2014 International Workshop on EUV Lithography

Vivek Bakshi

Workshop Summary

June 23-27, 2014

Makena Beach & Golf Resort, Maui, Hawaii

(Workshop Summary are notes taken by author during the workshop. Please point out any errors or omissions to the author)

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Workshop Agenda: Wednesday, June 25, 2014

- **8:40 AM ....Session 1: Keynote Presentations**
- **<u>EUV: The Computational Landscape (P1)</u>**
- Vivek Singh, *Intel Corporation*
- Moore's Law, at its heart, is about creating innovation to give the world what it wants.
- Intel is continuing Moore's Law because there is a demand for it, and because it makes economic sense. It can continue because the innovation-enabled technology pipeline is full, and that, paraphrasing Mark Twain and Mark Bohr, "rumors of scaling's death are greatly exaggerated!"
- In terms of choices for upcoming technology nodes, Intel is doing 14nm with 193nm lithography, and for 10nm, there is an EUV pilot line in addition to the primary approach of 193i extension.
- At the moment, one of the main imperatives for EUV is to have 40-80W stable sources in the field, which is not enough power for high volume manufacturing, but is enough to start technology development.
- Overall, Intel will insert EUV when productions tools are available and affordable.
- In terms of computational lithography, the infrastructure that has been developed for 193nm patterning will serve as a significant foundation for solving the unique challenges of EUV, including flare, shadowing, electromagnetic scattering, and out of band radiation. While these problems will require new solutions, like so much else about Moore's Law, these too will be invented.

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- **8:40 AM ……….Session 1: Keynote Presentations**
- **One hundred Watt Operation Demonstration of HVM LPP-EUV Source (P2)** Hakaru Mizoguchi, *Gigaphoton Inc.*
- EUV light transmission is only 2% for 11 mirror scanner!
- **Pre-pulse technology: ps pre pulse can increase CE to 5% (50% improvement over ns pre-pulse)**
- Components: Droplet generator technology: 20 micron with 480 micron spacing at 100 KHZ demonstrated
- Diffraction grating based collector mirror to reduce IR light (with <10% EUV light)
- **20kW CO_2 laser system upgrade planned**
- **Prototype # 2 284 W at source, 62 W at IF, 3.9%, 5% duty cycle, 50 K Hz. Doubling frequency will double power to >100 W. Continued adjustment. Planned shipment in 2015**

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- **10:20 AM ....Session 2: EUV Sources**
- **Development of Scalable Laser Technology for EUVL applications (Invited Talk) (P21)**
- Tomas Mocek, *HiLASE Project, Czech Republic*
- Working on many applications for new lasers
- Upscaling novel DPSSL geometries- **Beamline B: kW glass thin-disc laser system: 500 mJ, 1- 2 ps, 1 K Hz / 5 mJ, 1-2 ps, 100 KHz, M^2=1.2**
- High brilliance and high rep rate metrology source development
- **Beamline C: Goal -3.3 mJ, 150 K Hz, 500 W, <10 ps, Current: 0.8 mJ, 85 W 100 K Hz, <2 ps**

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- **10:20 AM ………………….Session 2: EUV Sources**
- **Gain Enhancements of CO_2 Laser Amplifiers by Using Transverse-gas-flow Configuration to Boost up Driving Powers for EUV Generation (Invited Talk) (P24)**
- Koji Yasui, *Mitsubishi Electric Corporation*
- **Transvers gas flow CO_2 lasers – higher amplifier gain (means higher power), lower gas flow speed and short length to achieve stable operation.**
- **1.6 x time power than axial-flow CO2 for same input of 400 kW**
- **Output power of 21 kW (33% duty cycle) – four amplifiers driven by two-line oscillator, output pulse 23 ns**
- Beam quality comparable to axial flow lasers

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- **In-Situ Cleaning of Sn EUV Sources (Invited Talk) (P42)** David N. Ruzic, *UIUC*
- Generate H radicals at the collectors. Flux from a point-source radical generator decreases as 1/r2
- No sputtering of Si or Mo observed. No damage of surfaces
- **Some loss (~4.4%) loss of reflectivity from H based tin cleaning.**
- **Reflectivity loss was smaller (1.26%) when only cap layer was exposed to plasma cleaning**

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- **EUV Source: Progress & Challenges (Invited Talk) (P27)**
- Klaus Schuegraf, Nigel Farrar, *Cymer*
- **Six NXE3300 B systems qualified and shipped (100 wafers per day needed for product development)**
- **NXE3350B integration started**
- 13 nm HP L/S, 18 nm HP CH from NXE3300B
- **NXE3100 sources have >70% availability with 70G pulses average lifetime (>100G pulses needed for HVM)**
- Initial usage – 10 G pulses /per month
- Source power and Source availability are the important factors for productivity
- >30kW from high power CO2 laser prototype achieved with good beam quality
- 4% CE demonstrated with pre-pulse (50 K Hz, high duty cycle) on lab source
- **Dose margin = Open loop power – Closed loop power. Current 35%, <10% control demonstrated in lab.**
- **75 W open loop power, 70W stabilized (stand alone lab source)**
- **Stand alone lab sources in field configuration - ~ 40 W, 20 kW lasers, 2.5 % CE and 35% dose margin. >5 G pulses collector protection demonstrated with no reflectivity loss**

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- **1:00 PM ....Session 3: Regional Reviews of EUVL Related Activities**

Strong commitment to EUVL as evident by activities at Universities, national labs and supplier.

