflectivity is an important quantity to be analyzed. Pre-and post-exposure reflectivity results on EUV mask blanks processed by the PACE technique will be studied and presented.

Presenting Author

Dr. Ramasamy Raju received the Ph.D. degree in physics from Bharathiar University, Coimbatore, India in 2001. After his Ph.D. he joined as a Postdoctoral Fellow at Kyushu Institute of Technolgy, Kita-kyushu, Japan and conducted a research on the plasma-spacecraft interactions. In 2003, He became a research engineer at Adtec Plasma Technology Co., Ltd, Fukuyama, Japan, where he involved in the development of atmospheric pressure microwave plasma torches. He is currently a Postdoctoral Research Associate in the Department of Nuclear, Plasma and Radiological Engineering at the University of Illinois, Urbana-Champaign. His current research interests are plasma material interaction, advanced debris mitigation technique for Sn- and Xe fueled EUV sources and removal of contamination from collector optics, removal of nano-size particles from EUV mask blanks and physical vapor deposition.

Mask 3

Overview of EUV Reticle Protection Technology: Progress and Current Status

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EUV lithography is the only candidate of lithography technology which can be used for hp22nm node and beyond. In order to utilize this technology for mass production of IC device manufacturing, we have to solve many remaining issues, e.g. source power, resist sensitivity and defect-free mask. Reticle protection technique during storage, shipping, handling and use is one of the issues because no practical pellicle has been found for EUV reticles as yet. MIRAI-Selete has been developing EUV reticle handling technology and evaluating EUV reticle pods for two years. In this paper, we will review the recent progress in EUV reticle protection technology and present the update on the Selete experimental data. Table 1 shows the summary of our shipping and storage tests using CNE pods; the CNE pod was designed by Entegris based on "Dual Pod Concept" which Canon and Nikon jointly proposed in 2004. There were only 0 to 2 particle adders except one case. We also evaluated the protective performance of the CNE pod during handling in vacuum using MPE Tool (Mask Protection Engineering Tool), the Selete original tool for developing EUV reticle handling technology. We found only less than one particle adders per 100 traveling cycles, where one traveling cycle means to transfer a reticle from a CNE pod to the electrostatic chuck chamber in vacuum and back. This work was supported by NEDO.

Table 1 Shipping and storage test results summary: Particle Adders

	Shipping1	Shipping2	Shipping3	Storage
Pod #1	0	1	0	0 (6w)
Pod #2	0	0	0	0 (6w)
Pod #3	10	-	-	-
Pod #4	0	-	-	-
Pod #5	1	1	-	0 (7w)
Pod #6	2	1	-	0 (7w)
Pod #7	0*	0*	0*	0* (6w)
Pod #8	0*	0*	0*	0* (6w)

* CrN coated substrates used.

Presenting Author

Kauzuya Ota is a Senior Researcher of Mask Handling Technology Group in Selete. Ota graduated in physics from Nagoya University and began his career in 1983 as a design engineer of a wafer alignment system for wafer steppers in Nikon Corporation. Ota carried out the aspherical surface metrology using interferometry at ASET EUVL Laboratory from 1998 to 2001. Ota joined Selete from April 2006 as a Nikon assignee.

Mask 4

Smoothing Based Model for Images of Buried EUV Multilayer Defects Near Absorber Features

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A new fast-CAD imaging model for buried extreme ultra violet (EUV) mask defects near absorber features is presented that exploits the smoothing process used to mitigate buried EUV multilayer defects.

Since the characteristics of the smoothing process dictate nearly identical surface shapes for all defects a single parameter, the peak height of the final profile, is sufficient to predict the projection printed image for an arbitrary isolated buried defect.

A compact algebraic model to predict the aerial image dip strength was presented that depends only on the surface height of the EUV mask blank. That paper showed the difficulty of predicting defect feature interaction when the defect is partially covered by the absorber pattern. A new fast model will be presented that weights the defect's perturbation of the printed absorber pattern based on the defect's proximity to and coverage by the absorber. The accuracy of this model will be evaluated for various defect sizes and positions relative to the absorber

Presenting Author

Chris Clifford is a graduate student in Professor Andrew Neureuther's Technology CAD group at UC – Berkeley. He holds a BS degree from the University of Wisconsin - Madison, where he graduated with Highest Distinction. At UC-Berkeley he has earned an M.S. degree, won the Tong Leong Lim Pre-Doctoral Prize for doing the best in his class on the preliminary exam, and is the president of the SPIE student chapter, Photobears.

Mask 5

EUV Mask Inspection System

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In order to reduce a number of printable defects in an EUVL mask, we have developed an actinic mask inspection system using a Schwerzchild optics. We prepared small pit programmed defects of lines and dots with a depth of less than 2 nm to clarify the critical size of printable defect.

As a result, the programmed defect with a line width of over 100 nm and pit depth of over 2.5 nm was observed clearly by the EUV microscope. However, the programmed defects with a 75-nm line width and a 1.5-nm depth could not be observed. Furthermore, 100 nm dot with a 2.5 nm depth was clearly observed, but 50 nm dot with a 2 nm depth could not observed. With these results, we determined that the critical dimension of printable defects on glass substrate is 75 nm in line width and 1.5 nm in depth and 50 nm dot with 2 nm width.

In this paper, we will show you a recent activity of actinic mask inspection system.

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

OPC Flare and Optical Modeling Requirements

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It is now widely considered a requirement that EUV production mask flows will need to employ optical and process proximity correction (OPC). OPC will be required in order to compensate for: very long range and substantial percentage layout dependent flare effects; shadowing effects due to non-telecentric imaging optics; mask 3D effects caused by the large mask absorber topography relative to the illumination wavelength; complex resist behavior effects; and across-field changes in wafer pattern due to the azimuthal angle of the optical axis changing across the field. In this paper we investigate OPC requirements for the 22nm logic node assuming an EUV patterning strategy. We present results and details of a significant improvement in algorithmic performance for EUV full chip flare calculations. We also present accuracy vs. runtime analysis results for OPC modeling requirements of EUV optical systems where we show the comparison of OPC model fit to rigorous EUV traditional lithography simulation results.

Presenting Author

Lena Zavyalova has joined the OPC modeling group at Synopsys, Inc. in 2008. Prior to joining Synopsys, she was a research staff member at Center for Nanolithography Research at the Rochester Institute of Technology from 2003 to 2007. From 1999 to 2003, she worked at Motorola APRDL in lithography development engineering department. She received her BS and MS degrees in Microelectronic Engineering and Imaging Science from RIT, in 1996 and 2001 respectively. She will be completing her PhD degree in Imaging Science in 2008.

Mask 7

A Study of Attenuated PSM Structure for EUVL to Minimize Mask Shadowing Effect

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Mask shadowing effect is a unique problem of EUVL caused by using multilayer mirror-based mask as well as oblique incident angle of EUV light. Printed critical dimension (CD) bias, horizontal-vertical (HV) biasing effect, pattern shift and ellipticity in contact hole pattern is expected due to this shadowing effect.

In this study, we propose an optimal attenuated phase shift mask (PSM) structure for EUVL to minimize mask shadowing effect without a loss of image contrast. The attenuated PSM proposed in this study which consists of TaN attenuator, Al_2O_3 spacer and Mo phase shifter is based on Fabry-Perot structure. DUV reflectivity can be lowered down to 5% at 257nm for higher efficiency in DUV inspection process through the optimal thickness combination of TaN and Al_2O_3. Since the thickness variation of Mo does not affect the DUV reflectivity, the phase shift effect could be controlled by Mo thickness only. As a result, attenuated PSM with 180±6° phase shift and absorber reflectivity higher than 6% could be obtained. Imaging properties including horizontal-vertical(HV) biasing effect, pattern placement error, and process window depending on both thickness and transmission of phase shifting pattern were compared to the conventional binary mask by aerial image simulation.

In this paper, we will discuss about the impact of mask shadowing for the attenuated PSM structure and then the strategies for shadowing effect mitigation. In addition, tendency of mask error enhancement-factor (MEEF) under the influence of attenuated PSM will be discussed.

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

Metrology Abstracts

Metology Abstracts Cont.

