

2022 Source Workshop

Held Online - October 22nd - 27th, 2022

www.euvlitho.com



Workshop Proceedings



Thank You to our 2022 Sponsors

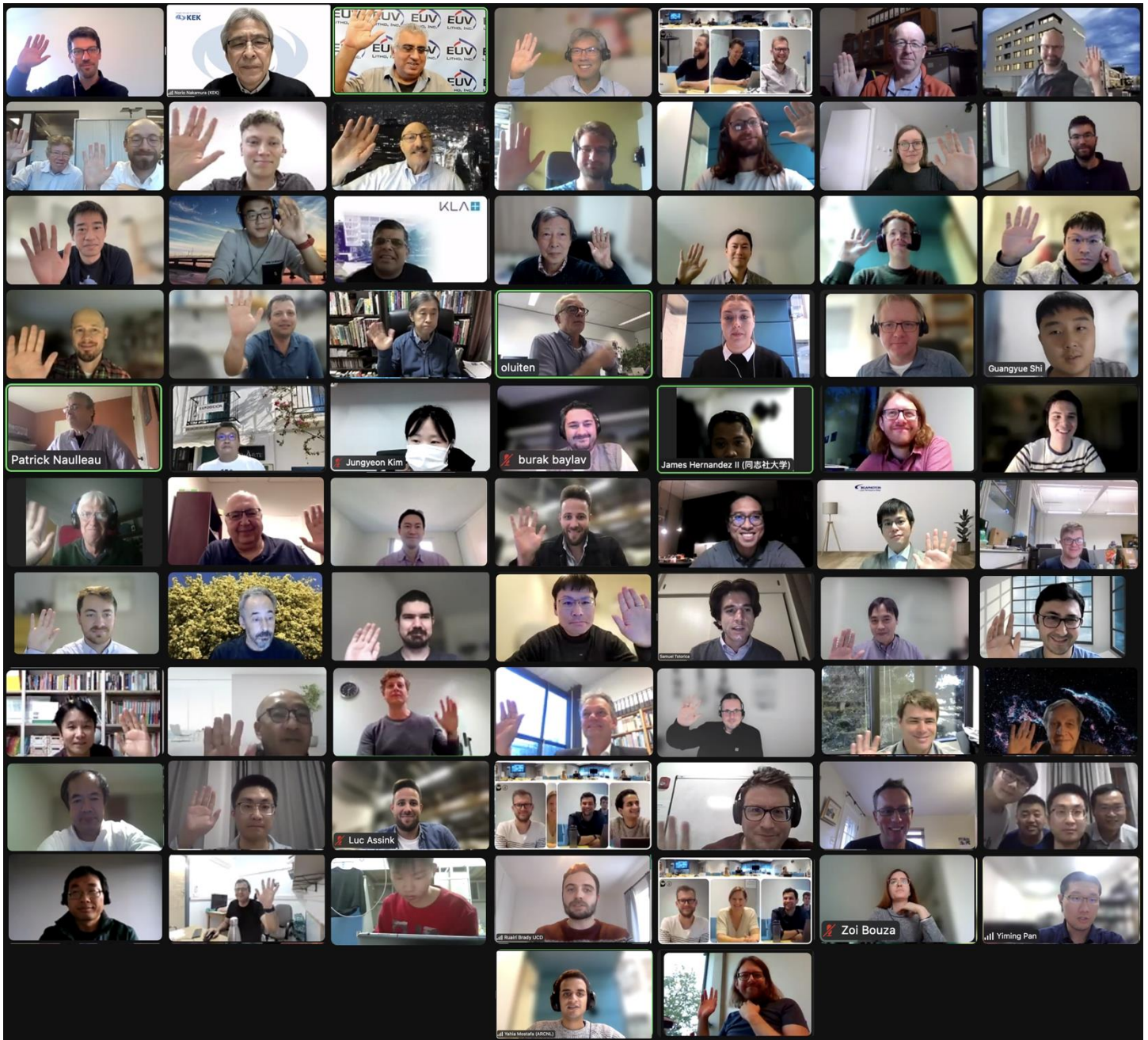


Organized by:

