2015 International Workshop on EUV Lithography

Vivek Bakshi

Workshop Summary

June 15-19, 2015

Makena Beach & Golf Resort, Maui, Hawaii

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

Workshop Summary

- **EUVL for HVM: Progress Update (P1)**
- Mark Philips, *Intel Corporation*
- **Two years of solid progress on source power.**
- **40 W tools are running as advertised (from 4 week demo)**
- Since April 2015, 3 tools >80 W, **availability and predictability are still poor.**
- **Introduction in production is a question of "when" rather than "if"**
  - **Availability, stability and operating cost are still concerns**
  - **Need to ensure infrastructure does not gate HVM**
- **Critical issue of APMI**
- EUV blanks with single digit ML defect count at 50 nm available
- ASML is now commercializing Pellicles. Does not eliminate post pellicle remount inspection. Working to handle pellicle heating issues. Defects in pellicles. **Pellicles can be made to withstand 250 W source power**
- **AMPI is unlikely to be available for HVM insertion. Will need much higher resolution DUV wafer inspection.** PWI requirements – 10 % delta CD, throughput for multiple reticle qual every day - 800 mm2 in 4 hours or less.
- **Mostly mask infrastructure can be a gate – limiting use of EUVL in HVM**

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- **<u>Challenges of EUV Lithography for HVM (P2)</u>**
- Takayuki Uchiyama, *Toshiba Corporation*
- **Requirements for pilot production (>100 W, >75% availability) and HVM listed**
  - Requirements for HVM ->250 W, >95% availability, low defectivity for high yield, T>90% for pellicle. 2017 – 500 W, After 2020 – 1000 W. Need High NA with 4x full field etched ML mask
- Current 80-100 W at 55% availability. Need to improve availability and power at the same time.
- **Example of k1 measurements for 2D and L/s for EUV and 193i**
- Resist challenges for CAR- LWR at > 5nm, target of <3 nm, etch sensitivity need to improve and sensitivity target of <20 mJ, current CAR at ~ 40 mJ. **Paradigm shift to new platform for EUV resists for current and high NA tools**
- **4x etched mask for high NA tools**
- **List of concerns for EUV- FEL to provide 1000 W+ power.**
  - **Many challenges but no show stopper**
  - **speckle noise from high coherence and optics damage**

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- **10:20 AM .... Optics and Contamination**
- **Progress with Capping Layer and Optics Refurbishment Development at RIT (Invited Talk) (P72)**
- Yuriy Platonov, *Rigaku Innovative Technologies*
- SiO_2 and TiO_2 capping layers: demonstrated practically a full oxidation.
- ZrO_2 capping layers: all Zr is bound to O with ~ 15% – 25 % in form of zirconium carbonate.
- ZrO_2 capping layer was improved since February'15 and now both TiO_2 and ZrO_2 show a similar reflectivity loss after EUV exposure
- **Wet etching successfully removes tin without effecting performance of Mo/Si ML coating**
- **Wet etching approach should work to strip ML from a collector optics but the process is quite messy**
- Plasma etching works well on flat optics but it results in surface roughness increase on curved optics
- Ion Beam Smoothing process reduces surface roughness after plasma etching but a further reduction is still needed

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- **Issues in the Testing of Non-CAR Materials in Hydrogen Atmospheres (Invited Talk) (P73)**
- C. Tarrio (NIST) and Patrick Naulleau (CXRO)
- Overview of outgassing testing facility
- **Interaction of new resist chemistries with Hydrogen is not well understood.**
  - H_2 Pressure in scanner (1 mbar) to suppress outgassing of H_2O and O_2
  - 2 mW EUV intensity at the sample
- **Need to protect synchrotron from Hydrogen**

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- **<u>In situ cleaning of Sn sources (Invited Talk) (P74)</u>** David N. Ruzic, UIUC
- **3D flow modeling of in-situ cleaning of Sn via H2.**
- **Modeling of SnH_4 distribution – probability of etching and re - deposition**
- **BEUV- if we can maximize the reflectivity, 6.7 nm stands the chance. This may be achieved via using ALD for ML fabrication**
- Sources consisting of combined fuel of Gd and Tb for increased effective reflectivity

- **<u>Scintillators and Imaging in EUV/XR Spectral Region (Invited Talk) (P71)</u>** Ladislav Pina, *Czech Technical University in Prague*

