Emerging Materials
Room Tamna Hall B - Session EM-TuM
Molecular Layer Deposition & Hybrid Materials I

Moderators: Jin-Seong Park, Hanyang University, **Henrik Pedersen**, Linköping University, Sweden

10:45am **EM-TuM-12 Zeolite-Like Frameworks Created by ALD/MLD as an All-Dry Resist Technology**, ***Howard Fairbrother,*** Department of Chemistry, Johns Hopkins University; *Peter Corkery, Kayley Waltz,* Department of Chemical and Biomolecular Engineering, Johns Hopkins University; *Patrick Eckhert,* Department of Chemistry, Johns Hopkins University; *Michael Tsapatsis,* Department of Chemical and Biomolecular Engineering, Johns Hopkins University **INVITED**

The drive to further decrease microelectronic device dimensions has led to the expansion of extreme ultraviolet lithography (EUVL) and EBL processes which require next generation resist materials to maximize feature resolution and improve product throughput. Conventional solvent-based resist processes use organic resists which typically requiring time consuming baking steps and generate of organic solvent waste. Furthermore, mechanical stress induced by solution-based development can lead to pattern collapse, limiting the maximum possible density of patterned features. The process described herein avoids the use of, and some issues associated with, organic solvents by depositing films using ALD/MLD to produce amorphous films from 2-methylimidazole and diethylzinc that are chemically similar to zeolitic imidazolate framework-8 with sub-nanometer roughness. Following electron irradiation, areas of the film which were exposed to the electrons maintain the C:N:Zn ratio of the original film and are rendered resistant to etching by vapor phase 1,1,1,5,5,5-hexafluoroacetylacetone (hfacH). In contrast, unexposed areas can be readily removed by exposure to hfacH vapor at 120 °C, demonstrating the efficacy of aZnMIm films as a negative tone resist. The low temperature thermal etching conditions are notable, as the typical requirement of high temperatures in other dry etching processes can be difficult to implement in nanofabrication processes. The use of a molecular etchant (hfacH) also avoids limitations of plasma-based processes. aZnMIm films deposited by atomic/molecular layer deposition (ALD/MLD), patterned with electron beam lithography (EBL), and developed with hfacH achieved well-resolved 22 nm thick, 30 nm pitch lines. Sensitivity, contrast, and critical dimensions of the patterns created on silicon substrates and patterned at 30 keV are determined to be 37 mC cm^{-2}, 0.87, and 29 nm, respectively. This work introduces a new direction for solvent-free resist processing, offering the prospect of scalable, high-resolution patterning techniques. Future work will explore substitution of the zinc metal centers for more EUV absorptive metals and the introduction of more reactive groups onto the organic linkers to increase resist sensitivity.

11:15am **EM-TuM-14 Atomic Layer Regulation of MIL-53 Metal-Organic Framework as Interconnect Low-k Dielectrics**, ***Fan Yang***, Luoyu Road 1037, Wuhan, China; *Jisheng Song, Rong Chen,* Huazhong University of Science and Technology, China

Metal-organic frameworks stand out as one of the promising low-k dielectrics candidate to alleviate the delay caused by interconnect resistance of metal wire and capacitance of interlayer dielectrics (RC delay) in the context of the ever-denser and miniaturized integrated circuits. However, achieving nanoscale control over thickness of the fabrication of MOF thin-films is a critical requirement for subsequent lithography and metallization steps as well as of adequate mechanical strength. Therefore, precision preparation and modification of MOF-based dielectric film becomes an urgent need.