Vivek Bakshi, (EUV Litho, Inc.), Chair

Oscar Versolato (ARCNL), Co-Chair

2022 Source Workshop (October 22nd – 27th, 2022) Held Online



Contents

Proceedings by Presentation Order.....	pg 5
--	------

Workshop Proceedings

Day One: Monday, October 24th, 2022

[Full Video](#)

7:00 AM – 7:05 AM Introduction and Announcements

7:05 AM Session One: EUVL Extension – Blue-X (1)

Co-Chairs: Vivek Bakshi (EUV Litho, Inc.) and Oscar Versolato (ARCNL)

[Recent Progress on EUV-FEL and Its PoC Using cERL \(Invited\) \(S32\)](#)
[Presentation Recording](#)

N. Nakamura, R. Kato, H. Sakai, K. Tsuchiya, Y. Tanimoto, Y. Honda, T. Miyajima, M. Shimada, T. Tanikawa, T. Obina, H. Kawata
High Energy Accelerator Research Organization (KEK), Tsukuba, Japan

[High-Power SSMB-EUV Source Development at Tsinghua University \(Invited\) \(S34\)](#)

[Presentation Recording](#)

Xiujie Deng, on behalf of Tsinghua SSMB Task force
Tsinghua University, Beijing, China

[Smart*Light \(Invited\) \(S38\)](#)

[Presentation Recording](#)

Jom Luiten
TU Eindhoven, P.O. Box 513, 5600 MB Eindhoven, Netherlands

[10kW EUV Regenerative Amplifier FEL with Energy Recovery – Review Paper \(S31\)](#)

[Presentation Recording](#)

Dinh Nguyen, Bruce Dunham, John Lewellen, Chris Mayes and Zhen Zhang
SLAC National Accelerator Laboratory

8:40 AM Session Two: ARCNL Program Showcase

Co-Chairs: Oscar Versolato (ARCNL) and Vivek Bakshi (EUV Litho, Inc.)

[Research at the Advanced Research Center for Nanolithography \(S71\)](#)

[Presentation Video](#)

Oscar Versolato

Advanced Research Center for Nanolithography (ARCNL), Science Park 106, Amsterdam

[Strongly Anisotropic Ion Emission in Laser-Produced Tin Plasma Expansion \(S72\)](#)

[Presentation Video](#)

Lucas Poirier^{1,2}, Diko Hemminga^{1,2}, Adam Lassise¹, Ronnie Hoekstra^{1,3}, John Sheil^{1,2}, Oscar Versolato^{1,2}

¹*Advanced Research Center for Nanolithography (ARCNL), Science Park 106, 1098 XG Amsterdam, the Netherlands*

²*Department of Physics and Astronomy, and LaserLaB, Vrije Universiteit, De Boelelaan 1081, 1081 HV Amsterdam, the Netherlands*

³*Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, 9747 AG Groningen, the Netherlands*

[A Theoretical Study of Extreme Ultraviolet Light Source Plasmas Driven by Laser Wavelengths in the 1.064 – 10.6 \$\mu\text{m}\$ Range \(S73\)](#)

[Presentation Video](#)

Diko Hemminga^{1,2}, Oscar Versolato^{1,2}, and John Sheil^{1,2}

¹*Advanced Research Center for Nanolithography (ARCNL), Science Park 106, 1098 XG Amsterdam, the Netherlands*

²*Department of Physics and Astronomy, and LaserLaB, Vrije Universiteit, De Boelelaan 1081, 1081 HV Amsterdam, the Netherlands*

[Charge Exchange in Collisions of \$\text{Sn}^{3+}\$ ions with \$\text{H}_2\$ Molecules in the Energy Range 50 eV – 50 keV \(S74\)](#)

[Presentation Video](#)

K Bijlsma^{1,2}, S Rai^{1,2}, L Assink^{1,2}, M Salverda¹, P Wolff¹, A Kleinsmit¹, E Lalkens¹, E de Wit¹, I Rabadán³, L Mendéz³, O Versolato^{2,4}, R Hoekstra^{1,2}

¹*Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, 9747 AG, Groningen, The Netherlands*

²*Advanced Research Center for Nanolithography, Science Park 106, 1098 XG, Amsterdam, The Netherlands*

³*Departamento de Química, Universidad Autónoma de Madrid, Cantoblanco, 28049, Madrid, Spain*

