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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