Advances in EUV Lithography
Room 316 - Session EUV-MoM

Advances in EUV Lithography II

Moderators: Prof. Alain Diebold, University at Albany-SUNY, **Mr. Lior Huli**, TEL, **Prof. Gregory Denbeaux**, University at Albany-SUNY, **Dr. Kandabara Tapily**, TEL

10:00am **EUV-MoM-1 Pushing the Limits of High-Volume Manufacturing with EUV Litthography**, ***Mike Lercel,*** ASML **INVITED**

EUV lithography has transitioned from an emerging technology to a core manufacturing enabler for advanced logic and memory. Continued innovation with EUV will sustain semiconductor scaling through the next decade. EUV is now established for critical layers in high-volume manufacturing, delivering a step-change in resolution relative to DUV and enabling continued transistor density scaling, while its evolution to higher numerical apertures (0.33 NA to 0.55 NA and beyond) will further improve resolution, simplify patterning, and reduce process complexity and cost through single-exposure solutions. Productivity, availability, and source power are continuing to evolve to make EUV cost effective while improvements in overlay and imaging continue EUV into future nodes. EUV is positioned within a holistic lithography strategy—integrating computational lithography, metrology, and systems—to control edge placement error and enable cost-effective scaling as device architectures evolve toward 3D integration. Overall, EUV for manufacturing will remain central to sustaining Moore's Law and enabling AI-driven semiconductor growth, with expanding opportunities across both 2D scaling and emerging 3D integration schemes.

10:30am **EUV-MoM-3 High NA EUV Challenges and Opportunities**, ***Christopher Penny,*** IBM Research **INVITED**

The recent demonstrations of High NA EUV lithography provide significant opportunities to extend scaling for future technology nodes. While many of the key capabilities of High NA EUV have been demonstrated, there remain many significant challenges that must be resolved for High NA EUV to be fully adopted in manufacturing. For example, initial demonstrations have demonstrated single expose patterning for interconnects at 21nm pitch and below; however, further co-optimization of the lithography and etch processes will be required to achieve yield and defectivity levels required for manufacturing. One specific challenge is the introduction of metal oxide resists, and the subsequent process optimization in resist, develop and etch that will be required. Minimizing defectivity (line breaks and bridges) and LER/LWR will continue to be challenging as pitches scale with High NA EUV. The introduction of new materials and processes, such as subtractive Ru patterning, may offer an alternate path to utilize High NA EUV for continued scaling.

11:00am **EUV-MoM-5 Climate-Aware Semiconductor Manufacturing:the Pivotal Role of Lithography**, ***Emily Gallagher,*** imec **INVITED**

The semiconductor industry is built on technological innovation, historically guided by familiar metrics: power, performance, area, and cost. Today, increasing emphasis on reducing electrical power demand and improving supply-chain resilience drives growing awareness of environmental impacts. Connecting manufacturing choices to climate impact can be challenging, particularly across highly complex process flows comprising more than 1,000 individual process steps. Addressing the processes that consume demands modelling. To this end, imec has developed a framework based on a bottom–up, virtual fab model to represent a high–volume manufacturing fab.

This "virtual fab" is used to identify global trends in semiconductor manufacturing and the dominant role that lithography plays. Through illustrative, lithography–focused examples, we demonstrate how design, process, and operational decisions influence impacts., and how quantified insights can guide lower–emissions manufacturing. Since performance optimization remains essential, we highlight the need to treat environmental impacts as co-optimized engineering objectives.

11:30am **EUV-MoM-7 EUV Pattern Rectification by the Directed Self-Assembly (DSA) of Block Copolymers**, ***Dustin Janes,*** *Jon-L Innocent-Dolor,* Tokyo Electron America, Inc.

Leading edge manufacturing customers are installing 0.55 NA EUV tools into development fabs, but their resist selection is still uncertain. Interest exists in finding ways to extend chemically amplified resist (CAR) usage to tighter pitch while maintaining a robust etch budget for pattern transfer. EUV rectification by DSA is one strategy to achieve that goal while increasing scanner throughput. Positive-tone developed CAR patterns were rectified by an integrated process flow containing intermediate etch and wet cleans process steps. The exemplary process benefit of DSA at 24 nm line-and-space pitch is achieving uLWR 3σ = 1.6 nm and healing >99% of stochastic defects.

11:45am **EUV-MoM-8 Real-Time Monitoring of Chemical Evolution in Vapor-Deposited Zn-Based Hybrid EUV Resists**, ***Thi Thu Huong Chu,*** *Dan N. Le, Minjong Lee, Dushyant M. Narayan,* University of Texas at Dallas, USA*; Nikhil Tiwale,* Brookhaven National Laboratory*; Oleg Kostko,* Lawrence Berkeley National Laboratory*; Chang-Yong Nam,* Brookhaven National Laboratory*; Jiyoung Kim,* University of Texas at Dallas, USA

Extreme ultraviolet (EUV) lithography is a key enabling technology for sub-10 nm metal half-pitch semiconductor nodes.[1] However, establishing a clear relationship between EUV resist chemistry and lithographic performance remains critical for advancing next-generation patterning with enhanced sensitivity, resolution, and stochastic control.[2] The inherently transient and environment-sensitive nature of irradiation-induced chemistry in EUV resists, however, has limited direct experimental access to reaction pathways under realistic processing conditions.

To address this challenge, we report real-time monitoring of chemical evolution in vapor-deposited Zn-based hybrid EUV resists, providing operando insight into resist reaction mechanisms during e-beam/EUV exposure. In particular, we investigate the distinct roles of organic components (aromatic versus aliphatic) in molecular atomic layer-deposited (MALD) Zn-based hybrid resist thin films to elucidate their influence on sensitivity and patterning performance under both EUV and low-energy electron exposures. By combining operando techniques such as Fourier transform infrared (FTIR) spectroscopy and residual gas analysis (RGA), we directly track chemical bond transformations in real time, enabling the identification of key reaction steps associated with crosslinking and bond scission. Our results reveal distinct exposure mechanisms underlying the observed performance differences. Aromatic-based resists predominantly undergo deformation of aromatic rings, as indicated by a dip at the C=C bond in the FTIR spectrum during 80 eV electron exposure. In contrast, aliphatic systems form dense networks through coordination-driven bonding. Furthermore, we conducted complementary in-operando RGA and electron emission measurements under EUV flood exposure, which revealed the major by-products released during EUV exposure. Together, these findings provide a more comprehensive understanding of the chemical transformations that occur under realistic exposure conditions and highlight the value of real-time, operando approaches in linking molecular structure to lithographic behavior.

The insights provide guiding principles for designing next-generation vapor-deposited hybrid EUV resists with improved performance and reduced stochastic variability.

This research was supported by the U.S. DOE Office of Science Accelerate Initiative Award 2023-BNL-NC033-Fund. This research used resources of the Advanced Light Source, which is a DOE Office of Science User Facility under contract no. DE-AC02- 05CH11231.

[1] I. Giannopoulos *et al.,* Nanoscale, **2024**, 16, 15533–15543.

[2] T. Manouras *et al.,* Nanomaterials, **2020**, 10, 1593.

