2014 International Workshop on EUV Lithography

June 23-27, 2014

Makena Beach & Golf Resort ▪ Maui, Hawaii

Workshop Abstracts

EUV
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Contents

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Welcome

Dear Colleagues;

I would like to welcome you to the 2014 International Workshop on EUV Lithography in Maui, Hawaii. In this leading workshop, with a focus on R&D, researchers from around the world will present the results of their EUVL related research. As we all work to address the remaining technical challenges of EUVL, to allow its insertion in high volume computer chip manufacturing, we look forward to a productive interaction among colleagues to brainstorm technical solutions.

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

Best Regards

Vivek Bakshi
Chair, 2014 International Workshop on EUVL

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Workshop Agenda

2014 International Workshop on EUV Lithography

Makena Beach & Golf Resort, Maui, Hawaii, USA

June 23-27, 2014

Workshop Agenda Outline

Monday, June 23, 2014

8:30 AM -5:00 PM

EUV Lithography Short Course

Tuesday, June 24, 2014

3:00 PM - 5:00 PM

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

6:00 PM - 7:30 PM

Reception (Pacific Lawn)

Wednesday, June 25, 2014

7:30 AM – 8:30 AM	Breakfast (Café Kiowai)
8:30 AM – 11:40 AM	Oral Presentations (Wailea Salon)
11:40 AM – 12:40 PM	Lunch (Molokini Room)
12:25 PM – 3:30 PM	Oral Presentations (Wailea Salon)
3:30 PM	Afternoon off for Networking

Thursday, June 26, 2014

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

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

11:30 PM – 12:30 PM Lunch (Molokini Room)

12:30 PM – 4:05 PM Oral Presentations (Wailea Salon)

4:30 PM - 5:30 PM Poster Session

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

Friday, June 27, 2014

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

2014 International Workshop on EUV Lithography

Makena Beach & Golf Resort, Maui, Hawaii, USA
June 23-27, 2014

Workshop Agenda

Monday, June 23, 2014

Short Courses

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

8:30 AM -5:00 PM

Tuesday, June 24, 2014

Registration and Reception

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

Wednesday, June 25, 2014

8:30 AM Welcome and Introduction

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

Session 1: Keynote – 1

EUV: The Computational Landscape (P1)

Vivek Singh
Intel Corporation, MS: RA3-254, 2501 N.W. 229th Ave, Hillsboro, OR 97124

One hundred Watt Operation Demonstration of HVM LPP-EUV Source (P2)

Hakaru Mizoguchi, Hiroaki Nakarai, Tamotsu Abe, Takeshi Ohta, Krzysztof M Nowak, Yasufumi Kawasuji, Hiroshi Tanaka, Yukio Watanabe, Tsukasa Hori, Takeshi Kodama, Yutaka Shiraishi, Tatsuya Yanagida, Georg Soumagne, Tsuyoshi Yamada, Taku Yamazaki, Shinji Okazaki and Takashi Saitou
Gigaphoton Inc. Hiratsuka facility: 3-25-1 Shinomiya Hiratsuka Kanagawa, 254-8567, JAPAN

Break

Session 2: EUV Sources

Development of Scalable Laser Technology for EUVL applications (Invited Talk) (P21)

Tomas Mocek, Akira Endo, Taisuke Miura
HiLASE Project, Institute of Physics ASCR, Prague, Czech Republic

Gain Enhancements of CO_2 Laser Amplifiers by Using Transverse-gas-flow Configuration to Boost up Driving Powers for EUV Generation (Invited Talk) (P24)

Koji Yasui[1] and Jun-ichi Nishimae[2]
[1]*Mitsubishi Electric Corporation, Head quarter, Tokyo, Japan*
[2]*Mitsubishi Electric Corporation, Advanced technology R&D center, Hyogo, Japan*

Colliding Laser-Produced Plasmas as Targets for Laser-Generated EUV Sources (P25)

T. Cummins[1], C. O'Gorman[1], P. Dunne[1], E. Sokell[1], G. O'Sullivan[1] and P. Hayden[1,2].
1)*School of Physics, University College Dublin, Belfield, Dublin 4, Ireland.*
2)*National Centre for Plasma Science and Technology, Dublin City University, Glasnevin, Dublin 9, Ireland*

In-Situ Cleaning of Sn EUV Sources (Invited Talk) (P42)

David N. Ruzic, Daniel Elg, Ivan Shchelkanov
Center for Plasma-Material Interactions; Department of Nuclear, Plasma and Radiological Engineering, University of Illinois at Urbana-Champaign, Illinois, USA

EUV Source: Progress & Challenges (Invited Talk) (P27)

Klaus Schuegraf et al
Cymer, San Diego, CA, USA

12:00 PM – 1:00 PM

Lunch

Session 3: Regional Reviews

Korea (Jinho Ahn)
Japan (Hiroo Kinoshita)
Taiwan (TBD)
China (Yanqui Li)
USA (Greg Denbeaux)
Europe (Padraig Dunne)

Break

Session 4: EUV Optics

Progress of Optical Design for EUV Lithography tools in BIT (Invited talk) (P56)

Yanqiu Li, Fei Liu, Qiuli Mei, Zhen Cao, Yan Liu

Key Laboratory of Photoelectron Imaging Technology and System (Ministry of Education of China), School of Optoelectronics, Beijing Institute of Technology, Beijing 10081, P.R. China

CNC Fabrication of High NA Aspheric Optics for EUVL Applications (P53)

Phil Baker, Richard Pultar, Dr. Riley Aumiller
HNu Photonics, LLC, 350Hoohana St, Kahului HI 96732

Error Compensation Phase Extraction Algorithm Used in Phase Shifting Point Diffraction Interferometer (P52)

Jie Yu, Haitao Zhang, Dongmei Ma, Chunshui Jin
State Key Laboratory of Applied Optics, Changchun Institute of Optics, Fine Mechanics & Physics, Chinese Academy of Sciences, No. 3888, Dongnanhu Road, Changchun, Jilin, People's Republic of China

Large Reflectometer for EUV Optics (P55)

Hiroo Kinoshita[1,2], Tetsuo Harada[1,2], Takeo Watanabe[1,2]
1) Center for EUV Lithography, University of Hyogo, Kamigori, Hyogo 678-1205, Japan
2) JST, CREST, Kawaguchi, Saitama 331-0012, Japan

Progress with EUV optics deposition at RIT (Invited Talk) (P56)