⁴*Department of Physics and Astronomy, and LaserLaB, Vrije Universiteit, De Boelelaan 1081, 1081 HV, Amsterdam, The Netherlands*

Computational Materials Modeling to Optimize Materials Properties and Applications (S75)

Presentation Video

Emilia Olsson

Advanced Research Center, Science Park 106, 1098 XG Amsterdam, The Netherlands

Extreme-Ultraviolet Interferometry of High-Harmonics Generated from Gases and Solids (S76)

Presentation Video

Nataliia Kuzkova

¹*ARCNL, Science Park 106, 1098 XG, Amsterdam, The Netherlands*

²*Department of Physics and Astronomy, and LaserLaB, Vrije Universiteit, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands*

Ptychographic Sensing of EUV Wavefronts (S77)

Presentation Video

Antonios Pelekanidis

Advanced Research Center for Nanolithography, Science Park 106, 1098 XG, Amsterdam, The Netherlands

Monday Sessions Adjourned

Day Two: Tuesday, October 25th, 2022

[Full Video](#)

7:00 AM – 7:05 AM Introductions and Announcements

7:05 AM Session Three: Code Comparison

Co-Chairs: John Sheil (ARCNL) and Howard Scott (LLNL)

[Introduction \(S10\)](#)

[Presentation Video](#)

Howard Scott¹, John Sheil²

¹LLNL

²ARCNL

Problems 1 – 3 ([S11](#)) ([S12](#))

[Presentation Video](#)

John Sheil¹, Howard Scott²

¹ARCNL

²LLNL

[Problem 3 \(S13\)](#)

[Presentation Video](#)

Katsunobo Nishihara

Osaka University

[Problems 1 – 2 \(S15\)](#)

[Presentation Video](#)

Akira Sasaki

QST

[Problems 1 – 3 \(S14\)](#)

[Presentation Video](#)

Ming Gu

Prizm Computations

[Problem 1 – 2 \(S16\)](#)

[Presentation Video](#)

John Sheil, O. O Versolato, A. J. Neukirch, J. Colgan

ARCNL

LANL

Problem 1 (S17)

Presentation Video

Hilik Frank
LLNL

All – Group Discussion

10:15 AM Session Four: HVM EUV Sources

Co-Chairs: Kentaro Tomita (Hokudai University) and John Sheil (ARCNL)

Tabulating NLTE Data with the Linear Response Method (Invited) (S45)

Presentation Video

Howard Scott
Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

Computational Study of Magnetically Controlled Plasma and Efficient EUV Generation (Invited) (S43)

Presentation Video

Joohwan Kim
Center for Energy Research, University of California San Diego, La Jolla, CA 92093

Observation of Plasma Inflow in Laser-Produced Sn EUV Sources Contributing to Increment of EUV Light Output Using Thomson Scattering Technique (Invited) (S44)

Presentation Video

Kentaro Tomita¹, Yiming Pan², Atsushi Sunahara^{3,4}, Katsunobu Nishihara⁴
¹*Division of Quantum Science and Engineering, Graduate School of Engineering, Hokkaido University, Kita 13, Nishi 8, Kita-ku, Sapporo, Hokkaido 060-8628, Japan*
²*Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Kasuga, Fukuoka, 816-8580, Japan*
³*Center for Materials Under eXtreme Environment (CMUXE), School of Nuclear Engineering, Purdue University, 500 Central Drive, West Lafayette, IN 47907, United States of America*
⁴*Institute of Laser Engineering, Osaka University, 2-6 Yamadaoka, Suita, Osaka, 565-0871, Japan*

Kinetic Modeling of Ion Acceleration in Laser-Produced Tin EUV Sources (Invited) (S42)

Presentation Video

Samuel Totorica, Will Fox, Kirill Lezhnin, John Sheil, Oscar Versolato
Princeton University, Princeton, NJ 08544, USA

Composition of Vaporized Tin Targets Unraveled Through Multi-Wavelength Shadowgraphy (Invited) (S41)

Presentation Video

D.J. Engels, R.A. Meijer, K. Schubert, W. Ubachs, and O.O. Versolato
ARCNL, Science Park 106, 1098 XG Amsterdam

Tuesday Sessions Adjourned

Day Three: Wednesday, October 26th, 2022

[Full Video](#)

7:00 AM – 7:05 AM Introduction and Announcements

7:05 AM Session 5A: Keynote

Chair: Oscar Versolato (ARCNL)

Keynote Rescheduled (See pg 15)

7:50 AM Session Six: Lasers, HHG, and Applications ([Held in the Memory of Dr. Akira Endo](#))

Chair: Vivek Bakshi (EUV Litho, Inc.)

