2011 International Workshop on EUV Lithography:

Workshop Summary

Vivek Bakshi

EUV Litho, Inc.

These are notes taken during the workshop. Please report any inaccuracies or omissions to the author.

Workshop Summary: Wed, June 15, 2011

- **8:40 AM ……Session 1: Keynote Presentations**
- **<u>EUV Lithography and EUVL Sources: From the Beginning to NXE and Beyond</u>** (P1) Vadim Banine, *ASML*
  - **Overview of development of EUVL field starting from 1985**
  - ADT shipped in 2006, currently under study >0.4 NA tools for 6/8 mirrors and possibly with new wavelength
  - 4 NXE 3100 shipped and one NXE3100 operational at customer site
  - 18 nm L/S resolution possible with dipole-60 inorganic negative tone resist
  - Power ~ 10 W from 2003-2010 although productivity had improved
  - Reviewed source technologies that made it and those which did not
  - End of Xe age due to low CE (0.5-1.1%) and start of Sn age
  - **Need 10 x improvement in exposure power by end of 2011**
  - Need to adjust peak transmission of 6.x throughput to match the source emission (0.6% BW for 6.x nm)
  - **<u>Need resist for 6.x nm region. Will need aperiodic ML to get better BW at 6.x and 13.5 nm</u>**
  - **<u>100X improvement in the last 10 years in the source power. Need engineering to get to 100 W.</u>**

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- **8:40 AM ……Session 1: Keynote Presentations**
- **<u>Development and Optimization of EUV Emission from Laser Produced Plasmas</u>** (P2), G. O’Sullivan, *UCD*
  - **Early work on LPP emissions in EUV region. Physics of LPP.**
  - Sn LPP emissions at various density and laser wavelengths 2.3 % at 100% Sn (P=) and 2.5% at 5 % Sn (at P =2E11 Wcm-2). Effect of power density, pulse shape.
  - Top-hat profile gave better CE than Gaussian profile.
    - Need correct pulse duration, viewing angle (2 ns long, right density and pulse shape for Nd YAG laser)
  - **For CO2 lasers-10 ns pulse CE of 5% for grove in Sn target. With pre pulse – CE upto 6% possible, with 180 nm pulse delay. <u>Need right pulse length (40 ns) for CO2 lasers to get closer to 6% CE.</u>**
  - **<u>Requirements for 6.x nm LPP for optimum emissions described.</u>**

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- **10:15 AM……………………Business Presentation**
- **Doing Business in Maui** (P39a)

  Kimberly Haueisen, *Maui Economic Development Board (MEDB), Inc.*

  - Not only resort but also excellent place for technical business.
  - Overview of facilities offered in Maui and listing of technical companies in Maui area
- **High Technology Development Corporation Manufacturing Extension Partnership** (P39b)

  Mark Ausbeck, *High Tech Development Corporation (HTDC)*

  - Offer support for startups for manufacturing

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- **10:30 AM ………………..Session 2: Patterning**
- **EUV Interference Lithography for 1X nm** (P8)

  Takeo Watanabe, *University of Hyogo*
  - **Provides platform for resist evaluation**
  - **15 nm HP L/S pattern, 28 nm CH pattern replicated. Plan to evaluate resists for 11 nm resolution**
  - Successfully addressed fabrication challenges of transmission gratings
- **EUV Lithography Simulation for the 16 nm Node** (P17)

  Eun-Jin Kim and Hye-Keun Oh, *Hanyang University*
  - Strong OAI and 8 degree oblique incidence may be needed for 16 nm
  - Higher shadow effect caused larger H-V bias
  - Higher NA gives better aerial image.
  - **Need dipole illumination for 70% contrast at 16 nm**
  - Flare needs to be < 4% for 16 nm node for acceptable delta CD or alternatively dose can be changed to get right CD
  - **Need strong OAI for 16 nm node**

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- **10:30 AM ……………….Session 2: Patterning**
- **<u>LER Metrology: Can We Trust the Numbers?</u>** (P31) (Invited Paper) Patrick Naulleau, *Center for X-Ray Optics*
  - LER is the biggest challenge facing EUV resist
  - LER and LWR- Are they interchangeable ?
  - **LWR = SQRT 2 *LER for uncorrelated roughness only – not correct if correlation is present due to LER contribution coming from mask LER**
  - Correlation length of 17 nm
  - For 10% uncertainty need 300 samples of 5 μ of images per 10 μ of edge data
  - For 1% uncertainly, need 52 images or 510 micron of edge data!
  - Analysis length 10%error – 150 nm. Do not need to measure 2 micron as required by ITRS, to get the required statistics
  - Sensitivity to changes in analysis length
  - ITRS defines LWR cutoff period as TC= HP. CD/LC =1.3
  - **Need frequency region defined for LER measurements**
  - **Average of 16 images needed for 0.1 nm precision**
  - **Care must be taken to ensure that region is not damaged by SEM**
  - **SEM noise has large effect – need to be averaging close to 100 frames**
  - **Multiple image averaging required to achieve target precision**