In this work, we report a synthetic strategy of ultra-low k (1.93 at 1 MHz) MIL-53 dielectrics by converting atomic layer deposited Al_2O_3 seed layer via microwave-assisted solvothermal method, where nanometer-scale regulated MIL-53 film can be obtained due to the linear dependence of the thickness of MIL-53 film on the Al_2O_3 seed layer. The synthesized the MIL-53 film also exhibits excellent hydrophobic properties and stability, with the dielectric constant remaining stable even after 12 days of aging, reflecting its potential as a dielectric insulating material. In addition, additional Al-O bond enhanced structures were formed in the MIL-53 framework by gas phase atomic layer infiltration (ALI) modification. After ALI treatment, the Young's modulus of MIL 53 increased by 27.7% (from 19.5 GPa to 24.9 GPa), hardness increased by 64.7% (from 0.17 GPa to 0.28 GPa), while only slightly increased on dielectric constant (from 1.93 to 2.32). The MOF film fabrication ALI modification strategy holds great promise for MOF based film synthesis and modification for interconnect dielectrics and various applications.

References

1. Atomic Regulation of Metal–Organic Framework Thin Film for Low-k Dielectric. Meng Cao, Jisheng Song, Haonan Ren, Fan Yang, Rong Chen,*Chem. Mater. 2024, 36, 22, 11160–11169*.

11:30am **EM-TuM-15 Nanolaminated Films with Negative Capacitance Fabriacted by ALD**, ***Xiang Yang Kong***, School of Materials Science Engineering Shanghai Jiao Tong University, Shanghai 200240, China

The relization of negative capacitance (NC) behavior has long attracted the interests of electrical engineers. Some evidences have been demonstrated by examining the NC response resulting from adding a ferroelectric layer in series with a dielectric. In this talk, we fabricate a series of multilayered films with negative capacitance by ALD. The NC behavior occurs at the hetero-interfaces between the ferroelectric and paraelectric nanolayers.Regarding NC in hafnia-based materials, the oxygen-deficiency is accounted for unstable features as well as their ferroelectric and dielectric properties. We proposed the mobile ions at interfaces could enhance the stability of NC effects with the induced polarization.Moreover, we also lay out the way for scaling the NC FET nanoelectronics down to 2.5–5nm ferroelectric gate as well as giant density of energy storage.

11:45am **EM-TuM-16 Thermal Annealing of Molecular Layer-Deposited Tincone : Unveiling Sulfur's Structural Impacts in Graphitic Carbon Formation**, *Jin-Seong Park,* ***Gi-Beom Park,*** *Hyolim Jung, Hae Lin Yang, Ji-Min Kim,* Hanyang University, Korea

As the scaling down of semiconductors based on Moore's Law continues, efforts to introduce 2D graphitic carbon is being considered for use as a Cu diffusion layer and as top/bottom capping electrodes for Storage Class Memory (SCM), leveraging its high electrical conductivity and small geometric pore size to prevent diffusion between layers.[1,2] Additionally, it has the advantage of low chemical reactivity, making it suitable as an inhibitor in Area-Selective Deposition (ASD).[3] Both Chemical Vapor Deposition (CVD) and Atomic Layer Deposition (ALD) have been studied as methods for depositing graphitic carbon. However, the direct deposition of graphitic carbon on dielectric layers using CVD is limited, requiring a transfer process after deposition on substrates like Cu or Ni.[4] On the other hand, using ALD to deposit on dielectrics increases the sp^3 bonds, which compromises the benefits of sp^2 bond-based carbon.[5] Therefore, research is needed on deposition methods that can directly deposit graphitic carbon on dielectrics, regardless of the substrate. Using Molecular Layer Deposition (MLD) to deposit metalcone thin films followed by thermal annealing has confirmed the formation of graphitic carbon as metal atoms are eliminated.[3] Additionally, metalcone thin films can be effectively deposited on dielectric layers, providing the advantage of forming graphitic carbon regardless of the substrate. However, research on the formation of graphitic carbon through the thermal annealing of metalcone thin films has been limited to organic precursors with hydroxyl groups, such as hydroquinone (HQ). Therefore, it is necessary to study the graphitization behaviors influenced by the composition variations depending on different organic precursors.