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Moderators: Prof. Alain Diebold, University at Albany-SUNY, **Mr. Lior Huli**, TEL, **Dr. Dustin Janes**, TEL, **Dr. Lovejeet Singh**, JSR Micro, **Dr. Kandabara Tapily**, TEL

1:30pm **EUV-MoA-1 EUV Resists: Chemistry, Mechanisms and Challenges***, **Robert Brainard,*** University at Albany **INVITED**

The lithography community has studied EUV photoresists for nearly thirty years. Yet, some of the most basic details of the interaction of EUV photons with photoresists remain poorly understood.In a typical photochemical reaction using longer-wavelength light (l = 157-1000 nm), photons create excited states in photoactive compounds, thereby creating known quantities of intermediates and photoproducts at measurable rates.The photochemical reactions occurring during EUV exposure are much more complex and, as yet, not fully explored.

This presentation will start with a quick introduction to photoresists and EUV lithography.It then will describe how 92 eV EUV photons ionize molecules in resists, creating holes and free electrons, and identify and discuss the individual interactions that occur with atoms (Figure 1).However, the number of electrons created, their reaction mechanisms, their lifetimes and their reaction cross-sections are not well known. The presentation will discuss experimental results and provide insight into these poorly understood aspects of EUV exposure mechanisms.

2:00pm **EUV-MoA-3 The Effect of Molecular Weight and Polydispersity Index on the Ultimate Roughness of EUV Photoresists***, **Greg Denbeaux,*** University at Albany

In EUV lithography, one of the critical challenges is the line edge roughness (LER) or line width roughness (LWR) of the resist pattern. There are many contributing sources to the roughness in the resist including photon stochastics. In this paper, we correlate molecular weight and the distribution of the molecular weight of the photoresist on the roughness of the exposed pattern using top-down low energy electron exposures and atomic force microscopy. Most of the results will be based on PMMA as a simple model system for exploration.

2:15pm **EUV-MoA-4 XPS Analysis of Inpria Metal-oxide Photoresists after Post-EUV Exposure to Oxygen and Water***, **Mark Johnson,*** Inpria Corporation*; Sonia Castellanos Ortega,* Inpria Corporation, Belgium*; Lauren McQuade, Kirsten Louthan, Michael Greer, Brian Cardineau,* Inpria Corporation

The field of Metal Oxide Resists (MOR) for EUV lithography has been pioneered by Inpria Corporation. The reactions that occur in Inpria materials following exposure to EUV photons (13.5 nm wavelength) are critical to their functioning. EUV radiolysis of these resists in UHV produces active sites that react with both oxygen and water, resulting in the differing solubility that is necessary for pattern formation during development. Previous work has shown the importance of both oxygen and humidity for photolithographic performance of similar resists [1]. It is hypothesized that both oxygen and water affect the condensation of the metal-oxo clusters and thus, their photolithographic performance [2,3]. In this study, compositional changes that occur post-EUV radiolysis, upon gas exposure to oxygen and humidity, are investigated by XPS. The post-exposure atmosphere and temperature were controlled, including the inert transfer of samples into the XPS. Some aspects and technical challenges associated with studying radiation-sensitive materials by XPS will be discussed, including the sensitivity to X-ray damage and strategies to minimize this effect. Results will be presented of Inpria MORs following EUV exposure and controlled post-treatment atmospheres with different thermal treatments in varying nitrogen, oxygen, and humidity concentrations, along with the resulting changes in composition, carbon chemistry, oxygen chemistry, and tin chemistry. A mechanistic interpretation of post-EUV chemical interactions will be proposed.

1. Ivan Pollentier, Fabian Holzmeier, Hyo Seon Suh, Kevin Dorney, Proceedings Volume 13983, Advances in Patterning Materials and Processes XLIII; 139831G (2026)
2. Sonia Castellanos, Peter De Schepper, Maireyee Bhattacharya, Jan Doise, Joren Wouters, Amrit K. Narasimhan, Brian Cardineau, Lauren McQuade, Craig Needham, Michael Kocsis, Kazuki Kasahara, and Stephen Meyers "EUV metal oxide resists: impact of the environment composition on CD during post-exposure delay", Proc. SPIE 12957, Advances in Patterning Materials and Processes XLI, 1295707 (10 April 2024); https://doi.org/10.1117/12.3010921
3. Yu Zhang, Jarich Haitjema, Xiaomeng Liu, Fredrik Johansson, Andreas Lindblad, Sonia Castellanos, Niklas Ottosson, and Albert M. Brouwer "Photochemical conversion of tin-oxo cage compounds studied using hard x-ray photoelectron spectroscopy", Proc. SPIE 10146, Advances in Patterning Materials and Processes XXXIV, 1014606 (27 March 2017); https://doi.org/10.1117/12.2257893

2:30pm **EUV-MoA-5 Closing the Stochastics Resolution Gap***, **Chris Mack,*** FRACTILIA **INVITED**

Background: Since the birth of the integrated circuit, electronics industry growth and innovation have relied on semiconductor manufacturers putting ever smaller features (described by their critical dimensions or CDs) into production. Yet today, stochastics, the randomness inherent to chip making near the atomic scale, is threatening the continued ability to manufacture the smallest possible features in volume production. Aim: To understand the impact of stochastics on semiconductor manufacturing today, the Stochastics Resolution Gap is defined and used as a framework assessing the value of reducing stochastics variability. Approach: This paper provides an introduction to stochastics, their emerging limitations on lithography resolution, technology solutions for improving resolution and yield, and the importance of accurate measurement technology for bridging the stochastics resolution gap. Results: Using one stochastics-aware design rule example, a method for determining the optimum via size in a specific 28-nm pitch process is presented in order to minimize the detrimental role of stochastics. Conclusions: The Stochastics Resolution Gap is a real limitation, but it is not fixed. Further efforts are needed to continue to close this gap.

3:00pm **EUV-MoA-7 The Role of Environmental Humidity During Processing on the Properties of Indium Nitrate Sol-Gel EUV Resists***, **Cody Allen,*** *Mohsen Moayedi, Raphael Nam, Kevin Brenner, Julia Hsu,* The University of Texas at Dallas

As EUV lithography moves to higher numerical aperture patterning, appropriate photoresists must simultaneously meet increasingly stringent requirements for reduced resist thickness, high sensitivity, and low stochastic variability. Metal-containing resists offer improved EUV absorption compared with conventional light-element organic resists, with organotin (Sn-oxo) materials being a prominent example. Our group has investigated indium nitrate-based sol-gel photoresists as an alternative metal-oxide resist platform, as indium has an EUV absorption cross-section similar to that of tin. In this work, we examine how film formation and dose response of indium nitrate resist are influenced by ambient moisture during resist processing.[1]