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- **12:15 PM …Session 3: EUV Source Modeling**
- **Radiative Hydrodynamic Simulation of Laser-produced Tin Plasma for Extreme Ultraviolet Lithography** (P10)

Atsushi Sunahara, *Institute for Laser Technology*

- Laser absorption fraction 65% and EUV CE 5.6% with pre pulse, with 300 micron laser spot diameter for 100 micron droplet
- Factors of laser absorption faction, x-ray conversion faction and spectral efficiency to be optimized with pre pulse setup to obtain best CE.
- **With 30 micron droplet, with Nd:YAG laser pre pulse, >200 micron laser focus size, 5.9% CE is possible.**

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- **12:15 PM …Session 3: EUV Source Modeling**
- **<u>Progress in Modeling of High Intensity Radiation Plasma Sources</u>** (P26), S.V. Zakharov, *EPPRA*
  - Described Capillary Discharge EUV Source. 3D-PIC modelling.
  - Non-equilibirium electron dynamics
  - EUV brightness limit of a source

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- **12:55 PM Session 4: Next Gen EUV Sources**

  Rare-Earth Plasma EUV Source at 6.7 nm for Future Lithography (P5) (Invited Paper)

  Takeshi Higashiguchi, *Utsunomiya University*

  – Start of 6.x nm choice due to presentation from ASML in 2010 EUV Source Workshop in Dublin
    - G. Tallents et al, Nature photonics, vol 4, 809 (2010).

  – Resonance line generation in 6.x nm plasma

  – Measurement of CE for Nd:YAG for target densities

  – **Used low density targets to suppress the self-absorption in the plasma**

  – **1.8 % CE before optimization**

  – **Need standard of BW for defining CE (as we did in the case of 13.5 nm)!**

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- **12:55 PM Session 4: Next Gen EUV Sources**

  Atomic and Radiative Processes in Plasmas for the Shorter Wavelength Extreme ultra-violet (EUV) Light Sources (P7)

  Akira Sasaki, *Japan Atomic Energy Agency*

  - High temperature 100 eV requires 10 x higher laser pumping power for 6.x nm plasma. Similar dependence as tin of CE on laser intensity.
  - **Advantage of using other atomic transitions like Kr and spectral properties of wide verities of lighter elements need to be conducted.**
  - Modeling of phase transition is useful for the simulation of laser ablation

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- **12:55 PM Session 4: Next Gen EUV Sources**

  Design of High Brightness Laser-Compton Light Source for EUV Lithography Research in Shorter Wavelength Region
  (P30) (Invited Paper), Kazuyuki Sakaue, *Waseda University*

  - High energy photon is produced using small accelerator system
  - **For 100 MHZ system, 10 μ W.2% BW, 20 micron size, 20 μ J pulse with 20 ps pulse for 6.7 nm source. Foot print of several m^2**

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- **2:10 PM ....Session 5: EUV Sources**
- **Optimization of Laser-produced Plasma Light Sources for EUV Lithography** (P6) Mark Tillack, *UCSD*
  - ***Study of plasma physics of Sn LPP from YAG laser***
  - Confinement by a crater results in a higher CE in a CO2 LPP (>5%)
  - **1 μ is too short and 10 μ is too long so may look at different laser wavelength and may need to look at CO laser for 5 μ wavelength**
  - Non-isothermal expansion occurs with CO2 LPP
  - Coronal density profile collapses after ~ 30 ns
  - Lower energy, fewer ions, higher charge states with CO2 laser
  - Goals for metrology source (>10 ns, stable, 10-30 μ size)
  - Nd:YAG – 40 μ spot size, max CE at 20 ns pulse length
  - EUV Source size depends more strongly on intensity and not pulse length
  - **Smallest source size may be less than 40 μ, measured brightness?**