Yuriy Platonov, Michael Kriese, Vladimir Martynov, Raymond Crucet, Yang Li, Jim Rodriguez, Licai Jiang, Gary Fournier, Jerry Hummel
Rigaku Innovative Technologies, 1900 Taylor Rd., Auburn Hills, MI 48326, USA

Adjourn: Time off for Networking

End Day 1

Day 2: Thursday, June 26, 2014

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

Session 5: Keynote-2

Current status and expectation of EUV lithography (P3)

Takayuki UCHIYAMA
Lithography Process Development Department, Center for Semiconductor Research and Development, TOSHIBA Corporation

Break

Session 6: EUV Masks

A New EUV Mask Blank Defect Inspection Method with Coherent Diffraction Imaging (Invited Talk) (P63)

Ding Qi[a], Kuen-Yu Tsai[a] and Jia-han Li [b]
[a] *Department of Electrical Engineering, National Taiwan University, Taipei 106, Taiwan*
[b] *Department of Engineering Science and Ocean Engineering, National Taiwan University, Taipei 106, Taiwan*

Recent Results from the Measurement of Reflectivity of EUV Lithography Masks Blanks and Absorbers (Invited Talk) (P64)

Rupert C. C. Perera
EUV Tech, 2840 Howe Road Suite A, Martinez, CA 94553, USA

Improved Stochastic Imaging Properties in Contact Hole Pattern by Using Attenuated PSM for EUVL (P65)

Jung Sik Kim[1], Seongchul Hong[2], Jae Uk Lee[2], Seung Min Lee[2], Jung Hwan Kim[2], Hyun Min Song[1], and Jinho Ahn[1,2]
[1]*Department of Nanoscale Semiconductor Engineering*
[2]*Department of Materials Science and Engineering*
Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 133-791, Korea

Advanced Mask Patterning: Inspection/Metrology and Cleans Requirements & Approaches (P68)

Sushil Padiyar et al
AMAT

Overview of Actinic Mask Inspection System in NewSUBARU (Invited Talk) (P67)

Hiroo Kinoshita[1,3], Tetsuo Harada[1,3], Yutaka Nagata[2,3], Takeo Watanabe[1,3] and Katsumi Midorikawa[2]
(1) *Center for EUV Lithography, University of Hyogo, Kamigori, Hyogo 678-1205, Japan*
(2) *Riken ASI, Wako, Saitama 351-0198, Japan*
(3) *JST, CREST, Kawaguchi, Saitama 331-0012, Japan*

Lunch

Session 7: EUV Resists

Theoretical Study on Stochastic Effects in Chemically Amplified Resist Process for Extreme Ultraviolet Lithography (Invited Talk) (P71)

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

Title TBA (P72)

Patrick Naulleau
LBNL, Berkeley, CA, USA

Novel EUV Resist Materials and EUV Resist Defects (Invited Talk) (P74)

Yoshi Hishiro
JSR Micro INC, 1280 N. Mathilda Ave, Sunnyvale, CA 94089, USA

The Role of Secondary Electrons in EUV Resist (Invited Talk) (P75)

Greg Denbeaux et al
University of Albany, Albany, NY, USA

Optics Contamination from Resist Outgassing: Lessons Learned (Invited Talk) (P41)

C. Tarrio, S. B. Hill, R. F. Berg, S. Grantham, and T. B. Lucatorto
National Institute of Standards and Technology, Gaithersburg, MD, USA

Additional Paper(s) in the EUV Resist session to be announced.

Break

Session 8: Panel Discussion

Topic: Can EUVL deliver patterning solutions for 7nm node?

Moderators

Sushil Padiyar
Applied Materials

Vivek Bakshi
EUV Litho, Inc.

Panelists

Vivek Singh
Intel

Hakaru Mizoguchi
Gigaphoton

Takayuki UCHIYAMA
Toshiba

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

Break

4:30- 5:30 PM Poster Session

Session 9: Poster Session

Modulation of the Langmuir Oscillation on the plasma radiation by Rabi oscillation (P22)

Xiangdong Li
State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Shanghai (201800), People's Republic of China

EUV Radiation Characteristics of Xe Cluster Ensemble Irradiated by Nanosecond and Femtosecond Lasers (P23)

Cheng Wang, Zongxin Zhang, Guande Wang, Yuxin Leng, Quanzhong Zhao, Ruxin Li
State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences (CAS), Shanghai 201800, China

The Energetiq EQ-10 EUV Source for Metrology (P26)

Stephen F. Horne, Matthew J. Partlow, Deborah S. Gustafson, Matthew M. Besen, Donald K. Smith, Paul A. Blackborow
Energetiq Technology Inc., 7 Constitution Way, Woburn MA 01801 USA

A Novel Model for Coated System Analysis in Extreme Ultra-Violet Lithography (P51)

Wang Jun
State Key Laboratory of Applied Optics, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, 3888# Dong Nanhu Road, Changchun, Jilin, 130033, China

Comparison of High Precision Profilometry to Lateral Shearing Interferometry Collected from High NA Aspheric Surfaces with Materials from SIC, Aluminum, ULE and Zerodur (P54)

Richard Pultar, Phil Baker, Dr. Riley Aumiller
HNu Photonics, LLC, 350 Hoohana St, Kahului HI 96732, USA

Simplified Model for Spectrum Simulation of Multilayer with Buried Defect in EUV Lithography (P61)

Xiangzhao Wang, Sikun Li, Xiaolei Liu

Laboratory of Information Optics and Opt-Electronic Technology, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China

Measurement of Deflection of the Full scale Free Standing EUV Pellicle (P62)

Eun-Sang Park, Zahid Hussain Shamsi, Ji-Won Kim, Dai-Gyoung Kim, and Hye-Keun Oh
Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 133-791, Korea

Friday, June 27, 2014

8:30 AM - 10:00 AM

EUVL Workshop Steering Committee Meeting (Kaeo Ballroom)

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

Abstracts

(Listed by Paper number)

P1

EUV: The Computational Landscape

Vivek Singh

Intel Corporation, MS: RA3-254, 2501 N.W. 229th Ave, Hillsboro, OR 97124

Moore's Law will continue to the 7nm technology node and beyond. The path to achieving this, however, is difficult, complex and expensive. While 193nm is still the workhorse on which current technology nodes are being developed, EUV (Extreme Ultraviolet) continues to be a leading option for next generation lithography. One way or another, new patterning technologies are helping to enable scaling to the 7nm technology node. For example, phase shift masks create superior images and are used to make gate patterning more robust. Inverse lithography computation methods enable better utilization of the resolution capability of a lithography tools and masks. Pitch division methods including pitch quartering help allow the use of 193nm lithography for patterning features for multiple technology nodes. Several of these methods can be combined with EUV lithography to further enhance scaling and design rule flexibility. This paper will elucidate the general technology landscape in which leading edge development is occurring, summarize the state of EUV lithography, and focus on computational solutions available for enabling EUV and other advanced lithography technologies.