Because access to EUV exposure tools remains limited for academic research, we primarily evaluate resist contrast using 100-eV electron-beam exposure as a practical alternative. The energy of the electrons is similar to that of EUV photons, 92.5 eV. The indium nitrate resists demonstrate sensitivity comparable to that of the Sn-oxo resist and can be patterned by electron-beam lithography (EBL) into 50 nm half-pitch line/space features.[2,3] EUV flood-gun dose curves further indicate sensitivities as low as 10 – 20 mJ/cm^2.[2,3] However, processing under elevated relative humidity produces nanoscale bump-like crystalline defects that degrade pattern fidelity by increasing line-edge roughness (LER).[2] Controlled-humidity processing suppresses these defects, enabling defect-free films made at relative humidities up to 35% RH.[4] At 25% RH, defect-free line/space patterns were achieved with an LER of 2 nm and a linewidth of 19 nm.[4]

These preliminary results motivate a systematic controlled-humidity EBL study in which indium nitrate films will be processed across defined relative humidity conditions and evaluated by dose response, retained film thickness, linewidth, LER, and nanoscale defect density. Correlating these lithographic metrics with film morphology measured by atomic force microscopy and chemical characterization using Fourier transform infrared (FTIR) spectroscopy will clarify how water uptake alters hydrolysis/condensation chemistry, defect formation, and resist sensitivity. More broadly, this work can help identify the mechanism through which ambient moisture acts as a critical processing variable for solution-processed metal-oxide resists.

3:15pm **EUV-MoA-8 Incorporating Bismuth into Hybrid Inorganic-Organic Films using Molecular Layer Deposition for Advanced Lithography Applications***, **Jane Keth**, Duncan Reece, David Bergsman,* University of Washington

To address the exponential rise in memory demand and improve energy efficiency per transistor, continued scaling of semiconductor feature sizes will be essential. The semiconductor industry has converged on the idea that achieving high-resolution patterning at sub-10 nm critical dimensions needed for next-generation devices will require extreme ultraviolet (EUV) lithography. Enabling this technology will further require photoresists compatible with EUV, often through incorporating high-Z elements that enhance radiation absorption. Several high-Z elements, such as tin, zirconium, hafnium, zinc, titanium, and indium have been investigated for use in metal-oxide or hybrid metal-organic photoresists for EUV/e-beam (EB) applications. However, many of the methods used to deposit these resists rely on wet chemical processing methods, such as spin-coating or sol-gel synthesis, which can complicate uniform ultrathin film formation and increase susceptibility to defects. One alternative approach for testing and manufacturing these resists is molecular layer deposition (MLD), which provides a compelling dry, solvent-free approach for photoresist fabrication. In MLD, vapor precursors are sequentially pulsed into a reactor, where they undergo self-limiting surface reactions to deposit molecular layers with precise thickness control. MLD is also amenable to area-selective patterning and high aspect ratio deposition, which could be used in processes inaccessible to chemical vapor deposition.

In this work, we examine a relatively underexplored hybrid MLD chemistry for use as a photoresist for EUV lithography: a Bismuth-based hybrid. Bi photoresists offer a promising photoresist candidate for EUV/EB lithography, due to its high EUV absorption and low toxicity comparatively to other high-Z metals. Here, we demonstrate the successful deposition of Bi-based hybrid MLD films. We describe the ambient and chemical stability of the biscone films, as verified by XPS and FTIR. We further expose the film to EB lithography to create a dose matrix and quantify the film's potential EUV-sensitivity. Through this work, we hope to expand the library of MLD chemistries and further demonstrate the potential for MLD as an approach for creating next-generation photoresist materials.

3:30pm **EUV-MoA-9 X-ray Spectroscopy of EUV Exposed SnOx Nanocluster Thin Films Yields Insights Towards Radiolytic Mechanism***, **Trey Diulus**,* NIST-Gaithersburg*; Priyanka Ketkar,* NIST*; Matthew A. Wade,* NIST-Gaithersburg*; Conan Weiland, Cherno Jaye,* NIST*; Daniel Sunday, R. Joseph Kline,* NIST-Gaithersburg

The semiconductor industry is focused on optimizing extreme ultra-violet (EUV) lithography to fabricate leading edge microchips with smaller device features. Metal-oxide (MOx) nanoclusters are being developed as EUV photoresists due to high photon absorption cross sections at the EUV wavelength (13.5 nm) and smaller component size relative to chemically amplified photoresists. Thin films of organo-tin clusters can be made with precise control using solution-based methods, utilizing precursor fragments that link together to form a wide range of structures and compositions, but the radiolytic mechanism that induces a solubility change in these films is still elusive. To identify EUV induced chemistry, we have prepared organotin dodecamer resist films with varying EUV dose exposures and utilized a suite of several synchrotron-based x-ray spectroscopy measurements, specifically synchrotron source hard x-ray photoelectron spectroscopy (HAXPES) to interrogate changes in composition, x-ray absorption spectroscopy (XAS) to examine the electronic structure of the film components, resonant soft x-ray reflectivity (RSoXR) to identify changes in optical constants, and standard x-ray reflectivity (XRR) to track film density. With XAS, we are getting bond-specific information that complements the oxidation state information from the HAXPES. RSoXR provides nanoscale resolved optical constant depth profiles, which complement the surface sensitive XAS. HAXPES shows a decrease in C 1s intensity along with an increase in the O 1s corresponding to the metal oxide, a result expected due to removal of ligands and cross-linking that was previously mentioned. Comparing the Sn L-edge in the TEY XAS for the unexposed versus exposed regions display a clear increase in absorption intensity, as the cross-linked nanocluster forms more of a metal-oxo lattice. This increase in intensity suggests an increase in film density, which was explicitly seen in XRR as the unexposed density increases upon exposure. Further XAS images of the C and K-edges provide spatial information with a chemical contrast corresponding to the resonant absorption energy for the elements present in the film. Evidence of a carbonyl species formed upon EUV exposure can be seen, which may play a role in the polymerization of the clusters. Overall, we highlight the importance of a comprehensive and multi-modal metrology approach that is necessary for providing improved resist designs for optimal performance. Identifying this chemistry will ideally lead to design of more efficient EUV photoresists that can help advance next generation EUV lithography.

4:00pm **EUV-MoA-11 CD-RSoXS: Latent Image Metrology for Source–Mask–Resist Co-Optimization in High-NA EUV Lithography***, **Cheng Wang**,* Lawrence Berkeley National Laboratory **INVITED**

As critical dimensions in extreme ultraviolet (EUV) lithography shrink below 10 nm, particularly for high-NA and hyper-NA systems with reduced depth of focus, three-dimensional effects and absorption gradients within photoresists become increasingly important. In this regime, latent image metrology is essential for co-optimization of the lithography stack, where the source and mask define the aerial image, and the heterogeneous photoresist chemistry governs subsequent reaction and development processes. We introduce critical-dimension resonant soft X-ray scattering (CD-RSoXS), a non-destructive metrology approach combining near-edge X-ray absorption spectroscopy, resonant scattering, and multiphysics modeling to probe 3D morphology and chemical profiles in photoresists. CD-RSoXS enables chemically sensitive characterization across lithographic stages, including latent image formation, post-exposure bake (PEB), and development, revealing nanoscale chemical gradients and structural evolution that drive stochastic variability. By directly mapping resist chemical heterogeneity and its evolution, CD-RSoXS provides critical input for co-optimization frameworks, linking aerial image design with material response. Complementary RSoXR measurements further quantify underlayer properties and their influence on EUV absorption and resist performance. Machine-learning-assisted reconstruction accelerates interpretation of complex scattering data. Together, this work establishes CD-RSoXS as a powerful platform for latent image metrology and integrated materials–process co-optimization in next-generation EUV lithography.

