2013 International Workshop on EUV Lithography

Workshop Summary

June 10-14, 2013

Makena Beach & Golf Resort

Maui, Hawaii

Workshop Agenda: Wednesday, June 12, 2013

- **8:40 AM ……Session 1: Keynote Presentations**
- **EUVL in HVM: Prospects and Challenges** (P1): Sam Sivakumar, *Intel Corporation*
- Main benefit in EUVL is from Cuts and vias due to reduction in number of masks
- NXT to NXE overlay is better than NXT to NXT overlay
- Basic 3100 performance appears to be in line with ArF
- **Power delivery reasonable and getting better. Slips of source power and Lack of power remains the main impediment to EUV HVM**
- **Reticle defects are tremendously expensive**

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- **8:40 AM …….Session 1: Keynote Presentations**
- **EUVL in HVM: Prospects and Challenges** (P1):
- **How you maintain a clean reticle? In-situ reticle inspection? Pellicles are needed to ensure reticle cleanliness**
- 22 nm baseline data –contact/metal resistance Electrical performance – match ArF performance
- **Yield data – There appears to be no fundamental roadblock to EUV achieving yield parity with ArF –as issues are not related to EUVL**
- **Need progress on key issues in the next 1- 1.5 years**

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- **8:40 AM ……Session 1: Keynote Presentations**
- **Tatsuhiko Higashiki (Toshiba)**
- **At 1x nm and below –non EUVL choices are not attractive –in fact they are scary! EUVL remains the only alternative – with the help of DP and DSA**
- **Cycle time cannot be described on CoO – opportunity time is lot of money and we cannot afford loss of cycle time**
- Economical factor is dominant criteria for a lithography strategy
  - For Memory Device; Throughput, Investment & Si Process Cost
  - For Logic Device ; Mask Cost, Cycle Time

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- **10:30 AM ……Session 2: Panel Discussion (EUVL HVM Insertion and Scaling)**
- Sam Sivakumar (P72), *Intel Corporation*
- **EUV currently targeted as primary option for 7nm node (2015 development, 2017 HVM)**
- Are the key technical challenges going to be solved in time to deliver a COO less than ArF MP in this time frame?

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- **10:30 AM .....Session 2: Panel Discussion (EUVL HVM Insertion and Scaling)**
- Sushil Padiyar (P74), *Applied Materials*
- **8-12nm HP Patterning Paths with EUVL for 2017-2020 (Options and Challenges)**
  - 13.5 nm DP
  - 13.5 nm with Hyper NA
  - 6.x nm
- **Best Guess for 5-7 nm (Options and Challenges)**
  - 13.5 nm EUV / SADP
  - 193i Multi patterning +EUV

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- **10:30 AM .....Session 2: Panel Discussion (EUVL HVM Insertion and Scaling)**
- Sushil Padiyar (P74), *Applied Materials*
- **450mm EUV Insertion**:- There are engineering challenges with chamber technologies on similar scale as beam tool TPT scaling (litho source power, implant etc). AMAT is solving the chamber engineering issues (edge uniformity and control for example) with ingenuity but the cost aspects of such engineering solutions (chamber as well as beam) is to be further understood. (slide 6)
- **On EUV vs. 193i**, our view is that 193i multi-patterning will exist even with 450mm with EUV 450mm dependent on source power hitting >150-250W in HVM. (slide 7)
- On EUV 13.5nm vs. 6.xnm in the 450mm era, the current view is that 13.5nm multi-patterning would be a better choice considering the long development time taken for 13.5nm development. (slide 8)
- **DSA Comments**:- The positional accuracy and repeatability requirements for self-assembled patterns will challenge sub-10nm node industry requirements. Current uncorrectable positional accuracy is ~3nm (3-sigma). So, it's not just defectivity as a risk for DSA adoption, it's also positional accuracy risk. It would have to be combined with some "self-aligned" process flow to mitigate the poor positional accuracy.
- (Comments provided by Sushil Padiyar – please refer to his presentation in the proceedings)

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- **10:30 AM ……Session 2: Panel Discussion (EUVL HVM Insertion and Scaling)**
- Tatsuhiko Higashiki (P71), *TOSHIBA*
  - All kind of memory will be shrinking
  - **Semiconductor business will mature, if lithography & mask cost reduction is not performed**
  - **For 450 mm, Investment improvement is 7%, ratio of gross up is 230%**
  - 9 inch Mask is prefer to shrink exposure field in memory device
  - EUVL+DSA DSA may become one big choice in the future.