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- **2:10 PM ....Session 5: EUV Sources**
- **<u>High Brightness EUV & Soft-X-ray MPP Discharge Source System Development</u>** (P27), Sergey V. Zakharov, NanoUV/*EPPRA*
  - Typical étendue of 1.7 E-2 mm^2 sr
  - Peak irradiance 37W/cm^2 (3 KHz, in EUV band of 3 nm)
  - 22 W at 1 KHz in 3 nm band
  - **4 sources aligned to a point without use of any solid optical collector with 2 W in 2% BW**

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- **2:10 PM ....Session 5: EUV Sources**
- **<u>EQ-10 Electrodeless Z-Pinch EUV Source for Metrology Applications</u>** (P38)

  Deborah Gustafson, *Energetiq*
  - 13.5% in 2% BW – 20 W
  - **18 systems in field. Includes two new higher power system**
  - **P>20 W with 8 W/mm^2.sr, Pulse to pulse stability of 2% with redesigned modulator**
  - Power of 25.7 W – 26.2 W/mm^2.sr via simple calculation is not correct

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- **2:10 PM ....Session 5: EUV Sources**
- **Progress on Liquid Metal Collector Mirrors as Robust Plasma Facing EUV and Soft X-ray Optics** (P18)
  Padraig Dunne, *University College Dublin*
  - 2 rev per min rotation of mirror coated with liquid metal
  - **LPP : 50 Hz, 25 W laser and 60 micron source size combined with liquid metal collector**
  - 420 μ FWHM for Xe DPP
  - Current wobble of 100 μ of mirrors is expected to go to 5 μ with new bearings

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- **2:10 PM ....Session 5: EUV Sources**
- **1st/2nd Generation Laser-Produced Plasma Light Source System for HVM EUV Lithography** (P34) (Invited Paper)

  Hakaru Mizoguchi, *Gigaphoton*
  - 13 kW, 20 ns, 100 KHz and 2% pulse stability CO2 Laser
  - **20 W average power at IF, 5% duty cycle, 7 hour operation, CE 2.1%, 20 micron droplet, 3.6 kW CO2 laser (limited due to thermal load handeling capability of support structure)**
  - **Measurement of Sn debris via LIF. Pre pulse allows full evaporation and no neutral atom remains (7% atom, 9% ions and no fragments)**
  - >99% of Sn go to Sn ion catcher
  - Cleaning rate achieved of 4.4 nm per M pls = no Sn deposition
  - **3.3 % CE realized by 20 μ droplet**

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- **9:10 AM ....Session 6: EUVL R&D Status**

  EUVL R&D in Japan (P14), T. Watanabe, *Hyogo University*
  - **EIDEC Ltd. Focus on Defect inspection of mask blank and patterned mask and Resist Development**
  - **5 Year program in Collaboration with Chip makers from outside Japan (Intel, Samsung, TSMC and Hynix)**
  - Center for EUVL in the University of Hyogo/ NewSubaru
  - 50% of EUV Mask and 70% of EUV resist suppliers are from Japan
  - Program on EUVL Pellicle. Please see presentation for details.
- **EUVL R&D in Taiwan** (P9), Bryan, B. Y. Shew, *NSRCC*
  - First EUVL Workshop in 2006 and program started in 2008
  - **EUVL1 completed and EUVL2 will continue for next three years**
  - **Programs: Fundamentals, Optics Metrology and EUVL Applications**
  - Built reflectometer, resist Outgassing test system with QMS, Interference Lithography, EUV Radiation of nano devices, optical Design and simulation

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- **9:10 AM ....Session 6: EUVL R&D Status**
- **EUVL R&D in Korea** (P33), Jinho Ahn, *Hanyang University*
  - Samsung, Hynix and Dongjin Semichen (PR) are the main customers
  - Hanyang and other universities, Pohang Accelerator Laboratory
  - Small/Med size tool makers starting work
  - **Actinic CD measurement by CSM, Attenuated PSM development, New resist material**
- **EUVL R&D in Europe** (P41), P. Dunne, *UCD*
  - UCD and collaborators in Dublin areas - ~ 30 researchers include 12 PhD students). Very Active research group.
  - **Projects in various countries**
  - COST Action MP0601 program –Final meeting (Nov 16-17, 2011)
- **EUVL R&D in USA** (P35)

  Vivek Bakshi, *EUV Litho, Inc.*

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- **10:40 AM ……………………..Session 7: EUVL Mask**
- **Developing a New State of the Art EUV Mask Imaging Research Tool at Berkeley** (P11) (Invited Paper)