Presenting Author

Vivek Singh is an Intel Fellow and director of computational lithography in Intel's Technology and Manufacturing Group.

He is responsible for all of Intel's CAD and modeling tool development in full chip OPC, lithography verification, rigorous lithography modeling, next-generation lithography selection, inverse lithography technologies and double patterning. He also represents Intel on several external Design for Manufacturability (DFM) forums, and is currently chairman of the SPIE DFM Conference.

Singh joined Intel in 1993 as a modeling applications engineer, was appointed team leader for the Resist and Applications Group in 1996, and was appointed overall leader of the Lithography Modeling Group in 2000.He holds 13 patents, has published 38 technical papers and won the Intel Achievement Award in 2007.

Singh graduated from the Indian Institute of Technology in Delhi with a bachelor's degree in chemical engineering in 1989. He earned a master's degree in chemical engineering in 1990, a Ph.D. minor in electrical engineering in 1993, and a Ph.D. in chemical engineering in 1993, all from Stanford University.

P2

One Hundred Watt Operation Demonstration of HVM LPP-EUV Source

Hakaru Mizoguchi, Hiroaki Nakarai, Tamotsu Abe, Takeshi Ohta,
Krzysztof M Nowak, Yasufumi Kawasuji, Hiroshi Tanaka, Yukio Watanabe,
Tsukasa Hori, Takeshi Kodama, Yutaka Shiraishi, Tatsuya Yanagida,
Georg Soumagne, Tsuyoshi Yamada, Taku Yamazaki, Shinji Okazaki and
Takashi Saitou

Gigaphoton Inc. Hiratsuka facility: 3-25-1 Shinomiya Hiratsuka Kanagawa,254-8567, JAPAN

We have been developing CO_2-Sn-LPP EUV light source which is the most promising solution as the 13.5 nm high power light source for HVM EUVL. Unique and original technologies such as combination of pulsed CO_2 laser and Sn droplets, dual wavelength laser pulses shooting and mitigation with magnetic field have been developed in Gigaphoton Inc. The theoretical and experimental data have clearly showed the advantage of our proposed strategy. Based on these data we are developing first practical source for HVM; "GL200E". This data means 250 W EUV power will be realized with around 20 kW level pulsed CO_2 laser. We have reported engineering data from our resent test such around 43 W average clean power, CE=2.0%, with 100 kHz operation and other data 1).

We have already finished preparation of higher average power CO_2 laser with more than 12 kW at plasma point, in cooperation with Mitsubishi electric cooperation2). Further improvements are underway and we will report the latest challenge to more than one hundred watt stable operation, with around 4% CE with 20 micron droplet and magnetic mitigation.

Reference

1) Hakaru Mizoguchi, et. Al, Sub-hundred Watt operation demonstration of HVM LPP-EUV source, Proc. SPIE 9048, (2014) [9048-12]
2) Yoichi Tanino et.al. A Driver CO2 Laser Using Transverse-flow CO2 Laser Amplifiers, EUV Symposium 2013, Oct.6-10.2013, Toyama

Presenting Author

Hakaru Mizoguchi is Executive Vice President and CTO of Gigaphoton Inc.

He is a member of The International Society of Optical Engineering, The Laser Society of Japan and The Japan Society of Applied Physics. He received a diplomat degree in plasma diagnostics field from the Kyushu university, Fukuoka, Japan in 1982 and join Komatsu Ltd. He joined CO_2 laser development program in Komatsu for 6 years. After that he was guest scientist of Max-Plank Institute Bio-Physikalish-Chemie in Goettingen in Germany 2 years, from 1988 to 1990. Since 1990 he concentrated on KrF, ArF excimer laser and F_2 laser research and development for lithography application. He was general manager of research division in Komatsu Ltd. until 1999. He got PhD degree in high power excimer laser field from Kyushu university in 1994. In 2000 Gigaphoton Inc. was founded. He was one of the founders of Gigaphoton Inc. From 2002 to 2010 he organized EUV research group in EUVA program. Now he is promoting EUV light source product development under his present position.

P3

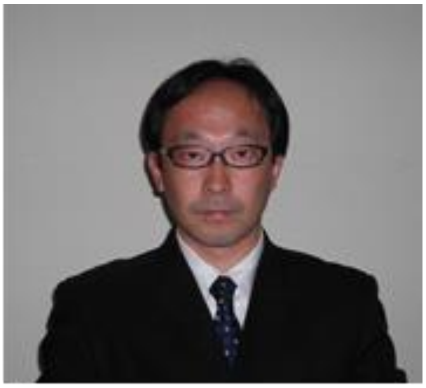
Current Status and Expectation of EUV lithography

Takayuki UCHIYAMA

Lithography Process Development Department,
Center for Semiconductor Research and Development
TOSHIBA Corporation

EUV lithography is still one of the strongest candidates of the next generation lithography. The NA of ArF immersion lithography has reached its maximum value. To keep the device scaling, the multiple patterning with ArF immersion lithography is applied for production. The multiple patterning requires complicated process control and many process steps which include CVD, etch and other processes, unavoidably. LELE (Litho-Etch-Litho-Etch) needs high accurate overlay. SAMP (Self-aligned multiple patterning) requires cut mask with small pattern and tight overlay. EUV lithography is the traditional projection exposure method and has a high resolution which can provide very simple process. But due to its very short wavelength, EUV lithography has many difficult technical challenges that must be overcome. Furthermore, cost of ownership and the timing are very important for implementation to mass production. In this paper, the current status of EUV lithography is mentioned, including the expectation of higher NA EUV lithography for sub-10nm patterning.

Presenting Author



Takayuki UCHIYAMA is the Chief Specialist of Lithography Process Technology Department, Center For Semiconductor Research & Development, TOSHIBA Corporation. He joined TOSHIBA Corporation in 2012 and has been involved in the research and development of the next generation lithography. He has 25 years of experience in lithography process development.

