

# **International Workshop on EUV Lithography 2017**

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# **2017 International Workshop on EUV Lithography**

**(2017 EUVL Workshop)**

*CXRO, LBNL, Berkeley, CA, USA  
June 12-15, 2017*

**Workshop Proceedings**

**Wednesday, June 14, 2017**

**8:00 AM Welcome and Introduction**

**[Welcome to LBL \(Historical Perspective on EUVL\) \(P0\) .....4](#)**

*Glen Kubiak, LBL*

Welcome to 2017 EUVL Workshop

*Vivek Bakshi*

*EUV Litho, Inc., Austin, TX, USA*

Introductions and Announcements (Intro-1) .....N/A

*Patrick Naulleau, LBL*

**Session 1: Keynote – 1**

*Session Chair: Anthony Yen (ASML)*

**[EUVL: Current Status & Remaining Challenges \(P1\) \(Keynote Presentation\) .....6](#)**

*Obert R Wood II*

*GLOBALFOUNDRIES, 400 Stone Break Road Extension, Malta, New York 12020, U.S.A.*

**[EUV Lithography for HVM \(P3\) \(Keynote Presentation\) .....9](#)**

*Britt Turkot*

*Intel Corporation*

**Break (20 minutes)**

**Session 2: EUV Masks and Mask Metrology**

Session Co-chairs: Jim Wiley (ASML) and Bryan Kasprowicz (Photronics)

**EUV Mask Economics: Impact of Mask Costs on Patterning Strategy (P33) .....27 (Invited Paper)**

Bryan S. Kasprowicz<sup>1</sup> and Michael Lercel<sup>2</sup>

<sup>1</sup>Photronics, Inc.

<sup>2</sup>ASML, Inc.

**Reduction of Large Killer Defects in EUV Mask Blanks (P39) (Invited Paper) .....33**

Adrian Devasahayam, Alan V. Hayes, Boris Druz, Sandeep Kohli, Rustam Yevtukhov, Veeco Instruments Inc (United States)

**NewSUBARU EUVL R&D Activities and EUV Mask Defect Inspection (P34) (Invited Paper) .....28**

Takeo Watanabe and Tetsuo Harada

Center for EUVL, Laboratory of Advanced Science and Technology for Industry, University of Hyogo

**Anamorphic Imaging: Emulating Future Nodes of EUV Lithography on the SHARP Microscope (P38) .....32**

Markus Benk, Weilun Chao, Ryan Miyakawa, Kenneth Goldberg, Patrick Naulleau  
Lawrence Berkeley National Laboratory, Center for X-ray Optics, 1 Cyclotron Road, Berkeley, California, United States, 94720

**Characterization of SiN-based membrane for EUV pellicle application (P60) .....N/A**

Jinho Ahn

Division of Materials Science and Engineering

Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 04763, Republic of Korea

**RESCAN - A Standalone Tool for EUV Mask Defect Inspection (P32) .....26**

Patrick Helfenstein<sup>a</sup>, Iacopo Mochi<sup>a</sup>, Rajeev Rajendran<sup>a</sup>, Istvan Mohacsi<sup>a</sup>, Yoshitake Shusuke<sup>b</sup>, Yasin Ekinci<sup>a</sup>

<sup>a</sup>Paul Scherrer Institute, Villigen PSI, Villigen, CH-5232, Switzerland

<sup>b</sup>NuFlare Technology, Inc., 8-1 Shinsugita-cho, Yokohama 235-8522, Japan

**Rigorous 3D Electromagnetic Simulation of Ultrahigh Efficiency EUV Contact-hole Printing with Chromeless Phase-shift Mask (P37) .....31**

Stuart Sherwin<sup>a</sup>, Thomas V. Pistor, Andrew Neureuther<sup>a</sup>, and Patrick Naulleau<sup>b</sup>

<sup>a</sup>University of California, Berkeley, Department of Electrical Engineering and Computer Sciences, Berkeley, California, United States, 94720

<sup>b</sup>Lawrence Berkeley National Laboratory, Center for X-ray Optics, 1 Cyclotron Road, Berkeley, California, United States, 94720