  Kenneth Goldberg, *Center for X-Ray Optics*

  - **AIT5 > 6 nm resolution and any σ and angle of incidence up to 10 degree**
  - **AIT 6.7 , >? nm resolution at any σ and up to 10 degree incidence**
  - **AIT 6.7 nm beamline power of 5.6 μ W(compared to 7.6 μW at 13.5 nm) will have 50% power compared to 13.5 nm tool**

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- **10:40 AM ……………………….Session 7: EUVL Mask**
- **Overview of EUV Mask Inspection Systems in New SUBARU** (P15) (Invited Paper) T Watanabe, *Univ. of Hyogo*
  - Line cut defect repairing by FIB using EUV Microscope. 1 nm programmed pit defects were confirmed to be printable.
  - EUV coherent Scatterometry microscope. Uses HHG as light source.
  - **CSM is simple and cheap EUV mask inspection system. It can provide the figure of the defect which can then be used as a feedback to the manufacturing process**

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- **10:40 AM ……………………..Session 7: EUVL Mask**
- **<u>Development Status of EUVL Mask Blank and Substrate</u>** (P12) (Invited Paper), K Maeshige, *Asahi Glass Co. Ltd.*
  - Working to reduce full blank bow < 300 nm
  - "**NEW CHAMPION**" defect density is **0.20/cm2 (34 defects/plate) at 50nm SiO2 (34nm SEVD) w/M7360**.
  - **Champion Data: Absorber – 12 defects @ 63 nm, ML 34 defects @34 SEVD (0.25 defects per cm2)**
  - Working on 2nd gen ML blanks with new cap layer and thin absorber material

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- **10:40 AM ………………………Session 7: EUVL Mask**
- **<u>EUV Mask Production and Cleaning</u>** (P13) (Invited Review Paper), David N. Ruzic, *UIUC*
  - Technology overview of various cleaning techniques with focus on PACMAN cleaning process
  - Able to remove 30 nm+ PSL using He metastables
  - Positive bias increases cleaning rate
  - Need to maximize electric field pointing from surface to the plasma, electron flux at the sample and the helium metastable density for best cleaning rate
  - **Carbon removal rate of 1.2 E7 +/- 5E5 nm^3/min**
  - **Removal rate of 30 nm /minute with positive bias. For no bias 4 nm/min**

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- **Session 8: EUV Resist and Resist Outgassing**
- **Recent Progress in Nano-space Radiation Chemistry Research on Sensitivity Enhancements of EUV Resists** (P37) (Invited Paper), Seiichi Tagawa, *Osaka University*
  - **Acid generation is very important in solving RLS tradeoff. Good acid amplifiers are quite important in increasing acid generation.**
  - **Each resist material would have its particular value of the absorbed dose (Gray:J/kg) for pattern formation, regardless of the exposure wavelengths in the range of EUV/soft X-rays from13.5 to3.1nm**
  - **If resist sensitivity to a certain wavelength is obtained, the sensitivities to other wavelengths could be roughly estimated with respective linear absorption coefficients in the range of EUV/soft X-rays. At 6.7 nm exposure, resists containing S, P, and Si atoms have large linear absorption coefficients.**
  - **Need to improve each step to its physical and chemical limit**
  - Photo absorption cross section at 6.7 nm and 13.5 nm reported.

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- **Session 8: EUV Resist and Resist Outgassing**
- **<u>Challenges in Development and Construction of Metrology, Calibration and Resist Testing Tools for the Implementation of EUV Lithography</u>** (P3) R. Perera, *EUV Technology*
  - **CXRO tables, now widely used by the EUVL community, developed about 35 years at University of Hawaii**
  - Pioneered development of reflectometer in 1999
  - Challenges: Low volume, specifications evolving, custom designs and particle issues
  - **30 s per measurement and can measure R with 3 lambda of 0.05% and lambda of 3 sigma of 0.0005 nm. Can meet HVM specs.**
  - Can have 50 x 50 μ spot for patterned mask inspection
  - 10E-9 mbar for contamination chamber, 2000 eV electron gun
  - Advantages of using EUV photons over electrons- true dose to clear, non destructive, represent bulk properties

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- **Cleaning of Capped Multi-Layer Samples and Cleaning with Hydrogen using the Evactron® De-Contaminator** (P23)