He received his B.E. and M.E. degrees in mechanical engineering from Tohoku University in 1987 and 1989, respectively. After graduation, he joined NEC Corporation, where his experience includes the production engineering of lithography process and the development of KrF, ArF and ArF immersion lithography. He has published numerous technical journal papers.

P21

Development of Scalable Laser Technology for EUVL applications

Tomas Mocek, Akira Endo, Taisuke Miura

HiLASE Project, Institute of Physics ASCR, Prague, Czech Republic

The main goal of HiLASE project (High average power pulsed LASErs, www.hilase.cz) is to create a solid platform for development of advanced fully diode-pumped solid state lasers (DPSSL) in the Czech Republic. Two key concepts are being explored within HiLASE: thin-disk laser amplifiers to reach kW average output power, and cryogenically cooled multi-slab laser amplifiers to reach 100 J at 10 Hz output scalable to kJ regime. Regarding EUVL applications, there are three separate thin-disk Beamlines under construction with different output parameters: Beamline A (750 mJ, 1.75 kHz, 3 ps), Beamline B (500 mJ, 1 kHz, 2 ps), and Beamline C (5 mJ, 100 kHz, 1 ps). The compact, high-repetition rate Beamline C is optimized for the prepulse irradiation of droplet trains in a HVM source, and a high brightness source by micro plasma generation. The high-energy Beamline B is devoted to pilot investigation of BEUV sources. These advanced DPSSL systems will be installed and commissioned in the HiLASE center by August 2015, and shall be at disposal of external users for testing and prototyping of various laser technologies and applications, especially for contract research and development.

Presenting Author

Tomas Mocek, Ph.D. (born 1970) received the master's degree in Physical Electronics from the Czech Technical University, Prague, Czech Republic, in 1994, and the Ph.D. degree in Physics from the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea, in 2000. He is currently Chief Scientist and Project Manager of the HiLASE project at the Institute of Physics, Academy of Sciences of the Czech Republic. He has focused his research on optical-field-ionization, X-ray lasers, X-ray generation from laser produced plasma, high-order harmonic generation, and development of high-average power diode-pumped solid state lasers. He published 87 papers in SCI journals with impact factor, 1297 citations, h-index 18.

P22

Modulation of the Langmuir Oscillation on the plasma radiation by Rabi oscillation

Xiangdong Li

State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Shanghai (201800), People's Republic of China

The Langmuir oscillation can be excited in the laser-plasma interaction. The experiments of the electron acceleration through laser plasma wake field show that the extremely high energy electrons of up to GeV can be produced. This implies that an ultra-high oscillation electronic filed exists in the plasma during the laser plasma interaction. This time-dependent high electronic field will inevitably affects the plasma radiations. AC Stark effect, which has been studied for a long time, is one way to vary the energy level structures. However, in this work a different mechanics is considered. The modulation of the Langmuir wave on the energy level population by Rabi oscillation is included in the plasma spectral simulation. The results reveal an optional nature for the Rabi oscillation in adjusting the energy level population. The effect of Rabi oscillation on line intensity by redistributing the level population seriously depend on the energy level structure, the intensity of the Langmuir electronic field and the transition matrix between levels. For some energy levels the exits of Rabi oscillation will significantly change their radiation intensity. This will be important in understanding the formation of the fine spectra from the laser-induced plasma.

References

[1] Marlan O Scully, M. Suhail Zubairy, "Quantum Optics", Cambridge University Press, 1997.
[2] D. Riley and O. Willi, Phys. Rev. Lett. 75, 4039(1995).
[3] X Li, F B Rosmej, EPL 99, 33001(2012).
[4] X Li, F B Rosmej, Phys. Rev. A 82, 022503 (2010).

Presenting Author

P23

EUV Radiation Characteristics of Xe Cluster Ensemble Irradiated by Nanosecond and Femtosecond Lasers

Cheng Wang, Zongxin Zhang, Guande Wang, Yuxin Leng, Quanzhong Zhao,
Ruxin Li

State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences (CAS), Shanghai 201800, China

Laser Produced Plasma (LPP) based EUV sources are one of the leading sources of EUV light for the application in EUV lithography (EUVL). Due to the enhanced absorption of laser energy by clusters, a high EUV conversion efficiency maybe obtained in laser cluster interaction. Xe cluster ensembles are used as target for LPP based EUV light source research in the Shanghai Institute of Optics and Fine Mechanics. In the experiments, three kinds of laser pulses are used, which include a 50 ns 80 mJ/pulse TEA CO_2 laser, a 10 ns 200 mJ/pulse Nd-YAG laser and a 30 fs 7 mJ/pulse Ti:sapphire laser. The EUV light is measured when Xe clusters are irradiated by the various laser pulses and their combinations and the measurements are compared. The experimental results will be presented in the conference.

Presenting Author

Dr. Cheng Wang, received Ph.D in plasma physics from the University of Science and Technology of China in 2000. After that he moved to the Shanghai Institute of Optics and Fine Mechanics (SIOM) as a post-doc. Since 2003 he has joined the State Key Laboratory of High Field Laser Physics in SIOM. His research interests are laser target interaction, laser accelerator, LPP-EUV source, and plasma diagnostic technology.

P24

Gain Enhancements of CO_2 Laser Amplifiers by Using Transverse-gas-flow Configuration to Boost up Driving Powers for EUV Generation

Koji Yasui[1] and Jun-ichi Nishimae[2]

[1]Mitsubishi Electric Corporation, Head quarter, Tokyo, Japan
[2]Mitsubishi Electric Corporation, Advanced technology R&D center, Hyogo, Japan

To generate high-power extreme ultraviolet (EUV) beams, enhancements of driving laser powers are required. As for driving lasers, commercially available CO_2 lasers for material processing applications are the best candidates. In this paper, we describe gain enhancements of CO_2 laser amplifiers to generate tens-kW laser powers as laser systems by using transverse-gas-flow configuration for CO_2 lasers. Transverse-gas-flow CO_2 lasers have several advantages to generate high quality beams for high quality cutting applications and they have another advantages when used as EUV generation drivers. Tens of percentage of gain enhancements can be achieved to ensure higher powers yet with more compact and simpler designs compared with other configurations. To demonstrate the performances, we constructed a system consisted of one oscillator and four transverse-gas-flow CO_2 laser amplifiers. Each amplifier added laser power by several kW with the discharge power of 100 kW and final fourth amplifier added 8 kW to generate 21 kW laser power in total. Further output should be available by adding further amplifiers. The pulse width of the seed two-line laser was 15 ns and the final pulse width was 23 ns.