Metrology 1

X-Ray Diffraction Microscopy: Reconstruction with Partial Magnitude and Spatial a Priori Information

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X-ray diffraction microscopy is rapidly gaining attention as a potential high resolution microscopy tool. This paper explores the use of x-ray diffraction microscopy for the detection of functional deviations from specification in fabricated devices. It is assumed that full a priori design specification information is known and that a small number of diffraction measurements are available. An iterative reconstruction algorithm is presented where the a priori information is exploited to partially recover the missing phase information and to estimate missing data. Simulation results are shown which indicate that detection of the presence of deviations can be achieved with as few as a single diffraction measurement in each dimension. Additional measurements localize the position of the deviations.

Metrology 2

New Prospects in Short Wavelength Materials Science and Spectroscopy Using Various EUV Sources

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Driven by the strong needs for EUV lithography, optical technologies such as optical components and light sources operting in the EUV region have advanced significantly. Additionally, short wavelength free electron lasers and laser-driven soft X-ray lasers have experienced considerable development all over the world in the past decade. Based on these advancements, significant progress research on materials science and spectroscopy in the short wavelength regime should be realized even more rapidly. As such, the design and emergence of new short wavelength light emitting devices, scintillators, and other optical materials for EUV lithography applications is to be expected from these developments.

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

Metrology 3

Development of Coherent EUV Scattering Microscopy

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In order to measure a CD value of EUV mask pattern with a high precision and high speed, we have developed a coherent EUV scattering microscope(CSM) installed at the BL3 beamline in the NewSUBARU synchrotron facilities. The light from coherent EUV light illuminate a sample, the reflective diffraction pattern is obtained by a CCD camera and the reverse Fourier transform is carried out with a computing system to reproduce a sample image. The lens-less imaging technique provides aberration-free diffraction-limited images without restriction on the resolution and depth-of-focus (DOF). The resolution is determined by the 2-D detector size and the length between CCD camera and sample, i.e., numerical aperture (NA). Up to now, 55nm is obtained. Using this system, CD measurements in an area of 100 mm x 100 mm were evaluated. The tendency for CD values was good coincidence with CD-SEM data.

We believe that the successful demonstration of the reflective-type EUV scattering microscopy paves the way for a reliable EUV imaging system with higher throughput and lower cost of ownership. There features make it potentially an important inspection technique with a wide applications in both EUV lithography and biology.

Metrology 4

Process Control of Lithography and CMP by Innovative Optical Methods

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Semiconductor manufacturing still follows Moore´s Law. Future key enablers will be much tighter process control, often deploying innovative optical metrology. This paper presents the development of optical sensors, their integration, and results for control of processes in lithography as well as use of novel geometrical metrology sensors for CMP processes – innovative process control systems and methodologies as a contribution and enabler for EUV lithography.

Lithographic processes require the precise control of resist thickness and CD. Spectroscopic reflectometry enabled superior capabilities and the suppression of diffraction effects. Results of control of resist thickness for different spinning speeds will be presented. In addition, by proprietary optical scatterometry denoted as Phi-Scatterometry it became possible to obtain information on CD, structural parameters and optical material properties on patterned wafers.

VLSI devices and Extreme Ultra Violet demand for ultra flat surfaces. It is essential to measure and control topography of wafer surfaces at nanometer scale. Today it is a challenge to measure local flatness especially on patterned wafers. Wave front sensing - according to Makyoh and Shack Hartmann methods - was identified as a possible, instantaneous and non-destructive solution for flatness analysis on patterned wafer surfaces. Experimental set-up and results will be presented.

Presenting Author

Lothar Pfitzner holds an M.S. (Dipl.-Ing.) degree in Materials Science and Ph.D. (Dr.-Ing.) in Electronics Engineering, both from the University of Erlangen-Nuremberg. From 1976 to 1985 he worked as an assistant lecturer at the Engineering Faculty at the University of Erlangen-Nuremberg. Since 1985 he is heading the department 'Semiconductor Equipment and Manufacturing Methods' of the Fraunhofer Institute of Integrated Systems and Device Technology (IISB) in Erlangen, performing research and development in the fields of Advanced Equipment Control and Advanced Process Control by in situ and on-line measurement as well as Integrated Metrology, in the fields of integrated vacuum cluster tools and contamination control. His department develops proprietary solutions and supports industrial companies in developing, improving and evaluating manufacturing equipment, metrology equipment, materials and relevant processes.

Metrology 5

Characterization of Performance and Lifetime of EUV Source Collectors with a Full Size EUV Collector Reflectometer

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The efficiency and lifetime of EUV collector optics have been found to be a critical issue in EUV lithography, because both parameters determine strongly the throughput and cost of ownership of the lithographic semiconductor production step. A metrology tool is required, which allows accurate measurements of the optical properties of EUV collectors on site and at wavelength.

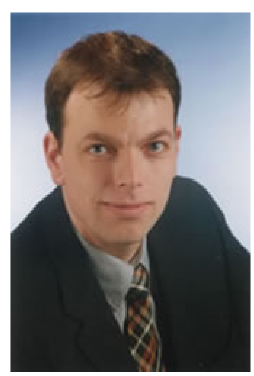
Therefore, a full size EUV collector reflectometer was designed and assembled. The tool supports the detection of small changes in reflectivity and homogeneity, which occur already after achieving a fraction of the pulse number as expected for the collector optics lifetime.

As an EUV source a commercial microfocus EUV tube is used. This source is highly stable in output power, emission spectrum, and spot position and it is debris-free. The radiation cone and radiation spectrum of the source emission are shaped by a Schwarzschild objective to fit to the geometrical and spectral characteristics of the Wolter-shell type EUV collector optics.

The collector reflectometer is running now for two years and a large number of collector optics measurements have been performed with new manufactured collector optics and with used collector optics repeatedly during collector lifetime tests. The concept and hardware of the reflectometer together with the obtained experimental results will be presented.

Presenting Author

Dr. Ulf Hinze received his diploma degree in Physics in 1996 and Ph.D. in 2000 from the Institue of Quantum Optics at the University of Hannover, Germany. In 2001 he started his work at the Laser Zentrum Hannover e.V. in the field of laser metrology as head of the laser metrology group. Since 2004 he is head of the EUV and X-Ray group. His current works focus on the development of stable EUV and X-ray sources and their application in metrology.



Metrology 6

A Survey of EUV At-Wavelength Optical Testing

K. Goldberg and P. Naulleau

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For EUV projection optics, wavefront errors on the scale of angstroms can ruin the diffraction-limited imaging performance. Owing to its rapid, detailed feedback, and demonstrated predictive ability, interferometry is the optical testing method of choice for testing and aligning high-quality imaging systems. Since all interferometry uses the light wavelength as the unit of measurement, shorter wavelengths have significant advantages in the final alignment steps. For EUV interferometry in particular, systems tested at their operations wavelength reveal the mirror surface shapes, multilayer-reflected phase, and even polarization effects, in the exact way that is most directly relevant to imaging, and with layers of accurate detail that visible-light testing does not provide.

EUV interferometry has been the subject of concentrated research in the US and Japan since 1993 resulting in several viable aproaches: techniques have been developed with precision surpassing 0.1 nm, and RMS accuracy close to 0.25 nm (based on inter-comparisons). Among the testing geometries and variations that have been established, the most successful methods include point-diffraction and shearing interferometry.

We will survey the full scope of techniques that have been developed, and provide insight into the percieved advantages and disadvantages. Each technique has its own aberration capture tolerance, and different coherence, flux, and stage positioning needs which have significant bearing for any method developed for use with non-synchrotron sources.

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.

Metrology 7

EUV Transmission Grating Spectrometer for Absolute Intensity Measurements from 2 to 250 nm

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We report on the development of an EUV transmission grating spectrometer for absolute intensity measurements over an extremely wide spectral range, from 2 to 250 nm. The spectrometer uses a transmission grating array and a CCD camera. The detector was absolutely calibrated in the 5 to 20 nm spectral range using a capillary discharge plasma source. Spectral calibration was accomplished using a laser-produced plasma source. Spectra from ablated Li, Al, Fe, Cu, Sn, Mo, W solid targets were recorded and analyzed. Spectral resolution of 0.1 to 0.2 nm was demonstrated from 2 to 85 nm. The device is very compact (60 x 200 mm). It is ideal for absolute intensity measurements at 13.5 nm as well as for characterizing EUV lithography sources.

Presenting Author

Scott Bergeson has published 35 papers in atomic physics and spectroscopy. His current research focuses on the dynamics of strongly-coupled plasmas, spectroscopy, and biophotonics.

