2012 International Workshop on EUV Lithography

Workshop Summary

Vivek Bakshi

EUV Litho, Inc.

Meeting notes. Please let the author know about any errors.

Workshop Agenda: Wednesday, June 6, 2012

- **8:40 AM ……………………Session 1: Keynote Presentations**

  EUV Lithography at Insertion and Beyond (P1) : Yan Borodovsky, *Intel*
- EUVL HVM insertion method – complementary patterning
- **Edge Placement Error – EPE reduction is one of the key benefit of EUVL**
  - **Image EPE is multivariate function of 3D EUV mask scattering, Overlay (OL), Stochastics, etc.**
  - **We want EPE EUVL (OL, Stochastics) <EPE 193i (OL, Stochastics) at HVM Insertion**
  - **Given 5 nm limit for EPE at HVM CD 3 sigma = 3 nm will be very tough for EUV Stochastic**
- **Significant OPC infrastructure needed for correcting EUV 3D mask effects**
- NXE33XX must have throughout >100 WPH at insertion
  - 193 I tools have **>250** WPH TPT and EUVL need to match **COO**.
- CD 3 sigma<3nm for contacts ~20 nm diameter. 60 mJ/cm^2 resist needed for HVM for pattering all of contacts on a chip with 98% probability and 5% Expose Latitude
- **Need 4 X more powerful sources than currently being considered (1 KW and higher)**
  - 100wph EUV scanner supporting complementary EUV by printing 20nm holes with +/-5% Exposure latitude resulte in need for slow (>60mj/cm2) resist to make sure that all 10^{10} contact holes on the chip are open with 98% probability in order to overcome shot noise statistics which in turn result in a need for 4X in band power at IF against currently targeted 250W for HVM.
- **New ideas and focused effort is necessary to enable concept, design and implement such sources**
- There is no benefit in developing higher resolution EUVL through NA>0.33 or λ=6.8nm unless resist stochastics effects can be reduced ~2X from current best CAR platforms levels

EIDEC: Status, Target & Persistent Effort

(Soichi Inoue, EIDEC< Keynote talk)

Core Element 0 Score 10	Current Status	Target	Persistent Effort
Source 	~10W @IF	250W @IF	- Laser stability - Droplet generator stability - Debris mitigation - OoB reduction
Scanner 	- NXE3100 / CDU: 1.4nm, DCOL: <1nm	Place NA0.33 to market in 2013	- Productivity
Mask 	- ϕ-defect : 20-30/plate (>50nm) - Particle:	Ideally : 0	- ϕ-defect mitigation - To establish ABI - Handling/cleaning/pellicle
Resist/Process 	- Resolution:16nm - Sensitivity : 30~mJ/cm^2 - LWR : ~ 5 nm	- 11nm - 10mJ/cm^2 - ~ 1.1 nm	- Thinner resist thickness - Hardmask process, bias control - LWR: build up consensus
Litho Integration 	Small experience	Ready for HVM	Learn more - Defectivity - Total CD control - Total OL control

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- **8:40 AM ……………………<u>Session 1: Keynote Presentations</u>**
- **Persistent Efforts to Overcome the Challenge of EUVL** (P3)

  Soichi Inoue, *EUVL Infrastructure Development Center, Inc. (EIDEC)*
- Presented scenario of EUVL insertion – device type / timing / nodes
- Technical challenges: Source (250 W @ IF, Stability, collector lifetime), Scanner (field data, long lifetime), Mask (blank inspection, particle free handling), Resist (Resolution , 20 nm, sensitivity < 10 mJ, LER < 2 nm, lower outgassing)
- 2011-13 (16 nm Hp), 2014-16 (HP 11 nm)
- Patterned mask inspector – several suppliers (e-beam or actinic)/ blank inspector –
- Challenges for "Effective" phase defect free blank
- LTEM-ML blank status (AGC, 2011) - 21 defects @ 50 nm
- New feature of ABI tool – defect review mode
- E-beam based PMI for 16 nm feature size progress – 24 nm defects identified
- SFET for resist exposure
- **16 nm L/S resolved using dipole illumination**
- **Flash Lamp Post-bake process for LWR reduction 3.8 nm for 18 mJ resist**
- Outgas evaluation procedure for resist outgassing tool using E-beam and EUV based tools
  - Fluorine was detected by XPS only at unexposed area of EUV sample
- **Pre-pulse is the main technology for improving the source power**