4:30pm **EUV-MoA-13 Outlook for Future EUV Patterning Opportunities and Challenges***, **Eric Liu**, Steven Grzeskowiak, Alexandra Krawicz, Katie Lukter-Lee, HungYu Chang, Surya Padinjarekutt, Yen-Tien Lu, Christopher Cole, Julian Michaels, Amrit Kaphle,* Tokyo Electron America, Inc.*; Akiteru Ko,* Tokyo Electron America, Inc., Japan **INVITED**

EUV (extreme ultraviolet) lithography has been the major driving force behind extending device density scaling. In both logic and memory devices, EUV improves imaging resolution and enables single-print patterning to replace the complex multi-patterning method. This technology simplifies the process and reduces design complexity, promoting manufacturability and cost control for high-volume production. One of the fundamental challenges that we observed is the slowing down of pattern variation scaling. By leveraging advancements in lithography technology, such as the transition from Low NA (numerical aperture) to High NA EUV, and process integration solutions, such as self-aligned multiple patterning (SAMP), the minimum pattern scaling is theoretically achievable to meet the requirements of area scaling going forward. However, the pattern variation has not improved with the reduction of designed pattern feature, which has a significant impact on device reliability and a narrow process window across technology nodes.

Controlling pattern variation, reducing dose-to-size, and maintaining the imaging resolution are the classic patterning trade-off relationships. The challenges and opportunities are aimed for improvement in pattern variation and dose-to-size without the penalty in imaging resolution. In this presentation, we examine several technology options and innovations to realize the formation of minimum metal pitch at the advanced node. These technologies include:

1. Advancements in EUV lithography single patterning and self-aligned multi-patterning.
2. Patterning challenges and plasma interaction in MOR (metalorganic resist) system.
3. Innovative patterning and process integration solution to improve pattern variation.

5:00pm **EUV-MoA-15 Edge Placement Error Reduction using Directional Etching for Via Resistance Improvement***, **Jennifer Oakley**, Takumi Nishinobo, Yen-Tien Lu, Jeffrey Smith, Reo Kosaka, Rintaro Yamamoto, Sheldon Meyers, Lior Huli, Eric Liu, Hirokazu Aizawa, Angelique Raley, Luis Fernandez,* TEL US

Back End of Line (BEOL) metal pitches are projected to scale to ~18 nm by 2029–2030 and ~12 nm by 2035–2036 driving an increased need for precise Edge Placement Error (EPE) control.This work reports simulation and experimental demonstrations of post-lithography EPE correction using a Gas Cluster Beam (GCB) system.The GCB system performs nanometer-scale,

location-specific film etching integrated with a wafer scanner. This system generates gas clusters from a fixed nozzle and uses scanner tilt and controlled wafer motion to deliver spatially selective etching in either X or Y directions. Chemistries were developed to enable etching of both organic and inorganic materials, permitting small, targeted adjustments to feature edges after lithography.

Simulations for a representative M0/M1 stack (16 nm M0 pitch, 28 nm M1 pitch, and 7 × 13 nm V0 slot via) indicate that correcting EPE by ~2 nm can reduce via resistance by over 20% for an M1 subtractive integration scheme, implying measurable device performance benefits. Experimentally, post-via-lithography GCB etching was applied to a two-level dual damascene Cu process (36p lower-level lines, 28–36p upper-level features) using a chemically reactive gas cluster to trim positive-tone chemically amplified resist. Controlled unidirectional etches showed predictable increases in via opening in the intended direction (CD growth consistent with programmed shifts) while preserving orthogonal CD. Measured overlay shifts matched expectations, demonstrating precise directional control.

To assess electrical impact, wafers were intentionally exposed with a 4 nm via misalignment; one set was corrected using GCB while a control set was left uncorrected. GCB-treated wafers reduced misalignment to under 1 nm and exhibited a ~17% decrease in via resistance at M2. TEM imaging confirmed restoration of via centering after GCB correction. These results validate GCB's capability to perform nanoscale, location-specific EPE corrections that improve critical BEOL electrical parameters. Future work will integrate measured overlay data into a Location Specific Processing (LSP) workflow to perform localized, data-driven corrections. The demonstrated GCB approach is extensible beyond BEOL to potential FEOL and other applications where sub-nanometer edge control can enhance device performance and yield.

5:15pm **EUV-MoA-16 Measurement of H* Radicals and SnHx Vapor Species in a Simultaneous Deposition and Etch Experiment***, Jameson Crouse, Nathan Bartlett, Emily Greene,* University of Illinois at Urbana-Champaign*; Shiva Rajavalu, Sergio Ferraris, Niels Braaksma,* ASML*; Andrew Herschberg, David Ruzic,* University of Illinois at Urbana-Champaign

Extreme ultraviolet (EUV) lithography sources use Sn in the process of generating 13.5nm wavelength light. This Sn expands out and coats plasma facing devices around the source. H2 buffer gas is added to mitigate transport to important surfaces such as the collector mirrors. Sn that has deposited on surfaces can only be removed in situ through etching by H*, which produces SnHx in the gas phase. The EUV light generates a background hydrogen plasma, which includes varying densities of H* radicals. Knowledge of the local H* radical density is important for understanding the etch rate on wall segments throughout the device, and errors propagate, leading to incorrect predictions of Sn accumulation. This work seeks to validate diagnostics for radical measurement in EUV sources, along with validation of predicted etch rates through the lowering of error bars in a Sn etching experiment being conducted at UIUC. This presentation covers initial results from spatial OES measurement of hydrogen radicals in the presence of an ICP generated hydrogen plasma at pressures between 10-100mTorr, and powers between 1-200W. The presentation also will cover the development of a TALIF based H* radical diagnostic at UIUC for the measurement of H* radicals. The spatial OES data will be benchmarked using the TALIF system, with actinometry used to measure trends in H* radicals and approximate absolute radical densities. Development of a unique collisional radiative model for the H2 plasma will be discussed with effects on local Sn gas species. Future work looking into Sn and SnH gas species will be addressed.

5:30pm **EUV-MoA-17 Enabling an Accelerated Pathway Within the Us for Learning on Lowna Euv, Hina Euv and What'S Next***, Erin Lavigne,* NY CREATES

Within the Albany Nanotech Complex, a deeply integrated ecosystem of state–of–the–art semiconductor fabrication tools, advanced materials laboratories, and data–driven infrastructure is already accelerating breakthroughs across device, process, and systems research. The introduction of HiNA further amplifies this capability by providing a tightly coupled, pre–competitive environment optimized for high–velocity collaboration across academia, industry, and government. Researchers gain direct access to advanced lithography, deposition, etch, metrology, and integration platforms—co–located and orchestrated to support rapid learning cycles at leading–edge and beyond–CMOS nodes.