- **Quantum efficiency of selected monocrystal scintillators was measured in EUV, SXR and XR radiation ranges**

- Submicron resolution EUV/BEUV/SXR/XR imaging detectors were characterized

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- **1:00 PM ....Session 3: EUV Resists**
- **Recent Progresses in Negative-tone Imaging using EUV Exposure (Invited Talk) (P62)**Toru Fujimori, *EIDEC*
- CAR Extension
- **Negative tone imaging NTI, has a huge advantage for improving LWR, due to low swelling and smooth dissolving behavior. Example for 14 mJ LWR 3 nm vs 4.5 nm**
- New materials – metal containing inorganic / organic hybrid non-CAR materials
- EIDEC standard metal resist (ESMR) -1.5 mJ/cm2 at 17 nm (100 nm pitch)
- **20 nm lines with 1.3 mJ/cm2 (exposure with EB litho) – plan to have EUV exposure at CXRO**

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- **Dissolution Dynamics of Chemically Amplified Resists for Extreme Ultraviolet Lithography Studied by Quartz Crystal Microbalance (Invited Talk) (P65)** Hiroki Yamamoto, *Osaka University*
- QE increases with increase in acid generation concentration
- Can measure via QCM change of film thickness less than 100 nm to study dissolution behavior of resist film
- Solubility in the developer depends on remaining PAG concentration and structure of acid generator.
- **In designing the EUV resists, it is important to take into account the concentration of undecomposed PAG**

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- <u>**Characterization of Inorganic Resists Using Temperature Programmed and Electron Stimulated Desorption (P61)**</u>
- Gregory S. Herman, Oregon State University
- **HfSOx – nano patterning**
- **Methods being developed will be applied to other resist materials**.

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- **<u>EUV Patterning Improvement Toward High-volume Manufacturing (Invited Talk) (P63)</u>**
- Yuhei Kuwahara, Tokyo Electron
- Coating related defects are still majority of the defectivity
- **Pattern collapse elimination via new rinse process (water based new material)**
- **Post etch defects reduced by 85%**

- **<u>Novel EUV Resist Development for sub-14 nm Half pitch (Invited Talk) (P64)</u>**
- Yoshi Hishiro, *JSR Micro INC*
- **Acid diffusion lenght is an important nob to improve performance** (resolution and LER)- developed new CAR based resists with short diffusion lenght and high PAG contents
- 13 nm HP resolution on NXE 3300
- **New sensitizers – imporves sensitivity by 16 % at the same resolution**

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- **3:00 PM ....Session 4: EUVL Regional Reviews**
- *Session Chair: Vivek Bakshi (EUV Litho, Inc.)*
- China - Wang Xiangzhao, *SIOM* (P21)
- Europe - Bob Rollinger , ETHZ (P22)
- Korea- Jinho Ahn. *Hanyang University* (P23)
- Japan- Takayuki UCHIYAMA, *TOSHIBA* (P24)
- USA - Patrick Naulleau, *CXRO* (P25)
- **3:50 PM ....Adjourn for the day**

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- **<u>Status and Outlook of LPP light Sources for HVM EUVL (P3)</u>** Igor Fomenkov, ASML - Cymer, San Diego
- NXE technology roadmap NXE3300 80-250 W
- Eight 3300 B systems shipped, 40 W stable, 80 W configuration being transferred. Fourth generation NXE 3350B integration on-going
- 3350 2x overlay improvement at 16 nm resolution
- **1000 wafers per day capability demonstrated**
- Delivering >100 W EUV power at multiple UP2 systems
- List of EUV LPP Source Key technologies- optics protection, targeting dynamics and CO2 laser power
- **CE: 3.5% shipped (16 kW, 2-2.5 mJ pulse, 80-100 W dose controlled power), 4% (2.5-4 mJ Pulse) in R&D and 4.5% planned**
- **5% CE demonstrated on research platform with "cloud shaped" target**
- MOPA pre-pulse and Droplet generator description
- **Collector lifetime of 0.1 Terapulse at 80 W**