In this study, tetrakis(dimethylamido)tin (TDMASn) and 4-mercaptophenol (4MP) were used to deposit tincone, followed by thermal treatment to explore the effect of sulfur within the metalcone thin film on the formation of graphitic carbon after thermal annealing. The MLD tincone films were deposited at 100 °C without impurities, then vacuum post-annealed in a tube furnace to induce graphitization. Spectriscopic Ellipsometry (SE), X-ray Photoelectron Spectroscopy (XPS) and Raman spectroscopy were employed to investigate the effect of thermal annealing on the tincone thin film. As a results, atomic concentration of Sn decreased as increasing annealing temperature but Sulfur deteriorate graphite structure above annealing temperature of 500℃. Threrefore, it is important to find appropriate annealing condition by composition of metalcone thin film.

Emerging Materials
Room Tamna Hall B - Session EM-TuA
Molecular Layer Deposition & Hybrid Materials II

Moderators: Jolien Dendooven, Ghent University, Belgium, **Chang-Yong Nam**, Brookhaven National Laboratory

1:30pm **EM-TuA-1 Vapor Phase Infiltration for Membrane Modification*, David Bergsman,*** University of Washington **INVITED**

Membrane filtration is a promising tool for reducing energy consumption and carbon emissions in areas like industrial manufacturing, food and beverage, municipal water treatment, and pharmaceuticals. However, improvements to membrane permeability, selectivity, thermal stability, chemical stability, and fouling resistance will be required before they are cost-effective enough to handle the acidic, alkaline, organic, and otherwise complex feed streams present in many applications. Of the commercial membranes commonly available, polymeric membranes are relatively low cost but often suffer from low thermal and chemical stability, while other membrane materials can be difficult or expensive to manufacture. Vapor phase infiltration (VPI), also known as sequential infiltration synthesis or atomic layer infiltration, is one potential cost-effective strategy for making higher-performance membranes. In VPI, a polymer is exposed to vapor phase metal-organic reactants which absorb, diffuse, and react in the polymer to form a composite material. This approach could be used to upgrade existing membranes through post-synthetic modification to improve their performance. However, more work is needed to understand the impact of this process on polymer properties and to discover new materials that best enable the wider implementation of membrane separations. This presentation will highlight our work to apply the VPI process to membrane separations. We will review examples of how we have used VPI to improve the conductivity of membranes through the formation of laser induced graphene, our work to understand the trade-off between infiltration and polymer toughness, and our exploration of organic reactants that could expand the library of infiltration processes. In doing so, this presentation will showcase the potential of VPI to create next-generation membranes for diverse and challenging separation applications.

2:00pm **EM-TuA-3 Dry Developing Process of Molecular Layer Deposited Hf-Based Hybrid Thin Films for EUV Lithography**, ***Minki Choe**, Dan Le, Thi Thu Huong Chu, Hyunah Sung,* University of Texas at Dallas*; Nikhil Tiwale,* Brookhaven National Laboratory*; In-Hwan Baek, Rino Choi,* Inha University, Republic of Korea*; Chang-Yong Nam,* Brookhaven National Laboratory*; Jiyoung Kim,* University of Texas at Dallas

EUVL plays a critical role in device down-scaling and thereby extending the life of Moore's law to beyond sub-7nm node. However, the current EUV photoresists based on spin-on processing and followed by wet development, which faces challenges such as high processing costs of organic solvents, pattern collapse due to capillary forces during wet development, and undercut. [1,2] These problems increase overall process costs and limit the patterning performance. In this context, fully dry lithography process has the potential to overcome the drawbacks of wet lithography and accelerate the advancement of EUV lithography.