- EUVL Related Activities in Korea: Jinho Ahn (P31)
- EUVL Related Activities in Europe: Tomas Mocek (P32)
- EUVL Related Activities in Taiwan: Kuen-Yu Tsai (P33)
- EUVL Related Activities in Japan: Hiroo Kinoshita (P34)
- EUVL Related Activities in USA: Greg Denbeaux (P35)
- EUVL Related Activities in China: Yanqui Li, Zhen Cao (P36)
- **1:50 PM ....Break (20 Minutes)**

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- **2:30 PM ....Session 4: Optics**
- **Progress of Optical Design for EUV Lithography tools in BIT (Invited talk) (P56)**

  Yanqiu Li, Zhen Cao, *Beijing Institute of Technology*
- Beyond 11 nm new designs strategies are required for 13.5 nm based EUVL
- **Design of co-axial objective systems**
  - 1. 6M objective with central obscuration (NA0.5)
  - 2. 8M unobscured objective (NA0.4)
  - 3. 10M objective with central obscuration (NA0.75)
- **Design of off-axial objective systems**
- 6M unobscured objective (NA0.4)
- **Design of EUV illuminator**

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- **<u>Large Reflectometer for EUV Optics</u> (P55)**
- Hiroo Kinoshita, *University of Hyogo*
- Largest reflectometer to measure 800 mm optics
- Requirements for LPP Collectors:
  - Figure: Ellipsoid
  - Diameter: > 660 mm
  - Sag: > 150 mm
  - Weight: > 40kg
  - Reflectivity: > 50% @13.50 ±0.03 nm
  - Removal of infrared light
  - Easy refurbishment
- Operational now and ready for measurements

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- **<u>Progress with EUV optics deposition at RIT (Invited Talk)</u> (P57)**
- Yuriy Platonov, *Rigaku Innovative Technologies*
- In-line Gen 2 system with improvement over Gen 1 system
  - **Deposition of upto 750 mm optics**
  - Velocity profiling for illuminator optics
  - High volume production
  - Separate reactive deposition chamber
- New EUVL Optics Refurbishment facility (etch and clean)
  - Upto 250 mm optics
  - Programmable refurbication and cleaning process

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- **9:10 AM ………Session 5: Keynote -2**
- **<u>Current Status and Expectation of EUV Lithography (P3)</u>**
- Takayuki UCHIYAMA, *TOSHIBA*
- **High NA EUVL is the most promising candidate for sub-10 nm lithography**, because of its patterning potential.
- **Higher power source will be required for sub-10 nm. An FEL is one of the candidates for future high power source. Comparison with FEL?**
- Damage due to high power EUV light for all optics is concern for durability.
- Alternative platform resist should be considered more for sub-10 nm.
- DSA will be complementary technology to all other lithography for sub-10 nm.

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- **A New EUV Mask Blank Defect Inspection Method with Coherent Diffraction Imaging (Invited Talk) (P63)**

  Kuen-Yu Tsai, *National Taiwan University*
- **A non-imaging defection inspection method with non-imaging optics hardware- Defect feature estimation from scattering signal**
  - For the first time, both hardware and software complexity become quite manageable for high-resolution defect detection
- Zero-bias size estimation seems feasible
- Some level of detector noise resistance
- Location determination manageable by subsequent defect reviews
- **Preliminary results indicate promising feasibility**

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- **Recent Results from the Measurement of Reflectivity of EUV Lithography Masks Blanks and Absorbers (Invited Talk) (P64)**
- Rupert C. C. Perera, *EUV Tech*
- Product overview
  - **Reflectometer 4th GEN – Change measurement angle from 5-10 degrees (from present 6 degrees)**
  - **Spot size 1.8mm x 1.8 mm^2 , 3 sigma of 0.3 %**
  - Can measure absorber reflectivity, measure reflectivity of patterned mask
  - Develop their own wafer transfer system
- Resist Outgassing tool
- Stand alone EUV Scatterometer

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- **10:00 AM ....Session 6: EUV Mask**

- **Improved Stochastic Imaging Properties in Contact Hole Pattern by Using Attenuated PSM for EUVL (P65)**
- Jung Sik Kim, *Hanyang University*
- PSN deteriorates CER and CDU in CH pattern
- **Thin attenuated PSM – improvement in image contrast and ILS, CDU and CER improved, Dose to size were reduced**
- **Simulation done using PROLITH**
- **PSN effect was effectively mitigated with PSM**
- **Verified performance for L/S and planned for CH**