The impact is immediate and tangible: rapid screening, design–of–experiments, and prototyping workflows enable accelerated exploration of novel materials systems, heterogeneous integration strategies, and next–generation device architectures. From custom optical and electronic materials to advanced interconnect, memory, and logic concepts, iteration cycles are shortened through shared process modules, standardized interfaces, and real–time characterization. High–throughput experimentation, coupled with advanced modeling and data analytics, enables faster convergence on viable process windows while dramatically reducing cost and risk relative to traditional development paths.

By lowering barriers to access—whether capital, tooling, or organizational silos—HiNA enables ambitious, cross–disciplinary ideas to transition from theoretical concepts to validated hardware with unprecedented speed. The platform supports seamless scaling from early material feasibility through device demonstration and system–level integration, creating a continuous pipeline from discovery to manufacturable solutions.

This talk will examine the technical drivers and roadmaps underpinning this acceleration, including next–generation light sources for advanced patterning and metrology, emerging process integration schemes, and co–optimization strategies spanning materials, devices, and architecture. Equally important, it will detail the engagement and partnership models that make this ecosystem uniquely effective—highlighting how shared infrastructure, aligned incentives, and collaborative governance enable participants to innovate faster together than any organization could alone.

Plasma Science and Technology
Room 315 - Session PS2+EUV-TuA

Plasma Processes for Feature Scaling

Moderators: Prof. Dr. Erwin Kessels, Eindhoven University of Technology, the Netherlands, **Dr. Pingshan Luan**, TEL Technology Center America

4:00pm **PS2+EUV-TuA-8 Advanced Logic Pitch Scaling in the High NA EUV Era***, Arame Thiam,* ***Yannick Feurprier,*** TEL Europe, Belgium **INVITED**

High NA (0.55 NA) EUV lithography enables the single exposure of critical layers for future generations of logic (14A and below) and DRAM (1d and below) devices. Its implementation, however, introduces challenges in meeting both technology and high-volume manufacturing requirements. We will review and discuss the challenges of certain processes for logic use cases (Place and Route and Tip-to-Tip CD control, random logic via) and for the memory cases (contact holes and pillar). Co-optimization of the lithography process (resist, source, mask and development method) together with the etch pattern transfer process and the defectivity assessment enables the demonstration of a failure free process window for Place and Route (PnR) logic clips at tight pitches (down to 18 nm pitch) and for 28 nm pitch pillars for the memory use case.

The stringent tip-to-tip (T2T) CD control required by the technology in the PnR also creates opportunities for directional etch techniques. Gas Cluster Beam (GCB) technology can complement high NA EUV lithography by providing precise T2T CD control, reducing LER and helping to mitigate defectivity. Finally, further validation of the high NA EUV and etch patterning transfer is presented through electrical test.

Keywords: High NA EUV, Etch patterning, PnR, DRAM, Defectivity, Directional etch, Electrical test

4:30pm **PS2+EUV-TuA-10 Dry Resist Patterning Solutions for High-NA EUV Lithography***, Ali Haider,* Lam Research Corp.*; Zhengtao Chen, Shruti Jambaldinni,* Lam Research Belgium BV, Belgium*; Anuja De Silva,* Lam Research*; Rich Wise,* Lam Research Corp. **INVITED**

High-NA EUV lithography patterning at increasingly tight pitches introduces significant challenges, including elevated defectivity, reduced depth of focus (DOF), shrinking process windows, and the need for dose reduction without degrading pattern quality. These challenges become increasingly severe near ultimate resolution at P18 L/S and limit the extendibility of conventional wet solution processed resists.

In this work, we demonstrate the performance of Lam's Aether® dry resist technology for dense P18 line/space patterning using high-NA EUV lithography. We address key challenges such as defectivity, DOF, and line wiggling through co-optimization of dry resist deposition, underlayer, post exposure bake (PEB), and dry development. We introduce next-generation dry resists based on novel precursor chemistries with enhanced EUV sensitivity, enabling reduced dose to size without compromising roughness, while expanding the defect-free process window through co-optimization with dry development. We further introduce new dry development schemes that increase the effective resist budget after development, resulting in improved defect performance and lower roughness.

To address the high NA EUV challenge of limited DOF and profile control, we have introduced 3D engineered dry resist films using multi layer deposition with controlled composition and tunable EUV sensitivity in the vertical direction.1,2 We show that 3D engineered resist provides lower dose to size, improved profile control, reduced line wiggling, and enhanced DOF.

Overall, we show that Aether dry resist and development solutions address key challenges in high-NA EUV P18 L/S through innovations in dry resist and development strategies with co optimization of process parameters.

[1]Gulati, Saumya, et al. "Evaluating three dimensionally engineered dry resist film performance for 0.33 NA and High-NA EUV patterning." Advances in Patterning Materials and Processes XLIII. Vol. 13983. SPIE, 2026.

[2]A. Haider et al., "Advances of dry resist towards next-generation lines-spaces patterning in high-NA EUV lithography," Proc. SPIE 13686, 1368608 (2025)

5:00pm **PS2+EUV-TuA-12 Study of Electron-Induced Etching Mechanisms for Chromium and Ruthenium** *, **Michael Hinshelwood**, Gottlieb S. Oehrlein,* University of Maryland, College Park*; Hubertus Marbach, Michael Remmel, Gerson Mette, Michael Budach, Daniel Rhinow, Klaus Edinger, Maik Szafarska,* Carl Zeiss SMT GmbH, Germany

Chromium (Cr) and ruthenium (Ru) are materials critical for semiconductor manufacturing, particularly as part of DUV and EUV photomasks, respectively. Both can be effectively etched with plasmas containing both oxygen and a halogen. Cr can be etched through the formation of CrO_2Cl_2 or CrO_2F_2, while Ru is etched through the formation of RuO_4 or volatile RuO_xCl_y. To limit surface damage caused by ion bombardment during plasma etching, there is significant interest in isolating ions from the reaction system.

Y. Li et al. demonstrated rapid etching of Ru by combining a low-energy electron beam (EB) with a remote plasma (RP)-created flux of O_2/Cl_2-derived neutrals [1]. The combination of EB and RP resulted in a synergistic etch effect, while RP or EB alone caused either low-rate etching or growth. Here, we aim to describe the mechanism that leads to this synergistic effect and expand it to the etching of Cr, and also investigate how etching selectivity between the two materials may be achieved.

Using in-situ ellipsometry, we model the real-time etching and modification of the metal surfaces. This modelling is complemented by direct chemical characterization of the surface with X-ray photoelectron spectroscopy (XPS). In the case of Ru, we have found that the EB increases the uptake of Cl on the Ru surface, which in turn activates the Ru toward oxidation to volatile compounds. The growth rate and composition of this chlorinated layer formed by the EB are investigated via XPS measurements with increasing EB/Cl_2 exposure time. In the case of Cr, we find a stronger synergistic effect with F/O etch chemistry as opposed to Cl/O. The etch rate with RP alone is highly dependent on the oxygen percentage in the feed gas as well as the oxidation state of the Cr. With a fluorine-rich feed gas, the surface quickly forms a CrF_x passivation layer, preventing further etching. The EB can break through this passivation and continue the Cr etch process by forming vacancies that allow O radicals to diffuse into the surface and form volatile Cr–O–F compounds. By combining ellipsometric observations with chemical quantification from XPS, we obtained mechanistic insight for the development of low-damage etch processes for Cr and Ru, and insights on paths to high Cr hard mask and Ru capping layer selectivity.

