

2015 International Workshop on EUV and Soft X-Ray Sources

November 9-11, 2015

Dublin ■ Ireland

Workshop Proceedings



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Workshop Proceedings

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2015 International Workshop on EUV and Soft X-Ray Sources

November 9-11, 2015, Dublin, Ireland

Monday, November 9, 2015 (Newman House)

6:00 PM – 7:00 PM Registration, Reception and Speaker Prep

Tuesday, November 10, 2015 (George Moore Auditorium)

9:15 AM Announcements and Introductions

Welcome, Announcements and Introduction (Intro-1)

Joe Carthy, *UCD, Dublin*

Vivek Bakshi, *EUV Litho, Inc., USA*

9:35 AM **Session 1: Keynote Session -1**

Session Chair: Padraig Dunne (UCD)

[EUVL Advancements Toward HVM Readiness \(S1\)](#)

Britt Turkot
Intel Corporation

[Performance Overview and Outlook of EUV Lithography Systems \(S2\)](#)

Wim van der Zande
ASML



Break 10:55 AM (20 Minutes)

11:15 AM Session 2: HVM EUV Sources

Session Co-Chairs: Wim van der Zande (ASML) and Hakaru Mizoguchi (Gigaphoton)

Performance of One Hundred Watt Source and Construction of 250Watt HVM LPP-EUV Source (S12) (Invited)

Hakaru Mizoguchi, Hiroaki Nakarai, Tamotsu Abe, 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, Hiratsuka Kanagawa, JAPAN

Studies of Laser-produced Tin plasmas for EUV Light Sources using Collective Thomson Scattering (S13) (Invited)

Kentaro Tomita¹, Yuta Sato¹, Toshiaki Eguchi¹, Shoichi Tsukiyama¹, Kiichiro Uchino¹, Tatsuya Yanagida², Hiroaki Tomuro², Yasunori Wada², Masahito Kunishima², Takeshi Kodama², Hakaru Mizoguchi²

¹ *Interdisciplinary Graduate School of Engineering and Sciences, Kyushu University, 6-1, Kasugakoen, Kasuga, Fukuoka 816-8580, JAPAN*

² *Gigaphoton Inc., 400 Yokokurashinden Oyama, Tochigi, 323-8558, JAPAN*

Experimental and Theoretical Studies of Tin Droplets Shaping by Picosecond Laser pre-pulses (S24) (Invited)

Slava Medvedev et al
Institute for Spectroscopy, Russian Academy of sciences

Correlation between Laser Absorption Process and Energy Conversion to Extreme Ultraviolet Radiation in Laser Produced Tin Plasma (S16)

Hiraku Matsukuma¹, Atsushi Sunahara², Tatsuya Yanagida³, Hiroaki Tomuro³, Kouichiro Kouge³, Takeshi Kodama³, Tatsuya Hosoda¹, Shinsuke Fujioka¹, and Hiroaki Nishimura¹

¹ *Institute of Laser Engineering, Osaka University, Suita, 565-0871, Japan*

² *Institute of Laser Technology, Suita, 565-0871, Japan*

³ *Gigaphoton, Inc., 3-25-1, Shinomiya, Hiratsuka 254-8555, Japan*

Lunch 12:35 PM



2:00 PM Session 3: Modeling

Session Dedicated to the Memory of Vladimir G. Novikov

Session Chair: Gerry O'Sullivan (UCD) and A. Sunahara (Osaka University)

In the Memory of Prof. Vladimir G. Novikov (S38)

Slava Medvedev
Institute for Spectroscopy, Russian Academy of sciences

Hydrodynamics Modeling of the Dynamics of Sn droplet Target for the EUV Source (S17)

Akira Sasaki
Kansai Photon Science Institute, Japan Atomic Energy Agency, Kyoto, Japan

Radiation Hydrodynamic Simulation of Laser-produced Tin Plasmas (S20) (Invited)

A. Sunahara¹, H. Matsukuma², K. Nishihara², and A. Sasaki³
¹*Institute for Laser Technology*
²*Institute of Laser Engineering*
³*Japan Atomic Energy Agency*

Experimentally Validated Neutral Cluster Debris Mean Velocity and Trajectory Model for Droplet-Based Laser Produced Plasma Sources (S34)

