

2013 International Workshop on EUV and Soft X-Ray Sources

November 3-7, 2013

Dublin ■ Ireland

Workshop Proceedings



2013 International Workshop on EUV and Soft X-ray Sources

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WORKSHOP PROCEEDINGS

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2013 International Workshop on EUV and Soft X-Ray Sources

November 3-7, 2013, Dublin, Ireland

Monday, November 4, 2013 (Newman House)

6:00 PM – 7:00 PM Reception and Registration

Tuesday, November 5, 2013 (George Moore Auditorium)

8:30 AM Session 1: Welcome and Announcements

[Introduction and Announcements \(Intro-1\)](#)

Joe Carthy, UCD

Vivek Bakshi, EUV Litho, Inc., USA

8:40 AM Session 2: Keynote Session -1

Session Chair: Katsuhiko Murakami (Nikon)

[EUV Lithography: Current and Future Requirements and Options? \(S2\)](#)

Vadim Banine
ASML, Netherlands

[Enabling EUVL for HVM Insertion \(S3\)](#)

Mark Phillips
Intel Corporation

Awards and Announcements – Padraig Dunne (UCD)



Break 10:10 AM

10:25 AM Session 3: HVM EUV Sources

Session Co-Chairs: Vadim Banine (ASML) and Hakaru Mizoguchi (Gigaphoton)

Update of High CE, High Power HVM LPP-EUV Source Development (S21) (Invited)

Hakaru Mizoguchi¹, Hiroaki Nakarai², Tamotsu Abe², Takeshi Ohta², Krzysztof M Nowak², Yasufumi Kawasuji², Hiroshi Tanaka², Yukio Watanabe², Tsukasa Hori², Takeshi Kodama², Yutaka Shiraishi², Tatsuya Yanagida², Tsuyoshi Yamada², Taku Yamazaki², Shinji Okazaki¹ and Takashi Saitou²

¹Gigaphoton Inc. Oyama facility, JAPAN

²Gigaphoton Inc. Hiratsuka facility, JAPAN

BEUV Nanolithography: 6.7 or 11 nm? (S19) (Invited)

N. I. Chkhalo and N. N. Salashchenko

Institute for physics of microstructures of RAS, Nizhny Novgorod, Russia

Development of High Brightness and High Average Power Picosecond Thin Disc Laser for Short Wavelength Light Sources in HiLASE Project (S24)

Taisuke Miura¹, Michal Chyla^{1,2}, Martin Smrž¹, Siva Sankar Nagisetty^{1,2}, Patricie Severová^{1,2}, Ondřej Novák¹, Pawel Sikocinski^{1,2}, Akira Endo¹, and Tomáš Mocek¹

¹HiLASE Project, Institute of Physics AS, CR, Na Slovance 2, 182 21 Prague 8, Czech Republic

²Czech Technical University in Prague, Břehová 7, 115 19, Prague, Czech Republic

Research Review on Plasma-based EUV Sources at RnD-ISAN/EUV Labs (S40)

V. M. Krivtsun^{1, 2}, R.R. Gayasov^{1, 2}, O. F. Yakushev¹, D. B. Abramenko¹, A. Yu. Vinokhodov¹ and K. K. Koshelev^{1, 2}

¹ RnD-ISAN /EUV Labs, Moscow, Troitsk, Russia

² Institute for Spectroscopy RAS, Moscow, Troitsk, Russia

A Systematic Study of Colliding Plasmas for EUVL (S25)

Emma Sokell, Colm O’Gorman, Bowen Li, Thomas Cummins, Padraig Dunne, Fergal O’Reilly, Paddy Hayden, and Gerry O’Sullivan

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

Lunch 12:05 PM



1:20 PM Session 4: Modeling

Session Co-Chairs: Padraig Dunne (UCD) and Chihiro Suzuki (NIFS, Japan)

Development of Radiation Hydrodynamic code STAR for EUV Plasmas (S15)

Atsushi Sunahara¹, Katsunobu Nishihara², Akira Sasaki³, Nozomi Tanaka², Shinsuke Fujioka², and Hiroaki Nishimura²

¹ Institute for Laser Technology, Japan

² Institute of Laser Engineering, Osaka University, Japan

³ Kansai Photon Science Institute, Japan Atomic Energy Agency, Japan

Modeling of the Laser Plasma Interaction for the Development of Efficient EUV Sources (S17)

Akira Sasaki

Quantum Beam Science Directorate, Japan Atomic Energy Agency, Kyoto, Japan

Observations of EUV Spectra from Highly Charged Heavy Ions in Optically Thin Plasmas for Benchmarking of Models (S16)