The first stage amplifier has been under operation at Gigaphoton's EUV test facility. We are going to report the latest results in the presentation.

Presenting Author

Koji Yasui received B.S. and Ph. D. degrees from the University of Tokyo in 1982 and 1989 respectively. He was a visiting scientist at the Stanford University in 1989. He joined Mitsubishi Electric Corporation in 1982, where he has developed high-power CO_2 lasers, high-power solid-state lasers, high-power green lasers, high-power UV lasers and laser processing machines using those laser sources. He is now in charge of laser technology, EDM technology, CNC technology and e-beam technology and related businesses.

P25

Colliding Laser-Produced Plasmas as Targets for Laser-Generated EUV Sources

T. Cummins[1], C. O'Gorman[1], P. Dunne[1], E. Sokell[1], G. O'Sullivan[1] and P. Hayden[1,2].

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For the past decade the main challenge and potential show stopper to be overcome in source development for extreme ultraviolet lithography (EUVL) has been the attainment of the in-band power required at 13.5 nm. One critical factor in increasing the conversion efficiency of EUV sources is the efficiency with which laser energy is coupled into the target. Colliding plasmas produced by Nd:YAG illumination of tin wedge targets form stagnation layers, the physical parameters of which can be controlled to optimize coupling with a CO_2 heating pulse and subsequent extreme ultraviolet radiation transport. The conversion efficiency (CE) of laser energy into EUV emission at 13.5 nm ± 1% was 3.6% for illumination by both lasers but this increased to 5.1% when the Nd:YAG contribution was removed. Allowance for the CO2 overfilling the interaction region increases this value to ~ 7%. Thus, with careful control of target plasma parameters and laser beam profile, a CE greater than 7% should be obtained.

Presenting Author

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

P26

The Energetiq EQ-10 EUV Source for Metrology

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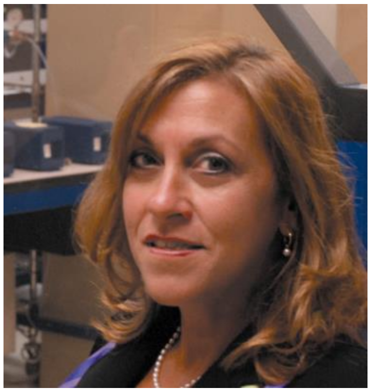
Mask infrastructure is second only to scanner source power as a gating factor for high-throughput EUV lithography. Actinic inspection of mask blanks, and aerial image analysis of patterned masks, are key near-term metrology challenges.

The Energetiq EQ-10 EUV source is in use today in several metrology and resist evaluation tools. Key parameters are brightness, stability (spatial and temporal), and etendue, and all of these are evolving from the initial specifications. In general, brightness requirements are being relaxed, while stability requirements are becoming more demanding. We will comment on the impact of these developments, and describe the specific algorithms used to calculate spatial stability and brightness for the Energetiq source.

The EQ-10 has applications at shorter wavelength as well. We will present data on operation at 6.7 nm (for advanced EUV R&D) and at 2.88 nm, where the source is in current use as a synchrotron replacement for water window microscopy.

Presenting Author



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

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

P41

Optics Contamination from Resist Outgassing: Lessons Learned

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Initially, EUV mirrors were degraded both by oxidation from EUV-activated adsorbed water and carbon deposition generated from EUV-cracked adsorbed hydrocarbons. The oxidation problem was more or less solved early on by the development of oxidation resistant capping layers thus turning industry focus entirely to the problem of carbonization. Attempts to model carbon deposition in the long term based on the results of short term experiments at elevated partial pressures of hydrocarbons proved extremely difficult for two reasons: (a) the adsorption of molecules on the surface was discovered to be coverage dependent, with little known about this dependence over the range of partial pressures to be expected in the tool; and (b) the mitigating effect of the residual water vapor could not be easily extrapolated from the laboratory conditions to the production environment. Instead, an approach to provide for continuous mitigation and periodic cleaning cycles was developed and limits were placed on the amount of organics that could be introduced into the tool from the outgassing of the resist. These limits were set by a well-defined "resist outgas witness sample test" now being performed at several sites worldwide. We will describe the present state of outgas testing, its limitations and potential pitfalls in this historical context.

Presenting Author

P42

In-Situ Cleaning of Sn in EUV Sources

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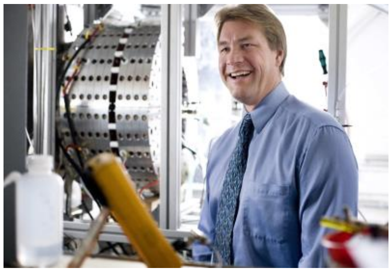
Extreme Ultraviolet (EUV) lithography sources use a highly-ionized Sn plasma to produce 13.5 nm light. This plasma expels high-energy Sn ions and neutrals. These ions and neutrals degrade the reflectivity of the collector optic used to collect the EUV light. Even only a few nm of Sn can significantly reduce EUV reflectivity and necessitate collector cleaning or replacement, causing significant machine downtime. An in-situ plasma-based collector cleaning method is in development to reduce downtime. This method uses hydrogen radicals to etch Sn and creates the radicals at the collector surface. Previous results have shown Sn removal rates on the order of 1nm/min on a 300 mm dummy collector using 300 W of capacitively-coupled RF power and 500 sccm H_2 flow at 130 mTorr. SIMS results indicate no change in structure or composition of multilayer mirror sample surfaces. New measurements of EUV reflectivity indicate no significant drop in multilayer mirror reflectivity caused by the etching process. Additionally, construction and testing are being performed on a system to clean a 650 mm dummy collector, equivalent in size to current industry collector optics. A successful cleaning system on this collector could be directly applicable to current industry EUV sources.