Duane Hudgins, Nadia Gambino, Bob Rollinger and Reza S. Abhari
Laboratory for Energy Conversion, Swiss Federal Institute of Technology Zurich (ETHZ), Switzerland
Adlyte AG, Zug, Switzerland

3:10 PM Break and Group Photograph (20 Minutes)

3:30 PM Session 4: EUV Sources for Metrology

Session Co-Chairs: Klaus Bergmann (Fraunhofer-ILT) and Reza Abhari (ETH)

Bright and Reliable Xe-based EUV Source for Metrology and Inspection Applications (S31) (Invited)

Oleg Khodykin
RAPID, KLA-Tencor Inc., USA

Discharge based EUV Source for Metrology and Inspection (S32) (Invited)

Klaus Bergmann, Alexander von Wezyk and Jochen Vieker
Fraunhofer Institute for Laser Technology – ILT, Aachen, Germany

High-radiance LDP Source: clean, Reliable and Stable EUV Source for Mask Inspection (S35) (Invited)

Yusuke Teramoto, Bárbara Santos, Guido Mertens, Ralf Kops, Margarete Kops, Hironobu Yabuta, Akihisa Nagano, Noritaka Ashizawa, Takahiro Shirai, Kunihiko Kasama, Alexander von Wezyk¹ and Klaus Bergmann¹
USHIO Inc.
¹*Fraunhofer ILT*

Light Sources for High Volume Metrology and Inspection Applications (S37) (Invited)

Reza S. Abhari
ETH Zurich, Switzerland

Break 4:50 PM (20 Minutes)

Adjourn for the day – Time off for Networking

5:10 PM Source TWG meeting (Closed) –Location TBA

End of Day 2



Wednesday, November 11, 2015

9:15 AM Announcements

Introduction and Announcements (Intro-2)

Vivek Bakshi, EUV Litho, Inc.

9:25 AM **Session 5: Keynote Session - 2**

Session Chair: Padraig Dunne (UCD)

[Laser Plasma Sources of Soft X-rays and Extreme ultraviolet \(EUV\) for Application in Technology and Science \(S3\)](#)

Henryk Fiedorowicz

Institute of Optoelectronics, Military University of Technology, Warsaw, Poland

10:05 AM **Session 6: Optics**

Session Co-chairs: Joost W.M. Frenken (ARCNL) and Eric Louis (University of Twente)

[The Advanced Research Center for Nanolithography \(S41\) \(Invited\)](#)

Joost W.M. Frenken

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

[Studies of Thermal Transport in Mo/Si Multilayer Structures \(S42\)](#)

Slava Medvedev

Institute for Spectroscopy, Russian Academy of sciences



EUV and Beyond EUV Optics Research at the University of Twente (S43) **(Invited)**

Eric Louis, Robbert van de Kruijs, Andrey Yakshin, Johan Reinink, Dmitry Kuznetsov, Ben Wylie van Eerd, Chris Lee and Fred Bijkerk, ¹Hartmut Enkisch and ¹Stephan Müllender
MESA+ Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500 AE, Enschede, The Netherlands
¹Carl Zeiss SMT GmbH, Rudolf-Eber-Straße 2, 73447 Oberkochen, Germany

11:05 AM Break (20 minutes)

11:25 AM Session 7: XUV Sources

Session Co-chairs: Rainer Lebert (Research Instruments) and Ladislav Pina (CTU)

Identification of Plasma Sources for Water Window Imaging: Recent Spectroscopic Studies (S58) (Invited)

G. O'Sullivan*, P. Dunne*, T. Higashiguchi[†], B. W. Li[§], R. Lokasani*, E. Long*, H. Ohashi[#], F. O'Reilly*, P. Sheridan*, J. Sheil*, E. Sokell*, C. Suzuki[†], and T. Wu*
*School of Physics, University College Dublin Belfield, Dublin 4, Ireland
[†]Department of Advanced Interdisciplinary Science and Center for Optical Research (CORE), Utsunomiya University, Utsunomiya, Tochigi 321-8585 Japan,
[§]School of Nuclear Science and Technology, Lanzhou University, Lanzhou, China
[#]Graduate School of Science and Engineering for Research, University of Toyama, Toyama, Japan
[†]National Institute for Fusion Science, Toki, Gifu 509-5292, Japan

UCD Physics Overview (S70)

Gerry O'Sullivan / Padraig Dunne (UCD)