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- **10:30 AM ……………<u>Session 2: Panel Discussion (EUVL HVM Insertion and Scaling)</u>**
- Moderator: Sushil Padiyar (AMAT) (P4)
- **Panelists Presentations:**

Yan Borodovsky (P5), Intel Corporation

- **Adopt EUVL when yields and COO will become beneficial. Logic complementary and DRAM Con Litho will drive early EUV HVM adoption**
- 1000 W Source, OL< 2 nm, Dose<0.5%, added print defect <<10E-2 cm2, OPC: Fast 3D Mask + stochastics, residual model and correction errors < 1.5 nm max, resist blur <5 nm
- **Full 100 WPH or more at insertion, gradual during Pilot phase**
- **Stay at 0.33 NA and 13.5 nm**
- **Alternate concepts – liquid metal jet (Koshelev), new DPP supplier? FEL, Laser Compton effect, higher rep rates, what about 11 nm Xe?**
- Increased source power requirements at smaller nodes – but power requirements have remain the same (for 32 and 22 nm HP have been missed so we need to think about higher power to overcome more prevalent stochastics at lower nodes)
- HVM insertion mode is shifting to Holes patterning so focus must shift from resist for best L/S LER/resolution/sensitivity to resist for best EPE for Contact holes.
- **Even if initial cost is large, if tools can be used for long time, investments can be recovered**

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- **10:30 AM ……………<u>Session 2: Panel Discussion (EUVL HVM Insertion and Scaling)</u>**
- **Panelists Presentations:**

  Takashi Kamo – Toshiba

  - **EUV-AIMS will not be available at the early stage of HVM. Use 3D-SEM and Litho simulation as alternative**
  - **Need mask R&D for high NA and shorter wavelength**

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- **10:30 AM ……………Session 2: Panel Discussion (EUVL HVM Insertion and Scaling)**
- **Panelists Presentations:**

  Pawitter Mangat (P7), GlobalFoundries
  - **2016 is the earliest opportunity for HVM insertion, most probably in 2017**
  - **Need to match productivity with 193i tools**
  - **All success is dependant on source power**
  - EUVL will be first used for contact and VIA levels – single exposure, low pattern density
  - Zero defect printability needs a lot of mask supporting infrastructure
  - Need to be ready for OPC for EUV.
  - Tight overlay specs but additional challenges associated with EUV
  - If EUV works, use double patterning, If not then triple patterning is very expensive option and not well received by foundry customers
  - **We must need to make it work at 13.5 before changing the wavelength.**

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- **11:45 AM ………………….Awards and Group Photo**
- **"EUV Technology" received Outstanding Contribution Award**
- Attendees voted to give the Workshop's **Best Poster Award** to ***High CE Technology for HVM EUV Source****,* by Hakaru Mizoguchi and Shinji Okazaki of Gigaphoton.

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- **1:00 PM …………………..<u>Session 3: Beyond EUV (BEUV)</u>**
- **Possibility of EUVL System at the Wavelength of 6.8 nm** (P34) Hiroo Kinoshita, *University of Hyogo*
  - Summarized the status of resist, ML and source. Transmission and penetration depth become larger, but the source power is low and bandwidth is small.
- **Fundamental Property of 6.X-nm EUV Emission** (P23)

  Takeshi Higashiguchi, *Utsunomiya University*
  - **Plasma properties at 6.x nm – low density targets 0.6% CE.**
  - Other plasma at 6.x via phosphorus
  - **Droplet generation for Gd may be difficult**
- **Investigating the Effects of Laser Power Density, Pulse Duration and Viewing Angle on a 6.7nm BEUV Source** (P15)

  Padraig Dunne, *University College Dublin*
  - Maximum CE of 0.44% for mass limited targets for 0,52% for double pulse.).6% BW of MLM.
  - **Target geometries and angle of measurements must be reported along CE. There may be an optimum angle for collection.**

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- **2:20 PM ………….Session 4: Mask and Mask Metrology**
- **Effect of Mask Roughness on Mask Inspection** (P35) Patrick Naulleau, LBNL
  - Mask phase roughness must be carefully considered when using defocus to enhance detection
  - **Increasing inspection NA is highly effective in reducing mask roughness effects**
  - The problem is worse for low NA 6.7 nm than high NA 13.5 nm
- **Development of Actinic Mask Inspection Systems** (P33) Hiroo Kinoshita, *University of Hyogo*
  - **Using the HHG-CSM system, the detection limit of defect size was improved from 10 nm with SR-CSM system to 2 nm**