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- **10:30 AM .....Session 2: Panel Discussion (EUVL HVM Insertion and Scaling)**
- Pawitter Mangat (P73), *GlobalFoundries*
- Semiconductor Industry cannot afford any more delay for EUV Industrialization. **Need EUVL ready in the next 2 years.**
- Maximizing Lithographic performance from current 0.33NA systems is critical for HVM for multi-node solutions
  - EUV mask optimization (thinner absorber) will enable EUV extensibility
- **High NA decision for future needs to be agreed upon by industry soon due to long lead time for development**

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- **Contamination Control in EUV Exposure Tools** (P22)
- Katsuhiko Murakami, *Nikon Corporation*
- **Oxygen introduction during EUV exposure effectively mitigates carbon contamination growth on optical elements in EUV exposure tools.**
- Carbon contamination on optical elements can be removed by UV dry cleaning. It can be applied to an on-body cleaning method in EUV exposure tools.
- **Surface oxidation of multilayer mirrors during EUV exposure can be prevented by using metal-oxide capping layer.**
- Particles in a vacuum chamber fly very long distance. **Silica aerogel** is suitable material to capture such flying particles in EUV exposure tools.

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- **Outgassing, Photoablation and Photoionization of Organic Materials by the Electron-impact and Photon-impact Methods** (P23) (Invited)
- Grace H. Ho, *NUK, Taiwan*
- **Demonstrated the accountability to measure "gases" qualitatively and quantitatively at NSRRC in Taiwan.**
- Studied underlying chemistry of Resist outgassing.
  - Fragmentation partition mainly at certain bond positions and evolved with the increasing impact energy.
  - Weak thickness but structural and absorption dependent.
- **Investigated electron-impact and photon-impact ionization over an extensive energy range**- Matching ~ the same impact energy.
- **Using EI may under-estimate the outgassing rate from aryl compositions.** Electron or Photon impact source for testing—using EI may underestimate?
- Studied Thickness dependence of resist outgassing

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- **Measurements of the Role of Secondary Electrons in EUV Resist Exposures** (P29) (Invited)
- Greg Denbeaux , *University at Albany*
- Experimental design to Study Electron chemistry of secondary electrons
- **Direct measurement of electron penetration depth and direct measurement of electron blur**
- Results to be used to improve resist modeling software

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- **Advancements in Understanding Plasma Cleaning** (P27)
- C. Moore, *XEI Scientific*
- **Study of Pressure and Geometry effect of plasma cleaning.**
- **Gas pressure selection is a key for maximizing cleaning rate**
- **Study of plasma effect on various materials**

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- **Multilayer Mirrors for EUVL: Progress status** (P52) (Invited), Yuriy Platonov, *RIT*
- **Collector optics**
  R(avg)≈54.3%, CWHM=±0.75% - un-polarized beam
- **Illuminator optics**
  CWHM for all 5 optics is within +/-0.8%
  Reflectivity at 45deg for s-polarized beam reaches 70%
- **SO optics**
  CWHM: +/-0.3%, R(M2 optics) ≥ 64%
- **Refurbishment**
  – **Mo/Si on a buffer layer: ~1% after two refurbishment cycles**
- **ML for 6.X nm**
  – **~52% reflectivity at AOI=6deg.**
  – Expected: R(La/B4C)~ 54%, R(La/C/B)~61%

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- **EUV related Technology Development at L-3 Integrated Optical Systems** (P51)
- Keith Carrigan (Invited), L-3 Communications
- **Advantages of Metal Optics –Electrodeless super polished Nickel-plated aluminum**
- **EUV Collector with IR rejection**
- EUV Project History

- **GI Collectors for EUV/BEUV Sources for Metrology** (P53) (Invited)
- Ladislav Pina, RIT Europe
- Long history of GI replicated optics for EUV and XUV applications

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- **A New Design Method for Extreme Ultraviolet Lithographic Objective (P54)**
- Yanqiu Li, *Beijing Institute of Technology*
- **High quality 0.3 NA EUVL Objective**
- **A grouping design method using off axis real ray calculation is proposed.**
- The method is effective for reducing design variables and controlling incidence angles on reflective mirrors.
- With this method, the initial configurations of objective is suitable for further optimization to meet the requirements