**Lunch 12:20 AM – 1:20 PM**

**Session 3: EUV Sources- I**

**Session Co-chairs: Akira Endo (HiLASE) and Oscar Versolato (ARCNL)**

**kW-class Picosecond Thin-disk Pre-pulse Laser PERLA for Efficient EUV Generation (P11) (Invited Paper) .....12**

Akira Endo<sup>1</sup>, Martin Smrž<sup>1</sup>, Jiří Mužík<sup>1,2</sup>, Ondřej Novák<sup>1</sup>, Michal Chyla<sup>1</sup>, Tomáš Mocek<sup>1</sup>

<sup>1</sup> HiLASE Centre, Institute of Physics AS CR, Za Radnicí 828, 252 41 Dolní Břežany, Czech Republic

<sup>2</sup> Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Břehová 7, 115 19 Praha 1, Czech Republic

**Scalability of CO<sub>2</sub> Amplifiers to Generate Stable > 500W Extreme Ultraviolet (EUV) Beams (P12) (Invited Paper) .....13**

Koji Yasui<sup>1</sup>, Naoyuki Nakamura<sup>2</sup>, Jun-ichi Nishimae<sup>2</sup>, Masashi Naruse<sup>3</sup>, Kazuo Sugihara<sup>3</sup>, and Masato Matsubara<sup>3</sup>

<sup>1</sup>Mitsubishi Electric Corporation, Head quarter, Factory Automation Systems Group, Tokyo, Japan

<sup>2</sup>Mitsubishi Electric Corporation, Advanced technology R&D center, Hyogo, Japan

<sup>3</sup>Mitsubishi Electric Corporation, Nagoya works, Nagoya, Japan

**Simulating EUV Production – an Overview of the Underpinnings (P13) (Invited Paper) .....14**

Howard Scott and Steve Langer

Lawrence Livermore National Laboratory, USA

**Short-pulsed Nd:YAG Laser Interaction with Tin Micro-droplets (P14) (Invited Paper) .....15**

Oscar O. Versolato

Advanced Research Center for Nanolithography (ARCNL), Science Park 110, 1098 XG Amsterdam, The Netherlands

**Break and Group Photograph 2:20 PM (30 Minutes)**

**Session 4: EUV Sources - II**

Session Chair: Erik R. Hosler (GLOBALFOUNDRIES) and Hiroshi Kawata (KEK)

**Next Generation Source Power Requirements: What will we need at the 3 nm node and beyond? (P15) (Invited Paper) .....16**

Erik R. Hosler

GLOBALFOUNDRIES, 400 Stone Break Road Extension, Malta, NY 12020

**A Compact Linac-Driven EUV Light Source utilizing a Short-Period Microwave-Driven Undulator (P16) .....17**

Filippos Toufexis\*, Cecile Limborg-Deprey, Valery A. Dolgashev, Sami G. Tantawi  
SLAC National Accelerator Laboratory, 2575 Sand Hill Rd, Menlo Park, California 94025

\* Also at the Department of Electrical Engineering, Stanford University

**Concept for 1kW EUV Source for Lithography Based on FEL Emission in Compact Storage Ring (P17) (Invited Paper) .....18**

Michael Feser

*Lyncean Technologies Inc.*

**Challenges to Realize the EUV-FEL High Power Light Source - Present Status on the EUV-FEL R&D Activities (P18) (Invited Paper) .....19**

Hiroshi Kawata

*High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan*

**Session 5: Poster Session 5:30 7:00 PM**

**Session Chair:** Gregory Denbeaux (SUNPU Poly)

**Large Collector Mirror Reflectometer for the High Power EUV Light Source Achievement (P25) .....24**

Takeo Watanabe and Tetsuo Harada

Center for EUVL, Laboratory of Advanced Science and Technology for Industry, University of Hyogo

**Measuring Aberrations with Mask Roughness (P35) .....29**

Aamod Shanker

Dept. of Electrical Engineering and Computer Sciences, University of California, Berkeley, CA

**Impact of Tool Design on Defect Detection Sensitivity for EUV Actinic Blank Inspection (P36) .....30**

Yow-Gwo Wang<sup>a,b,\*</sup> Andrew R. Neureuther<sup>a,b</sup> Patrick P. Naulleau<sup>b</sup>