Presenting Author



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

P51

A Novel Model for Coated System Analysis in Extreme Ultra-Violet Lithography

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The Extreme Ultraviolet (EUV) light will not totally penetrate the substrate of the highly reflective Mo/Si multilayer coated mirrors. So, there will be dozens of exposure waves from reflective surfaces between the optical design and actual exposure. This paper theoretically raised a novel model for coated system analysis based on the energy conservation principle. In terms of energy transfer function, each multilayer coated mirror in a system is transferred into an individual single reflective surface. They are regarded as equivalent work surfaces (EWS) at which the EUV is reflected backwards geometrically, in the optical design software. In practice, a new high NA EUV projection with different coating solutions was compared side-by-side by aids of the EWS model and the optimal solution was picked up. Then the optimally coated EUV projection optics system was exposed under EUV, DUV and visible light for different applications. The results indicate that a well assembly coated system under visible light or DUV works well under EUV exposure, only through a simple shift of image plane.

Presenting Author

Wang Jun is a doctoral candidate in optics from State Key Laboratory of Applied Optics (SKLAO), Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP), Chinese Academy of Sciences (CAS), China. His main research interests are EUV lithography and optical design. He is a student of Prof. Jin Chun-shui who has been working on short-wavelength optics for about 30 years, especially on thin films, EUV optics, optical testing and integration.

P52

Error Compensation Phase Extraction Algorithm Used in Phase Shifting Point Diffraction Interferometer

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Phase-shifting point diffraction interferometer is influenced by various errors, resulting in the reduction of the precision of the measurements. Some of these errors can be eliminated by phase extraction algorithm. An error compensation phase extraction algorithm designed by the author is compared with some universal phase extraction algorithms. The simulation results illuminate that the present algorithm is much more insensitive to PZT linearity and nonlinearity of the second order, intensity fluctuation linearity and nonlinearity of the 2nd order and the frequency of light source fluctuation than the other two algorithms. The results also illuminate that the 13-step algorithm have the advantage over other universal algorithms in eliminating the phase-shifting noise, intensity noise, frequency noise, vibration, temperature change, humidity change and pressure change.

We have developed a point diffraction with phase-shifting technique to measure optical surface figure. A spherical concave mirror was tested with this interferometer. The error compensation phase extraction algorithm was applied during measurement. The measurement repeatability comes out better than 0.1 nm RMS and validates the simulation well.

Presenting Author

Yu Jie received his BS in Electronic Science and Technology and MS in optical engineering at Beijing Institute of Technology in 2007 and 2009 respectively. In the same year he joined the State Key Laboratory of Applied Optics at Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP), Chinese Academy of Sciences (CAS) and is working in the field of optical metrology.

Zhang Hai-tao received his BS in instrument science and technology at Shandong University and MS in instrument science and technology at Beijing Institute of Technology in 2007 and 2009 respectively. In the same year he joined the State Key Laboratory of Applied Optics at Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP), Chinese Academy of Sciences (CAS) and is working in the field of optical instrument researcher and development.

Ma Dong-mei received her BS in Optical Instruments and MS in Optical Metrology and Testing at Tianjin University in 1986 and 1993 respectively. She received her PhD at Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP), Chinese Academy of Sciences (CAS) in 2007. She is working in the field of Optical testing for about 30 years, and has received several state awards.

Jin Chun-shui is working on short-wavelength optics for about 30 years, especially on thin films, EUV optics, optical testing and integration. The EUV multilayer technology has always being taking as the research core and the 69% reflectivity has been achieved. This promoted the related EUV applied researches and especially a small field EUV exposure system is being developed. As one of the chief scientists for EUVL projection of China, he leads a young but potential and energetic group in China. In recent years, he has published more than 60 papers, including 3 that are included by SCI with RF>2.0 and more than 30 by EI. He has more than 20 patents applications pending and has been granted four patents.

P53

CNC Fabrication of High NA Aspheric Optics for EUVL Applications

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High NA EUV optics are required for achieving the extreme resolutions that are achievable using the latest EUV light sources. As the NA of aspheric optics is increased, the departure from sphere is also increased, resulting in manufacturing challenges. To manufacture these optics, the aspheric profile is first ground into the surface using fixed abrasive diamond tooling. The profile is then polished to the desired final surface figure using CNC polishing. During the grinding process the shape and position of the tool must be precisely known and accounted for. This paper will describe the effects of tool position and tool shape error during the fabrication process of both rotationally symmetric and free form off-axis segments. Sag differences between theoretical and as-ground surfaces will be simulated along with corresponding Ronchi-grams. A method of tool characterization will also be presented, along with techniques used to compensate for the measured errors in the fabrication tools. These techniques are appropriate for materials such as Silicon Carbide, Zerodur, and ULE, where fixed abrasive grinding tools are used.

Presenting Author

P54

Comparison of High Precision Profilometry to Lateral Shearing Interferometry Collected from High NA Aspheric Surfaces with Materials from SIC, Aluminum, ULE and Zerodur

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Manufacturing processes to produce high numerical aperture aspheric optics have always been dependent on the use of specialized surface measurement techniques. These techniques can produce high-precision wavefront analysis to provide requisite surface figure control to validate functionality and performance. In this paper we provide data that present the interfacing of these different approaches to produce usable and interpretable information to guide computer controlled precision grinding and final ductile finishing of both free form and centric forms of aspheric surface.

Both contact profilometry and rough surface grating interferometry are demonstrated. Interpretation and analysis of the surface topography is presented. The importance of having in-situ measurements to guide surface removal functions is discussed.

Presenting Author

P55

Large Reflectometer for EUV Optics

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This paper will describe the large reflectometer which can measure the reflectivity of optics over 800 mm in diameter has set in NewSUBARU BL-10. This system consists of θ—2θ, Y, Z, R (rotation of 360 degree) and tilt stages. Measuring position is aligned by Y, Z, R stage set on the θ stage, the maximum reflectivity of the desired position is determined by the tilt and 2θ stages. This system will be useful for measurement of condenser optics of source and masks.

Presenting Author

Hiroo Kinoshita received Bachelor and Master of engineering degree in Mechanical Engineering from KEIO University in 1972 and 1974, 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.

P56

Progress of Optical Design for EUV Lithography tools in BIT

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Extreme ultraviolet lithography (EUVL) is assigned for chip fabrication at 11 nm node. At 11 nm node, the numerical aperture (NA) of imaging optics should be larger than 0.45. Although eight-mirror imaging system without obscuration could correct the aberration arising from high NA and achieve required imaging performance, the transmission would reduce to 40% of a six-mirror imaging system and the integration or maintenance of the tool would be more difficult. So that six-mirrors imaging system is still expected at 11 nm node in order to reduce the source power requirements and difficulty of system integration. However the optical design of high NA exposure system is very difficult. We present progress of optical design of higher NA imaging optics for EUVL in BIT. Both on- and off-axis imaging systems with high NA (0.5 and 0.55) are designed using grouping and tilting method to meet the requirement of EUVL. Illumination systems are also designed to match the different imaging optics. Some key issues about design and control of obscuration are discussed in detail.