Effects of Optical Thickness on Soft X-ray Spectral Feature Observed in Gd and Tb Plasmas (S54)

Chihiro Suzuki¹, Takeshi Higashiguchi², Atsushi Sasanuma², Goki Arai², Yusuke Fujii², Thanh Ding Hung², Fumihiko Koike³, Izumi Murakami¹, Naoki Tamura¹, Shigeru Sudo⁴
¹National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan
²Utsunomiya University, 7-1-2 Yoto, Utsunomiya 321-8585, Japan
³Sophia University, 7-1 Kioi-cho, Chiyoda-ku, Tokyo 102-8554, Japan
⁴Chubu University, 1200 Matsumoto-cho, Kasugai 487-8501, Japan



Laser-Produced Plasma Spectroscopy of Medium to High-Z Elements in the 2 to 9-nm Spectral Region (S55)

Elaine Long¹, Chihiro Suzuki², John Sheil³, Elgiva White³, Ragava Lokasani¹, Bowen Li¹, Paul Sheridan¹, Patrick Hayden⁴, Emma Sokell¹, Pdraig Dunne¹, Fergal O'Reilly¹ & Gerry O'Sullivan¹

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

² *National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan*

³ *Summer Intern at UCD School of Physics*

⁴ *National Centre for Plasma Science & Technology and School of Physical Sciences, Dublin City, Dublin, Ireland*

12:35 PM Lunch

1:40 PM Session 8: Applications of XUV Sources

Session Co-chairs: Torsten Feigl (optiX fab) and Larissa Juschkina (RWTH)

Multilayer Collector Optics for Water Window Microscopy (S65) (Invited)

Torsten Feigl
optiX fab, Germany

Application of Lens-less Imaging Techniques for Nano-scale Microscopy Employing Plasma-based EUV Source (S64) (Invited)

Larissa Juschkina^{1,2}, Jan Bußmann^{1,2}, Michal Odstrcil³, Raoul Bresenitz^{1,2}, Denis Rudolf²

¹ *RWTH Aachen University and JARA— Fundamentals of Future Information Technology, Chair for the Experimental Physics of EUV, Aachen, Germany*

² *Peter Grünberg Institute 9 and JARA— Fundamentals of Future Information Technology, Research Centre Jülich, 52425 Jülich, Germany*

³ *Optoelectronics Research Center, University of Southampton, United Kingdom*

Laboratory-based Photoemission Spectro-microscopy at 71.7 eV for Studies of Complex Materials (S61)

Daniel Wilson^{1,2,4,5}, Christoph Schmitz^{1,5}, Denis Rudolf^{2,3,5}, Sally Rieß^{3,5}, Martin Schuck^{3,5}, Carsten Wiemann^{1,5}, Astrid Besmehn⁶, Hilde Hardtdegen^{3,5}, Detlev Grützmacher^{3,5}, Claus M. Schneider^{1,5}, F. Stefan Tautz^{4,5}, and Larissa Juschkin^{2,3,5}

¹ Forschungszentrum Jülich, Peter Grünberg Institut (PGI-6), Germany

² RWTH Aachen University, Experimental Physics of EUV, Aachen, Germany

³ Forschungszentrum Jülich, Peter Grünberg Institut (PGI-9), Germany

⁴ Forschungszentrum Jülich, Peter Grünberg Institut (PGI-3), Germany

⁵ Jülich-Aachen Research Alliance (JARA), Fundamentals of Future Information Technology, Germany

⁶ Forschungszentrum Jülich, Central Institute for Engineering, Electronics and Analytics (ZEA-3), Germany

Water-Window Microscope Based on Nitrogen Plasma Capillary Discharge Source (S63)

T. Parkman¹, M. F. Nawaz², M. Nevrkla², M. Vrbova¹, A. Jancarek²

¹Czech Technical University in Prague, Faculty of Biomedical Engineering, 272 01 Kladno, Czech Republic

²Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, 180 00 Prague 8, Czech Republic

3:00 PM Survey (ALL) (10 Minutes)

3:10 PM Break (20 Minutes)

3:30 PM Session 9: FEL Sources for EUVL

Session Co-Chairs: Akira Endo (HiLase) and Alexander Chao (SLAC)

Picosecond, kW Thin-disc Laser Technology for LPP and FEL EUV Sources (S21) (Invited)