[1] Y. Li *et al.*, "Investigation of ruthenium etching induced by electron beam irradiation and O_2/Cl_2 remote plasma-based neutral fluxes: Mechanistic insights and etching model," *J. Vac. Sci. Technol. A*, vol. 43, no. 2, p. 023005, Feb. 2025, doi: 10.1116/6.0004219.

5:15pm **PS2+EUV-TuA-13 3 Layers Dielectric Patterning in Grid Module for OSC 3DDRAM Application***, **Yuchao Jiang**, Jeongsoo Kim, Alejandro Fernandez Rodriguez, Hemant Kumar Raut, Nouredine Rassoul, Eren Canga, Robert Carpenter, Attilio Belmonte, Katia Devriendt,* IMEC, Belgium

3 layers dielectric patterning in Grid module for OSC 3DDRAM application

Yuchao. Jiang[1], Jeongsoo Kim[1], Alejandro Fernandez Rodriguez[1], Hemant Kumar Raut[1], Nouredine Rassoul[1], Eren Canga[1], Robert Carpenter[1], Attilio Belmonte[1] and Katia Devriendt[1]

[1]Imec, Kapeldreef 75, B-3001 Heverlee, Belgium

DRAM applications have reached a limiting point with 2D design (planar device) because of the process challenges for ~12nm nodes and scaling difficulty of density. Since 2011, monolithic 3DDRAM has been explored with different integration approaches (HBL, VBL, capacitorless etc), and recently it has experienced renewed interest by major players in memory market.

In this presentation, a dry–etch process for grid patterning in MOLD–based monolithic 3D DRAM was reported, the process enables robust isolation of active regions in vertical–bit–line architectures. The method addresses morphology degradation and sidewall profile asymmetry arising from pattern–loading effects and hard–mask facet evolution in multi–layer SiN/SiO_2 ONO stacks. By optimizing passivation balance, ion directionality, and process conditions, the approach achieves stable dielectric grid formation with controlled critical dimensions and near–vertical sidewalls. The demonstrated process provides reproducible grid patterning suitable for high–aspect–ratio 3D DRAM integrationIn monolithic 3DDRAM with MOLD–based vertical–bit–line (VBL) architecture, the Grid module (SINGRID) is the key dielectric–etch step that isolates active areas by etching through a multi–layer SiN/SiO_2 ONO structure (~355 nm). The grid lines have tight CD requirements and require near–vertical profiles (>87°) to ensure VBL alignment and prevent capacitor/gate shorts.

The grid exhibits major–axis vs. minor–axis HM (hard–mask) facet differences, caused by imbalanced ion/radical flux between dense vs. semi–dense regions. Consequences include:

1. Unequal CD narrowing
1. Facet tilt differences (leading to asymmetric top rounding)
2. Risk of local bowing when ARDE.

For morphology improvements, a leaner DARC open step is applied (with reduced CHF3 and increased CF4/O2 flow) to reduce the morphological deformation.

For sidewall profile improvements, the process mitigates these effects through controlled anisotropic dry etching, combining directional ion bombardment with carefully tuned sidewall passivation.

5:30pm **PS2+EUV-TuA-14 Role of Interfacial Force Balance in Gap Filling of TEOS-based Flowable CVD: Insights from Molecular Dynamics*, Hu Li,*** Tokyo Electron America Inc.,*; Takeo Nakano, Nobuo Matsuki, Masaaki Matsukuma,* Tokyo Electron Ltd., Japan*; Raymond Joe, Anthony Dip,* Tokyo Electron America Inc.,

Achieving void-free gap filling in high-aspect-ratio structures is one of the key challenges in advanced semiconductor processing. Flowable chemical vapor deposition (CVD) has been widely studied as a promising approach, and its behavior is often interpreted in terms of wettability or viscosity. However, these conventional descriptors do not always explain the differences observed in gap-fill performance across various precursor chemistries and geometries.

In this work, we focus on the pre-cure stage of flowable CVD and investigate the transport-driven filling behavior using classical molecular dynamics simulations. By intentionally excluding chemical reactions, we isolate the role of intermolecular interactions and interfacial forces in confined geometries. The simulation system consists of siloxane-based liquids on SiO_2 substrates, with trench structures of varying aspect ratios.

To better understand the filling mechanism, we introduce a force-based analysis by decomposing the total force acting on liquid molecules into liquid-substrate and liquid-liquid contributions. This approach reveals a clear spatial variation in the driving forces within the trench. Near the sidewall, strong downward forces promote infiltration, while in the center region, the driving force is significantly reduced, which leads to incomplete filling and void formation.

We further show that increasing the aspect ratio enhances this imbalance in force distribution, making uniform filling more difficult. In addition, surface modification, such as Si-rich surface, can reduce the interfacial interaction strength and improve liquid mobility.

These results suggest that gap-fill behavior cannot be fully described by wettability alone, and that a force-based perspective provides more direct insight into the underlying mechanism. This study offers a more detailed understanding of pre-cure transport processes and may help guide the design of future flowable CVD processes.

Advances in EUV Lithography
Room Ballroom A - Session EUV-ThP

Advances in EUV Lithography Poster Session

EUV-ThP-1 Multilayer Graphite Pellicles with Engineered SiNx Capping for High-Power Extreme Ultraviolet Lithography, *Hye-Young Kim, Sung Kyu Jang, Jihun Kim, Jong-Hyun Choi,* ***Hyun-Mi Kim****, Seul-Gi Kim, Hyeongkeun Kim,* Korea Electronics Technology Institute, Republic of Korea

To withstand the severe thermal and chemical environments of next-generation extreme ultraviolet lithography (EUVL), this study demonstrates a high-performance multilayer pellicle comprising a low-temperature directly synthesized graphite core and a dense silicon nitride (SiNx) protective layer optimized via plasma-sequence-engineered atomic layer deposition (PSE-ALD).

First, to overcome the non-uniformity and transfer damage inherent in conventional CVD, a low-temperature (500 °C) metal-induced crystallization of amorphous carbon (MICA) process was developed using a nickel (Ni) catalyst. Nucleation and crystallization occur predominantly at the Ni/amorphous carbon (a-C) interface, where the lateral growth rate significantly exceeds vertical growth. By optimizing the a-C to Ni thickness ratio to 45 nm: 30 nm (~1:1 atomic ratio), uniform graphite films free of residual metal clusters were directly synthesized on 8-inch wafers without a transfer step. Freestanding 15-nm-thick graphite membranes fabricated by backside etching exhibited an outstanding EUV transmittance of 91.56% and a high thermal emissivity of 0.37, satisfying industrial criteria for high-power EUV operation.

