

2016 International Workshop on EUV Lithography

June 13-16, 2016

CXRO, LBNL ▪ Berkeley, CA

Workshop Proceedings

2016 International Workshop on EUV Lithography
(EUVL Workshop)

June 13-16, 2016, The Center for X-Ray Optics (CXRO),
Lawrence Berkeley National Laboratory, Berkeley, CA



2016 International Workshop on EUV Lithography

WORKSHOP PROCEEDINGS



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Organized by

EUREKA



Vivek Bakshi (EUV Litho, Inc.), Chair

Patrick Naulleau (CXRO), Co-Chair

2016 International Workshop on EUV Lithography

*CXRO, LBNL, Berkeley, CA, USA
June 13-16, 2016*

Workshop Agenda

Monday, June 13, 2016

Short Courses

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

8:30 AM -5:00 PM (Building 66 – Room 316)

Tuesday, June 14, 2016

Registration and Reception

3:30 PM- 5:00 PM CXRO Tour (Building # 2, Fourth floor)

5:00 PM- 6:30 PM Registration, reception & Speaker Prep (Building 54, Bay View Cafeteria)

Wednesday, June 15, 2016

8:30 AM Welcome and Introduction

Welcome to LBL
Mike Witherell, Director, LBL

Introduction to Agenda (Intro-1)

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

Session 1: Keynote – 1

Session Chair: Patrick Naulleau (CXRO)

EUV Lithography's Present and Future (P1)

Harry J. Levinson
GLOBALFOUNDRIES

EUVL Readiness for High Volume Manufacturing (P3)

Britt Turkot
Intel Corporation

Break (20 minutes)

Session 2: EUV Sources

Session Co-chairs: H. Mizoguchi (Gigaphoton) and Padraig Dunne (UCD)

Development of 250 W EUV Light Source For HVM Lithography (P34) (Invited)

H. Mizoguchi*, H. Nakarai, T. Abe, K. M Nowak, Y. Kawasuji, H. Tanaka, Y. Watanabe, T. Hori, T. Kodama, Y. Shiraishi, T. Yanagida, G. Soumagne, T. Yamada, T. Yamazaki, S. Okazaki and T. Saitou
Gigaphoton Inc. Hiratsuka facility, JAPAN

CO₂ Amplifiers to Generate > 20 kW Laser Power for Stable > 250 W Extreme Ultraviolet (EUV) Power (P33) (Invited)

Koji Yasui¹, Naoyuki Nakamura², Jun-ichi Nishimae², Masashi Naruse³, and Masato Matsubara³

¹*Mitsubishi Electric Corporation, Head quarter, Tokyo, Japan*

²*Mitsubishi Electric Corporation, Advanced technology R&D center, Hyogo, Japan*

³*Mitsubishi Electric Corporation, Nagoya works, Nagoya, Japan*

New Concepts for a High Brightness LPP EUV Source (P35)

Konstantin Koshelev, Alexander Vinokhodov, Mikhail Krivokoritov, Oleg Yakushev, Samir Ellwi, Denis Glushkov, Pavel Seroglazov
RnD-Isan, Moscow, Russia and ISTEQ B.V., Eindhoven, the Netherlands

Laboratory Soft X-ray Tomography with a Simple Robust Laser Plasma Light Source (P32) (Invited)

F. O'Reilly^{1,2}, G. Wielgoszewski², J. Howard², F. McGrath², R. Byrne², A. Mahon², O. Hammad², T. McEnroe², T. McCormack¹, G. O'Sullivan¹, E. Sokell¹, P. Dunne¹, N. Kennedy¹, K. Fahy², P. Sheridan²

1 University College Dublin, School of Physics, Dublin, Ireland

2 SiriusXT Ltd, Science Centre North, Belfield, Ireland

Lunch 11:50 AM – 1:00 PM

Session 3: FEL based EUV Sources

Session Chairs: Alex Murokh (Radiabeam) and Erik R. Hosler (GLOBALFOUNDRIES)

Free-electron Lasers: Beyond EUV Lithography Insertion (P41) (Invited)

Erik R. Hosler, Obert R. Wood II

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

High Efficiency Free Electron Lasers (P44) (Invited)

Alex Murokh

Radiabeam

Design and Development of a 10-kW Class EUV-FEL Project in Japan (P43) (Invited)

Ryukou Kato

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

Break and Group Photograph 2:00 PM (30 Minutes)

Session 4: EUV Optics

Session Chair: Regina Soufli (LLNL) and Ladislav Pina (Rigaku)

EUV Lithography High-NA Scanner for Sub 8 nm Resolution (P61) (Invited)

