2011 International Workshop on EUV Lithography:

Workshop Summary

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These are notes taken during the workshop. Please report any inaccuracies or omissions to the author.
• **8:40 AM ……Session 1: Keynote Presentations**

**EUV Lithography and EUVL Sources: From the Beginning to NXE and Beyond** (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)
- **Need resist for 6.x nm region. Will need aperiodic ML to get better BW at 6.x and 13.5 nm**
- 100X improvement in the last 10 years in the source power. Need engineering to get to 100 W.
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• 8:40 AM ......Session 1: Keynote Presentations

• Development and Optimization of EUV Emission from Laser Produced Plasmas (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. Need right pulse length (40 ns) for CO2 lasers to get closer to 6% CE.
  – Requirements for 6.x nm LPP for optimum emissions described.
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• **10:15 AM........................Business Presentation**

• **Doing Business in Maui** *(P39a)*
  – 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
• LER Metrology: Can We Trust the Numbers? (P31) (Invited Paper) Patrick Naulleau, Center for X-Ray Optics
  – LER is the biggest challenge facing EUV resist
  – LER and LWR- Are they interchangeable?
  – \( LWR = \sqrt{2} \times LER \) 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**
- **Progress in Modeling of High Intensity Radiation Plasma Sources** (P26), S.V. Zakharov, *EPPRA*
  - Described Capillary Discharge EUV Source. 3D-PIC modelling.
  - Non-equilibirium electron dynamics
  - EUV brightness limit of a source
• 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
- 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 \( \mu \) W.2% BW, 20 micron size, 20 \( \mu \) 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
• High Brightness EUV & Soft-X-ray MPP Discharge Source System Development (P27), Sergey V. Zakharov, NanoUV/EPPRA
  – Typical étendue of 1.7 E-2 mm² sr
  – Peak irradiance 37W/cm² (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
• EQ-10 Electrodeless Z-Pinch EUV Source for Metrology Applications (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 $\sigma$ and angle of incidence up to 10 degree
- AIT 6.7, >? nm resolution at any $\sigma$ and up to 10 degree incidence
- AIT 6.7 nm beamline power of 5.6 $\mu$W (compared to 7.6 $\mu$W at 13.5 nm) will have 50% power compared to 13.5 nm tool
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

• Development Status of EUVL Mask Blank and Substrate (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**

  **EUV Mask Production and Cleaning** (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 nm³/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 from 13.5 to 3.1 nm.
  - 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**
- **Challenges in Development and Construction of Metrology, Calibration and Resist Testing Tools for the Implementation of EUV Lithography** (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**
  - **Status of Multilayer Coatings for EUV Lithography**
    - (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
    - La$_2$O$_2$/B$_4$C 42.8% at 6.63 nm  La/B$_4$C 49.83% at 6.656 nm
    - Higher NA optics will need further development
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- **2:45 PM....................Session 9: EUV Optics**

  - **Surface Metrology and Polishing Techniques for Current and Future-generation EUVL Optics** (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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• 2:45 PM........................Session 9: EUV Optics

• Surface Metrology and Polishing Techniques for Current and Future-generation EUVL Optics (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.
  – More work is needed in this field of research.
2:45 PM...............Session 9: EUV Optics

**Developing Reflective Multilayer Coatings, an Enabling Component of Extreme Ultraviolet Lithography and Beyond** (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
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!!**
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