Second, to shield the inert graphite from harsh hydrogen radicals (H*) in EUV scanners and KOH solutions during membrane fabrication, PSE-ALD was introduced using HCDS (Si_2Cl_6) and NH_3 plasma, followed by a sequential N_2 plasma step. Real-time mass spectrometry verified that the sequential N_2 plasma effectively extracts volatile HCl by-products, facilitating dense cross-linking and eliminating chlorine and hydrogen impurities. Under a mild plasma power of 50 W, the NH_3-N_2 sequence yielded a stoichiometric, oxygen-free SiNx ultra-thin film (5 nm) with a high mass density of 3.07g/cm^3.

Third, permutation tests confirmed that film mass density is the primary factor governing wet-etching resistance. The optimized SiNx capping layer exhibited a pinhole-free structure and an extremely low etch rate of 0.17 nm/h in a 30 wt% KOH solution for 16 hours. Finally, the capped graphite pellicle was evaluated under a 250 W H_2 plasma for 5 minutes. While the pristine graphite suffered severe degradation and a thickness loss over 5 nm, the SiNx-capped graphite showed negligible change. This integrated strategy offers a robust framework for carbon-based multilayer pellicles in next-generation high-power EUVL systems.

EUV-ThP-2 Understanding the Initial Deposition and Etching of Tin in an Extreme Ultraviolet (EUV) Source, ***Nathan Bartlett****, Jameson Crouse, Andrew Herschberg, Emily Greene, Jaime Robertson, Lucia Suarez Heredero, Marisol Velapatino, Karl Vu,* University of Illinois at Urbana-Champaign*; Niels Braaksma, Sergio Ferraris,* ASML*; David Ruzic,* University of Illinois at Urbana-Champaign

Tin laser produced plasmas (LPPs) are used to generate 13.5 nm light in state-of-the-art extreme ultraviolet (EUV) lithography tools. Inside these tools, hydrogen gas is used as a buffer gas to decelerate ions from the LPP and is photoionized in the process creating a steady background hydrogen plasma. This plasma etches away tin as it accumulates on the wall of the EUV source forming the volatile compound stannane. The interaction of hydrogen plasma species and tin lead to complex morphologies. In this work, we study the initial growth of tin thin films in a relevant hydrogen plasma environment. Tin is deposited using a high temperature thermal evaporation source and a hydrogen plasma is generated using an RF power supply. Thin films are measured using a scanning electron microscope and resistivity probes. The plasma is measured using optical emission spectroscopy, Langmuir probes, and radical probes. Impurity gasses, such as water, are also injected into the experiment to determine the effect on tin growth and etching. Water is expected to affect surface reactions which in turn increases the concentration of hydrogen radicals in the plasma. These results are used to validate both plasma models as well as tin thin film growth models.

EUV-ThP-3 Development of Mass Limited Targets for Enabling Fundamental Studies of Next Generation of EUV Lithography, ***Ajay Karakoti****, Peipei Wang, Mathew Polek, Tyler Ray, Sivanandan Harilal,* Pacific Northwest National Laboratory

Extreme ultraviolet (EUV) lithography at 13.5 nm is a cornerstone of advanced semiconductor manufacturing, where continued device scaling depends on improvements in source brightness, spectral purity, and optics lifetime. The ANGEL (Accelerating Next-Generation EUV Lithography) project, led by Pacific Northwest National Laboratory, targets significant improvements in the conversion efficiency of EUV sources based on low-density Sn targets by carrying out fundamental experimental studies and modeling to understand and control the underlying plasma physics.

Studies of laser produced plasma from bulk Sn sources emit substantial particulate, ionic, and neutral debris, with high-velocity ions and neutrals capable of damaging nearby collection optics. In addition, fully dense Sn plasmas produce a broad recombination continuum that limits spectral purity in the in-band region around 13.5 nm. Mass-limited, low-density targets, in which Sn is dispersed as a dilute dopant within a low-Z foam matrix, offer a route to mitigate both issues. Incorporating Sn as an impurity in a low-Z host reduces the average plasma ionization state and recombination continuum, narrowing the unresolved transition array (UTA) around 13.5 nm, while simultaneously limiting the total Sn inventory available to generate debris. Low-density foam targets further provide a well-defined geometry and density prior to laser illumination, enabling reproducible laser–plasma interactions.

This poster presents the fabrication and comparative characterization of Sn-doped mass-limited foam targets synthesized from two distinct low-Z matrices. It compares the performance of resorcinol-formaldehyde (RF) aerogels, a well-established foam chemistry for laser-plasma targets, and nanocrystalline cellulose (NCC) foams, an emerging bio-derived alternative. We compare the (i) ease and reproducibility of synthesis, (ii) morphology, Surface area and pore-size distribution, and (iii) spatial uniformity of Sn dispersion as characterized by different in-situ and ex-situ tools. Finally, we correlate these structural and compositional metrics with EUV emission characteristics, comparing the spectral profiles of doped RF and NCC foam targets against bulk Sn references to assess their suitability as mass-limited targets for spectrally clean, low-debris EUV generation.

EUV-ThP-5 High Purity Component Cleaning for EUV: Current Challenges in the Process Chain, ***Michael Flaemmich****,* VACOM USA

Unlike classic component cleaning, high purity cleaning for EUV Lithography is not about cleaning off large amounts of production residue (e.g. several gallons of oil per batch or several pounds of chips). Rather, high purity cleaning for EUVL focuses on removing even the slightest residual contamination (particulate, organic, and inorganic) and then keeping the cleaned surfaces clean and preserving them. As a consequence, the creation of high purity surfaces for EUVL is not only the task of the process step cleaning. This induces some familiar and some new challenges for cleaning technology and the entire process chain, which will be highlighted in the talk.

Furthermore, we will introduce our approach to transfer our high purity parts cleaning concepts for EUVL cleaning from Europe to the US. VACOM recently opened a parts cleaning facility in Lewistown, Montana. We will give some insights into the machines, processes and the current challenges in the high purity process chain for EUVL component cleaning.

Besides EUVL, industries requiring high-purity cleaning and ultra-clean parts are those where microscopic contamination causes component failure, product spoilage, or safety hazards, primarily semiconductor manufacturing, aerospace/defense, pharmaceuticals, and medical device production. These sectors necessitate specialized cleaning techniques to remove contaminants - such as particulate matter, lubricants, and ions - from surfaces, often requiring ISO-certified cleanroom environments.