A. Endo^{1,2}, M. Smrz¹, O. Novak¹, H. Turcicova¹, J. Muzik¹, J. Huynh¹, T. Mocek¹, K. Sakaue² and M. Washio²

¹ HiLASE Centre, Institute of Physics AS CR, Dolní Břežany, Czech Republic

² RISE, Waseda University, Tokyo, Japan



Current Progress on Design Work of High Power EUV-FEL based on ERL (S22) (Invited)

Kensei Umemori

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

A Kilowatt Storage Ring EUV Source Based on Steady State Microbunching (S23) (Invited)

Alexander Chao, Daniel Ratner

SLAC National Accelerator Laboratory, Menlo Park, CA, USA

4:30 PM Workshop Summary and Announcements

Workshop Summary and Announcements (Summary)

Vivek Bakshi, EUV Litho, Inc.

4:50 PM Break (20 Minutes)

**5:20 PM Session 10: Poster Session (90 Minutes)
(Poster Paper Listing on Following Pages)**

7:00 PM Depart for Dinner

5:20 PM Session 10: Poster Session

Session Chair: Padraig Dunne (UCD)

Topic: EUV Sources for HVM

[Research of the Tin Droplet Generator and Plume Expansion of Laser Produced Tin Droplet Plasma \(S11\)](#)

Chen Ziqi, Wang Xinbing and Zuo Duluo
Wuhan National Laboratory for Optoelectronics,
Huazhong University of Science & Technology, Wuhan 430074, China

[Research of CO₂ Laser Produced Sn and SnO₂ plasma \(S14\)](#)

Lan Hui^{1,3}, Wang Xinbing², Zuo Duluo², Zhen Guang³
¹School of Optical and electronic information, Huazhong University of Science and Technology, Wuhan 430074, China
²Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan 430074, China
³School of Physics and information engineering, Jiangnan University, Wuhan 430056, China

[Droplet Generator for High Brightness LPP EUV Source \(S15\)](#)

Alexander Vinokhodov¹, Vladimir Krivtsun^{1,2}, Mikhail Krivokorytov¹, Yury Sidelnikov^{1,2}, Viacheslav Medvedev^{1,2}, Konstantin Koshelev^{1,2}
¹ EUV Labs/RnD ISAN, Moscow, Russia
² Institute for Spectroscopy RAS, Moscow, Russia

[ARCNL's Laser-produced Plasma EUV Source \(S18\)](#)

D. Kurilovich, F. Torretti, W. Ubachs, R.A. Hoekstra, O.O. Versolato
Advanced Research Center for Nanolithography, Science Park, Amsterdam

[A Study of Colliding Plasma Processes for Elements of Different Mass \(S19\)](#)

D.Kos¹, O. Maguire¹, P. Oudayer², P. Dunne¹, F. O'Reilly¹, and E. Sokell¹
¹School of Physics, University College Dublin, Belfield, Dublin 4, Ireland
²University of Paris-Sud, 15 Street Georges Clemenceau, 91400 Orsay, France

Topic: EUV Sources for Metrology

Combination of Discharge and Laser-produced Plasmas for High Brightness Extreme ultraviolet (EUV) Light Sources (S33)

Florian Melsheimer^{1,2,3}; Richard Lensing^{1,2,3}, Gorum Beyene^{1,2,3,4}, Xiaoduo Wang^{1,2,5}, Larissa Juschkin^{1,2,3}

¹Experimental Physics of EUV, RWTH Aachen University;

²Peter Grünberg Institut (PGI-9), Research Centre Jülich GmbH

³Jara – Fundamentals of Future Information Technology

⁴School of Physics, University College Dublin

⁵Changchun Institute of Optics, Fine Mechanics and Physics, University of Chinese Academy of Sciences)

Plasma Design of the EQ-10 EUV Source (S39)

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

Topic: XUV Sources

Feature of Unresolved Transition Array Emission in Water Window Soft X-ray Spectral Region from a Dual-pulse Laser-produced Bismuth Plasma (S51)

Hiroyuki Hara, Goki Arai, Thanh-Hung Dinh, and Takeshi Higashiguchi
Department of Advanced Interdisciplinary Sciences, Center for Optical Research & Education (CORE), Utsunomiya University, Utsunomiya, Tochigi 321-8585 Japan

Laser-produced Multiply Charged Ion Plasma Sources for a Compact Water Window Soft X-ray Microscope (S52)