Investigation on Characteristics of W-B-C-N Diffusion Barrier according to Nitrogen Concentration through Applications of Various Thickness Measurement Techniques

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This paper includes analysis of experimentation on finding the relationship between the Nitrogen concentration and the newly proposed proficient W-B-C-N diffusion barrier characteristics accompanied by preparatory experiments of various thickness measuring techniques.

This paper first shows preparatory experiments of using different thickness measuring techniques in order to be acquainted with the thickness measurement equipment and its errors. The thicknesses were measured by using four different types of equipments; α-step(Tencor), β-ray Backscattering Spectroscopy(Veeco), SpectraThick(KMAC ST-2000 DLX) and the SEM(FEI Nova 200) and also the information achieved here was applied to the actual experiment.

On the basis on the familiarity of various thickness measuring techniques, we have carried out the main purpose of this experiment of finding the optimized diffusion barrier. This paper proposes W-B-C-N diffusion barriers for a proficient diffusion barrier and includes experimentation on the relationship between the Nitrogen concentration and the diffusion barrier characteristics. The diffusion barriers were annexed with B, C, N via RF Magnetron Sputtering with variation in sputter time, annealing rate, Nitrogen proportion inside of the sputtering equipment. The resistivity, deposition rate, heat stabilizations were measured and observed and finally the XRD diffraction equipment was used to analyze the composition of the diffusion barriers.

Guidance Professor : Chang-Woo Leeb; Assistant Supervisor : Soo-In Kim; Nano Electro-Physics, Kookmin University,136-702 Seoul, South Korea

Presenting Author

Born in London, England in 1990, Hyoun Ju attended Blue Coat School in Birmingham, England. After moving to Korea in 1997, he attended Indianhead international school in Uijeongbu and transferred to a Korean school which led to graduation from Jeongbal elementary and middle school. Currently, at the age of 18, he is attending KSA (Korea Science Academy) in Busan, South Korea. During his freshman R&E (Research and Education) program at KSA, he has done research on semi-conductors with the topic of "Investigation on Characteristics of W-B-C-N Diffusion Barrier according to Nitrogen Concentration through Applications of Various Thickness Measurement Techniques" and on proteomics in his sophomore year with the topic of "Development of crime scene investigation (CSI) technology using proteomic analysis". He is also Korea's national representative for the 2008 annual IYPT (International young physicist tournament) competition.

Optics Abstracts

Optics 1

High-NA Optical Systems for EUV Lithography (Production and Development)

R. Hudyma

Hyperion Development LLC

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

Optics 2

Multilayer Mirrors for EUV Lithography – Pushing Technological Limits

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The demand for enhanced optical resolution in order to structure ever smaller details has pushed optics development in recent years. There is an increasing interest in optical components for short wavelengths mainly triggered by EUV lithography.

At Fraunhofer IOF Jena multilayer optics development cover the full range between the soft X-rays around 2 nm wavelength and the vacuum ultraviolet. However, the paper will focus on multilayer optics for EUV lithography at 13.5 nm. Besides the development of high-reflective multilayers with enhanced thermal and radiation stability using interface engineering and optimized capping layers collector and imaging optics for diverse applications in the EUV spectral range have been realized. The deposition of EUV collector mirrors for high-power laser produced plasma (LPP) sources as well as the realization and testing of diffraction limited EUV Schwarzschild objectives are discussed.

The paper summarizes recent progress and the present knowledge in preparation and characterization of multilayer optics for the EUV spectral range with regard to different designs, minimization of structure imperfections, thermal and radiation stability.

Optics 3

Diffractive Optical Elements and their Potential Role in High Efficiency Illuminators

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If feasible, diffractive optical elements in the EUV regime could, in principle, provide a high efficiency mechanism to generate modified illumination for EUVL steppers. The strong absorption of EUV by most materials and its extremely short wavelength, however, makes it very difficult to implement such components that are commonplace in the longer wavelength regimes. Here we demonstrate the fabrication and characterization of EUV binary phase-only computer-generated holograms allowing arbitrary far-field diffraction patterns to be generated.

Presenting Author

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

Resist Abstracts

Resist 1

Our Approaches to EUV Resist Materials

N. Ohshima

Fujifilm

It is strongly demanded to overcome tradeoffs among sensitivity, resolution and LWR in EUV resist materials. Our approaches to overcome these tradeoffs are increasing the aerial contrast of de-protection images and decreasing the dissolving unit size. We are especially focusing on controlling the diffusion of both electrons and acids during EUV exposure and the following baking processes to increase the aerial contrast of de-protection images.

Molecular weight and inter-molecular interaction of polymers are important factors influencing the dissolving unit size during the development. We will talk about how these factors are controlled and affect the lithographic performances. We will also present the latest lithographic data of the materials introduced these design concepts.

Presenting Author

Naoto Ohshima was graduated from the Waseda University in 1979, and from the graduated school of science and engineering in the same university, receiving masters degree in electrical engineering in March of 1981. From April of 1981, he was employed by Fuji Photo Film Co., Ltd. at its Ashigara Research Laboratories, and was engaged in research of color photographic materials. From April of 2006 to date, he has been engaged in research of resist materials, at Electronic Materials Research Laboratories in FUJIFILM Corporation.

Resist 2

Progress in EUV Resist Development

T. Kai, D. Shimizu, K. Maruyama, A. Saitou, T. Shimokawa and Y. Hishiro*

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For next generation lithography, several technologies have been proposed to achieve the ultra-fine patterning required for the 32nm hp and beyond.

Extreme ultraviolet (EUV) lithography is one of the promising candidates but faces several critical issues with resist performance. Sensitivity and Line width roughness (LWR) are regarded as the major issues to be improved to ensure device reliability and performance. One direction for high sensitivity is to apply new materials such as high absorption resin. One direction for decreasing LWR is to apply new materials such as molecular glass and polymer bound photoacid generators (PAG). In this study, the performance of EUV resist to which high absorption resin and molecular glass have been investigated. Compared with the PHS resin, the novel resin which fluorine atom was introduced gave an increase in the amount of the acid generation. It was found that the resist based on new molecular glass, Noria which was partially protected with an acid labile group resolved 28nm line and space patterns. The optimization of resist formulation using high absorption resin and protected Noira is on-going.

Presenting Author

Tsutomu Shimokawa, Ph.D, works as Research Director for JSR Corporation Semiconductor Materials Laboratories. Dr. Shimokawa graduated from Kanagawa University Department of Applied Chemistry, Faculty of Engineering in 1987 and joined Japan Synthetic Rubber Company (JSR Corp.) where he started the research of photoresist materials development. In 1995 he completed his Ph.D. from Kanagawa University and then joined the University of Texas at Austin in the C.G.Willson Laboratory as a Post-Doc. He received the Semiconductor Research Corporation, Excellent Research Award by ArF Resist Development in 1997. In 1998 he returned to JSR where in 2004 he served as General Manager of Semiconductor Materials Laboratories. He is currently the Research Director of Semiconductor Materials Laboratories and received the the Ministry of Education Japan, Japan Industrial Technology Award by ArF Immersion Lithography Material System in 2007.

Resist 3

Stochastic Approach to Modeling Line Edge Roughness in Photolithography

C. Mack

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

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

Presenting Author

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

Resist 4

Influences of Polymer Protection Groups on EUV Resist Performances

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Extreme Ultra Violet (EUV) lithography is one of the most promising candidates for semiconductor device manufacturing for 32nm half pitch and beyond. The lithography characteristics required for EUV resist are pattern resolution, line-edge roughness, photo-sensitivity, and out-gassing.
In this paper, we have prepared two types of polymers, having different protection groups. One is acetal type hydroxyl phenol polymer, the other is annealing type polymer. Also we have obtained various kinds of polymers for our research by applying different protection groups.

First of all we have measured acid diffusion length of each resist and studied its influence on resolution, line-edge roughness and photo-sensitivity, respectively. Acid diffusion lengths of acetal protection polymers were shorter than annealing protection ones. So the resolution performance of acetal protection type polymer was appeared to be relatively promising. This EUVL resist showed resolution to 28nm, photo-speed of 19.0mJ/cm2. This resist also had minimal LER, 3σ, of 5.2nm for HP32nm 1:1 line and space.