Chihiro Suzuki¹, Fumihiro Koike², Izumi Murakami¹, Naoki Tamura¹, Shigeru Sudo¹, Takeshi Higashiguchi³, Gerry O'Sullivan⁴

¹National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan

²Sophia University, 7-1 Kioi-cho, Chiyoda-ku, Tokyo 102-8554, Japan

³Utsunomiya University, 7-1-2 Yoto, Utsunomiya 321-8585, Japan

⁴University College Dublin, Belfield, Dublin 4, Ireland

Fundamental Atomic Process in Source Development for Beyond EUV Lithography and "Water Window" Imaging (S38)

Bowen Li¹, Takeshi Higashiguchi², Takamitsu Otsuka¹, Weihua Jiang³, Akira Endo⁴, Emma Sokell¹, Padraig Dunne¹, and Gerry O'Sullivan¹

¹School of Physics, University College Dublin, Belfield, Dublin 4, Ireland

²Department of Advanced Interdisciplinary Sciences, Center for Optical Research & Education (CORE), and Optical Technology Innovation Center (OpTIC), Utsunomiya University, Yoto 7-1-2, Utsunomiya, Tochigi 321-8585 Japan

³Department of Electrical Engineering, Nagaoka University of Technology, Kami-tomiokamachi 1603-1, Nagaoka, Niigata 940-2188 Japan

⁴HiLASE Project, Institute of Physics AS, CR, Prague 8, Czech Republic

Advances in Modeling of Physical Processes in Plasma-based Sources of EUV Radiation (S39)

V.V. Ivanov^{1, 2}, V. G. Novikov^{1, 3}, A.S. Grushin^{1, 3}, I. Yu. Vichev^{1, 3}, D.A. Kim^{1, 3}, V. Konovalov^{1, 3}, A.D. Solomyannaya^{1, 3}, K.K. Koshelev^{1, 2, 3}, V. M. Krivtsun^{1, 2}, A.M. Yakunin⁴, A. Bratchenia⁴, V.Y. Banine⁴

¹ RnD-ISAN, Troitsk, 142190 Russia

² Institute for Spectroscopy RAS, Troitsk, 142190 Russia

³ Keldysh Institute of Applied Mathematics RAS, Moscow, 125047 Russia

⁴ ASML, Veldhoven, The Netherlands



Pulsed-power Based Bright EUV Light Source for Metrology (S48)

S. Zakharov
NAEXTSTREAM, France

Break 3:20 PM (15 Minutes)

3:35 PM Session 5: Optics

Session Co-Chairs: Yuriy Platonov (RIT) and Torsten Feigl (optiXfab)

Collector Development with IR Suppression and EUVL Optics Refurbishment at RIT (S30) (Invited)

Yuriy Platonov¹, Michael Kriese¹, Raymond Crucet¹, Yang Li¹, Vladimir Martynov¹, Licai Jiang¹, Jim Rodriguez¹, Ulrich Mueller², Jay Daniel², Shayna Khatri², Adam Magruder², S. Grantham³, C. Tarrío³, T. B. Lucatorto³

¹Rigaku Innovative Technologies, Auburn Hills, MI, USA

²Integrated Optical Systems – Tinsley, Richmond, CA, USA

³National Institute of Standards and Technology, Gaithersburg, MD, USA

EUV Optical Elements with Enhanced Spectral Selectivity for IR Radiation (S31)

V. V. Medvedev¹, A. E. Yakshin¹, R. W. E. van de Kruijs¹, V. M. Krivtsun², E. Louis^{1,3} and F. Bijkerk^{1,3}

¹FOM Institute DIFFER, P.O. Box 1207, 3430 BE Nieuwegein, The Netherlands

²Institute for Spectroscopy RAS, Fizicheskaya Str., 5, Troitsk, Moscow Region, 142190 Russia

³MESA+ Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands

Design of Freestanding Film Elements for HVM tools of EUV Nanolithography (S28) (Invited)

Alexey Yakovlevich Lopatin, Nikolay Nikolaevich Salashchenko
Institute for Physics of Microstructures, Nizhny Novgorod, Russia

Characterization of Metrology Tools and Optical Components for HVM EUV Sources (S35) (Invited)

F. Scholze^a, C. Laubis^a, A. Gottwald^a, and T. Feigl^b

^aPhysikalisch-Technische Bundesanstalt, Abbestr. 2-12, 10587 Berlin, Germany

^boptiX fab GmbH, Hans-Knöll-Str.6, 07745 Jena, Germany

LPP Collector Mirrors – Coating, Metrology and Refurbishment (S34)