[In Memory of Dr. Akira Endo \(S20\)](#)

[Presentation Video](#)

Vivek Bakshi, Hakaru Mizoguchi, J. Mužík

EUV Litho, Inc.

HiLASE Centre, Institute of Physics CAS, Za Radnicí 828, 252 41 Dolní Brěžany, Czechia

[High-Brightness Table-Top Ultrafast Thin-Disk Laser Platform PERLA for Advanced Applications \(Invited\) \(S21\)](#)

[Presentation Video](#)

J. Mužík*, M. Chyla, J. Huynh, P. Sikocinski, O. Novák, H. Turčičová, M. Cimrman, M. Smrž, and T. Mocek

HiLASE Centre, Institute of Physics CAS, Za Radnicí 828, 252 41 Dolní Brěžany, Czechia

[Stand-alone EUV Spectrometer for Material, Structure and Line Roughness Analysis \(Invited\) \(S22\)](#)

[Presentation Video](#)

Sascha Brose^{1,2}, Sven Glabisch^{1,2}, Sophia Schröder^{1,2}, Henning Heiming^{1,2}, Jochen Stollenwerk^{1,2,3}, and Carlo Holly^{1,2,3}

¹*RWTH Aachen University TOS - Chair for Technology of Optical Systems, Steinbachstr. 15, 52074 Aachen, Germany;*

²*JARA - Fundamentals of Future Information Technology, Research Centre Jülich, 52425 Jülich, Germany;*

³*Fraunhofer ILT - Institute for Laser Technology, Steinbachstr. 15, 52074 Aachen, Germany*

Multipass Cell Based Nonlinear Compression of High Energy and High Average Power Amplifiers (Invited) (S23)

Presentation Video

Yanik Pfaff^{1,2}, Catherine Y. Teisset¹, Clara J. Saraceno², Thomas Metzger¹

¹TRUMPF Scientific Lasers GmbH & Co. KG, Feringastr. 10a, 85774 Unterföhring, Germany

²Photonics and Ultrafast Laser Science, Ruhr University Bochum, Universitätsstr. 150, 44801 Bochum, Germany

9:25 AM Session Seven: EUVL Extension – Blue-X (II)
Co-Chairs: Hayato Ohashi (University of Tomaya) and Fergal O'Reilly (UCD)

EUVL Extension via Blue-X – An Update (S30)

Presentation Video

Vivek Bakshi

EUV Litho, Inc.

Recent Progress and Issue of Beyond EUV Source – Review Paper (S36)

Presentation Video

Takeshi Higashiguchi

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

Soft X-ray Spectroscopy of Multiply Charged Bismuth Ions with an Electron Beam Ion Trap (Invited) (S39)

Presentation Video

Hayato Ohashi^{1,2}, Ryota Iwami², Dingbao Song³, Daiji Kato^{4,3}, Hiroyuki A. Sakaue⁴, Izumi Murakami^{4,5}, Nobuyuki Nakamura^{6,4}

¹Institute of Liberal Arts and Sciences, University of Toyama, Toyama, Toyama 930-8555, Japan

²Graduate School of Science and Engineering for Research, University of Toyama, Toyama, Toyama 930-8555, Japan

³Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Kasuga, Fukuoka 816-8580, Japan

⁴National Institute for Fusion Science, Oroshi-cho, Toki, Gifu 509-5292, Japan

⁵Department of Fusion Science, The Graduate University for Advanced Studies, SOKENDAI, Toki, Gifu 509-5292, Japan

⁶Institute for Laser Science, The University of Electro-Communications, Chofu, Tokyo 182-8585, Japan

Laser Plasmas for Soft X-Ray Sources (Invited) (S35)

Presentation Video

Benedict Delaney, Kevin Mongey, Ruairí Brady, Nicholas Wong, Mickaël Renaud, Emma Sokell, Fergal O'Reilly
UCD

2- μ m-Wavelength Laser-Produced Tin Plasma Sources of Extreme Ultraviolet Light (Invited) (S37)