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- **2:20 PM ………….Session 4: Mask and Mask Metrology**

- **Optical Design of Absorber Materials for Reduced H-V CD Bias in EUV Lithography** (P38)

  Seongchul Hong, *Hanyang University*

  - **H_V CD bias are not only effected by CD bias but also by illumination conditions (thickness of absorber stack and optical constants of the absorber material)**

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- **8:40 AM ……………………Session 5: Contamination**
- **Resist-outgas Testing and EUV Optics Contamination at NIST** (P21)

  Shannon Hill, *NIST*
  - **ASML Resist Test Protocol Review**
  - Working with four commercial resist suppliers
  - Admitted-gas studies at NIST for contamination studies
  - **Contamination rate may NOT increase proportionately with power (one less thing to worry about 1 kW power requirement)**
  - **However at higher power, carbon may be more difficult to clean by atomic hydrogen (as deposited carbon gets closer to graphite)**
  - **Presence of S doe not necessarily result in high contamination rate**
  - **DUV Out-of-band light may pose greater risk to optics than in-band 13.5 light**
  - Cleaning by atomic hydrogen. Loss due to repeated H cleaning?
  - Effect of cap material?

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- **8:40 AM ……………………Session 5: Contamination**
- **Development of the Novel Evaluation Tool with an In-situ Ellipsometer for the Thickness Measurement of the Contamination Originated by the High Power EUV Irradiation on EUV Resist** (P27)

  Takeo Watanabe, *University of Hyogo*
  - Some PAG has higher sensitivity to EUV as compared to E Beam.
  - Undulator based beam line for high EUV intensity
  - **In-situ spectroscopic ellipsometer operational**
  - Relationship between rate of contamination in real time and adhesion

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- **Nanoparticle/AMC Contamination Control and Metrology for the Extreme Ultraviolet Lithography (EUVL) Systems** (P19)

  David Y.H. Pui. *University of Minnesota*
  - Review of mask protection schemes
  - Effect of secondary packaging – helps in reducing particle contamination
  - Particles come mostly from contact points
  - Best protection – little particle deposition with face down mounting and a cover plate
  - Thermophoresis overcomes diffusion
  - Si02 particle down to 30 nm have been deposited on quartz mask blanks
  - **Use soft X-rays to illuminate particles in the presence of AMC**
  - **Method developed to avoid Haze during AMC**
  - Difficult to clean small particles generated during shipping in containers

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- **Strategies for Cleaning EUV Optics, Masks and Vacuum Systems with Downstream Plasma Cleaning** (P42)

  Christopher G. Morgan, *XEI Scientific, Inc.*

  - Carbon cleaning from Si-capped ML optics
  - Large chamber cleaning with higher power and lower pressure
  - **50 W – 12 A /min cleaning rates for deposited carbon with jumbo electrodes, 55 cm away from the plasma source. Upto 0.4 nm at 1 m distance. Uniform cleaning**
  - **Localized cleaning via "TEM sample holder type" design with cleaning rates of 7 A /min with lower pressure**
  - ASML requirements of no ions – testing using Langmuir probe to see the presence of ions if any
  - Looking at source of particles

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- **Recent Developments in Construction of Metrology, Calibration, and Resist Testing Tools for the Successful HVM Implementation of EUV Lithography** (P43)

  Rupert Perera, *EUV Technology*
  - EUV reflectometer / EUV resist outgassing tools / Hydrogen cleaners
  - Challenges in developing tools with low volume, evolving specifications, custom designs, particle issues (detecting <60 nm particles and lack of third party particle data)
  - Use LPP source with Cu tape target in 5 to 20 nm range
  - Required performance for the HVM reflectometer (0.7% precision in 3 σ)
  - Upgraded resist outgassing tool to NXE3100 guidelines
  - No significant outgassing from stage movements – via RGA testing
  - **Difference between E Beam and EUV source for outgassing testing is observed for carbon deposition:**
    - **EUV – 1.77 nm and E gun 1.09 or 1.4 nm (Resist 1)**
    - **EUV - 3.2 nm E gun 1.44 (Resist 2)**
  - Hydrogen radical cleaner