<sup>a</sup>University of California, Berkeley, Department of Electrical Engineering and Computer Sciences, Berkeley, California, United States, 94720

<sup>b</sup>Lawrence Berkeley National Laboratory, Center for X-ray Optics, 1 Cyclotron Road, Berkeley, California, United States, 94720

**Variable Separation Method for Three-dimensional EUVL Mask Diffraction Simulation (P40) .....34**

Xiangzhao Wang\*, Heng Zhang, Sikun Li

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

**Improved Inspection Ability of Coherent Scattering Microscopy by Applying Ptychography (P31) .....25**

**Winner of First Place in the Poster Session**

Young Woong Kim<sup>1</sup>, Dong Gon Woo<sup>1</sup>, Seung Hyuk Shin<sup>2</sup>, Hoon Jo<sup>2</sup>, Whoi-Yul Kim<sup>2</sup> and Jinho Ahn<sup>1</sup>

<sup>1</sup>Division of Materials Science and Engineering

<sup>2</sup>Department of Electronics and Computer Engineering

Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 04763, Republic of Korea

**Coherent diffraction imaging with partially coherent discharge plasma based EUV sources (P61) .....45**

Jan Bußmann<sup>1,2</sup>, Michal Odstřil<sup>1,3</sup>, Raoul Bresenitz<sup>1</sup>, Yusuke Teramoto<sup>4</sup>, Marco Perske<sup>5</sup>, Torsten Feigl<sup>5</sup>, William S. Brocklesby<sup>3</sup>, Larissa Juschkina<sup>1,2</sup>

<sup>1</sup>Chair for Experimental Physics of EUV, JARA-FIT, RWTH Aachen University, Steinbachstrasse 15, 52074 Aachen, Germany

<sup>2</sup>Peter Grünberg Institute 9, JARA-FIT, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

<sup>3</sup>Optoelectronics Research Center, University of Southampton, SO17 1BJ, United Kingdom

<sup>4</sup>BLV Licht- und Vakuumtechnik GmbH, Steinbachstraße 15, Aachen, Germany

<sup>5</sup>OptiXfab. GmbH, Hans-Knoell-Str. 6, 07745 Jena, Germany

**Achromatic Talbot lithography with partially coherent EUV radiation (P62) .....46**

Sascha Brose<sup>1</sup>, Jenny Tempeler<sup>1</sup>, Hyun-su Kim<sup>2,3</sup>, Serhiy Danylyuk<sup>1</sup>, Peter Loosen<sup>1</sup>, Larissa Juschkin<sup>2,3</sup>

<sup>1</sup> Chair for the Technology of Optical Systems, JARA-FIT, RWTH Aachen University, Germany

<sup>2</sup> Chair for the Experimental Physics of EUV, JARA-FIT, RWTH Aachen University, Germany

<sup>3</sup> Peter Grünberg Institute 9, JARA-FIT, Forschungszentrum Jülich GmbH, Germany

**Spectroscopic EUV reflectometry for characterization of thin films and layered structures (P63) .....47**

Maksym Tryus<sup>1</sup>, Serhiy Danylyuk<sup>2</sup>, Daniel Wilson<sup>3</sup>, Stefan Herbert<sup>2</sup>, Lukas Bahrenberg<sup>2</sup>, Angelo Giglia<sup>4</sup>, Piergiorgio Nicolosi<sup>5</sup>, and Larissa Juschkin<sup>1,3</sup>

<sup>1</sup> Chair for the Experimental Physics of EUV, JARA-FIT, RWTH Aachen University, Germany

<sup>2</sup> Chair for the Technology of Optical Systems, JARA-FIT, RWTH Aachen University, Germany

<sup>3</sup> Peter Grünberg Institut 9, JARA-FIT, Forschungszentrum Jülich GmbH, Germany

<sup>4</sup> CNR - Istituto Officina Materiali, Trieste, Italy

<sup>5</sup> Dipartimento di Ingegneria dell'Informazione, Universita' degli Studi di Padova, Italy

**EUV scattering metrology: Benchmarking of discharge plasma source based table-top scatterometry versus PTB synchrotron based EUV radiometry (P64) .....48**