Herein, we report a Hf-based hybrid resist thin film system that synthesized via molecular layer deposition (MLD) using Tetrakis(dimethylamido)hafnium (TDMA-Hf) and 2,3-Dimercapto-1-propanol (DMP). In our other study, we found that the Hf-based resist thin film system exhibited negative-tone behavior and excellent sensitivity, with pattern formation observed at a remarkably low dose of ~96 $\mu C/cm^2$ under 100 eV e-beam exposure. In this study, we specifically focus on investigating the dry development process using inductively coupled plasma reactive ion etching (ICP RIE) that suitable for the deposited Hf-based resist thin films. To mitigate the contribution of fluorinated greenhouse gases (F-gases) to global warming, we employed fluorine-free gases. During the etching process with fluorine-free gas, we conducted parameter optimization by varying crucial factors such as bias power, substrate temperature, and working pressure. This optimization aimed to find optimal conditions that maximize the etch rate difference between exposed and non-exposed regions. This research focuses on developing a fully dry lithography approach by combining MLD-deposited organic-inorganic hybrid photoresists with a dry development process using fluorine-free gas in ICP RIE. The goal is to establish a cost-effective and environmentally friendly lithography technique that can facilitate the realization of high-resolution patterns in EUV lithography while overcoming the limitations associated with conventional wet processes.

This work is supported by the U.S. DOE Office of Science Accelerate Initiative Award 2023-BNL-NC033-Fund. Minki Choe supported by KIAT/MOTIE (RS-2024-00435406).

[1] IRDS., "Lithography & Patterning: The International Roadmap for Devices and Systems", IEEE, 1-13 (2023).

[2] Marsella, J. A., et al., "Handbook of Cleaning for Semiconductor Manufacturing",Scrivener Publishing LLC ,565-584 (2010).

2:15pm **EM-TuA-4 Inverted Living Molecular Layer Deposition: Rapid Conformal Polymer Coatings through Vapor-Phase Living Polymerization**, ***Karina Ashurbekova**, Mato Knez,* CIC nanoGUNE, Spain

This study presents an inverted living MLD technique that enables precise polymer growth with tailored architectures, functional groups, and customizable properties. We present the first vapor-phase synthesis of polyoxazolines (POx) via a living cationic ring-opening polymerization (CROP) mechanism.

The two-step process involves a pulsed delivery of vaporized initiator (P-Toluenesulfonyl chloride) into a reactor, where it adsorbs onto the substrate as a molecular layer, functionalizing it. This is followed by chain propagation, where the monomer is introduced and reacts with the chemisorbed initiator layer.

We utilized three substituted oxazolines as monomers: 2-methyl-2-oxazoline, 2-phenyl-2-oxazoline, and 2-isopropenyl-2-oxazoline. The substrate was exposed to the monomer vapors for several seconds, after which the chamber was purged, and another dose of vaporized monomer was introduced. With each pulse of monomer, the polymer layer thickness gradually increased until the monomer was consumed. This allows precise control over the final coating thickness through the monomer dose and the number of feeding cycles, while still maintaining conformality of the coating. The growth process is terminated by introducing water vapor into the reactor.

The living nature of the polymerization has been confirmed by in situ QCM studies. We observed fascinating surface effects, while the composition and morphology of the POxs were examined using ATR-FTIR, XPS, SEM/TEM, and AFM. In this presentation, we focus solely on the growth of POx homopolymers, though copolymerization through sequential monomer addition is also achievable.

The key advantages of this approach include the elimination of multicomponent solution-based impurities, precise thickness control, conformality, and strong adhesion of the polymer films to a wide range of substrates.

Our approach opens the door for customization of materials for plentiful applications. As such, this development marks the beginning of a novel approach to rapid surface functionalization with highly conformal coatings with functional polymeric materials.

2:30pm **EM-TuA-5 ALD Outstanding Presentation Award Finalist: Recent Advancement of Inorganic-Organic Hybrid Resist Thin Films Deposited via Molecular Atomic Layer Deposition for Dry EUV Resist Platforms**, *Dan N. Le, Thi Thu Huong Chu, Hyunah Daniela Sung, Minki Choe, Minjong Lee,* University of Texas at Dallas*; Won-Il Lee,* Stony Brook University*; Nikhil Tiwale,* Brookhaven National Laboratory*; Jean-Francois Veyan, Doo San Kim,* University of Texas at Dallas*; Chang-Yong Nam,* Brookhaven National Laboratory*; **Jiyoung Kim**,* University of Texas at Dallas