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- **Advanced Mask Patterning: Inspection/Metrology and Cleans Requirements & Approaches (P68)**
- Sushil Padiyar, Applied Materials
- EUV Mask Cleans
  - **Defect free blank/mask interfaces during blank mfg. and fab HVM will require multiple cleans and they need to be effective damage free cleans**
  - **0.018% reflectivity loss per clean. 0.02 nm Ru surface roughness change for 50 cleans (for Ru Cap mask blanks)**
  - **<0.05 nm clean CD loss per clean**
  - **Decrease in defects from 5K to 200 (10-50 nm defects)**
- EUV Mask Etch
  - <2 nm 3s EUV mask etch CDU demonstrated. Ready for EUV HVM
- Defect Evolution through SADP Flow
  - How to identify defect adders in the process flow (using programmed Defects)
  - DUV Dual-channel inspection results (<10 nm)
  - Need for polarization, improved optics and sources

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- **10:00 AM ....Session 6: EUV Mask**
- **<u>Overview of Actinic Mask Inspection System in NewSUBARU (Invited Talk) (P67)</u>**
- Hiroo Kinoshita, *University of Hyogo*
- **Coherent EUV Scattering Microscope (CSM)**
- HHG sources at 13.5 developed with RIKEN
- 1 μ W, divergence 0.17 mrad, coherent EUV power 1000 x improvement over SR
- **2 nm defect can be observed in 1000 s (NOW)**
- Improvement of low beam flux
  - 80 x 120 nm defect detection is now possible in 1 s
- Phase defect observation by CSM
  - height estimation of 6.1 nm compared to 6.2 nm from AFM
- **Phase Defect of 25.5 nm width with 1.4 nm height can be detected**

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- **12:40 PM...........................Session 7: EUV Resist**
- **<u>Theoretical Study on Stochastic Effects in Chemically Amplified Resist Process for Extreme Ultraviolet Lithography (Invited Talk) (P71)</u>**
- Takahiro Kozawa, *Osaka University*
- Relationship between Protection unit fluctuation and pattern defects
- To eliminate pinching with 6.1 μ length, 1.2-1.6 sigma difference is required
- Probability for stochastic defect generation rapidly decreases with decreasing HP
- The increase of molecular weight is effective for the suppression of stochastic effects but not an option for 11 nm node
- **For the suppression of LER and Stochastic effects it is essential to increase the protection ration without decreasing the quantum efficiency**
- **Summary of design of materials for 16 and 11 nm node. Identified the parameter that are needed for the characterization of the material**

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- **<u>Direct Visualization of the Impacts of EUV Mask Roughness (Invited Talk) (P72)</u>**
- Patrick Naulleau, *LBNL, Berkeley, CA, USA*
- Focus plays dominant role in roughness induced LER
- AFM is blind to true EUV roughness, as it measures on the top of ML only
- **Scatterometry measures true EUV roughness**
- **Measurement of multilayer speckle with SHARP good fit between SHAPRP and modeling**
- **System modeling points to EUV roughness requirements close to 50 pm**

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- **Novel EUV Resist Materials and EUV Resist Defects (Invited Talk) (P74)**
- Yoshi Hishiro, *JSR Micro*
- **LWR and Z factor are improved by the increase of resin Tg**
- **Proved that well-suppressed acid diffusion, potentially provides better resolution**
- Profle control improves pattern collapse
- **By reducing resist hydrophobicity, good defectivity could be achieved**
- **May be able to push to 14 mJ sensitivity**

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- **The Role of Secondary Electrons in EUV Resist (Invited Talk) (P75)**
- Greg Denbeaux , *University of Albany*
- **EUV resist exposures are fundamentally secondary electron chemistry, not photon chemistry**
- Need to know secondary electron distribution
- Better EUV resist = higher quantum yield, lower Z value
- Fast reaction indicates benzene is a good indicator of PAG reactions
- PAG decomposition reactions per incident electron

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- **Optics Contamination from Resist Outgassing: Lessons Learned (Invited Talk) (P41)**
- C. Tarrio, *National Institute of Standards and Technology*
- 2007 round robin of outgassing measurements showed 4 orders of magnitude difference, which was then reduced to 30%
- Water has strong effect on benzene and isobutene contamination at low pressure
- In 2007 ASML proposed witness-sample testing
- **2013 round robin showed large variation in outgassing results (4 resists, 4 sites).**
- **Potential reasons – chamber geometry, ambiguity in interpreting SE measurements and Interpreting E0 measurements, Temperature**
- **When fully analyzed, data from round robin agrees well**

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- **2:40 PM…………………Session 8: Panel Discussion**

- **Panel Presentations**

Hakaru Mizoguchi, *Gigaphoton* (P12)

Takayuki Uchiyama, *Toshiba* (P13)

Sushil Padiyar, *AMAT* (P14)

Nigel Farrar, Cymer /ASML (P15)

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Upcoming Workshops

Thank you!

- We will like to thank following for making 2014 EUVL Workshop a very productive workshop!
  - Workshop Sponsors
  - EUVL Workshop Steering Committee
  - Session Chairs and Presenters
  - Makena Resort Staff – Michelle, Sandy and others
  - Donna Towery, Tanner Towery Bethany and Art Mariscal
- **Please complete and return the EUVL Workshop Survey!**

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