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- **8:40 AM ……Session 5: EUVL Regional Reviews**
- **<u>EUVL Activities in Japan (P61)</u>**
- Takeo Watanabe, Hyogo University, Japan
- **New Subaru** Synchrotron – reflectometer and contamination studies
- EUV Microscope for EUV mask inspection
- Coherent EUV Scatterometry Microscope for CD measurements
- EUV Interference Lithography using transmission grating – 15 nm L/s, 28 nm CH
- Resist chemical reaction study via SR absorption spectroscopy
- **EIDEC program review – EUV Resist Material and Processing**

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- **8:40 AM ……Session 5: EUVL Regional Reviews**

- **<u>EUVL Activities in Europe (P62)</u>**
- Padraig Dunne, *University College Dublin, Ireland*
- ISAN: On-line MLM cleaning, LPP source modeling, BEUV sources
- Aachen- EUV/XUV microscopy for mask blank inspection
- University of Padova- study of damage threshold on ML optics
- EPPRA- Modeling and experiment (with NaexStream)
- UCD, TCD and DCU
- ETHZ – ALPS II with 259 W/mm^{2}sr
- Prague - EUV and XUV
- ASML – 11 systems under preparation
- IMEC – working on EUV Extendibility
- Xtreme n

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- **EUVL Activities in USA (P63)**
- Gregory Denbeaux, University of Albany, USA
- NIST – resist outgassing testing studies
- **UIUC – Magnetic ion mitigation and Hillock formation, tin cleaning**
- EUV technology – EUV reflectometer and resist outgassing tool, EUV hydrogen radical cleaner
- XEI Scientific – plasma cleaning
- **Purdue – plasma simulation**
- Energetiq- In and out of band EUV sources
- **UCSD – Xe LPP development**
- Cymer – 50 W with 0.5% dose stability
- EUV –ERC Overview mask imaging and Nano imaging/ metrology
- LLNL and Zygo – NA 0.5 MET development
- RIT – Ready for volume production of optics as well as R&D
- **CXRO – High NA**
- **SEMATECH – Resist Performance test at Berkley, Mask blank defect reduction**
- SEMATECH EMI consortium and SEMATECH Nano defect Center

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- **EUVL Activities in S. Korea (P64)**
- Jinho Ahn, Hanyang University, S. Korea
- **Device makers – Samsung and SK Hynix**
  - **Samsung to get NXE3300 in 2013 and 2014, Hynix in 2014**
  - **Samsung plans to insert EUVL in mid 2014 for 2x node**
- Kumho Petrochemical – Photoresist
- Hanyang University, SKKU, Inha University, POSTECH
- Tool makers : FST, Auros Tech
- **Hanyang Univ. Projects**
  - Inspection of printed defects
  - Coherent scattering microscope
  - EUV pellicle simulation

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- **<u>EUVL Activities in Taiwan (P65)</u>**
- Yang-Tung Huang, National Chiao Tung University, Taiwan
- Bryan Shew – organized NSRRC activities of dedicated beamline for EUVL –ready by July 2013
  - **Projects: Reflectometer, Resist Evaluation system and EUV interferometer**
- Timeline of EUVL development @ Taiwan (since 2006)
- EUVL II Project description

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- **<u>EUVL Activities in China (P66)</u>**
- Yanqui Li, Beijing Institute of Technology, China
- EUVL Work funded by four government organizations
- 2-mirror system for 0.1 NA, LPP source, 250 nm L/S in 2007
- EUVL Optical design for 4,6, and 8 mirror systems
- EUVL optics – Mo/Si ML coatings with reflectivity of 65% for 450 mm wafers
- EUVL Metrology project in BIT- PS/PDI measurements – 5 nm rms accuracy with 0.55 nm rms
- Source – DPP and LPP very basic research
- EUV resist patterning – 30 nm with LER<2 nm from SR source
- Lithography simulation