In order to sustain the device down scaling below the sub-1nm node, the implementation of high/hyper numerical aperture (NA) extreme ultraviolet (EUV) lithography is essential. This advancement drives the need for innovative resist platforms that meet rigorous performance criteria, including ultra-thin film (<15 nm), uniformity, mechanical and chemical robustness, and superior etch resistance. Conventional polymer-based spin-coated resists struggle to meet these stringent requirements. In contrast, ALD-based synthesized inorganic-organic hybrid dry resist thin films offer significant advantages, providing precise atomic-scale thickness control, enhanced material uniformity, and strategic incorporation of metal elements to improve sensitivity, mechanical strength, and etch resistance.

Herein, we report various molecular-atomic layer deposited hybrid resist thin film systems, contributing to the advancement of the dry EUV resist platform. We explore different combinations of metal ALD precursors, such as TMA, DEZ, TDMA-Hf with organic sources like hydroquinone (HQ), 4-mercaptophenol (4MP), and 2,3-Dimercapto-1-propanol (DMP). By using various combinations of these inorganic and organic sources, we achieve hybrid thin film systems consisting of Al-HQ, Zn-HQ, Al-4MP, Zn-4MP, Hf-4MP, Hf-DMP, and Zn-DMP. The growth characteristics of these hybrid resist

thin films were thoroughly evaluated, along with detailed material characterization. The electron sensitivity of various hybrid resist thin films was investigated using electron beam lithography (EBL) at 100 V acceleration voltage, mimicking EUV exposure conditions. Upon electron irradiation, all these hybrid resist thin film systems exhibited negative tone resist characteristics when evaluated in different developer solutions. Among these resist thin films, the Hf-DMP system demonstrated the highest sensitivity when subjected to 100 eV electron energy irradiation, requiring the lowest exposure dose to maintain most of their thickness. The chemical transformations in these hybrid resists are also investigated using *in-situ* IR spectroscopy equipped with an electron gun and a residual gas analyzer (RGA). The IR absorbance and operando RGA spectra suggested that aromatic and chain organic moieties exhibited different crosslinking pathways. Detailed experimental procedures and results will be discussed including actual EUV sensitivity of hybrid dry PRs.

This work is supported by the U.S. DOE (2023-BNL-NC033-Fund), and NRT/MSIT (2022M3H4A3052556) in Korea. We acknowledge Drs. Sangsul Lee, Geonhwa Kim, Jiho Kim at Pohang Accelerator Lab (PAL) for EUV exposure test.

2:45pm **EM-TuA-6 Rethinking Thermoelectrics: The „Power" of Hybrids Engineered by Vapor Phase Infiltration***, **Kristina Ashurbekova,*** CIC nanoGUNE, Spain*; Maksim Naumochkin, Heiko Reith, Kornelius Nielsch,* Leibniz Institute for Solid State and Materials Research, Germany*; Mato Knez,* CIC nanoGUNE, Spain **INVITED**