Resist 5

Sensitization Mechanisms of Chemically Amplified Resists and Resist Design for 22 nm nNode

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When EUV photons enter resist materials, they are absorbed by resist molecules in accordance with Lambert's law. After the absorption, photoelectrons are emitted from the resist molecules. The photoelectrons with excess energy (~80 eV) induce further ionization and excitation. A single EUV photon generates 4.2 electrons on average in poly(4-hydroxystyrene), which is a typical backbone polymer for EUV resists. The secondary electrons lose their energy through the interaction with surrounding molecules and finally thermalized. The thermalized electrons migrate in resist materials until they find the reaction or localization sites. Acid generators are decomposed through the direct excitation by secondary electrons and the reaction with thermalized electrons. The latter reaction is a major process for acid generation. The protons of acids are mainly generated through the deprotonation of polymer radical cations generated through ionization. On the basis of the sensitization mechanisms and the spatial distribution of reactive intermediates, the resist design for 22 nm node is discussed.

Resist 6

Harnessing EUV Photons to Design Fast and High Resolution Resists

J. Thackeray, E. Aqad, M. Cronin, K. Spear-Alfonso

Rohm and Haas

The major conundrum involving EUV resists is the tradeoff between photospeed and resolution and Line Edge roughness (LER). In earlier work, we have shown that we can produce resists with high resolution (<25nm hp, 2.3nm LER) but only with a photospeed of 49 mj (ref). Based on studies done in the literature (ref), it is well known that the acid generation mechanism for EUV lithography is distinctly different from that of longer wavelength exposures. It is believed that the high energy EUV photon (92.5 eV) is absorbed primarily by the polymer matrix and secondarily the matrix generates a cascade of secondary electrons, followed by electron transfer to the PAG allowing the ensuing acid generation event. In this manner, the polymer matrix indeed becomes important to insure the maximum amount of secondary electron generation. If we can design the polymer matrix to maximize secondary electron generation, then the opportunity may exist to improve photospeed of high resolution, low blur resist materials. We will report on a new low blur resist that has nearly the same resolution and LER as our previous material (<25nm hp, 2.8nm LER) with a much improve photospeed of 16 mJ.

Dr. James Thackeray has worked in the fields of photoresists and antireflective coatings for 22 years. He has 49 US patents and has directed and invented the development of numerous products used by lithographers all over the world. He has spent all of his working career at Rohm and Haas, the formerly named Shipley Co, and General Electric. While at Rohm and Haas, Dr Thackeray has won its highest award for scientific achievement, the Otto Haas Award, twice. Dr. Thackeray received his Ph. D in Chemistry from the Massachusetts Institute of Technology in 1986.

Resist 7

Resist process development for the EUV Alpha Demo Tool at IMEC

A. Goethals, A. Niroomand*, F. Van Roey, J. Hermans, G. F. Lorusso, B. Baudemprez, I. Pollentier, J. de Marneffe, R. Jonckheere and K. Ronse

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Having completed the installation of the EUV ASML ADT full-field scanner, IMEC has a fully-integrated 300mm EUVL process line. This paper will discuss the resist status, resist selection and initial imaging and patterning performance of these resists on the ADT.
In preparation for a resist process on the scanner, the progress in resist performance with regard to the ITRS requirements for 32nm HP and below, has been followed up through screening of new resist materials and chemistries from commercial suppliers using EUV interference lithography. Currently, several resist materials are capable of 25nm HP resolution with interference litho. Line edge roughness however remains the major challenge. Based on these screenings results, candidate resists are selected for the ADT. For implementation on the ADT, resists need to cope with higher flare level on full field scanners and must comply with the outgassing specifications of ASML. Imaging performance of the selected resists is demonstrated on the ADT, showing 32nm line/space resolution and down to 35nm contact holes. Finally, the feasibility of pattern transfer of 50nm contact holes using the current resist materials is shown.

Presenting Author

Anne-Marie Goethals received a M.S. and a Ph.D. degree in Electrical Engineering from the University of Leuven, Belgium. She joined IMEC in 1985 where she was initially concentrating her research on top surface imaging lithography processes. She has been subsequently involved in resist process development and implementation for i-line, DUV, 193nm, 157nm and EUV lithography. Currently, she holds the position of EUV sub-program manager in the advanced litho program at IMEC.

Resist 8

EUV Interference Lithography Employing 11-m Long Undulator as a Light Source

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Three top issues for the EUVL are 1) high power source, 2) resist, and 3) defect free mask. In the resist development issues, high sensitivity and low line-edge-roughness (LER) have to be achieved simultaneously.

Considering the resist evaluation system, since a mirror-optics for the exposure system has abberation and flare, low LER cannot be achieved by using this kind of optics. Thus EUV interference lithography (IL) which has no flare is a promising method to evaluate the sensitivity, LER, and the resolution limit of EUV lithography.

The EUV-IL system was constructed at the BL9 beamline in NewSUBARU synchrotron radiation facility. A world largest 11-m-long undulator was used for a light source, which can produce excellent coherence light for the EUV-IL. A specific configuration of the EUV-IL system and its results will be discussed.

Source Abstracts

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Source Abstracts

Source 1

Efficient EUV Source by Use of a Micro-target Containing Tin Nanoparticles

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A laser-produced plasma (LPP) should be one of the most possible EUV light sources. LPP liquid jet targets and droplet targets are mainly utilized for high repetition rate operation and low debris emissions due to their respective regenerative and quasi-mass limited natures. Laser-produced tin plasmas have a significant potential for achieving a high conversion efficiency at 13.5 nm. The use of a regenerative target as an efficient EUV source has been demonstrated using a tin-based aqueous droplet target with a conversion efficiency of 1.2%. Furthermore, one of the highest conversion efficiencies (2.5%) was achieved using a liquid tin jet target. A low concentration target would minimize the debris emission and reduce the self-absorption.

Our approach is to use a low concentration (6 mass%) colloidal jet target containing tin dioxide nano-particles and apply a double laser pulse irradiation to control plasma characteristics. As a result, the EUV conversion efficiency of 1.2% at 13.5 nm was observed, which was almost equal to that of using a planar tin target. In addition, the CE of 2.3% was also observed by use of 17 mass% target.

By employing the double pulse irradiation, the kinetic energy and intensity of emitted ionic debris were both decreased. This observation was important to construct practical EUV sources, since such low-energy ion debris could be screened out by using a static electric and/or magnetic-field shielding. Time-integrated deposited debris characteristics should, therefore, be investigated to construct realistic debris mitigation system.

To produce the high brightness EUV emission, we also develop the capillary discharge-produced plasma channel for guiding the high-order-harmonic and/or laser-Compton scattering experiments. I will present properties of the plasma and laser-beam parameters.

Presenting Author

Takeshi Higashiguchi received Ph.D. degrees in electrical and electronic engineering from Utsunomiya University, Japan, in 2001. From 1999 to 2001, he was a JSPS Researcher for young scientists. He conducted research on high field physics and the short microwave sources based on the laser-plasma interaction. In September 2001, he joined the University of Miyazaki, Japan, where he was a Research Associate with the Department of Electrical and Electronic Engineering. In June 2006, he joined the Utsunomiya University, Japan, where he is a Research Associate. His main research interests include the areas of EUV emission based on a laser-produced plasmas, ultrafast lasers, and capillary discharge-produced plasmas. He is a member of the Physical Society of Japan, the Japan Society of Applied Physics, the Laser Society of Japan, the Japan Society of Plasma Science and Nuclear Fusion Research, Optical Society of America, and the American Physical Society, respectively.

Source 2

Fundamental Investigation on CO_2 Laser-produced Sn Plasma for an EUVL Source

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CO_2 laser-produced Sn plasma has been considered as one of the main candidates for EUV light source used in EUVL due to its high conversion efficiency, relatively low cost, and scalability to high EUV power. However, in order to efficiently couple CO_2 laser pulse into tiny droplet target and to mitigate energetic ions from CO2 laser-produced Sn plasma, fundamental understandings of the Sn plasma physics are still necessary.
A clean pulse CO_2 laser with flexible pulse parameters is developed at UCSD. The CO_2 laser is a master oscillator and power amplifier (MOPA) system, consisting of three transversely excited atmosphere (TEA) CO_2 lasers. It produces a clean 10.6 μm laser pulse with pulse durations from 20 to 110 ns. Laser intensity on target is up to 10^{10} W/cm^2. Higher in-band conversion efficiency as compared with that of 1.06 μm driving laser, i.e., 3 % are obtained. Correlations between the properties of the plasma and the properties of the EUV and debris will be presented in this report.

This research was partially supported by UC discovery grant sponsored by Cymer Inc.