(Invited)

Torsten Feigl^a, Marco Perske^a, Hagen Pauer^a, Tobias Fiedler^a,
Christian Laubis^b, Frank Scholze^b

^a*optiX fab GmbH, Hans-Knöll-Str.6, 07745 Jena, Germany*

^b*Physikalisch-Technische Bundesanstalt, Abbestr. 2-12, 10587 Berlin, Germany*

5:30 PM – 6:30 PM Session 7: Poster Session

**7:00 PM Depart for Off-site Dinner
(Marion Hotel)**

End of Day 2

5:30 PM Session 7: Poster Session

Session Chair: Greg Denbeaux (University of Albany)

Topic: HVM Sources

[Energy Fraction of CO₂ Laser Absorbed in EUV Source Plasma \(S14\)](#)

Shinsuke Fujioka¹, Teruyuki Ugomori¹, Kensuke Yoshida¹, Chaogang Li¹,
Atsushi Sunahara², Katsunobu Nishihara¹, Nozomi Tanaka¹, and
Hiroaki Nishimura¹

¹ Institute of Laser Engineering, Osaka University, Japan

² Institute for Laser Technology, Japan

[Radiation of Gd and Tb Plasmas in 6.X nm Spectral Region \(S46\)](#)

V. Krivtsun, O. Yakushev, R. Gayazov, D. Abramenko and K. Koshelev
RnD-ISAN / EUV Labs, Troitsk, Moscow

Topic: EUV Sources for Mask Metrology

[Microwave EUV Light Sources for Photolithography \(S13\)](#)

Sho Oe¹, Saya Tashima¹, Masami Ohnishi¹, Waheed Hugarass² and Hodaka Osawa¹
¹Kansai university, Faculty of Engineering Science, Department of Electrical and
Electronic Engineering, 3-3-35 Yamate-cho, Suita-shi, Osaka 564-8680, Japan

²University of Tasmania, School of Computing and Information Systems,
Private Bag, 1359, Newnham, Tasmania 7250, Australia

[The Energetiq EQ-10 EUV Source for metrology - Review of Recent Data \(S29\)](#)

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

[Effect of Misalignment in Laser-droplet Interaction on the Three Dimensional EUV Emission and Ion Distribution \(S37\)](#)

Andrea Giovannini and Reza S. Abhari

Laboratory for Energy Conversion, Swiss Federal Institute of Technology Zurich
(ETHZ), Switzerland

[2D-Gas Dynamics Transient Modeling of Hot Gas Bubble Formation EUV Source Chamber \(S43\)](#)

V. Konovalov^{1,3}, V.G. Novikov^{1,3}, V.V. Ivanov^{2,3}, K. N. Koshelev^{2,3}, A.M. Yakunin⁴,
V. Y. Banine⁴

¹ Keldysh Institute of Applied Mathematics, Moscow, Russia

² Institute for Spectroscopy RAS, Troitsk, Russia

³ RnD-ISAN/RnD-M, Troitsk, 142190 Russia

⁴ ASML, Veldhoven, Netherlands



Transmission Grating Spectrometer for EUV Source Characterization from the UV to the EUV (S47)

H.M.J. Bastiaens¹, C. Bruineman², B. Vratzov^{1,3}, and F. Bijkerk^{1,4}

¹ MESA+ Institute for Nanotechnology, University of Twente, The Netherlands

² Scientec Engineering, The Netherlands

³ NT&D -Nanotechnology and Devices, Germany

⁴ FOM Institute DIFFER, The Netherlands

Transmission Grating Spectrometer for EUV Source Characterization from the UV to the EUV (S52)

H.M.J. Bastiaens¹, C. Bruineman², B. Vratzov^{1,3}, and F. Bijkerk^{1,4}

¹ MESA+ Institute for Nanotechnology, University of Twente, The Netherlands

² Scientec Engineering, The Netherlands

³ NT&D -Nanotechnology and Devices, Germany

⁴ FOM Institute DIFFER, The Netherlands

Comparison of ns vs ps Laser Assisted Vacuum Arc EUV Source (S53)

Girum A. Beyene¹, Enda Scally¹, Patrick Hayden¹, Larissa Juschkina², Vasily S. Zakharov³, Sergey V. Zakharov³, Padraig Dunne¹, Gerry O'Sullivan¹ and Fergal O'Reilly¹