Jan van Schoot¹, Eelco van Setten¹, Gerardo Bottiglieri¹, Kars Troost¹, Sascha Migura², Jens-Timo Neumann², Bernhard Kneer², Winfried Kaiser²

¹ASML, De Run 6501, 5504 DR Veldhoven, Netherlands

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

Multilayer coatings for the first Micro-Exposure Tools with NA=0.5 (P64) (Invited)

Regina Soufli¹, Jeff Robinson¹, Eberhard Spiller², Monica Fernández-Perea¹, Eric Gullikson³, Luc Girard⁴, Lou Marchetti⁴, John Kincade⁴

¹Lawrence Livermore National Laboratory, Livermore, CA 94550

²Spiller X-ray Optics, Livermore, CA 94550

³Lawrence Berkeley National Laboratory, Berkeley, CA 94720

⁴Zygo Corporation, Extreme Precision Optics, Richmond, CA 94806

Atomic-scale investigations of formation and aging processes of EUV optics (P66) (Invited)

Joost W.M. Frenken

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

Diffraction Optics for EUV Applications (P67)

Ryan Miyakawa, Henry Wang, Weilun Chao, and Patrick Naulleau

Center for X-ray Optics, Lawrence Berkeley National Lab, 1 Cyclotron Rd, Berkeley, CA 94720

Fabrication of EUVL Micro-field Exposure Tools with 0.5 NA (P68)

Luc Girard¹, Lou Marchetti¹, Jim Kennon², Bob Kestner², Regina Soufli³, Eric Gullickson⁴

¹Zygo Corporation, Extreme Precision Optics (EPO), Richmond, CA 94806, USA

²Akumen Engineering, LLC. (former employees of Zygo EPO)

³Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550

⁴Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720

Multilayer EUV Optics with Integrated IR Suppression Gratings (P69)

Torsten Feigl¹, Marco Perske¹, Hagen Pauer¹, Tobias Fiedler¹, Uwe Zeitner², Robert Leitel², Hans-Christoph Eckstein², Philipp Schleicher², Sven Schröder², Marcus Trost², Stefan Risse², Christian Laubis³, Frank Scholze³

¹ optiX fab GmbH, Hans-Knöll-Str. 6, 07745 Jena, Germany

² Fraunhofer IOF, Albert-Einstein-Str. 7, 07745 Jena, Germany

³ PTB Berlin, Abbestr. 2-12, 10587 Berlin, Germany

Adjourn: Time off for Networking

End Day 1

Thursday, June 16, 2016

Welcome and Announcements (Intro-2)

Vivek Bakshi
EUV Litho, Inc.

Session 5: Keynote-2

Session Chair: Patrick Naulleau (CXRO)

EUVL Exposure Tools for HVM: Status and Outlook (P2)

Igor Fomenkov
Cymer LLC, An ASML Company, San Diego, CA 92127, USA

Session 6: Mask-1

Session Co-Chairs: Ted Liang (Intel)

Eigenmode Analysis of Electromagnetic Fields in Binary EUV Masks (P51)

Michael Yeung¹, Eytan Barouch² and Hye-Keun Oh³
¹Fastlitho, 123 E. San Carlos Street, #251, San Jose, CA 95112
²Boston University, 15 St. Mary's Street, Boston, MA 02215
³Hanyang University, Ansan, Gyeonggi 426-791, Republic of Korea

Challenges for Predictive EUV Mask Modeling (P82) (Invited)

P. Evanschitzky, A. Erdmann
Fraunhofer IISB, Schottkystrasse 10, 91058 Erlangen, Germany

Break 10:00 AM (20 Minutes)

Session 7: Mask -2

Session Chair: Ken Goldberg (LBNL)

Actinic Mask Inspection System Using Coherent Scattreometry Microscope (P84) (Invited)

H. Kinoshita, T. Harada, Y. Nagata, T. Watanabe and K. Midorikawa
University of Hyogo, Japan

Near Wavelength Limited, 15nm Spatial Resolution, Ptychographic Imaging using a 13.5nm Tabletop High Harmonic Light Source (P59) (Invited)

Henry Kapteyn
KMLabs Inc., 1855 S. 57th Court, Boulder, CO 80301 USA

Improvement of Coherent Scattering Microscopy by applying Ptychographical Iterative Engine (P55)

Dong Gon Woo¹, Seongchul Hong¹, Hoon Jo², Whoi-Yul Kim², and Jinho Ahn¹

¹Department of Materials Science and Engineering

²Department of Electronics and Computer Engineering

Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 133-791, Korea

Lunch 11:20 PM (90 Minutes)

Steering Committee working lunch meeting (Closed meeting)

12:50 PM Session 8: Mask -3

Session Chair: Jim Wiley (ASML)