Presenting Author
Yezheng Tao received a Ph.D. in plasma physics from China Institute of Atomic Energy in 2001, where he was also a senior researcher. He was a postdoctoral researcher at Institute of Laser Engineering, Osaka University, Japan. He has experiences in high-energy excimer laser, ultrashort intense laser, high field physics, plasma diagnostics, and laser plasma interaction for more than 15 years. Dr. Tao is currently an assistant project scientist at University of California, San Diego, working on extreme ultraviolet source from laser-produced plasma and its applications in lithography, microscopy, and plasma diagnostics etc.

Source 3

Comparison Between Atomic Structure Calculations and Laser Produced Plasma Spectra for Tin

P. Hayden[a,b], G. O'Sullivan[a] and P. Dunne[a]

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Knowledge of the detailed atomic structure and transition strengths of tin ions are essential to model plasmas formed from tin and to calculate the intensity of radiation produced by, and transported out of, source plasmas. This detailed modeling is required to explain observed spectra and to optimize useful emission from plasmas as high volume manufacturing approaches.

Experimentally spectra were recorded from tin laser produced plasmas, created with a 1 J, 15 ns Nd:YAG laser pulse, in the 9{17 nm region with a 0.25 m grazing incidence calibrated °at-¯eld spectrometer, at a power density of 1.4×10^{11} W/cm^2. It was observed that the contribution to emission and self-absorption of individual ion stages, from 6+ to 11+, depended to a large extent, on the laser target geometry and on the angle of observation relative to the target surface.

Analysis for these spectra were performed using the Cowan atomic codes. Calculations for the transitions 4p64dn ¡! 4p64dn¡14f in ion stages Sn VII to Sn XII were compared to the experimental spectra. Configuration interaction was taken into account by including the eleven configurations which had the greatest effect, for both the odd and even configurations. Scaling of the Slater, spin- orbit and radial integrals was performed systematically to achieve a best ¯t to the experimental spectra.

Presenting Author

Patrick Hayden obtained a Ph.D. from University College Dublin in 2007 for work on spectroscopy of tin based laser produced plasmas. This work included the optimisation of 13.5 nm emission from such plasmas as functions of laser pulse power density, target composition and target geometry, while also recording absolute intensities of in-band, out-of-band radiation and ions produced. He is currently an Irish Research Council for Science, Engineering and Technology Postdoctoral Fellow at Dublin City University, working on tin based materials as EUV sources.

EUVL Source Based on the Tabletop Storage Ring MIRRORCLE

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The tabletop storage rings MIRRORCLE are light sources for hard X-rays as well as EUV and far infrared, which store electron beams with energy of 4, 6, and 20 MeV respectively, and beam orbit radius between 8 and 15 cm. Unique technology solutions allow obtaining a large stored beam current and a small beam cross section. The machine works at relatively high vacuum pressure ~ $1x10^{-5}$ Pa resulting in significant residual gas ionization in the beam region which forms a positive ions trap there. Combined with energy supplied by RF cavity this increases both the beam stability and the beam lifetime, and speeds up the radiation damping. Correspondingly, MIRRORCLE provides on average 3 A electron beam current, one minute long lifetime, 10 ms radiation damping and beam size 3*3 mm^2. Beam injection is carried out at 100Hz to keep high the average beam current. Recent technological developments of MIRRORCLE are introduced in this paper. To generate hard X-rays and EUV we introduce tiny and thin targets in the electron orbit of MIRRORCLE.
Inserting suitable targets leads to radiation of a powerful EUV. The EUV spectra radiated from single foil targets are contentious. The 2% band width necessary for EUVL will be generated by developing multilayer structure resonant radiation targets. Resonant Cherenkov radiation Si based targets emit at 12.55 nm. Resonant transition radiation targets can emit at 13.5 nm. Details of the design and the performance of our EUVL source with such targets will be presented.

Source 5

High-power Cryogenic Yb:YAG Lasers and Optical Particle Targeting for LPP EUV Sources*

J.D. Hybl**, T.Y. Fan, W.D. Herzog, T.H. Jeys, D.J.Ripin, and A. Sanchez

MIT Lincoln Laboratory, Lexington, MA United States

Economical LPP EUV sources require both high-efficiency, high-power lasers and precise targeting of the source droplets. Cooling of Yb-doped solid-state lasers to liquid N2 temperatures substantially improves laser efficiency and beam quality relative to room-temperature Yb-, or Nd-doped lasers. These improvements have been demonstrated for Yb:YAG at MIT Lincoln Laboratory (MIT/LL) at the >450-W average-power level in a cw-waveform with nearly diffraction-limited output. This technology is currently being scaled to the multi-kW power level in a short-pulse waveform that is compatible with the requirements for LPP sources. The excellent beam quality of cryo-Yb:YAG lasers relative to other solid-state lasers will allow less complex schemes for multiplexing laser beams onto the target and potentially lower shot-to-shot variability in the plasma. This improved beam quality is achieved without sacrificing efficiency.

Plasma stability is a key issue for generating EUV light in the correct energy band efficiently. Methods to accurately target the source droplets are required to achieve highly stable plasmas. MIT/LL has developed a simple method to measure the positions and velocities of aerosol particles in real-time using a single low-power laser beam. This technique could be easily integrated into an LPP source to ensure accurate targeting of each droplet for optimal EUV yield.

Presenting Author

John Hybl has been a member of the technical staff at MIT Lincoln Laboratory since 2002. At Lincoln he has worked on developing optical methods for the rapid detection of biological and chemical agents. Recently, he has been working to developed cryogenic Yb:YAG for high power laser applications. He received his B.S. in Chemistry from Michigan State University in 1996 and his Ph.D. in Physical Chemistry from the University of Colorado at Boulder in 2001.

Source 6

Optical Particle Targeting for LPP EUV Sources**

J.D. Hybl*, W.D. Herzog, T.H. Jeys, A. Sanchez, and S.M. Tysk

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Plasma stability is a key issue for generating EUV light in the correct energy band efficiently. Methods to accurately target the source droplets are required to achieve highly stable plasmas. We present a new concept for the measurement of droplet trajectories. The technique uses a light source and a mask to generate a spatial pattern of light within a volume in space. Particles traverse the illumination volume and elastically scatter light to a photo-detector where the signal is recorded in time. The detected scattering waveform is decoded to find the particle trajectory. We present our design for the structured laser beam and demonstrate the accuracy of the technique in determining particle position and velocity. This technique could be easily integrated into an LPP source to ensure accurate targeting of each droplet for optimal EUV yield.

** This work is sponsored by the Department of the Air Force under Air Force Contract FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the authors, and do not necessarily represent the view of the United States Government.

Presenting Author

John Hybl has been a member of the technical staff at MIT Lincoln Laboratory since 2002. At Lincoln he has worked on developing optical methods for the rapid detection of biological and chemical agents. Recently, he has been working to developed cryogenic Yb:YAG for high power laser applications. He received his B.S. in Chemistry from Michigan State University in 1996 and his Ph.D. in Physical Chemistry from the University of Colorado at Boulder in 2001.

Source 7

Laser Probing of Tin Based Laser Produced Plasmas

P. Hayden*, P. Hough, J. Dardis and J. T. Costello

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Non-invasive techniques of probing laser produced plasmas (LPPs) provide an excellent method of extracting useful plasma parameters, such as electron density and temperature, without significantly altering the LPP under investigation. The results from two such techniques are presented here: optical Nomarski laser interferometry and Thomson scattering.

Experimentally, a LPP is formed from a bulk tin target, using the 1064 nm output of a Nd:YAG laser (Energy ~ 800 mJ, pulse width ~6 ns). A second synchronised laser pulse, from a frequency doubled Nd:YAG laser (532 nm, ~ 6ns), is then used to probe the resulting plasma at controllable time delays. The probe pulse is attenuated in order to reduce reheating of the tin LPP. This probe pulse is used to perform both Nomarski interferometry and Thomson scattering.

The interferometer enables time resolved two-dimensional (spatial) determination of the electron density of the LPP at early times in the plasma lifecycle, while Thomson scattering provides electron temperatures and average densities. The results for the later stages of the plasma cycle are compared to electron temperature and densities obtained from optical spectroscopy.

Presenting Author

Patrick Hayden obtained a Ph.D. from University College Dublin in 2007 for work on spectroscopy of tin based laser produced plasmas. This work included the optimisation of 13.5 nm emission from such plasmas as functions of laser pulse power density, target composition and target geometry, while also recording absolute intensities of in-band, out-of-band radiation and ions produced. He is currently an Irish Research Council for Science, Engineering and Technology Postdoctoral Fellow at Dublin City University, working on tin based materials as EUV sources.