¹ School of Physics, University College Dublin, Ireland,

² Department of Physics, RWTH Aachen University, Germany

³ EPPRA sas, Villebon sur Yvette, France

Topic: Applications of EUV Sources

Fast Rigorous Model for Mask Spectrum Simulation in EUV Lithography (S11)

Xiaolei Liu^{a,b}, Xiangzhao Wang^a, Sikun Li^a, Guanyong Yan^{a,b}, Andreas Erdmann^c

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

^b Graduate School of the Chinese Academy of Sciences, Beijing 100039, China

^c Fraunhofer Institute of Integrated Systems and Device Technology, Schottkystrasse 10, 91058 Erlangen, Germany

Topic: Modeling

Hydrodynamics Modeling of Liquid Droplet Deformation with Laser Pulses (S44)

I. Yu. Vichev^{1, 2}, V. G. Novikov^{1, 2}, V. V. Ivanov^{1, 3}, V. V. Medvedev^{3, 4}, V. M. Krivtsun^{1, 3}, K. N. Koshelev^{1, 3}, A. M. Yakunin⁵, A. Bratchenia⁵, V. Banine⁵

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⁴ FOM Institute DIFFER, Nieuwegein, The Netherlands

⁵ ASML, Veldhoven, The Netherlands

RZLINE Code Modeling of Sn Laser-produced Plasma Sources of EUV Radiation (S45)

A.S. Grushin^{1,3}, D.A. Kim^{1,3}, V.V. Medvedev⁴, V.V. Ivanov^{1,2}, V. G. Novikov^{1,3}, V. M. Krivtsun^{1,2}, A.M. Yakunin⁵, V. Y. Banine⁵ and K. N. Koshelev^{1,2}

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⁵ ASML, Veldhoven, Netherlands

Radiative Properties of Krypton Plasma in Water-window Spectral Range (S49)

Vassily S. ZAKHAROV, Sergey Zahkarov

EPPRA sas, Villebon/Yvette 91140, France

Keldysh Institute of Applied Mathematics RAS, Moscow 125047, Russia

NRC Kurchatov Institute, Moscow 123182, Russia

Topic: XUV

"Water Window" Laser-Produced Plasma Sources based on High-Z Alloys (S50)

Elaine Long¹, Takamitsu Otsuka^{1,2}, Bowen Li¹, Gerry O'Sullivan¹, Pdraig Dunne¹, Emma Sokell¹ & Fergal O'Reilly¹

¹UCD School of Physics, University College Dublin, Belfield, Dublin 4, Ireland

²Department of Advanced Interdisciplinary Sciences, Center for Optical Research & Education (CORE), and Optical Technology Innovation Center (OpTIC), Utsunomiya University, Yoto 7-1-2, Utsunomiya, Tochigi 321-8585, Japan

Studies of Mixed Lead-Tin Alloys as Targets for EUV LPP Sources (S51)

Enda Scally, Paul Sheridan, Gerry O'Sullivan & Fergal O'Reilly

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

Tailored Multilayer Optics for New X-ray Source Types (S47)

Stephen O'Rourke¹, Markus Krämer¹, Reiner Dietsch¹, David Windt², Thomas Holz¹,
Danny Weißbach¹

¹ AXO DRESDEN GmbH, 01237 Dresden, Germany

² Reflective X-Ray Optics LLC, New York, NY 10027, USA

Wednesday, November 6, 2013

8:30 AM Announcements

[Introduction and Announcements \(Intro-2\)](#)

Vivek Bakshi, EUV Litho, Inc.

Announcements

Padraig Dunne (UCD)

8:40 AM Session 7: Keynote Session - 2

Session Chair: Padraig Dunne (UCD)

[Coherent X-Rays from Tabletop Femtosecond Lasers and Applications in Nanometrology \(S1\)](#)

Margaret Murnane

University of Colorado, Boulder, CO

9:20 AM Session 8: XUV

Session Dedicated to the Memory of Prof. Alan Michette

Session Co-Chairs: Takeshi Higashiguchi (Utsunomiya University) and Klaus Mann (Laser-Laboratorium Göttingen)

[Efficient Light Sources at BEUV & Water Window Soft X-ray Wavelengths \(S41\) \(Invited\)](#)

Takeshi Higashiguchi¹, Yuhei Suzuki¹, Masato Kawasaki¹, Hayato Ohashi¹, Nobuyuki Nakamura², Ryoichi Hirose³, Takeo Ejima³, Weihua Jiang⁴, Taisuke Miura⁵, Akira Endo⁵, Chihiro Suzuki⁶, Kentaro Tomita⁷, Masaharu Nishikino⁸, Shinsuke Fujioka⁹, Hiroaki Nishimura⁹, Atsushi Sinahara¹⁰, Daisuke Nakamura⁷, Akihiko Takahashi⁷, Tatsuo Okada⁷, Shuichi Torii¹¹, Tetsuya Makimura¹¹, Bowen Li¹², Padraig Dunne¹², and Gerry O'Sullivan¹² ¹DEEE & CORE, Utsunomiya University