Hybrid thermoelectric (TE) materials aim to outperform traditional TEs by creating synergies between organic and inorganic materials. The simultaneous exploitation of the low thermal conductivity (λ) of organics and the high Seebeck coefficient (S) and electrical conductivity (σ) of inorganics is particularly attractive. To achieve this, we developed a new family of hybrid TE materials by applying vapor phase infiltration (VPI) of Sb_2Te_3, Bi_2Te_3, Sb_2Se_3, or Bi_2Se_3 into polymeric matrices. The resulting hybrid materials feature a unique structure, with chalcogenide nanocrystals grown within the bulk of the conducting polymers.To fully understand the complexity of these hybrid materials, we extensively characterized the infiltrated chalcogenides. We observed a clear correlation between the polymer thickness and the precursor exposure time with the evolving chalcogenide crystals size within the final hybrid material. Thinner polymers resulted in smaller crystals, likely related to the faster out-diffusion of unbound precursors from the polymer during the process. TEM was used to investigate the structural organization of the nano clusters in the hybrids and to study the nucleation processes of chalcogenide nanocrystals, distinguishing between those chemically bound to the polymer chains and those physically entrapped within the polymer. SEM tomography was used to evaluate a network of chalcogenide nanocrystals inside the polymer matrix and the degree of their three-dimensional connectivity. The TE properties of the hybrids were characterized between 293–433 *K* using a lab-on-chip ZT test platform, which allowed simultaneous characterization of all in-plane parameters of the films, including the σ, *S*, λ, Hall coefficient R_H, and the derived Power Factor (PF) and ZT. Interestingly, all the measured parameters (*σ, S,* Hall coefficient R_H, λ) changed considerably within the first several heating-cooling cycles. For example, in the case of Sb_2Te_3-infiltrated PEDOT:PSS, the difference in σ between successive measurements increased to values of exceeding 80 S cm^{-1}, while the change in λ decreased. This decoupling of σ from λ is attributed to suppression of the lattice λ by enhanced boundary-scattering of heat-carrying phonons. Simultaneously, the chemical bonds between the inorganic and organic phases promote direct electronic interaction, facilitating electron transport. Finally, remarkable PF and ZT values of were obtained. This presentation will provide an overview over the conceptualization, fabrication, and evaluation of this new hybrid TE materials system, highlighting its advantage over traditional TE material concepts.

Emerging Materials
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Emerging Materials Poster Session

EM-TuP-1 A Novel Topological Semi-Metal: MoP Pathfinding for Future Interconnects at Nanoscale*, **Jeong-Seok Na**, Kyle Blakeney, David Mandia, Jeremie Dalton,* LAM Research

Metal interconnect resistance increases as devices continue to shrink, which poses challenges for metallization schemes in future device nodes.

Topological semi-metals (TSMs) were recently introduced and have demonstrated promising resistivity scaling performance at nanoscale. This is due to their unique properties related to topologically protected surface states and suppressed electron backscattering. MoP is considered one of promising candidates due to its high carrier concentration (~10^{23} cm^{-3}) and relatively low bulk resistivity (~9 μΩ·cm) compared to other TSMs.

We describe the fundamental problem of metal resistivity increasing as interconnect dimensions shrink. Recently, some materials have been observed to show an unconventional resistivity decrease with decreasing dimensions. Among these topological semi-metals, MoP is a promising candidate. There have been few reports about MoP synthesis process that is compatible with interconnect applications.

In this study, we investigate the growth behavior and film properties of MoP using thermal ALD process. First, we compared different reducing agents in the ALD of MoP films. Second, comprehensive film characterization was conducted to evaluate resistivity and crystal phase/structure using 4-point probe, XPS depth profile, AR-XPS, GI-XRD and XRR analyses. The selective growth was tested to evaluate bottom-up gapfill in via structures over a wide temp range for both logic and memory applications. Finally, we discuss the need for thermal stability studies and nanoscale device characterization in order to prove the resistivity scaling benefits of MoP films.

EM-TuP-2 Vapor Phase Infiltration of Poly(1-Trimethylsilyl-1-Propyne) with Trimethylaluminium*, Jonathan Jenderny,* Applied Electrodynamics and Plasma Technology, Ruhr-University Bochum, Germany*; Nils Boysen,* Fraunhofer Institute for Microelectronic Circuits and Systems, Duisburg, Germany*; Florian Preischel,* Inorganic Materials Chemistry, Ruhr-University Bochum, Germany*; Teresa de los Arcos,* Technical and Macromolecular Chemistry, Paderborn University, Germany*; Aleksander Kostka,* Center for Interface-Dominated High-Performance Materials, Ruhr-University Bochum, Germany*; Peter Awakowicz,* Applied Electrodynamics and Plasma Technology, Ruhr-University Bochum, Germany*; Jean-Pierre Glauber,* Leibniz Institute for Solid State and Materials Research, Germany*; **Harish Parala**,* Institute for Materials Chemistry, Leibniz Institute for Solid State and Materials Research, IFW Dresden, Germany*; Anjana Devi,* Institute for Materials Chemistry, Leibniz Institute for Solid State and Materials Research, Germany