EUV-ThP-6 Investigation of Cold Spitted Sn Particle Transport in a Hydrogen Plasma, ***Jaime Robertson****,* University of Illinois at Urbana-Champaign

In Extreme Ultraviolet (EUV) lithography, defectivity in printed wafers is a significant concern due to yield loss. Defects hinder the performance of semiconductors, dependent on its size and location. Defectivity, in relation to this work, arises from the migration of particles and the subsequent contamination that occurs when these particles stick to sensitive components. This includes the reticle, which holds the pattern to be printed on the wafer. Sn particles are a significant contributor to reticle defectivity, resulting in substantial downtime for EUV machines at customer fabs. Sn

defectivity arises from the complex interaction mechanisms of Sn particles with EUV-induced plasma. Each of these pathways contributes to the overall presence and movement of Sn particles within the system, potentially leading to contamination of sensitive components. These mechanisms need to be investigated in detail to tackle Sn defectivity and ensure high uptime for EUV machines, as understanding each process can inform the development of targeted mitigation strategies. Therefore, the studies described here investigate the interactions between hydrogen plasma, similar to the EUV scanner environment, and Sn found in certain regions within the EUV scanner. Three known plasma material interactions occur with Sn, which result in mass migration. These include ion etching, chemical etching, and electrostatic particle lift-off. Although these methods have been studied to varying degrees, modeling of the EUV scanner has shown that these mass migration processes cannot contribute to particles reaching the reticle. Therefore, the aim has been to determine whether other methods of mass migration occur, which result in particles found on the reticle. Specifically, cold spitting has been proposed as a potential mechanism for particle migration to the reticle. Cold spitting refers to the ejection of solid particles due to a buildup of hydrogen gas beneath the surface. Once the pressure of hydrogen bubbles formed is sufficiently high, the bubble bursts, ejecting nano-particles away from the surface. The difficulty in independently studying cold spitting has been in separating the migration mechanisms to ensure that the particles analyzed were formed by cold spitting. We present a method which allows for cold spit Sn particles to be collected on an adjacent surface while preventing particles formed through other mechanisms from being captured. Therefore, proving that cold spitting occurs for Sn. From the initial findings, the rate of ejections from a $1cm2$ sheet of Sn was approximated. The resulting flux was *5.1*101±1Sn particlescm2s.*

EUV-ThP-7 Open-Use, Synchrotron-Based EUV Exposure/Characterization System at LLS*, Ali Parastesh, Anthony Engler,* ***Phillip Sprunger,*** Louisiana State University

A designated synchrotron-based EUV exposure/characterization system has been commissioned at the Louisiana Light Source, or LLS (LSU's Center for Advanced Microstructures and Devices). Using both a toroidal mirror and a Si/Mo multilayer spherical mirror, the system delivers focused EUV light (~2% bandpass centered at the required 13.5 nm wavelength) to the sample holder, with a simulated FWHM spot size of ~1.2 × 0.5 mm at ~3 W/cm^2. In addition to a low-energy external electron gun, an in situ quadrupole mass spectrometer and a hemispherical electron analyzer (with an X-ray source) enable operando characterization of photoresists during EUV exposure. The goal is to elucidate key aspects of the physics and chemistry of EUV exposure mechanisms and to better develop photoresists with enhanced performance (higher sensitivity, lower line edge roughness, and higher resolution) than those currently used in high-volume chip manufacturing. The beamline is an open-use EUV exposure/characterization facility for both academic and industrial users.

Initial studies on polyaldehyde-based resists capable of thermally driven, dry development are underway. Specifically, we have studied the effects on thin-film poly(phenyl glyoxal)s (PPG). Employing 100eV electrons, soft-X-ray XANES of the O- and C-edges reveals details of carbonyl elimination and the conversion of the pristine PPG backbone to a degraded state capable of developing the latent image. These results are supported by EPR, consistent with a Norrish mechanism of photodegradation.

EUV-ThP-8 Development and Performance of a University-Scale EUV Lithography Source*, **Dren Qerimi,*** University of Illinois

To expand our lab's capabilities in EUV photoresist research, we developed an in-house EUV light source that provides lithography exposures at a cost feasible for a university setting. The system uses an Nd:YAG laser to produce plasma on a tin target, which generates EUV radiation without relying on the extremely expensive infrastructure found in commercial systems. A 150 nm zirconium transmission filter isolates the EUV wavelengths and allows direct exposure of the photoresist. The exposure dose is monitored in real time using an EUV-sensitive photodiode, and we have confirmed the accuracy of these measurements through successful exposures and development of EUV photoresists. Using this setup, we have demonstrated a clear contrast curve with exposure times typically under 120 seconds, showing that the system can reliably deliver controlled and repeatable EUV doses. During optimization, we adjusted the laser power, the focusing conditions, the chamber pressure, and the movement of the target to stabilize the dose and improve EUV output. Debris from the plasma remains one of the primary challenges, so we are continuing to refine the target handling and filtering approach to extend the lifetime of internal components. Even with ongoing improvements, the system already provides consistent and tunable EUV exposure that supports photoresist testing and development. Compared to commercial EUV lithography platforms that cost several million dollars, this tool offers a practical and flexible option for research. It enables the study of new photoresist materials, dose response behavior, and exposure strategies without depending on limited industrial access. Current work includes blanket exposure testing and efforts to lower the required dose for full development. In this way, the system provides a meaningful bridge that allows academic research groups to work directly in the EUV regime.

EUV-ThP-9 A Computational Molecular Framework to Investigate EUV Lithography Photoresist Sensitivity: Poly(Pthaladyhede) and Poly(Methyl Methacrylate) Degradation Study*, **Amrutha Raghu,*** Louisiana State University*; Tianyi Wang,* Lousiana State University*; Revati Kumar,* Louisiana State University

High-volume EUV lithography at sub-7 nm nodes is constrained less by optics than by photoresist performance. The resolution-LER-sensitivity tradeoff tightens with every technology node, and stochastic failures from photon shot noise set hard limits on what current resist platforms can deliver. Chemically amplified resists compound the problem by introducing chemical inhomogeneity that worsens stochastic acid generation and diffusion at the length scales that matter for sub-10 nm features. Single-component depolymerizable resists such as poly(phthalaldehyde) (PPA) avoid acid diffusion entirely, and cyclic PPA (c-PPA) achieves spontaneous dry development at doses competitive with CARs. Two questions have remained open: why does cyclic topology outperform linear PPA in EUV sensitivity, and what drives dose-dependent crosslinking at higher doses? We address both using reactive molecular dynamics with the ReaxFF force field. The framework simulates the aftermath of EUV-induced ionization through the Primary Knock-on Atom (PKA) method: backbone carbon atoms are randomly selected across a 40-chain, 20-mer simulation box and assigned velocities equivalent to 10 eV secondary electron momentum, then the system evolves chemically in an NVE ensemble. The same protocol is applied to PMMA, a well-established EUV photoresist with extensively characterized experimental behavior, making it an ideal validation system. Together, PPA and PMMA allow us to connect repeat unit structure and polymer topology to the full spectrum of EUV-induced chemistry and establish molecular design principles for next-generation photoresist platforms. PKA recoil redistributes charge across the simulation system, generating active sites whose charges deviate significantly from equilibrium. For PPA, c-PPA shows 3.6 times more active sites than l-PPA, and active site locations correlate directly with bond breaks, indicating elevated bond stress from energetic neighboring atoms. The origin is thermodynamic: the ring blocks angular relaxation that linear chains use to absorb the perturbation, forcing energy into bonds instead. Bond angle distributions, angle strain, conformational entropy, and radius of gyration all support this picture. For PMMA, PKA simulations show backbone bonds undergo higher scission than side-chain linkages, consistent with experimental EUV chemistry of methyl methacrylate polymers. This is traceable to the higher concentration of active sites on the backbone relative to side-chain carbons. Active site distribution and bond stress together explain the emergent EUV chemistry in both systems and provide a structural basis for rational photoresist design.

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