  Christopher G. Morgan and Ronald Vane, *XEI Scientific, Inc.*
  - Developed in 1999 for cleaning electron microscope chambers
  - Cleaning via plasma radicals
  - **Cleaning rate of 20 nm/min with oxygen for resist on wafers**
  - Cleaning rate of 8 A /min at 0.1 torr with hydrogen for carbon films
  - Developing EUVL compatible versions of cleaning tool

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- **Mass Spectrometer Characterization of Reactions in Photoresists Exposed to Extreme Ultraviolet Radiation** (P29)

  Chimaobi Mbanaso, Gregory Denbeaux, *University at Albany*

  - **Outgassing data can provide insight to reactions occurring in resist films.**
  - Observed different levels of PAG decomposition depending on the PAG anion present in the resist film.
  - Higher levels of PAG decomposition may be due to higher absorption in resist film (Higher fluorine content in PAG)
  - The mass spectrometer measurements correlated reasonably with sensitivity measurements on a hot plate.
  - Not clear from measurements the dominant reaction pathway for PAG decomposition upon EUV exposure.
    - Photo-absorption of PAG or
    - Reactivity with generated electrons from ionization of polymer

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- **2:45 PM……………………Session 9: EUV Optics**
- **<u>Status of Multilayer Coatings for EUV Lithography</u>** (P25) (Invited Review Paper) Y. Platonov, *RIT*
  - **Spec and achieved performance of various EUV optics**
  - 70.15% at 13.5 nm present record from FOM
  - Stress level reduced to -20 MPa and Good thermal stability achieved
  - **Infrastructure review**
  - **La2O2/B4c 42.8% at 6.63 nm La/B4C 49.83% at 6.656 nm**
  - **Higher NA optics will need further development**

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- **2:45 PM……………………Session 9: EUV Optics**
- **<u>Surface Metrology and Polishing Techniques for Current and Future-generation EUVL Optics</u>** (P32) (Invited Review Paper), R. Soufli, LLNL
  - **Review of evolution of polishing capabilities for EUVL optics**
  - Zerdour – dual phase, limit on polishing-0.14 nm rms
  - ULE – single phase material (Striae and inhomogeneties have been preventing its use in EUVL projection optics
    - Guessed to be material of choice as substrate for future projection optics
  - **Advanced polishing techniques developed for synchrotrons and FEL can be used for EUVL collector optics**
  - **Perspectives on 6.x nm Lithography**

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Workshop Summary: Thursday, June 16, 2011

- **2:45 PM……………………Session 9: EUV Optics**
- **<u>Surface Metrology and Polishing Techniques for Current and Future-generation EUVL Optics</u>** (P32) contd… (Invited Review Paper), R. Soufli, LLNL
  - Accurate values for the optical constants (refractive index) of materials are crucial for the modeling of EUV multilayer performance.
  - **Recently determined experimental values for the optical constants of B4C (R. Soufli et al, Appl. Opt. 47, 4633-4639, 2008) and Boron (M. Fernandez-Perea et al, J. Opt. Soc. Am. A 24, 3800-3807, 2007) enable accurate modeling of B4C- and B-based multilayers in the 6.x nm region, for next-generation EUVL.**
  - More work is needed in this field of research.

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Workshop Summary: Thursday, June 16, 2011

- **2:45 PM……………………Session 9: EUV Optics**

  <u>Developing Reflective Multilayer Coatings, an Enabling Component of Extreme Ultraviolet Lithography and Beyond</u> (P24) (Invited Paper)

  E. Louis, *FOM*

  - STW funded imaging work at 13.5 nm (1992)
  - Development of Barrier layers
  - Depth graded ML
  - Compounded interlayer systems – 70.3% @ 13.5 using Y interlayer
  - Mo/Si ML >600 C is possible
  - **6.x optics development -Simultaneous optimization of source and optics needed**

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Thank you!

- Thanks for making 2011 EUVL Workshop a success! Special thanks to:
  - EUVL Workshop Steering Committee
  - Session Chairs
  - Presenters
  - Makena Beach and Golf Resort Staff
  - Donna Towery and Thomas Cummins
  - **2011 EUVL Workshop is planned for June 4-8, 2012 in Maui, Hawaii!**
- **Hope to see you again in June, 2012 in Maui, Hawaii!!**

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2011 International Workshop on EUV Sources

2011 International Workshop on EUV Sources

UCD, Dublin, Ireland, Nov 7-9, 2011

Agenda

Nov 7, 2011: Registration

Nov 8-9, 2011: Presentations

Additional info to be made available at:
WWW.EUVLITHO.COM