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- **9:20 AM ....Session 6: EUV Sources**
- **Update of One Hundred Watt HVM LPP-EUV Source (Invited Talk) (P33)** Hakaru Mizoguchi, *Gigaphoton Inc.*
- **52% share of DUV light source units and expect 68% by end of 2015**
- **Special features – pre pulse at 1 μ, ion catcher**
- 14 kW CO_2 for prototype # 2, >20 kW CO_2 laser in preparation
- Proto type #1 , 77 hours with 10 W average power
- **Proto type # 2, working on tin back-diffusion from ion catcher, 62 degrees from horizontal – line of emission. 70 W in 95% DC, Availability at 12% and improving**
- **New Pilot system (250 W), Utility specifications, 20 kW laser, Q3 2015 completion target with first data in Q4 2015**

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- **States and Prospects of Laser Drivers for 250W and Toward > 500W Extreme ultraviolet (EUV) Generation (Invited Talk) (P35)** Koji Yasui, *Mitsubishi Electric Corporation*
- **Higher power extraction at higher input power via transverse gas flow CO_2 laser**
- Optical path interfaces must be reduced for efficient operation at high input power
- **>500 W or >1 kW possible via (a) addition of more CO_2 amplifiers or (b) better reflective mirror systems**

- **XUV Research with Compact DPP and LPP Laboratory Sources (Invited Talk) (P31)** Rainer Lebert, *RI Research Instruments GmbH*
- Review of various instruments for metrology, Mask blank reflectometer
- Specialized in one-of-a kind system for R&D

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- **<u>Plasma Design of the EQ-10 EUV Source (Invited Talk) (P34)</u>** Deborah S. Gustafson, *Energetiq Technology Inc*
- SiC gave least debris and longest life for Bore (Consumable piece in EQ-10)
- **Lessons learned**
  - 25 eV Xe plasma causes lots of sputtering
  - Small etendue can be acceptable
  - Plasma can be manipulated to match optics design by design of bore insert and operating conditions
- Existing metrology sources do not meet brightness, COO and stability requirements
- **Lifetime improved from 114 hours to 168 hours, availability improved from 80% to 97%**
- **Power at sample 1 mW (on 1 mm2). Part of systems for dose measurements (EUV Tech and LTJ)**

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- **High Brightness LPP Light Sources for High Volume Inspection (Invited Talk) (P36)** Bob Rollinger, *ETH Zurich*
- ALPS II Sn LPP for HVM
- **1.6 kW YAG for >1 % CE and 350 W/mm^{2}sr brightness (source size 60 μ, laser focus size 70μ)**
- **Pulse to pulse stability of EUV energy of 3%**
- Fast ns imaging of plasma (visible wavelength)
- 9x reduction is debris (without loss of EUV) via gas based mitigation

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- **11:20 AM ....Session 7: Panel Discussion**
- Vivek Bakshi (Moderator), EUV Litho, Inc., Panel Introduction (P10)
- **Panelists:**
- Mark Philips, *Intel* (P11)
- Takayuki Uchiyama, *Toshiba* (P12)
- Igor Fomenkov, *ASML-Cymer* (P13)
- Hakaru Mizoguchi, *Gigaphoton* (P14)
- **12:00 PM ....Lunch**

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- **1:00 PM ………….Session 8: FEL based Sources for EUVL**
- **<u>LCLS-II and Free Electron Laser Drivers for EUV Lithography (Invited Talk) (P44)</u>** Aaron Tremaine, *SLAC*
- GF has published FEL requirements for EUV sources
- **Basic designs of FEL for EUV – Straight Shooter (SS) and Energy recovery LINAC (ERL) Pros and Cons**
- **<u>SS – natural extension of LCLS-II and the lowest risk option</u>**

- **<u>An ERL-Based High-Power Free-Electron Laser for EUV Lithography (Invited Talk) (P42)</u>** Norio Nakamura, *KEK*
- **Target 10 kW at 13.5 nm, 800 MeV beam (Current 20 MeV)**
- Bunch compression and decompression schemes
- **Design of 9 kW FEL power (9.75 mA w/o tapering), 11 kW with tapering**
- Further design work and optimization planned

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- **EUV Radiation from a Microbunched Storage Ring (Invited Talk) (P41)** Daniel Ratner, *SLAC*
- **Can we combine high brightness of FEL and combine with high stability of synchrotrons?**
- Can we obtain micobunching in a synchrotron?
- Steady-state micobunching – RF Buckets to Optical Buckets
- **30 m, 1 A, 600 MeV, low dispersion mode, 4 kW EUV Power**
- **Proof of principal – 10 kW laser power, stored laser 10 MW, 2.5 m modulation length. Results expected in few weeks**
- **No need for high power beam dump. No long term radiation issue expected.**