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- **10:40 AM ……………………………<u>Session 6: Optics</u>**

  EUV Multilayer Coatings: Potentials and Limits (Review Paper) (P26)

  Sergiy Yulin, *Fraunhofer*

  - Interface engineering important for reflectivity and stability
  - Address interface roughness, diffusion and top surface contamination
  - **Enhance reflectivity with diffusion barriers Mo_2C better than B_4C and the Maximum reflectivity benefit is 1-2 %**
  - Thermal stability of Mo/Si – Max temperature of 100 C, structural damage at 700 C
  - Collector with R>56 % T<= 600C developed
  - TiO_2 and Nb_2O_5 as new oxidation resistant layers as for Ru cap, loss of 0.3% within six months in ambient atmosphere, more sever loss in the presence of H2O vapor
  - **Loss of Ru, TiO2 and Nb2O5 cap layers by H2 cleaning for carbon removal –high diffusion through cap**
  - **La and B are not the best material for multilayer mirrors due to stability**
  - **Lifetime of EUVL optics is still actual issue for EUVL community**

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- **Multilayer Mirrors for EUVL: Status and Progress** (P22)

  Yuriy Platonov, *Rigaku Innovative Technologies*
  - **Collector optics - Radial variation of reflectivity improved to 0.5% angular variation of reflectivity upto 300 mm, R of 67%**
  - **Illuminator optics – average 66% reflectivity**
  - 69.2 % reflectivity via ion beam polishing of substrate
  - Carbon as interface layer gives better results for thermal stability and reflectivity, as compared to B4C
  - **ML for 6.x nm – set of experiments (still 49% of RIT is the best)**
- **Recovery Strategies for Mirrors with Boron Carbide-based Coatings for 6.x nm Lithography** (P24)

  Mónica Fernández-Perea, LLNL
  - B and B_4C Optical constants calculations verified experimentally
  - **UV- ozone technique for recovery of B and B4C layers (oxygen radicals react with HC to form volatile species) – roughness, X-ray reflectance, thickness and thickness uniformity of B4C is decreased. Will explore alternative techniques**
  - This can be used as a technique for removal of B4C layer

- **1:00 PM……………Session 7: High Power EUV Sources**
- **Component Technologies of HVM Source for Reliable, High Average Power Operation (Review Paper)** (P32)

  Akira Endo, *Waseda University* and *HiLASE Project*
  - **Gigaphoton Update: 90 K Hz, 30% Duty Cycle, 4.7% CE**
  - Main challenges of LPP : No fragment generation and deposition, metal vapor control (Ideal Sn Target – total tin atoms needed - 5E12 -13 corresponding to ~ 10 micron droplet). Mist target is realized with 10 micron droplets
  - V_{ion} (ns plasma)> V_{ion} (ps plasma) Strong impulse continues < 10 ps due to plasma shield.
  - **ps laser is better for pre-pulse and need high beam quality for 10 micron spot size focusing**
  - **Laser options: thin disk laser (100 micron for effective cooling) – 500 W and ps pulse length**
  - Main pulse radiation – ion flux characterization
  - **We can increase the operation frequency to 1 M Hz (also in order to increase the source power)**
  - **Laser Pedestal causes cluster pre-heating so low pedestal is necessary**
  - **CO2 laser absorption is via giant resonance in optical absorption**
  - **Pre pulse – 5 mJ, ps thin disc laser, ns low pedestal ns CO2 laser**
  - **25 kW four modules, mist target generated via pre pulse for kW EUV sources**

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- **1:00 PM……………Session 7: High Power EUV Sources**
- **Investigation of Atomic Processes of High-Z ions in Plasmas for EUV Applications** (P14)

  Akira Sasaki , *Japan Atomic Energy Agency*
- Investigate properties of new atomic transitions that can be applied for 6.7 nm sources
- NLTE code comparison workshops
- Rare earth targets of Tb/Gd are expensive and high melting temperature
- 3d-4f transitions of near Ni-like Kr Ions
- 180- 200ev from Kr (Co like and Fe like ions) – not strong emissions
- **Co-like Mo^{15+} gives peaks at 6.9 and 7.5 nm - T_e 43 eV at 6.8 nm 0.5% BW, spectral efficiency of 1%**