Extreme Ultraviolet Mask Manufacturing: Challenges and Opportunities (P52) **(Invited)**

Bryan Kasprovicz¹, Henry Kamberian²

¹Photronics Inc., Allen, Texas, USA

²Photronics Boise nanoFab, Boise, Idaho, USA

Progress and Opportunities in EUV Mask Development (P53) (Invited)

Ted Liang

Intel Mask Operations, 3065 Bowers Avenue, Santa Clara, CA USA

EUREKA Overview (P85) (Invited)

Patrick Naulleau

CXRO

Extending CO₂ Cryogenic Aerosol Cleaning for EUV Mask Cleaning (P57) (Invited)

Ivin Varghese and Charles W. Bowers

Eco-Snow Systems, RAVE N.P. Inc., 4935A Southfront Rd., Livermore, CA, USA 94551

Break 2:10 PM (20 Minutes)

Session 9: Resist -1

Session Co-Chairs: Stephen Meyers (Inpria) and Yoshi Hishiro (JSR)

EUV Radiation Chemistry Fundamentals: Novel Probing Techniques (P72)

Oleg Kostko, B. Xu, D. S. Slaughter, K. D. Closser, S. Bhattarai, B. Hinsberg,
G. M. Wallraff, D. L. Olynick, D. G. Prendergast, P. D. Ashby, D. F. Ogletree, Y. Liu, P.
Naulleau, M. Ahmed

Chemical Sciences Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Rd,
Berkeley, CA 94720, USA

Mechanisms of Exposure of Resists to EUV Light: Photons, Electrons and Holes (P76) (Invited)

Amrit Narasimhan, Steven Grzeskowiak, Greg Denbeaux, Robert Brainard
SUNY Polytechnic Institute, Albany NY 12203

Fundamentals of X-Ray Excitation and Relaxation in EUV Resists (P78) (Invited)

D. Frank Ogletree
Molecular Foundry, Materials Sciences Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley CA 94720 USA

Session 10: Resist -2

Session Co-Chairs: Robert Brainard (SUNY) and Frank Ogletree (LBNL)

Fundamental Aspect of Photosensitized Chemically Amplified Resist: How to overcome RLS trade-off (P73) (Invited)

Seiichi Tagawa^{1,2} and PSCAR Collaboration Members

¹*Graduate School of Engineering, Osaka University, Ibaraki, Osaka 567-0047, Japan,*
²*Institute of Scientific and Industrial Research, Osaka University, Ibaraki, Osaka 567-0047, Japan*

Molecular Resist Materials for Extreme Ultraviolet Lithography (P74) (Invited)

Hiroki Yamamoto¹, Hiroto Kudo², and Takahiro Kozawa¹

¹*The Institute of Scientific and Industrial Research, Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan (Osaka Univ.)*
²*Department of Chemistry and Materials Engineering, Faculty of Chemistry, Materials and Bioengineering, Kansai University, 3-3-35, Yamate-cho, Suita-shi, Osaka 564-8680, Japan*

Metal Oxide EUV Photoresist for N7 Relevant Patterns (P79) (Invited)

Stephen T. Meyers, Andrew Grenville

Inpria Corporation, 2001 NW Monroe Avenue, Corvallis, OR, USA 97330

Novel EUV Resist Development for 13 nm Half Pitch (P91) (Invited)

Yoshi Hishiro
JSR

2016 EUVL Workshop Summary

Vivek Bakshi
EUV Litho, Inc.

5:50- 7:00 PM Poster Session

7:30 -9:30 PM Dinner

Session 11: Poster Session (5:50 PM - 7:00 PM)

Session Chairs: Vivek Bakshi (EUV Litho Inc.) and Patrick Naulleau (CXRO)

1. Inspection Efficiency Comparison between Phase Contrast and Dark Field Microscopy for EUV Actinic Blank Inspection (P86)

Yow-Gwo Wang^{*a,b}, Andy Neureuther^{a,b}, Patrick Naulleau^b

^aDepartment of Electrical Engineering and Computer Sciences, University of California, Berkeley, CA USA 94720; ^bCenter for X-ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA USA 94720

2. Off-axis Aberration Estimation in an EUV Microscope using Natural Speckle (P54)

Aamod Shanker¹, Antoine Wojdyla², Gautam Gunjala¹, Jonathan Dong³, Markus Benk², Andy Neureuther¹, Kenneth Goldberg², Laura Waller¹