Oleksiy Maryasov<sup>1,2</sup>, Christian Laubis<sup>2</sup>, Mewael Sertsu<sup>1,3</sup>, Frank Scholze<sup>2</sup>, Larissa Juschkin<sup>1,4</sup>

<sup>1</sup> Chair for the Experimental Physics of EUV, JARA-FIT, RWTH Aachen University, Steinbachstr. 15, 52074 Aachen, Germany

<sup>2</sup> Physikalisch-Technische Bundesanstalt (PTB), Abbestraße 2-12, 10587 Berlin, Germany

<sup>3</sup> Dipartimento di Ingegneria dell'Informazione, Universita' degli Studi di Padova, Italy

<sup>4</sup> Peter Grünberg Institute 9, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

**Estimation of Lithographically-relevant Secondary Electron Blur (P51) .....43**  
**Winner of Second Place in the Poster Session**

Roberto Fallica and Yasin Ekinici

Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

**EUV Lithography Research and Development Activities at University of Hyogo (P52) .....44**

Takeo Watanabe and Tetsuo Harada

Center for EUVL, Laboratory of Advanced Science and Technology for Industry, University of Hyogo

**EUV Light Source Development at Energetiq (P65) (Commercial Poster) .....N/A**

Matthew Partlow, Energetiq

**Laser Driven Light Sources (LDLS) from Energetiq (P66) (Commercial Poster) .....N/A**

Matthew Partlow, Energetiq

**Veeco's Technologies Enable High Growth Markets (P67) (Commercial Poster).....N/A**

Sandeep Kohli, Veeco

**End Day 1**



**Thursday, June 15, 2017**

**Welcome and Announcements (Intro-2)**

Patrick Naulleau, LBL

**Session 6: Keynote-2**

*Session Chair: Patrick Naulleau (LBL)*

**Tabletop Coherent EUV Sources and Applications: Full Field Sub-Wavelength Imaging at 13.5nm and Materials Metrology (P4) (Keynote Presentation) .....10**

Margaret Murnane

*JILA, University of Colorado at Boulder and KMLabs Inc.*

**High Power HVM LPP-EUV Source with Long Collector Mirror Lifetime (P2) (Keynote Presentation) .....7**

Hakaru Mizoguchi

*Gigaphoton Inc., Hiratsuka Kanagawa, 254-8567, JAPAN*

**EUV Lithography: Progress in LPP Source Power Scaling and Availability (P5) (Keynote Presentation) .....11**

Igor Fomenkov

*Cymer LLC, An ASML Company, San Diego, CA 92127, USA*

**Break (20 Minutes)**

**Session 7: Optics and Contamination**

*Session Co-Chairs: Jan van Schoot (ASML) and Ladislav Pina (RITE)*

**EUV Optics Life-time Research: Past, Present and Future (P21) (Invited Review paper) .....20**

Norbert Koster, Edwin te Sligte, Arnold Storm, Herman Bekman, Jacques van der Donck, Diederik Maas, Jochem Janssen, Rogier Verberk

*TNO, Stieltjesweg 1, 2628 CK Delft, The Netherlands*

**The Future of EUV Lithography: Enabling Moore's Law in the Next Decade (P22) (Invited Paper) .....21**

Jan van Schoot, Kars Troost, Alberto Pirati, Rob van Ballegoij, Peter Krabbendam, Judon Stoeldraijer, Erik Loopstra, Jos Benschop, Jo Finders, Hans Meiling, Eelco van Setten, Bernhard Kneer\*, Bernd Thuring\*, Winfried Kaiser\*, Tilmann Heil\*, Sascha Migura\*

*ASML Netherlands B.V., De Run 6501, 5504 DR Veldhoven, The Netherlands*

*\*Carl Zeiss SMT GmbH, Rudolf-Eber-Straße 2, 73447 Oberkochen*

**Latest Developments in EUV Optics (P23) (Invited Paper) .....22**

Jack Little, Joerg Zimmermann, Jens Timo Neumann, Matthias Roesch, Ralf Gehrke, Bernhard Kneer, \*Eelco van Setten, \*Jan van Schoot

