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
Workshop Summary

• **Challenges of EUV Lithography for HVM (P2)**
  • 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
Workshop Summary

- 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.**
  • H2 Pressure in scanner (1 mbar) to suppress outgassing of H2O and O2
  • 2 mW EUV intensity at the sample

• **Need to protect synchrotron from Hydrogen**
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- **In situ cleaning of Sn sources (Invited Talk) (P74)** David N. Ruzic, UIUC
- 3D flow modeling of in-situ cleaning of Sn via H2.
- Modeling of SnH₄ 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

- **Scintillators and Imaging in EUV/XR Spectral Region (Invited Talk) (P71)** 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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- Characterization of Inorganic Resists Using Temperature Programmed and Electron Stimulated Desorption (P61)
- Gregory S. Herman, Oregon State University
- HfSOx – nano patterning
- Methods being developed will be applied to other resist materials.
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- **EUV Patterning Improvement Toward High-volume Manufacturing (Invited Talk) (P63)**
  - 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%**

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

• 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
Workshop Summary

- **Status and Outlook of LPP light Sources for HVM EUVL (P3)**
  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 CO₂ for prototype # 2, >20 kW CO₂ laser in preparation
- Prototype #1, 77 hours with 10 W average power
- Prototype # 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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- **Plasma Design of the EQ-10 EUV Source (Invited Talk) (P34)** 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/mm²sr 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 in 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**
  - **LCLS-II and Free Electron Laser Drivers for EUV Lithography (Invited Talk) (P44)**  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**
    - **SS – natural extension of LCLS-II and the lowest risk option**

- **An ERL-Based High-Power Free-Electron Laser for EUV Lithography (Invited Talk) (P42)**  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, *RadiaBeam 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 (100,000 kW-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
- Current Status and Outlook for EUV Mask (Invited Talk) (P52)
  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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- 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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- **Critical Defect Size on EUV Mask and Cleaning Process for its Removal (Invited Talk) (P54)**  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

- **Tabletop-Scale EUV Coherent Phase-And-Amplitude Imaging Using High Harmonics (P55)**  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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- **Multilayer Mask Roughness: the Relative Importance of Phase and Amplitude (Invited Talk) (P56)** 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
Upcoming Workshops

2016 International Workshop on EUV Lithography (EUVL Workshop)
Center for X-ray Optics, Berkeley, CA
June 13-16, 2016

2015 International Workshop on EUV and Soft X-Ray Sources (Source Workshop)
Dublin, Ireland
November 9-12, 2015
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!