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- **10:40 AM ……Session 6: EUV Sources**
- **Progress in Laser-Plasma Sources – 13.5 nm & Beyond** (P12)
- Padraig Dunne*, University College Dublin*
- *Early EUVL at LPP at NIST in 1984*
- *13.5 nm – time resolved Sn emission, simulation of Sn LPP using CRETIN, NLT Source*
- *Novel colliding plasma substrate for HVM source, CE of 3.5%*
- *6.x nm Tb and Gd work. Temporal width reduced at lower power density*
- ***6.x nm emission from Gallium (liquid at 30 C) and Ge targets. Te of 50-60 eV. CE may be greater than Gd.***
- Water window – 2.4 -4.4 nm Zr

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- **10:40 AM .....Session 6: EUV Sources**
- **Modeling of Laser plasma Interaction for EUV Sources toward Higher Power and Efficiency** (P14)
- Akira Sasaki, Japan Atomic Energy Agency
- Accurate modeling of atomic process and radiation hydrodynamics is required for 6.x nm sources
- Atomic structure of Ni-like W –modeling and experiment – for 6.x nm sources
- **Formation of Sn mist (proposed for higher CE Sn LPP) and interaction of laser with mist cannot be calculated using conventional models.**
- **Developed models using Lagrange mesh and remeshing to calculate large motion of fluid –take into account instability of initial plasma formation**
  - **Need hydrodynamic models that take into account phase transition are needed –molecular dynamic simulation cannot be used**

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- **10:40 AM .....Session 6: EUV Sources**
- **Electrodeless Z-Pinch EUV Source for Metrology Applications** (P15) (Invited)
- Deborah Gustafson, *Energetiq Technology, Inc.*
- Mask inspection tool results from Lasertech
- Mask inspection tool roadmap from Zeiss
- Critical parameters for EUV sources and Performance Data
- **Introduction of laser to Xe pinch for higher brightness source – modeling shows potential of increasing brightness of 100 mW/sr.mm2**
  - **Looking for funding for the project**

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- **10:40 AM .....Session 6: EUV Sources**
- **High Brightness Source at ETHZ, Bob Rollinger**
- 3 sources in operation
- **New ALPS II facility**
- **1 kW YAG laser, upto 20 KHz, 35 mW, >200 W/mm2sr, >8KHz, 90 micron FWHM source, > 1% CE**
- High Brightness collector
- Droplet generator and probe description
- Multi-scale modeling of droplet-based LPP
- Droplet based LPP specific studies
- Looking at gallium droplets for 6.x nm sources

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- **1:20 PM……Session 7: EUV Mask**
- **Remaining Challenges for EUV masks for HVM introduction** (P33) (Invited), Pawitter Mangat, Global Foundries
- **Zero defect printability is not the same as zero defect mask**
- EUV Mask manufacturing flow
- **Challenges**
  - **Fiducial strategy and Blank supply with Fiducials**
  - **Defect location accuracy relative to fiducials**
  - **Upfront identification of blank defects that print**
  - **Defects >100 nm**
  - **Fiducial SEMI P-48 under reconsideration. AGC wants 50-200 nm depth for marks.**
  - **EUV Electron Backscatter – 50 keV electron beam**
  - **Black border –Added Challenges**
  - **Mask Cleans – Maximizing Lifetime is essential – Opportunity for dry cleans to maximize lifetime**
  - **Added Mask Lifetime Challenges-Back side Mask defectivity after exposure**
- **New Opportunities**
  - **Thinner absorber**
  - **Pellicle development**

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- **Recent Activities of the Actinic Mask Inspection using the EUV Microscope at Center for EUVL** (P32) (Invited)
- Takeo Watanabe, *University of Hyogo*
- EUV actinic inspection with EUV microscope
  - Source-bending magnet, 300- 6000 x, 10 nm resolution, bright field, amplitude and phase defect observation
  - Printability of programmed defects established
  - **Repair of clear defect – by removing the ML under the clear defect by Ga ion beam of FIB, EUV light will not be reflected**
- EUV Microscope using a high magnification objective of 3-ML mirrors
  - **Higher magnification 1460 x resolution using EUV CCD camera**
  - Larger field of view over 160 microns
  - **88 nm mask pattern was observed**

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- **<u>Improved Photon Shot Noise Effect on LWR by using attenuated PSM for EUVL (P31)</u>**
- Seejun Jeong, Hanyang University
- Larger photon shot noise due to higher photon energy and fewer photons
- Simulation by PROLITH
- LWR
  - 12% PSM - 7, 17 % improvement over binary
  - 6% PSM -8, 8.5 % improvement over binary
  - binary – 9
- **LWR vs. 1/sqrt N**
- **Confirmed that it is first order diffracted photons are informative photons that effect PN**