Presentation Video

Lars Behnke
ARCNL, Science Park 106, 1098 XG Amsterdam, The Netherlands

EUV ML optics for high(er) NA (Invited) (S3)

Presentation Video

Marcelo Ackermann, Andrey Yakshin
University of Twente | MESA+ | XUV

1 GW Peak Power and 100 J Pulsed Operation of a Diode-pumped $\lambda = 1.9 \mu\text{m}$ Laser (Invited) (S33)

Presentation Video

Brendan A. Reagan, Issa Tamer, Thomas Galvin, František Batysta, Emily Sistrunk, Drew Willard, Andrew Church, Hansel Neurath, Justin Galbraith, Glenn Huete, Craig Siders, Steven Langer, and Thomas Spinka
Lawrence Livermore National Laboratory

11:25 AM Session 5B: Keynote
Chair: Oscar Versolato (ARCNL)

Performance, Availability, and Power Scaling of EUV Sources for High-Volume Semiconductor Manufacturing (Keynote) (S2)

Presentation Video

Elio Champenois, Igor Fomenkov, Michael Purvis, Alex Schafgans, Jayson Stewart, Peter Mayer, Klaus Hummler, Alex Ershov, Sam Crisafulli, Andrew LaForge, Yezheng Tao, Slava Rokitski, Chirag Rajyaguru, Georgiy Vaschenko, Payam Tayebati, Daniel Brown, David Brandt
ASML, 17075 Thornmint Ct, San Diego, CA 92127

Wednesday Sessions Adjourned

Day Four: Thursday, October 27th, 2022

[Full Video](#)

7:00 AM – 7:05 AM Introductions and Announcements

7:05 AM Session Eight: Speed Presentations

Chair: Vivek Bakshi (EUV Litho, Inc.)

[Development Progress of The Key Component Technologies for a Laser Produced Plasma EUV Light Source \(S81\)](#)

[Presentation Video](#)

Yuichi Nishimura, Yoshifumi Ueno, Shinji Nagai, Fumio Iwamoto,
Kenichi Miyao, Hideyuki Hayashi, Yukio Watanabe, Tamotsu Abe, Hiroaki
Nakarai, Takashi Saito and Hakaru Mizoguchi
*Gigaphoton Inc., 400 Yokokura Shinden, Oyama City, Tochigi Prefecture, 323-8585,
JAPAN*

[Investigation of Laser-Produced Plasmas During the Irradiation Using Collective Thomson Scattering \(S82\) \(Third Place Recipient\)](#)

[Presentation Video](#)

Yiming Pan¹, Kentaro Tomita², Atsushi Sunahara³, Katsunobu Nishihara⁴
¹*Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Kasuga,
Fukuoka, 816-8580, Japan*
²*Division of Quantum Science and Engineering, Graduate School of Engineering,
Hokkaido University, Kita 13, Nishi 8, Kita-ku, Sapporo, Hokkaido 060-8628, Japan*
³*Center for Materials Under eXtreme Environment (CMUXE), School of Nuclear
Engineering, Purdue University, 500 Central Drive, West Lafayette, IN 47907, United
States of America*
⁴*Institute of Laser Engineering, Osaka University, 2-6 Yamadaoka, Suita, Osaka, 565-
0871, Japan*

[Seeing the Light: In-Band and Spectrally Resolved EUV Source Imaging \(S83\)](#)

Yahia Mostafa
*Advanced Research Center for Nanolithography, Science Park 106, 1098 XG Amsterdam,
The Netherlands*

In-Band and Out-Of-Band Images of Tin Laser Produced Plasma Source Using Coupled Imaging/Spectroscopy Device (S84) (Second Place Recipient)

Zoi Bouza¹, Yahia Mostafa¹, Jane Babenko¹, James Byers², Oscar O. Versolato¹,
Muharrem Bayraktar²

¹Advanced Research Center for Nanolithography, Science Park 106, 1098 XG
Amsterdam, The Netherlands

²Industrial Focus Group XUV Optics, MESA+ Institute for Nanotechnology, University of
Twente, Drienerlolaan 5, 7522 NB Enschede, The Netherlands

Measuring the Soft X-Ray Emission Area of Water Window LPP Light Sources Using Deconvolution (S85) (First Place Recipient)