Yoshiki Kondo¹, Thanh-Hung Dinh¹, Goki Arai¹, Takeo Eijima², and Takeshi Higashiguchi¹

¹Department of Advanced Interdisciplinary Sciences, Center for Optical Research & Education (CORE), Utsunomiya University, Utsunomiya, Tochigi 321-8585 Japan

² Institute of Multidisciplinary Research for Advanced Materials (IMRAM), Tohoku University, 2-1-1, Katahira, Aoba-ku, Sendai, 980-8577 JAPAN

Absorption Spectral Structure in Highly-charged Zirconium Plasmas in Water window Soft X-ray Spectral Region (S53)

Takanori Miyazaki^{1,2}, Goki Arai², Hiroyuki Hara², Thanh-Hung Dinh², Takeshi Higashiguchi², Akinobu Irie², Chihiro Suzuki³, Daiji Kato³, Akira Sasaki⁴, Padraig Dunne¹, and Gerry O'Sullivan¹
¹*School of Physics, University College Dublin, Belfield, Dublin 4, Ireland*
²*Department of Advanced Interdisciplinary Sciences, Center for Optical Research & Education (CORE), Utsunomiya University, Utsunomiya, Tochigi 321-8585 Japan*
³*National Institute for Fusion Science (NIFS), Toki, Gifu 509-5292, Japan*
⁴*Quantum Beam Science Center, Japan Atomic Energy Agency, 8-1-7 Umemidai, Kizugawa, Kyoto 619-0215, Japan*

Experimental Study of the Interaction of Sub-nanosecond and Nanosecond Duration Laser Pulses with Solid Targets at Different Laser Energies (S56)

Ragava Lokasani^{1, 2}, Elaine Long², Oisin Maguire², Domagoj Kos², Paul Sheridan², Patrick Hayden², Fergal O'Reilly², Padraig Dunne², Emma Sokell², Akira Endo³, Jiri Limpouch¹ and Gerry O'Sullivan²
¹*Czech technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Brehova 7, 11519 Praha 1, Czech Republic*
²*UCD School of Physics, University College Dublin, Belfield, Dublin 4, Ireland.*
³*Institute of Physics of Academy of Sciences of the Czech Republic, HiLase Center, Za Radnici 828, 252 4, Dolni Brezany, Czech Republic*

Colliding Laser - produced Plasma Experiments on Carbon Group Elements (S57)

O. Maguire¹, D. Kos¹, P. Oudayer², P. Dunne¹, F. O'Reilly¹, T. McCormack¹ and E. Sokell¹
¹*UCD School of Physics, University College Dublin, Dublin 4, Ireland*
²*University of Paris-Sud, Orsay, France*

Efficient EUV Sources by Short CO₂ Laser-produced Plasmas (S59)

Atsushi Sasanuma¹, Reiho Amano¹, Thanh-Hung Dinh¹, Goki Arai¹, Takeshi Higashiguchi¹ and Taisuke Miura²
¹*Department of Advanced Interdisciplinary Sciences, Center for Optical Research & Education (CORE), Utsunomiya University, Utsunomiya, Tochigi 321-8585 Japan*
²*HiLASE Centre, Institute of Physics ASCR, v.v.i., Dolni Brezany, Czech Republic*

X-ray Generation Enhancement from a Nano-structured Targets Irradiated by Long Laser Pulses (S62)

Ragava Lokasani^{1, 2}, Ellie Barte¹, Jan Proška¹, Lucie Stolcova¹, Oisin Maguire², Domagoj Kos², Paul Sheridan², Fergal O'Reilly², Padraig Dunne², Emma Sokell², Tom McCormack², Jiri Limpouch¹, and Gerry O'Sullivan²

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

ABSORPTION OF EUV RADIATION IN MATTER AND RELATED PROCESSES (S66)

Chiara Liberatore¹, Klaus Mann⁵, Matthias Müller⁵, Andrzej Bartnik⁶, Inam Ul Ahad⁶, Ladislav Pina³, Libor Juha⁴, Ludek Vyšín⁴, Jorge J. Rocca⁷, Akira Endo² and Tomas Mocek²

¹*INRS-EMT, Varennes, 1650 Boulevard Lionel-Boulet, Varennes, QC J3X 1P, Canada*

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⁷*Department of Electrical and Computer Engineering, Colorado State University, Fort Collins, CO 80523, USA*