Acknowledgement: This work is supported by National Science and Technology Major Project.

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Presenting Author

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

P57

Progress with EUV Optics Deposition at RIT

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New deposition system for coating a large EUV mirrors was installed at RIT this year. The system has two deposition chambers capable to coat optics of up to 750 mm in diameter. One of the chambers is dedicated for coating Mo/Si multilayers with buffer and barrier layers. Another chamber has a reactive sputtering capability for coating a capping layer. Parameters and characteristics of the new deposition tool will be discussed. Also, a new etch/cleaning station has been installed for stripping damaged EUV multilayer coatings and preparing substrates for the optics refurbishment. Some experimental results with the new station will be presented.

Presenting Author

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

P61

Simplified Model for Spectrum Simulation of Multilayer with Buried Defect in EUV Lithography

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A simplified model is developed for spectrum simulation of multilayer with buried defect in EUV lithography. In the model, the defect is treated as phase perturbation and amplitude attenuation of reflection coefficient, while the multilayer is approximated as a mirror. The phase perturbation depends on the surface defect size of defective multilayer and the amplitude attenuation depends on the substrate defect size. This simplified model gives a method for the spectrum simulation of multilayer with buried defect that is as fast as the advanced single surface approximation model while more accurate. The amplitude errors of multilayer spectrum decrease more than 50% in 6º incidence angle. The errors are also with little fluctuation in different incidence angles, especially smaller than 12º. In addition, an analytical expression of diffraction spectrum of defective multilayer is given, which is beneficial to the understanding and the analysis the effects of defect to multilayer spectrum and provides the basis for repair of the defective mask.

Presenting Author

Xiangzhao Wang received his BE degree in electric engineering from Dalian University of Technology, China, in 1982, and his ME and Dr Eng degrees in electric engineering from Niigata University, Japan, in 1992 and 1995, respectively. Now he is a professor at the Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences. His research interests include lithography imaging theory and technology, information optoelectronics.

P62

Measurement of Deflection of the Full scale Free Standing EUV Pellicle

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A defect on the extreme ultra-violet (EUV) mask can become a serious problem and can worsen the image quality. Therefore, the pellicle is necessary to prevent the printing of defects and to increase the yield. The thickness of the pellicle should be nanometer thin because of the strong absorption of the EUV light. The deflection due to gravity of this nanometer-thick pellicle was previously thought to be very large. Thus, people thought to add the mesh support to the thin membrane pellicle in order to avoid large deflection. However, the mesh support might cause serious non-uniform intensity distribution on the top of the mask and hence on the wafer. This would cause local critical dimension uniformity variation. Therefore, if possible, the free-standing pellicle is preferred. We revisited the possible large deflection of the thin membrane, and found that the non-linear deflection term was added to the deflection equation if the deflection at the center is large compared to the thickness of plate. The Newton-Raphson Method is used for the large deflection equation and compared to the solution of the Finite Element Method. It turned out that the deflection of the thin free-standing full scale pellicle was less than the desired specification. Our result shows that a mesh grid support to prevent the deflection is not necessary for the EUV pellicle.

Presenting Author

P63

A New EUV Mask Blank Defect Inspection Method with Coherent Diffraction Imaging

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Mask blank defectivity is a crucial issue in bring EUV lithography to high-volume manufacturing. Currently a diffractive EUV mask defect inspection system is being constructed at NSRRC in Taiwan. It is based on X-ray diffraction microscopy with a synchrotron light source wavelength of 13.5 nm. The actinic inspection ensures deep wave penetration into multilayer stacks. Such kind of lens less systems are aberration free and thus the resolution is diffraction limited. Since the pupil images contain only intensity information of the diffraction signals, an iterative phase retrieval process is usually required to achieve coherent diffraction imaging. Most algorithms developed up to date remain too computational intensive for full-mask inspection. A new inspection method which significantly reduces the computation complexity will be proposed and discussed. Preliminary simulation results indicate that good robustness of this method can be achievable even with the presence of some type of system noise.

Presenting Author

Kuen-Yu Tsai (Kenneth), PhD is an Associate Professor in the Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan.

Dr. Tsai's main research themes are the design and application of advanced control, simulation, signal processing, and optimization techniques to solve nanolithography and nanotechnology related problems, especially for the design and fabrication of cutting-edge nanoscale integrated circuits currently targeting at the ITRS 10 nm half-pitch node and beyond. He is also interested in the research on control system design automation, biomedical equipment design, and consumer electronics such as audio-visual systems.

P64

Recent Results from the Measurement of Reflectivity of EUV Lithography Masks Blanks and Absorbers

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The optical system of a EUV Lithography tool is entirely comprised of reflective elements. Most of these are near-normal incidence mirrors are coated with molybdenum-silicon multi-layers reflecting at a wavelength around 13.5 nm. Measurement of the reflectivity of these components at this wavelength is thus a crucial aspect of the development of a viable EUV tool. In particular, knowledge of the reflectivity of the masks is essential.

One of the principal challenges in the ongoing EUVL research effort is the development of necessary at-wavelength metrology tools. EUV Technology has developed a recipe driven automated Reflectometer for the measurement of reflectivity and uniformity of multilayer coatings for EUV lithography mask blanks, without removal from the clean environment. By translating the mask blank using a high precision, clean x-y stage, measurements can be made at any point on its surface. A multilayer reflectivity curve is obtained in about 20 seconds. The instrument achieves a peak reflectivity precision better than 0.1% (1 sigma), and a centroid wavelength precision (1 sigma) of 0.0004 nm, figures which compare very favorably with results obtained at synchrotron radiation facilities. In this paper we present data from numerous mask blank samples, absorbers and masks, along with our new design of a Reflectometer to achieve the HVM requirements.

Presenting Author

P65

Improved Stochastic Imaging Properties in Contact Hole Pattern by Using Attenuated PSM for EUVL

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In extreme ultraviolet lithography, photon shot noise effect (PSN effect) has become a fundamental issue which leads to degradation of stochastic imaging performance. In this study, we used the lithography simulation tool PROLITH X4 (KLA-Tencor) that can perform stochastic resist patterning simulation including PSN effect to quantify stochastic imaging characteristics such as CD uniformity and contact edge roughness in contact hole (C/H) pattern. Since the diffraction of light in C/H pattern is different from that in line and space (L/S) pattern, the stochastic imaging properties will be affected differently.