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- **2:00 PM ………..Session 8: EUV Sources for Metrology**
- **Novel EUV Light Sources for Photolithography** (P13)

  Masami Ohnishi, Kansai university
  - Small rotamak 13.56 MHz, 10 kW input, 14 W EUV, 1-1.5 cm, CE 0.85%
  - Large rotamak 200 K Hz, 50 K W, 60 W EUV
  - **Microwave plasma – 1.5 mm size, 10.6 W EUV, CE 3.5 %, 2.45 G Hz, broadband EUV measurement using Zr filter**
- **Recent Progress on High Brightness Source Collector Module for EUV Mask Metrology** (P17)

  Padraig Dunne, *UCD*
  - **Etendue 10E-4 mm2sr, Brightness 80 W/mm2sr, 24 hours operation, 34 x 55 micron spot measured, CE > 1%, viewed at 45 degrees, sigma 0.3%, 3% collection, at IF 250 x 400 microns, IF stability – position 7%, size 8%**
  - Roadmap to >500W/mm^{2}sr, 100 hours continuous

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- **2:00 PM ………..Session 8: EUV Sources for Metrology**
- **Electrodeless Z-Pinch EUV Source for Metrology Applications for Today and the Future** (P16)

  Deborah Gustafson, *Energetiq Technology*
  - 400 micron Electrodeless Z-pinch source at 13.5 nm
  - 20 W in 2% BW in 2 pi, 8 W/mmm2sr brightness, 20 ns plasma lifetime
  - **6.7 nm source for resist development - Ne VII, 70 mW of 2 pi**

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- **3:20 PM…………Session 9: EUV Resist and Patterning**
- **Status and Challenge of Chemically Amplified Resists for Extreme Ultraviolet Lithography (Review Paper)** (P29) Takahiro Kozawa, *Osaka University*
  - Relationship between LER and chemical gradient fo CA resists
  - Chemically amplified resist with Anion bound acid generator
  - Sensitization mechanism of EUV resists
  - Non CA resists
  - **The advantage of high NA is lost due to increase in transparency of the resist.**
  - **For 6.x nm lithography we need high absorption resists**
- **Evaluation of Resist Performance with EUV Interference Lithography for 22 to 11 nm HPs** (P18)

  Yasin Ekinci, *Paul Scherrer Institute*
  - Interference lithography
  - For EUV resist 16 nm HP is demonstrated (30 mJ resist)
  - For sub 16 nm sensitivity is HP independent
  - At 6.5 nm for HSQ resist – HP 22 nm resolved

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- **Chemical Reaction Analysis based on the SR Absorption Spectroscopy for the High Sensitive EUV Resist** (P28) Takeo Watanabe, University of Hyogo
  - Sensitivity of CA resist
  - **Ionization reaction and PAG excitation needs to be taken into account to understand and potentially increase the EUV resist sensitivity**
- **EUV Resist Development Status toward sub-20nm Half-Pitch** (P36) Tooru Kimura, *JSR Corporation*
  - **For sub 20 nm HP resists we need short acid diffusion PAGs, suppression of pattern collapse and optimization of development process**
  - **Acid diffusion length was reduced by 86% via changing PAG backbone to rigid structure – such resists show higher resolution**
  - **Development of underlayer – silicon hard mask helps with pattern collapse**
  - **Short develop time helps with process window**
  - **20 nm HP, 3.3 nm LER and 16 mJ resist (16 nm HP achieved)**

Thank you!

- Thanks for making 2012 EUVL Workshop a success! Special thanks to:
  - EUVL Workshop Steering Committee
  - Session Chairs
  - Presenters
  - Sheraton Maui Resort Staff
  - Donna Towery , Larry Eichinger and Imam Kambali
  - **2013 EUVL Workshop is planned for June 10-14, 2013 in Maui, Hawaii!**
- **Hope to see you again in June, 2013 in Maui, Hawaii!!**

EUV Litho, Inc.

2012 International Workshop on EUV and Soft X-Ray Sources

Dublin, Ireland
October 8-11, 2012

First Call for Papers

Abstract Submission Deadline: **August 17, 2012**
Abstract Submission: abstracts@euvlitho.com

Contact for additional information:
Vivek Bakshi (vivek.bakshi@euvlitho.com) and Padraig Dunne (padraig.dunne@ucd.ie)

Registration and Travel Information Coming Soon at www.euvlitho.com

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