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- **TESSA – a Novel High Efficiency EUV Source (Invited Talk) (P43)** A. Murokh, R*adiaBeam Technologies*
- X-ray FEL have surpassed synchrotrons in brightness and average power (1 kW-hr/ yr)but they not are not year at industrial levels (100,000kW-hr/ yr)
- Cost per kW-hr – LCLS II 200K, Industrial FEL – 2K, LPP at 20K
- Can we run IFEL in reverse or TESSA?
- **TESSA-3 kA beam can achieve 50% efficiency in 15 m at 13.5 nm**
- **Major reduction in cost and engineering cost**
- **Order of magnitude improvement in FEL efficiency**
- **Proof of concept (NOCIBUR – at Brookhaven) planned for Q3 2015**

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- **Simulation of an Electron Gun for ERL-FEL Based EUV Lithography System (Invited Talk) (P45)** Taisuke Kawasaki, *TOSHIBA Corporation*
- Basic design –electron gun, injector and superconducting cavity
- Photo cathode and drive laser for generation of electrons which are accelerated by the anode
- **Optimized parameters of E-gun (50 parameters) via simulation are presented**
- Plan to make a prototype to test the effect of large current on components
- **Formed a working group with KEK and GP**

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- **3:00 PM ....Session 9: EUV Masks**
- **<u>Current Status and Outlook for EUV Mask (Invited Talk) (P52)</u>**
  Takashi Kamo, *TOSHIBA Corporation*
- Overview of current Mask technology status and challenges
- Listing of challenges for defect management
- **Lower mask 3D effect of etched ML mask has been demonstrated**
- **Challenges of CD control (improved) and pattern collapse (Solution – reduced 40 ML pairs to 20 loss of 15% reflectivity).**
- **Need to work on inspection and repair on High NA mark**

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- **Progress Towards Actinic Patterned Mask Inspection (Invited Talk) (P51)** Oleg Khodykin, *KLA-Tencor Inc.*
- Metrology source requirements to support APMI
- Cryogenic rotating drum Xe Source with YAG laser
- **0.6% CE, 100 micron, 5 K Hz, 25 Hours run, 8 W/mm2sr. Can ~double brightness at 10 KHz**
- 200 nm/hour erosion of collector surface at 26 cm. Collector is at 40-70 cm. Collector protection via buffer gas flow. Base pressure 2E10-8 torr
- 80% duty cycle, no collector reflectivity degradation
- Xe recirculation with 99% capture rate
- **Long lead time on optics delivery!**

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- **<u>Critical Defect Size on EUV Mask and Cleaning Process for its Removal (Invited Talk) (P54)</u>** Jin-Goo Park, *Hanyang University*
- Particles should be removed without damage on EUV mask
- Below 30 nm can cause 10% CD error
- Megasonic cleaning for removing 30 nm particles. Higher frequency can reduce the damage from cleaning.
- At high pH the interaction energy is repulsive

- **<u>Tabletop-Scale EUV Coherent Phase-And-Amplitude Imaging Using High Harmonics (P55)</u>** Daniel E. Adams, *JILA*
- Coherent diffractive imaging using 30 nm HHG source
- **3D imaging of 20 nm defects. Working with EUV mask samples**

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- **<u>Multilayer Mask Roughness: the Relative Importance of Phase and Amplitude (Invited Talk) (P56)</u>** Patrick P. Naulleau, CXRO
- AFM is blind to EUV roughness
- Scattering cannot distinguish between amplitude and phase roughness
- Aberrations show similar effect but smaller
- Aerial image data shows <1% amplitude roughness for all 3 masks – so we can use scatterometry

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Dublin, Ireland
November 9-12, 2015

Upcoming Workshops

Center for X-ray Optics, Berkeley, CA

June 13-16, 2016

Thank you!

- I will like to thank following for making 2015 EUVL Workshop a very productive workshop!
  - Workshop Sponsors – Financial support
  - EUVL Workshop Steering Committee - Guidance
  - Session Chairs and Presenters _ Organization
  - Patrick Naulleau for workshop support!
  - Makena Resort Staff – Michelle, Sandy for excellent support!
  - Donna Towery and Art Mariscal for great organization!

- **Please complete and return the EUVL Workshop Survey!**

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