We suggest an attenuated phase shift mask (PSM) in order to improve defocusing and stochastic imaging properties in C/H pattern, especially at smaller feature size. This mask stack has a reflectivity of ~6% at the dark region and a phase shift of 180° at 13.5nm wavelength. We will compare PSM with conventional binary intensity mask, proving the improved stochastic imaging characteristics by reducing PSN effect.

Presenting Author

P67

Overview of Actinic Mask Inspection System in NewSUBARU

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EUV coherent scatterometry microscopy (CSM) systems has been developed. The CSM system employs a high-order harmonic generation (HHG) 13.5 nm coherent source to detect pattern defects and measure the CD of patterns. The resolution of pattern defects and repeatability of CD measurement are 20 nm and 0.1 nm, respectively.

To achieve these purposes, it was necessary to return to the basic principles of optics and develop a new inspection method, rather than relying on conventional optics, such as those of a microscope. The system consists of a coherent EUV light source, EUV mask, an X-ray CCD camera, and a computer system. The procedure for detecting defects is as follows:

1) Irradiate EUVL mask pattern with coherent light.
2) Record the intensity distribution of the diffracted light with the CCD camera.
3) Reconstruct an image of the absorber pattern using a computer algorithm that employs an iterative inverse Fourier transform for phase retrieval.

In collaboration with RIKEN, an HHG light source for EUV (λ = 13.5 nm) that employs a femtosecond laser was developed. An output power of 1 μW and a divergence of 0.17 mrad were achieved. This divergence is the best yet reported for a commercial laser source. This source makes the inspection time 1000 times shorter than that for an SR light source. In addition, the width of the absorber pattern can be estimated from the intensity of the light diffracted by a periodic absorber pattern, and it can be measured as the focal pattern width on a wafer. The results of CD measurement by CSM in 22-nm-node line-and-space patterns compared with those in the case of CD-SEM. A good correlation between the results of CSM and CD-SEM was obtained. Furthermore, an excellent repeatability of 0.13 nm (3σ) for the CD measurement of line-and-space patterns was obtained. This value satisfies the ITRS requirement of a repeatability of less than 0.65 nm (3σ).

Using HHG light, hole pattern, missing pattern and bridge defects were detected. Furthermore, using focused 13.5 nm coherent source, phase defects of less than 30 nm were detected. We will present the overview of actinic mask inspection system in NewSUBARU.

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.

P68

Advanced Patterning: Inspection/Metrology and Cleans Requirements & Approaches

Sushil Padiyar

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With 193i lithography single exposures limited to 38-40nm HP at 1.35NA and EUV high productivity platforms delayed, multiple patterning has taken over as the preferred technique for critical lithography scaling. Multiple patterning however, brings its own cost as well as process control challenges in terms of optimal process integration, design co-optimization and fast yield ramp requirements. On the EUV challenges side, higher source power and multi-layer mask defect requirements as a function of shrinking nodes continue to impact HVM introduction. This paper will highlight the results of the work being done within the process control segments for low 1xnm HP patterns using bright field inspection techniques and programmed defects. Programmed defects with specified size, shape and coordinates were printed using the EUV scanner at IMEC and on dense patterned layouts. Additionally, concepts and work on EUV mask cleans to remove particles, contamination and thus retain reflectivity post mask cleans (in the absence of a pellicle) and minimize CD variations post-cleans is also presented.

Presenting Author

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

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

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

P71

Theoretical Study on Stochastic Effects in Chemically Amplified Resist Process for Extreme Ultraviolet Lithography

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For the high resolution lithography using highly sensitive resists, the stochastic effects such as line edge roughness (LER) and stochastic defect generation is a serious concern. In this study, the formation of line-and-space patterns was simulated using a Monte Carlo method on the basis of the sensitization mechanisms of extreme ultraviolet resists to investigate the stochastic effects in chemically amplified resist processes of extreme ultraviolet (EUV) lithography. It was found that the probability for the defect generation rapidly increases with the reduction of feature sizes. The suppression of stochastic defect generation is an urgent task for the realization of high volume production of semiconductor devices with 11 nm critical dimension. The effects of material factors on stochastic effects are discussed from the viewpoint of the suppression of stochastic effects.

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Novel EUV Resist Materials and EUV Resist Defects

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The key challenge for EUV resist is simultaneous achievement of low line edge roughness (LER), high sensitivity, and ultrahigh resolution for lines and spaces features. The relationship between LER, Tg and acid diffusion length was studied. Resist LER and Z-factor change linearly on polymer Tg. Better LER and Z-factor were obtained with higher Tg polymer, thus in shorter acid diffusion length system. EUV resist absorbance should be increased to achieve high resist sensitivity. Incorporating fluorine atom into polymer is one of the most attractive ways to improve absorbance of EUV resist because the fluorine atom absorbs EUV light strongly. However, resist hydrophobicity (or contact angle (CA)) also increases when fluorine atoms exist in the resist polymer. It is difficult to rinse off water completely from high CA resist surface in the development process. So the fluorine atoms in resist will induce additional defects associated with water. The resolution often is limited by pattern collapse for high contact angle EUV resist. Incorporating fluorine into resist to improve sensitivity has negative impact on defectivity and resolution. Material was developed to reduce pattern collapse so that resolution was improved. The same material that improved resolution reduced also defects caused by high contact angle (CA). With all novel materials developed, resists demonstrated high lithographic performance as well as good defectivity.

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Yoshi Hishiro is Director of Research, JSR Micro Inc. He is responsible for Lithography research including advanced patterning like EUV and DSA as well as CMP research. He is responsible for joint development programs and joint research programs of lithography and CMP. He holds various patents in the US and Japan. Before JSR, he worked for Sumitomo Chemical as product manager for electronic materials then Micron Technology as Advanced lithography group supervisor. He was engaged in various advanced patterning projects and responsible for materials development at Micron such as 95nm KrF lithography development with initial SMO, KrF double patterning development, ArF lithography introduction, ArF advanced patterning with SMO, ArF double patterning development, new litho materials introduction into patterning integration, and initial ArF immersion lithography development. He has been in the semiconductor industry for more than 20 years.

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