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- **2:40 PM……Session 8: Resist and Patterning**
- **Development of Novel Molecular Resist Materials based on Ladder-Type Cyclic Oligomers for Extreme Ultraviolet Laser Exposure System** (P41) (Invited)
- Hiroto Kudo*, Kansai Univ*ersity
- **Molecular resists based on Noria Derivatives (Oligomer derivatives)- smaller LER roughness as compared to polymer resists is expected in future**
- Sensiometric curves of resists as well as exposure at NewSubaru

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- **2:40 PM……Session 8: Resist and Patterning**
- **EUV Resist Development for 16 nm Half Pitch** (P43) (Invited)
- Yoshi Hishiro, JSR Micro Inc.
- LWR improved via short acid diffusion length
- **Higher Tg polymer to reduce LWR – via incorporation of high Tg monomers into standard resins**
  - **15.4 mJ, 5 nm LWR, Z factor – 3.32E-08**
- **Resists with high Tg resin shows good resolution**
- **Development of high absorption resin by introducing species in the back bone - -improve sensitivity by 15%**
- **Development of underlayer Hard mask- Si HM to resist pattern collapse – best contact angle 109 degrees. It also increased sensitivity by 15%**
- **EUV topcoat to remove OOB – OOB increase LWR from 4.6 to 6.8. Topcoat brings LWR to 5.0 nm**
- **Firm rinse reduces pattern collapse & decreases LWR by 15%**
- **EUV+DSA allowed increase of sensitivity and improved CDU**
- **Achieved 14 nm L/S and 18 nm CH,**
- **On NXE3300 – 13 nm HP and 14 nm CH resists**

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- **2:40 PM……Session 8: Resist and Patterning**
- **Stochastic Effects in Chemically Amplified Resists for Extreme Ultraviolet Lithography** (P44) (Invited)
- Takahiro Kozawa, Osaka University
- It is important to extract as much as possible information from SEM image as much as possible
- Half pitch, exposure does and LER relationship measured on SFET
- **Amount of chemical reaction required at 16 nm HP increases by 74% compared to 60 nm HP**
- **Optimum diffusion length for 16 nm L/S pattern is ~ 10 nm**
- **Relationship between protected unit fluctuation and LER**
- **+/-0.31 -+/- 37 sigma fluctuation of protective units contributed to LER formation**
- Resolution dependence of dissolution point was estimated

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- **Recent Activities of the EUV Resist Research and Development at Center for EUVL** (P45) (Invited)
- Takeo Watanabe, *University of Hyogo*
- **Patterning at EUVL –IL**
  - **Improvement of resolution by reduction of vibration effect**
  - **At EUVL-IL for 15 nm L/S**
- SR Absorption Spectroscopy
  - Why the sensitivity of resists (A,B,C) is different?
- **Contamination Evaluation**
  - Contamination thickness vs. Exposure Condition
  - **Linear correlation between EUV and EB was observed for carbon contamination**
  - **Non-cleanable elements from anions of PAG were observed**

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- **Sub-10nm HP Patterning using EUV based Self-Aligned Double Patterning** (P46)
- Sushil Padiyar, Applied Materials
- **8 nm L/S demonstrated via Source /resist optimization**
- **193iSAQP: the other alternative to EUV SADP – has 2 x process time and cost issues**
- 9/10 nm HP EUV –SADP demonstrated post etch
- **Low temp CON hole shrink may provide the path to CON scaling for sub 10 nm node**
-

Thank you!

- Thanks for making 2013 EUVL Workshop a very productive workshop! Special thanks to:
  - Workshop Sponsors
  - EUVL Workshop Steering Committee
  - Session Chairs
  - Presenters
  - Makena Resort Staff – Michelle and Sandy
  - Donna Towery, Sean Huang, Bethany and Art Mariscal
  - **2014 EUVL Workshop is planned for June 23-27, 2014 in Maui, Hawaii!**
- **Hope to see you again in June, 2014 in Maui, Hawaii!!**

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2013 International Workshop
on EUV and Soft X-Ray Sources

Dublin, Ireland
November 4-7, 2013

Upcoming Workshops

2014 International Workshop on EUV Lithography

Maui, Hawaii

June 23-27, 2014