Source 8

Measurement of Ionic and Neutral Debris in a DPP EUV Source and Investigation of Reflectivity Degradation of EUV Mirrors

R. Raju, J. Sporre, H. Shin, D .N. Ruzic

Center for Plasma Material Interactions, University of Illinois at Urbana- Champaign, Urbana, Illinois, 61801

This paper presents the measurement of ionic and neutral debris measurements and mitigation techniques developed at Center for Plasma Material Interactions (CPMI) for Xe and Sn discharge-produced plasma (DPP) EUV source. It also describes the ionic and neutral debris measurement system and procedure. Angularly resolved ionic and neutral debris measurement is made for Xe and Sn sources at different angle from the axis of the pinch. Impingement of energetic ion and neutral debris usually degrades the reflectivity of the mirrors. Degradation of reflectivity of EUV mirror is extensively investigated in the Xe produced plasma EUV source. Mirror samples were exposed to 0.5, 1, 2.5 and 4 million shots and AFM measurement of samples after exposure reveals that roughness of the sample increases with increase in exposure time. AES measurements on exposed samples were done to learn the nature and amounts of contamination. Reflectivity of the exposed samples is measured at NIST and degradation of reflectivity after exposure is observed. In order to understand the degradation of reflectivity theoretical simulation which incorporates the contamination on mirror sample surface is carried out. Measured reflectivity is in good agreement with the theoretically predicted values.

Presenting Author

Dr. Ramasamy Raju received the Ph.D. degree in physics from Bharathiar University, Coimbatore, India in 2001. After his Ph.D. he joined as a Postdoctoral Fellow at Kyushu Institute of Technolgy, Kita-kyushu, Japan and conducted a research on the plasma-spacecraft interactions. In 2003, He became a research engineer at Adtec Plasma Technology Co., Ltd, Fukuyama, Japan, where he involved in the development of atmospheric pressure microwave plasma torches. He is currently a Postdoctoral Research Associate in the Department of Nuclear, Plasma and Radiological Engineering at the University of Illinois, Urbana-Champaign. His current research interests are plasma material interaction, advanced debris mitigation technique for Sn- and Xe fueled EUV sources and removal of contamination from collector optics, removal of nano-size particles from EUV mask blanks and physical vapor deposition.

Source 9

Investigating the Emission Angle, Charge, and Energy of Ions Produced from Laser Produced Extreme Ultraviolet Sources

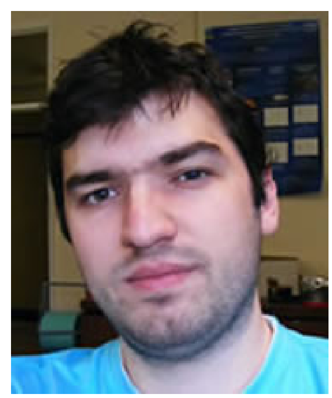
A. O'Connor, P. Dunne, P. Hayden, O. Morris, G. O'Sullivan, F. O'Reilly, and E. Sokell

Atomic, Molecular, and Plasma Physics Group, School of Physics, Science Centre North, University College Dublin, Belfield, Dublin 4; Email: aodh.oconnor@ucd.ie

The angular distribution of ions from Tin based laser produced plasma EUV sources has been investigated using a spherical sector energy analyser (absolutely calibrated by an Electron Cyclotron Resonance Ion Source). The angular resolution was achieved using a custom built optical system which can be rotated in relation to the detector, whilst maintaining a normal angle of incidence for the laser pulse with respect to the target. The optical system provides angular measurement with 1 degree accuracy over a range from 20 – 85 degrees. The Tin plasma was generated using a Nd:YAG laser operating at 1064 nm with a full width half maximum pulse duration of 10 ns. Tin charge states from SnII to SnX, with energies / charge ratios spanning 0.2 – 3.2 keV, over a range of angles (20, 30, 40, 45, 50, 60, 70, and 80 degrees) were analyzed.

Presenting Author

Mr. Aodh O'Connor is currently undertaking PhD research entitled: "Determination of charge stage, energy, and angular distribution of ions from laser produced plasma EUV sources", in the Atomic, Molecular, and Plasma Physics group, University College Dublin, Ireland. In 2006 Mr. O'Connor completed his BSc in Experimental Physics (Hons) at, University College Dublin, Ireland.



Source 10

EUV Radiation from Laser Triggered Tin Target

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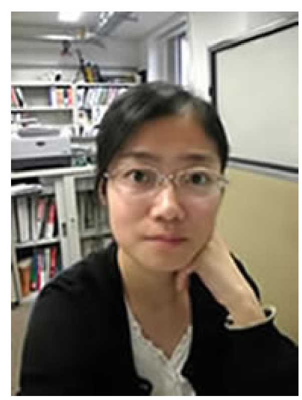
A laser triggered tin target discharge produced plasma EUV source has been developed, which comprises an Nd:YAG laser, focusing on a tin rod embedded in one of electrodes to evaporate tin and create plasma, and a power supply system to generate a pulse-current of 6kA with ~600ns pulse width. When plasma plume expands toward the opposite electrode, discharge path is created; discharge current itself, together with the pinch effect, causes ionization and heating of the plasma, and then EUV radiation is generated consequently.
With this experimental setup, EUV radiation has been observed using a photodiode. Meanwhile, an EUV pinhole camera sensitive to 10-18nm wavelength region and a visible high speed camera have been employed to study the characteristics of EUV emission and Z-pinch dynamics, by varying the Nd:YAG laser energy, shape and polarity of the electrodes and gap distance. The results show that when the tin electrode serves as the cathode, at the same discharge current, the pinch plasma formed with an acute anode has the highest quality, however, concerning the pinch intensity and pinch last time, a semicircle anode is superior to an acute anode.

Presenting Author

Qiushi Zhu received the Bachelor degree from Dept. of Electronic Science and Technology at Harbin Institute of Technology, Harbin, China, in 2006, where she was also working toward the Master's degree, focusing on capillary discharge Ne-like Ar soft X-ray laser till Sep. 2007. Now, she is a master student studying on laser triggered tin target discharge produced plasma extreme ultraviolet source in the Dept. of Energy Science, Tokyo Institute of Technology, Japan.



Source 11

Multipass Slab CO_2 Amplifiers for Application in EUV Lithography

V. Sherstobitov*, A. Rodionov**, D. Goryachkin*, N. Romanov*, A. Endo***, K. Nowak***

*JSC "Laser Physics", St. Petersburg, Russia, **Vavilov Optical Institute, St. Petersburg, Russia, ***Gigaphoton Inc., Kanagawa, Japan

Development of high-efficiency multipass CO_2 laser amplifiers based on commercially available RF-pumped slab CO_2 lasers with a large area of electrodes is one of the promising approaches to building a compact MOPA system of multikilowatt average-power operating in a repetitively pulsed mode with pulse duration about 10-20 nanoseconds and repetition rate ~100 kHz. The radiation with such parameters is necessary for generation of EUV plasma source and subsequent application of this source in EUV lithography.

In this paper we proposed and for the first time to our knowledge experimentally tested a novel concept of a multipass CO_2 amplifier of short-pulse radiation based on slab CO_2 laser with CW RF pumping. The optical arrangement of the amplifier comprises only two mirrors and can be realized by simple modification of commercial CO_2 laser with an unstable resonator. The experiments were carried out with the use of the model of RF-pumped slab CO_2 laser that provided 175 W output CW with the optimum unstable resonator. The master oscillator generated up to 5 W at the repetition rate of 100 kHz and pulse duration of 15 ns.

We investigated spatial, energy, spectral and temporal characteristics of the amplifier output radiation at different number (n=9, 11 and 13) of input radiation transits over the gain medium. At the input average power of 4.2 W the amplifier output of 42 W was demonstrated for the 13-pass-amplifer. The theoretical model for simulation of short-pulse multi-pass slab CO_2 amplifiers operating at a high repetition rate is elaborated. The model enables scaling up the amplifiers and optimization of their parameters. The results of simulation show that with the input power ~ 200 W the output exceeding 3 kW can be obtained with a multipass amplifier based on an RF pumped large scale CW slab CO_2 laser.