¹Dept of Electrical Engineering and Computer Sciences, UC Berkeley, CA

²Center for X-Ray Optics, Lawrence Berkeley National Lab, Berkeley, CA

³Département de Physique, Ecole Normale Supérieure, Paris 75005, France

3. Improving SRAF margin and imaging performance by using PSM in EUVL (P56)

Yong Ju Jang¹, Jung Sik Kim¹, Seongchul Hong², Jinho Ahn^{1,2}

¹Department of Nanoscale Semiconductor Engineering

²Department of Materials Science and Engineering

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

4. CSM with Ptychography (P55 Poster)

Dong Gon Woo¹, Seongchul Hong¹, Hoon Jo², Whoi-Yul Kim², and Jinho Ahn¹

¹Department of Materials Science and Engineering

²Department of Electronics and Computer Engineering

Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 133-791, Korea

5. Multilayer Development for EUV Lithography in CIOMP (P62)

Bo Yu¹, Chunshui Jin¹, Chun Li¹, Shun Yao¹

¹Changchun Institute of Optical, Fine Mechanics and Physics, Chinese Academy of Sciences, 3888 Dong Nanhu Road, Changchun, China, 130033

6. Realization of EBL2, an EUV exposure facility for EUV induced contamination research (P65)

Norbert Koster, Edwin te Sligte, Freek Molkenboer, Alex Deutz, Peter van der Walle, Pim Muilwijk, Wouter Mulckhuysen, Bastiaan Oostdijck, Christiaan Hollemans, Björn Nijland, Peter Kerkhof, Michel van Putten

TNO, Stieltjesweg 1, 2628 CK Delft, The Netherlands

7. Modeling the Interaction of EUV radiation with Photoresist Materials (P71)

¹Kristina D. Closser, ¹David Prendergast, ²Musa Ahmed, ¹Paul D. Ashby,

²Oleg Kostko, ¹D. Frank Ogletree, ¹Deirdre L. Olynick, ²D. Slaughter, ²Bo Xu, ³Patrick Naulleau

¹Molecular Foundry, Lawrence Berkeley National Laboratory

²Chemical Sciences Division, Lawrence Berkeley National Laboratory

³Center for X-ray Optics (CXRO), Lawrence Berkeley National Laboratory

8. Tin Cage Photoresists for EUV Lithography (P75)

Jarich Haitjema

*Nano photochemistry Group, Advanced Research Center for Nanolithography (ARCNL),
The Netherlands*

9. Study of Energy Delivery and Mean Free Path of Low Energy Electrons in EUV Resists (P92)

Suchit Bhattarai^a, Andrew R. Neureuther^a, Patrick P. Naulleau^b

^a*Department of EECS, Univ. of California, Berkeley, CA, USA 94720*

^b*Center for X-Ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA, USA
94720*

10. Advances in EUV Resists 2010-2016 (P77)

Robert Brainard,^a Gregg Gallatin,^b and Mark Neisser^c

^a*SUNY Polytechnic Institute*

^b*Applied Math Solutions, LLC*

^c*Whitehouse Station, NJ*

11. Influence of Pulse Duration on CO₂ Laser Produced tin Plasma by 1D Plasma Modeling (P31)

Wang Xinbing, Yao Liwei and Zuo Duluo

*Wuhan National Laboratory for Optoelectronics, Huazhong University of Science Technol
Technology, Wuhan, 430074, China*

12. Stable Droplet Generator for High brightness LPP EUV Source (P36)

Konstantin Koshelev^{1,2}, Alexander Vinokhodov¹, Mikhail Krivokorytov¹, Yuri Sidelnikov²,
Oleg Yakushev¹, Denis Glushkov³, Pavel Seroglazov³, Samir Ellwi³

¹*RnD-ISAN/EUV Labs, Troitsk, 142190 Russia*

²*Institute for Spectroscopy RAS, Troitsk, 142090 Russia*

³*ISTEQ, 5656 AG Eindhoven*

13. Laboratory Cryo Soft X-ray Tomography: Progress in the Development of a Commercial Microscope (P37)

Kenneth Fahy¹, Fergal O'Reilly^{1,2}, Tony McEnroe¹, Felicity McGrath¹, Jason Howard¹,
Aoife Mahon¹, Ronan Byrne¹, Osama Hammad¹, and Paul Sheridan¹

¹*SiriusXT Ltd., Science Centre North, UCD, Belfield, Dublin 4, Ireland*

²*School of Physics, UCD, Belfield, Dublin 4, Ireland*

14. Light Source Development at Energetiq (P38)

Stephen F. Horne, Donald K Smith, Matthew M Besen, Paul A Blackborow, Deborah S
Gustafson, Matthew J. Partlow, Huiling Zhu
Energetiq Technology, Inc.

15. Commercial Poster – Sponsor Product Description

Arnd Baurichter

Research-Instruments, Germany