²Institute for Laser Science, The University of Electro-Communications

³Institute of Multidisciplinary Research for Advanced Materials, Tohoku University

⁴Nagaoka University of Technology ⁵HiLASE Project, Institute of Physics AS

⁶National Institute for Fusion Science ⁷Kyushu University, Japan

⁸Japan Atomic Energy Agency ⁹Institute of Laser Engineering (ILE), Osaka University

¹⁰Institute of Laser Technology (ILT) ¹¹Institute of Applied Physics, University of Tsukuba

¹²School of Physics, University College Dublin



[A Tunable Source of Quasi-Phase-Matched Coherent EUV Radiation \(S23\)](#)

Kevin O’Keeffe, David Lloyd, Simon Hooker

Clarendon Laboratory, Parks Road, Oxford, OX1 3PU, United Kingdom

[Complete Spatial Characterisation of EUV Harmonic Wavefronts \(S22\)](#)

David Lloyd, Kevin O’Keeffe, Simon Hooker

Clarendon Laboratory, Department of Physics, University of Oxford

[Table-top EUV/Soft X-ray Source and Wavefront Measurements at Short Wavelengths \(S18\) \(Invited\)](#)

K. Mann, J. O. Dette, F. Köhl, M. Lübbecke, T. Mey, M. Müller, B. Schäfer

Laser-Laboratorium Göttingen e.V., Göttingen, Germany

[In Memory of Prof. Alan Michette \(S54\)](#)

Peter Anastasi

Silson

10:40 AM Break (15 minutes)

10:55 AM Session 9: Metrology

Session Co-Chairs: Reza Abhari (ETHZ) and Paul Sheridan (NewLambda Technologies)

[Droplet-based LPP Light Source for HVM Inspection Applications \(S36\)](#)

Bob Rollinger, Nadia Gambino, Andrea Giovannini, Luna Bozinova, Flori Alickaj, Konrad Hertig, Reza S. Abhari and Fariba Abreau¹

Laboratory for Energy Conversion, Swiss Federal Institute of Technology Zurich (ETHZ), Switzerland

¹Adlyte Ltd., Zug, Switzerland

[Laser Produced Plasmas using Cryogenic Xe for Actinic Metrology and Inspection Tools \(S20\)](#)

Mark Tillack and Andrew Effenberger

University of California San Diego, La Jolla, CA

[Dynamics of a Laser-assisted Z-pinch EUV Source \(S27\)](#)

I. Tobin^a, L. Juschkin^b and J. G. Lunney^a

^aSchool of Physics, Trinity College Dublin, Dublin 2, Ireland.

^bDepartment of Physics, RWTH Aachen University, Aachen, Germany.



[Influence of an Intensive UV Preionization on Evolution and EUV-emission of the Laser Plasma with Xe Gas Target \(S12\)](#)

A.Garbaruk¹, M. Gritskevich¹, S. Kalmykov², A. Mozharov², M. Petrenko², M. Sasin², R. Seisyan²

¹State Polytechnical University

²A. F. Ioffe Physico-Technical Institute, St.-Petersburg, Russia

[Development of Microwave Discharge Plasma for Extreme Ultraviolet Lithography \(S10\)](#)

Saya TASHIMA, Masami OHNISHI, Waheed HUGRASS¹, Hodaka OSAWA and Sho OE

Department of Electrical and Electronic Engineering, Faculty of Engineering Science, Kansai University, 3-3-35 Yamate-cho, Suita, Osaka 564-8680, Japan

¹*School of Computing and Information Systems, University of Tasmania, Locked Bag 1359, Launceston, Tasmania 7250, Australia*

[Tunable, High Brightness Lab-Scale Soft X-Ray Photons \(S32\)](#)

P. Sheridan^{1,2}, F. O'Reilly^{1,2}, and K. Fahy^{1,2}

¹*NewLambda Technologies Ltd, Science Center North, Belfield, Dublin 4*

²*School of Physics, University College Dublin, Dublin 4*

12:40 PM Workshop Summary and Announcements

[Workshop Summary and Announcements \(S61\)](#)

Vivek Bakshi, EUV Litho, Inc.

1:15 PM Workshop Adjourned