Presenting Author

Vladimir Sherstobitov was born in Yaroslavl, Russia, in 1943. In 1960 he entered Technical University in St. Petersburg and graduated from it in 1966 with the Master Degree in Physics of Semiconductors and Dielectrics. From 1966 up to 1993 his activity was associated with the Vavilov Optical Institute (St. Petersburg) where he received his Ph.D. Degree in Optics in 1972 His activities during these years involved research and development of unstable resonators for solid-state and CO_2 *lasers, laser beam control in gas-flow* CO_2 *and mid-infrared lasers and nonlinear-optical methods of wavefront correction in* CO_2 *lasers. In 1993 he took a position of a Head of Laser Optics Department at the Institute for Laser Physics (St. Petersburg). From 1993 until 2006 his research interests involve phase conjugation techniques for correction of laser beam distortions in laser systems, long-distance power beaming in space, application of dynamic holography for correction of dynamic distortions in imaging optical systems.*

Since 2007 V. Sherstobitov is working with the Joint-Stock Company "Laser Physics" (St. Petersburg) as a Head of R&D Division. His current activity is associated with laser material processing and development of short-pulse slab CO_2 *laser amplifiers for application in EUV sources for high resolution lithography.*

Dr. Sherstobitov is the author or co-author of more than a hundred of scientific publications. He is a member of the Rozhdestvensky Optical Society (ROS), the Optical Society of America (OSA) and the International Society for Optical Engineering (SPIE).

Source 12

Technological Aspects of DPP EUV Source Development for HVM Lithography

V.M. Borisov*, G.N. Borisova, A.S. Ivanov, Y. B. Kirukhin, O.B. Khristoforov, V.A. Mishchenko, A.V. Prokofiev, A.Y. Vinokhodov

The State Research Center of the Russian Federation - Troitsk Institute for Innovation and Fusion Research (SRC RF TRINITI)

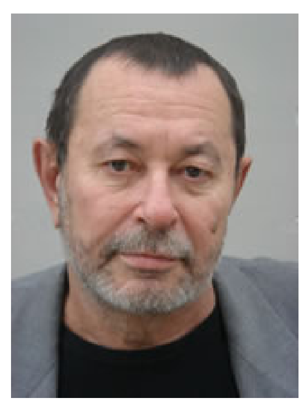
The application of the pinch discharge in tin vapor between rotating disk electrodes (RDE) is perspective way of the development of a light source for EUV HVM lithography. Concept of RDE source with a regeneration of tin surface solves fundamental problems of electrode erosion and high heat removing. On the other hand, power scaling meets such technological problems as maintenance of conversion efficiency and small pinch size at increase of pulse repetition rate or/and input energy per pulse, accumulation of tin particles (atoms and ions) in discharge region, interaction of liquid tin with electrode metal and so on.

Experiments were carried out with three RDE sources which differed by the methods of tin delivery and tin surface regeneration. Also we checked a difference of using cathodes with solid or liquid tin. As the vacuum chambers of the sources were not cooling, the sources could operated continuously 0.5 hour at the input electrical power about 10 kW or 15 minutes at power 20 kW.

The experimental results obtained for various RDE sources operating in continuous mode at pulse repetition rate in the range 1-5 kHz and input energy 3-12 J per pulse are discussed in point view of achievement of HVM source characteristics.

Detailed analysis of large body of experimental results makes possible to offer new pulse power system that provided a stable small pinch size and low level of a background EUV emission.

Presenting Author



Vladimir M. Borisov received a M.Sc in physics from Moscow Engineering Physical Institute (MEPhI) in 1970 and joined Branch Kurchatov Institute of Atomic Energy which now renamed as State Research Center of Russian Federation -Troitsk Institute for Innovation and Fusion Research (SRC RF TRINITI). He received Ph. D from Kurchatov Institute of Atomic Energy in 1976 and Doctor of Science in Physics from SRC RF TRINITI in 1986. He is now Deputy Director of Pulse Processes Division and Head of Pulse Laser System Laboratory. He has experience in plasma physics, high power CO_2 and excimer lasers, EUV DPP sources. He is professor at MEPhI, author over 150 scientific publications and holds 24 patents.

Source 13

Absolute Characterization of Xenon EUV Radiation Generated by a Compact ECR Plasma Source for Lithographic Applications

R. Bista[a,#], R. Bruch[a], and H. Merabet[b]

a: Department of Physics, University of Nevada, Reno, NV 89557 USA; b: Mathematics and Sciences Unit, Dhofar University, Salalah 211, Sultanate of Oman; #Email: rajan@unr.edu

The generation of EUV light by a Compact Electron Cyclotron Resonance Ion Source (CECRIS) has been studied. The EUV emission diagnostics of the ECR plasma was accomplished by means of an absolutely calibrated 1.5 m Grazing Incidence Monochromator. The sensitivity of our EUV diagnostic system (dependence of the efficiency as a function of wavelengths) for a wide wavelength range was evaluated using a light source of known wavelength and photon flux at the Advanced Light Source (ALS) of Lawrence Berkeley National Laboratory (LBNL) in conjunction with previously recorded data. This spectrometer calibration technique is employed for the absolute characterization of xenon EUV radiation generated from an ECR plasma source. We have recorded and absolutely normalized several spectra in the wavelength range from 10 to 80 nm under the condition of medium to high resolution to discriminate between ionic line spectra arising from different xenon (Xe^{q+}, q = 1-10) charge states. Particularly, we focused our investigation on the wavelength range of 13.5 nm roadmap region that has significant EUV lithographic applications. From this study, we have found that the major radiative lines in this vicinity may be mainly ascribed as decay of Xe^{10+} ionic state.

Presenting Author

Rajan Bista is a graduate student at University of Nevada, Reno (UNR) and currently pursuing Ph.D. degree in Physics. He is originally from Nepal. Mr. Bista's research is related to the investigation of xenon based compact electron cyclotron resonance plasma source for EUV generation for its possible lithographic application. Recently, he received his Master's degree in Physics from UNR with thesis titled "Absolute calibration of 1.5 m Grazing Incidence Monochromator for Extreme ultraviolet (EUV) diagnostic of a plasma source". This work was done in Advance Light Source (ALS) of Lawrence Berkeley National Laboratory. He is am now in fifth year at UNR and plans to graduate with Ph.D. degree in May 2009.

Source 14

Ablation Dynamics of Tin Micro-droplet Target used in LPP-based EUV Light Source

D. Nakamura, T. Akiyama, K. Tamaru, A. Takahashi, T. Okada

Kyushu University

The CO_2 laser-produced tin (Sn) plasmas is one of the most practical candidates for the EUV lithography light source, where Sn micro-droplets are expanded by the irradiation of a pre-laser pulse before CO_2 laser irradiation to improve the coupling efficiency between long-wavelength CO_2 laser and micro-droplets.
In this study we have investigated the ablation dynamics of Sn micro-droplet irradiated by a Q-switched Nd:YAG laser, that will be used as a pre-irradiation pulse in EUV source plasma, using the LIF imaging and the time-resolved shadowgraph.
Sn atms were emitted in all directions with a kinetic speed as high as 20 km/s.
On the other hand, high density Sn clouds spread in the backward against laser irradiation with a slow speed of typically 500 m/s.
The Sn clouds contained small Sn molten particles with a diameter of typically 1-4 um which were collected on a witness plate.
Although Sn clouds may be used as a target for the CO_2 main pulse irradiation, some of neutral atoms always escape from the CO_2 laser beam due to large difference in the speed of Sn atoms and the Sn clouds.

Source 15

20kW Short Pulse CO_2 Laser System for LPP Sn EUV Source

K. Nowak, H. Hoshino, T. Suganuma, and A. Endo*

EUVA, *Gigaphoton, Inc.

Key component of Sn EUV source is a CO2 laser driver of average power level in excess of 20kW. We have reported recently on a 10kW MOPA system at 100kHz repetition rate with 20ns pulse width, utilizing commercially available Fast Axial Flow (FAF) CO2 amplifiers. The general performance was evaluated at 10kW output power. Fundamental problem of high average power operation is a distortion of the beam due to thermal loading of optical components, which is especially significant in solid state material. In solid state laser arena, thin disc, fiber and thin slab geometry amplifiers are now employed to minimize thermal loading and mitigate optical damage, but short pulse power is limited to about 1kW. In contrast, the measured beam quality of our CO2 laser is M2<1.1 at 10kW power level. In an effort to further efficiency we develop a compact system by using modern RF pumped CO2 laser technology. A multi-pass amplifier based on RF-excited slab waveguide CO2 laser technology was numerically modeled and the result shows the feasibility of this approach. An amplification experiment was performed to validate the numerical model using small slab geometry amplifier with encouraging results. These results enable us to design and optimize a next generation of short pulse CO2 laser based on compact slab-waveguide amplifiers, bringing considerable improvement of power, efficiency and footprint.