*Carl Zeiss SMT GmbH, Rudolf-Eber-Straße 2, 73447 Oberkochen*

*\*ASML Netherlands B.V., De Run 6501, 5504 DR Veldhoven, The Netherlands*

**[EUV/SXR Optics and Metrology Development at RITE \(P24\) \(Invited Paper\) .....23](#)**

Ladislav Pina

*Rigaku Innovative Technologies Europe (RITE), Prague, Czech Republic*

**Lunch 12:00 PM (60 Minutes)**

**Steering Committee working lunch meeting (Closed meeting)**

**Session 8: Resist and Patterning -1**

*Session Co-Chairs: Greg McIntyre (IMEC) and Yoshi Hishiro (JSR)*

**[EUVL Developments at Imec \(P47\) \(Invited Paper\) .....40](#)**

Greg McIntyre

*IMEC*

**[Reactivity of Metal Oxalate EUV Resists as a Function of the Central Metal \(P41\) \(Invited Paper\) .....35](#)**

Steven Grzeskowiak,<sup>a</sup> Amrit Narasimhan,<sup>a</sup> Michael Murphy,<sup>a</sup> Lee Napolitano,<sup>b</sup>

Daniel A. Freedman,<sup>b</sup> Robert L. Brainard,<sup>a</sup> and [Greg Denbeaux](#)<sup>a</sup>

<sup>a</sup> *State University of New York Polytechnic Institute - CNSE, 257 Fuller Rd. Albany, NY 12203*

<sup>b</sup> *State University of New York at New Paltz, 1 Hawk Drive New Paltz, NY 12561*

**[Novel EUV resist development for sub-7 nm node \(P43\) \(Invited Paper\) .....37](#)**

Yoshi Hishiro

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

**[Metal Oxide Photoresists: Breaking Paradigms in EUV Lithography \(P50\) \(Invited Paper\) .....42](#)**

Jason Stowers

*Inpria*

**[Fundamental Aspect of Photosensitized Chemically Amplified Resist: How to overcome RLS trade-off \(P46\) \(Invited Paper\) .....N/A](#)**

Seiichi Tagawa<sup>1,2</sup>

<sup>1</sup>*Graduate School of Engineering, Osaka University, Ibaraki, Osaka 567-0047, Japan,*

<sup>2</sup>*Institute of Scientific and Industrial Research, Osaka University, Ibaraki, Osaka 567-0047, Japan*

**Break 2:50 PM (20 Minutes)**

## **Session 9: Resist and Patterning -2**

*Session Co-chairs: Greg Denbeaux (SUNY Poly) and Frank Ogletree (LBL)*

### **Towards Real-Time Analysis of Morphologies using Scattering (P42) (Invited Paper) .....36**

Alex Hexemer

*Lawrence Berkeley National Laboratory, Berkeley, California, United States, 94720*

### **Extreme ultraviolet Induced Chemical Reactions in Photoresists and Model Systems (P44) (Invited Paper) .....38**

S. Castellanos<sup>a</sup>, Y. Zhang<sup>a</sup>, J. Haitjema<sup>a</sup>, L. Wu<sup>a</sup>, O. Luigier<sup>a</sup>, D. Kazazis<sup>b</sup>, M. Vockenhuber<sup>b</sup>, T. R. Fallica<sup>b</sup>, Y. Ekinci<sup>b</sup>, A.M. Brouwer<sup>a</sup>.

<sup>a</sup> *Advanced Research Center for Nanolithography, Science Park 110, 1098XG Amsterdam, The Netherlands*

<sup>b</sup> *Paul Scherrer Institute, 5232 Villigen PSI, Switzerland*

### **Fundamentals of X-Ray Excitation and Relaxation in EUV Resists (P45) (Invited Paper) .....N/A**

D. Frank Ogletree

*Molecular Foundry, Materials Sciences Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley CA 94720 USA*

### **Fundamental Aspects of Low Energy Electron Driven Chemistry (P48) (Invited Paper) .....41**

Dan Slaughter

*Chemical Sciences Division, LBNL*

### **EUVL Workshop Summary (P70) .....N/A**

Vivek Bakshi

*EUV Litho, Inc.*

## **Depart for Dinner**

**6:00 -9:00 PM    Dinner Cruise**