Presentation Video

Ruairí Brady, Kevin Mongey, Ben Delaney, Emma Sokell, Fergal O'Reilly
School of Physics, University College Dublin, Ireland

Compact Rotating Sn Disc Target LPP Source (Invited) (S86)
Presentation Video

Yusuke Teramoto¹, Bárbara Santos¹, Guido Mertens¹, Ralf Kops¹, Margarete Kops¹, Wilko
van Nunspeet¹, Marcel Schneider¹, Klaus Bergmann², Hidenori Watanabe³, Yoshihiko
Sato³

¹ Ushio Germany GmbH, Steinbachstrasse 15, 52074 Aachen, GERMANY

² Fraunhofer ILT, Steinbachstrasse 15, 52074 Aachen, GERMANY

³ Ushio Inc., 1-90 Komakado, Gotemba 412-0038, JAPAN

7:50 AM Session Nine: Metrology Sources

Co-Chairs: Reza Abhari (ETHZ) and Yusuke Termamoto (Ushio)

High Power LPP-EUV Source for Semiconductor HVM; Lithography and Other Applications (Keynote) (S1)

Presentation Video

Hakaru Mizoguchi, Hiroaki Nakarai, Tamotsu Abe, Hiroshi Tanaka, Yukio Watanabe,
Tsukasa Hori, Yutaka Shiraishi, Tatsuya Yanagida, Georg Soumagne, Tsuyoshi Yamada
and Takashi Saitou

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

Laser Produced Plasma EUV Source Development at ETH Zurich (Invited) (S51)
Presentation Video

Reza S. Abhari
ETH Zurich

X-Ray Generation with Industry-Class Lasers – A Model to Estimate Emission Properties (Invited) (S52)

Presentation Video

Jochen Vieker, Klaus Bergmann

Fraunhofer Institute for Laser Technology – ILT Steinbachstr. 15, 52074 Aachen, Germany

Improvement of LDP Source Performance for Patterned-Mask Inspection (Invited) (S53)

Presentation Video

Yusuke Teramoto¹, Safak Sayan², Kishore K. Chakravorty², Bárbara Santos¹, Akihisa Nagano³, Noritaka Ashizawa³, Takahiro Shirai³, Shunichi Morimoto³, Kazuya Aoki³, Hidenori Watanabe³, Yoshihiko Sato³

¹ Ushio Germany GmbH, Steinbachstrasse 15, 52074 Aachen, GERMANY

² Intel Corporation, 3065 Bowers Ave, Santa Clara, CA 95054, USA

³ Ushio Inc., 1-90 Komakado, Gotemba 412-0038, JAPAN

Probe Diagnostics for a Discharge Produced Plasma (DPP) EUV Source (Invited) (S54)

Presentation Video

David Reisman, Daniel Arcaro, and Wolfram Neff

Energetiq Technology, Inc., Wilmington, MA 01887, USA

9:05 AM Session Ten: Spectroscopy

Co-Chairs: Ronnie Hoekstra (ARCNL) and James Colgan (LANL)

Evidence for the Production of Energetic Singly-Charged Tin Ions (Invited) (S61)

Presentation Video

Ronnie Hoekstra

Advanced Research Center for Nanolithography (ARCNL), Amsterdam, the Netherlands
Zernike Institute for Advanced Materials, University of Groningen, Groningen, the Netherlands

Non-LTE Modeling of Sn Plasmas (Invited) (S62)

Presentation Video

J. Colgan¹, A. J. Neukirch¹, J. Sheil^{2,3}, O. O. Versolato^{2,3}

¹Los Alamos National Laboratory, Los Alamos, NM 87545, USA

²Advanced Research Center for Nanolithography, Science Park 106, 1098 XG Amsterdam, Netherlands

³Department of Physics and Astronomy, and LaserLaB, Vrije Universiteit Amsterdam, De Boelelaan 1081, 1081 HV Amsterdam, Netherlands

2022 Source Workshop (October 22nd – 27th, 2022) Held Online

[Experimental Determination of Relative Electron Collisional Excitation Cross Sections of Highly Charged Tin in an EBIT \(Invited\) \(S63\)](#)
[Presentation Video](#)

Marc Botz

Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany

9:50 AM Announcements

2022 Source Workshop Adjourned