Presenting Author

Dr. Akira Endo, Chief Development Manager at Gigaphoton, Inc., has been responsible for LPP source R&D in EUVA program from 2002. Scientific backgrounds are laser, accelerator, plasma, X-ray etc. Responsible for Femtosecond Technology Project in Japan from 1996 to 2002, especially for femtosecond X-ray source based on laser Compton method. Worked in University of Tokyo and Max Planck Institute, Goettingen in a excimer laser program.

Source 16

Beaming of CO2 Laser-produced Sn Plasma Along B-field for Efficient Exhaustion

Y. Ueno, T. Suganuma and A. Endo*

EUVA, *Gigaphoton, Inc., 1200 Manda Hiratsuka, Kanagawa, 254-8567, Japan

We evaluated the characteristics of Sn plasma generated by a CO_2 laser (10.6μm). Experiments were performed with bulk Sn-plate targets and Mo/Si multilayer mirror samples. We observed very thin and uniform Sn layers of nano/sub-nano size debris particles. The layer deposition rate at 120mm from the plasma is, without magnetic field, about 30nm per million shots. Fast Sn ion and neutral particle flux were measured at C1 mirror position with Faraday cups and MCP, the signal decreased by more than 3 orders of magnitude by applying a magnetic field of 1T. Beaming of Sn plasma was observed along B field onto a Sn collection. It is now evident that Sn is fully recovered from the EUV chamber into Sn collector cavity.

Presenting Author

Dr. Akira Endo, Chief Development Manager at Gigaphoton, Inc., has been responsible for LPP source R&D in EUVA program from 2002. Scientific backgrounds are laser, accelerator, plasma, X-ray etc. Responsible for Femtosecond Technology Project in Japan from 1996 to 2002, especially for femtosecond X-ray source based on laser Compton method. Worked in University of Tokyo and Max Planck Institute, Goettingen in a excimer laser program.

Source 17

CO_2 Laser-produced Sn-plasma Source for High-volume Manufacturing EUV Lithography

A. Endo

Gigaphoton, Inc., 1200 Manda Hiratsuka, Kanagawa, 254-8567, Japan

A review is given on a laser produced plasma light source for high volume manufacturing (HVM) EUV lithography. The EUV source is based on a high power, high repetition rate CO_2 laser system, a tin target and magnetic plasma guiding for tin processing. The laser system is a master oscillator power amplifier (MOPA) configuration. We have achieved an average laser output power of 12 kW at 100 kHz by a single laser beam with good beam quality. Corresponding EUV in-band power is equivalent to 120 W at intermediate focus. This EUV source is scalable to 250 W EUV in-band power based on a 20-kW CO_2 laser. Collector mirror life is extended by using minimum mass droplet target and magnetic plasma guiding. Effectiveness of the magnetic plasma guiding is demonstrated by monitoring Sn plasma beam in a large vacuum chamber along magnetic field of 2 T.

Presenting Author

Dr. Akira Endo, Chief Development Manager at Gigaphoton, Inc., has been responsible for LPP source R&D in EUVA program from 2002. Scientific backgrounds are laser, accelerator, plasma, X-ray etc. Responsible for Femtosecond Technology Project in Japan from 1996 to 2002, especially for femtosecond X-ray source based on laser Compton method. Worked in University of Tokyo and Max Planck Institute, Goettingen in a excimer laser program.

Source 18

Next Generation EUV Lithography Light Source

P. Choi [1,2], S. V. Zakharov [2+], O. Sarroukh[2], R. Aliaga-Rossel[2], O. Benali[2], C. Leblanc[2], V. S. Zakharov[2]*, C. Zaipffel[2]

1: NANO-UV sas, 16-18 av du Québec, SILIC 705, Villebon/Yvette 91140, France
2: EPPRA sas, 16 av du Québec, SILIC 706, Villebon/Yvette 91140, France, + also with RRC Kurchatov Institute, Moscow, Russia, * also with KIAM RAS, Moscow, Russia; E-mail: zakharov@eppra.org

EUVL at 13.5 nm was considered as the NGL tool holding the most promise for industrial application at the 32 nm node, due in 2009/2010. This ambitious roadmap is facing some technical challenges. Lack of progress to date in increasing resist sensitivity has driven EUV power requirements higher than originally envisaged. Theoretical analysis with the help of the numerical code Z* has been performed to specifically address certain key issues in EUV plasma sources with radiation transfer. The study shows that self-absorption and etendue constraint make it impossible to increase the usable power of a single EUV source beyond an optimal limit without losing efficiency. Conventional DPP sources without multiplexing (re-packing radiators from 1 into *N* separate smaller volumes) will not meet the requirement of the HVM tool. For a fixed etendue, the EUV source power from a near optimal plasma is shown to increase with $N^{1/2}$. We present here experimental results from a new generation of EUV light source with an intrinsic photon collector, the i-SoCoMo™ concept, where strong multiplexing (N>20) is made possible. This source possesses exceptional brightness. Characteristics of the source unit will be presented together with early experience in operating 4 sources in a multiplexed configuration.

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 19

Production of Narrow Band Tunable EUV Radiation Using Optimized High Field Optical Undulators

J. Madey, E. Szarmes and S. Kan

Department of Physics, University of Hawai'i at Manoa, Honolulu, HI 96822

The synchrotron radiation emitted by relativistic electrons moving through the strong magnetic fields in magnetic undulators has proven to be a useful means for generation of narrow band tunable EUV and X-Ray radiation. But the high electron energy synchrotron radiation sources currently available for use operate at undulator periods, electron energies and duty cycles which are far from optimum for use in EUV lithography: the power radiated by such sources at constant e-beam can be shown to increase rapidly with decreasing period assuming operation at the optimal value of the normalized undulator vector potential K. We are developing an optimized compact light source for use at EUV, X-ray and Gamma-ray wavelengths which substitutes an intense near-infrared optical pulse operating at normalized vector potentials K of the order of 0.1 – 1.0 and a matched, low emittance pulsed e-beam source that takes advantage of the scaling inherent in the radiation mechanism for such sources and the time-dependent thresholds for optical and electrical breakdown to investigate the possibility of compact, inexpensive e-beam based light sources capable of supporting the development of the next generation of EUV lithography systems.

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 20

Liquid Metal Collector Mirrors for EUV Lithography

K. Fahy, G. O'Sullivan, P. Dunne, P. Hayden & F. O'Reilly

UCD School of Physics, University College Dublin, Belfield, Dublin 4 Ireland

Ongoing work at University College Dublin has centred on the development of a liquid metal coating process for collector optics. The work involves using a room temperature liquid metal coated onto a metal substrate with the appropriate form. The advances made demonstrate that a stable thin coating on the interior surface of a rotating optic substrate is possible. This offers promise as a solution to the problem of producing an atomically flat coating that can remain unspoiled while operating in proximity to an EUV source plasma of greater that 30 kW power. Images formed with visible radiation using a concave optic will be presented.

This work has been funded under grant no. PC/2007/069 by Enterprise Ireland.

Presenting Author

Patrick Hayden obtained a Ph.D. from University College Dublin in 2007 for work on spectroscopy of tin based laser produced plasmas. This work included the optimisation of 13.5 nm emission from such plasmas as functions of laser pulse power density, target composition and target geometry, while also recording absolute intensities of in-band, out-of-band radiation and ions produced. He is currently an Irish Research Council for Science, Engineering and Technology Postdoctoral Fellow at Dublin City University, working on tin based materials as EUV sources.

Source 21

Development at Energetiq, Inc.

S. F. Horne, M. J. Partlow, M. M. Besen, D. K. Smith , P. A. Blackborow, D. Gustafson

Energetiq, 7 Constitution Way Woburn, MA 01801 USA

The EQ-10 is a commercially available, medium-power (10 W /2 pi,13.5nm +/- 1%, Xenon) EUV source suitable for a variety of resist exposure, mirror testing, and inspection applications. Since the launch of the product in 2005, significant field experience and customer feedback have accumulated.

In response, a development program is under way to re-engineer and optimize the EQ-10 source to to better match market requirements as they have evolved over time. Parameters being addressed include power (a 15 W version is under development), source size, and stability. Data will be presented on the effect of varying source geometry, materials, frequency, and input power on these parameters.

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.

Index by Author

EUV

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