Inorganic–organic hybrid materials are gaining importance for different applications, combining the advantages of both organic and inorganic materials. Vapor phase infiltration (VPI) has emerged as a promising technology for the synthesis of hybrid materials. In the field of polymeric gas separation membranes, a common problem is long-term stability, as filtered gases can lead to material deterioration or swelling [1]. In addition to increasing the membrane stability, VPI has also been shown to beneficially impact the separation performance, e.g., when infiltrating polymer of intrinsic microporosity 1 (PIM-1) with trimethylaluminium (TMA) [2].

In this study, VPI of poly(1-trimethylsilyl-1-propyne) (PTMSP) with TMA is investigated. PTMSP was chosen due to its exceptionally high free volume and its organic nature, featuring a carbon-carbon double bond as functional group. Saturation of the precursor inside the polymer is attained after already 60 seconds of infiltration time inducing significant densification of the material as observed by transmission electron microscopy (TEM). Water contact angle measurements indicate a shift towards hydrophilic behaviour after infiltration. Depth profiling using time-of-flight secondary ion mass spectrometry (TOF-SIMS) shows accumulation of aluminium (Al) in the PTMSP polymer. The presence of Al was detected along the whole polymer, confirming that the VPI process affects the whole polymer and is not limited to the sub-surface or the gradient layer region. Depending on the infiltration time, a significant densification of the porous structure was observed that directly influences the selectivity of the gas permeation, up to a complete blocking for long infiltration times. These results represent the first VPI process of a polymer featuring only a C-C double bond and outline the versatility of the VPI technique, being applicable for both gas-barrier and membrane applications in the future.

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EM-TuP-3 Study of (TaN)1-XCx Electrode to Investigate Its Impact on OTS Selector Devices*, **Minkyu Lee**, Taeyoon Lee,* Yonsei University, Korea

Conventional transition metal nitrides (TMNs) have gained significant attention in the field of memory devices due to their low resistivity and high thermal & chemical stability. In particular, tantalum nitride (TaN) has been widely applied in various memory industries owing to its high melting point, uniform resistivity, and diffusion barrier properties. However, recent research in the direction of reducing the reset current in phase change memory (PCM) faces limitations with TaN due to its low resistivity. Therefore, it is essential to study materials that can control resistivity while having low roughness and good adhesion with the substrate. Carbon, an element with a small atomic size, can be incorporated into TMN materials to modulate their resistivity and control surface roughness through grain size variations. Here, we demonstrate novel $(TaN)_{1-x}C_x$ electrodes that can adjust electrical resistivity depend on the compositions of carbon. X-ray diffraction (XRD) patterns were analyzed to confirm each crystal lattice and peak shift. Applying measured XRD patterns, full width half maximum (FWHM) and grain sizes were extracted using Debey-Scherrer equation. To visualize crystal structure and amorphous state of $(TaN)_{1-x}C_x$ films, transmission electron microscope (TEM) was employed along with the diffraction pattern using fast fourier transform (FFT).

EM-TuP-4 Study for Deposition of CuI onto Indium-Gallium-Zinc-Oxide for Light Detection Application*, **Woosuk Sohn**, Taeyoon Lee,* Yonsei University, Korea

IGZO phototransistors have been recently paid attentions in various fields such as displays, image sensors, and wearable devices, owing to their high charge mobility and photosensitivity. Although the IGZO phototransistors are widely recognized, some improvements are required as they can detect a limited wavelength range of visible light due to the wide bandgap of IGZO (approximately 3.7–3.8 eV). Generally, the bandgap of IGZO can be adjusted by introducing impurities, however, such approaches often lead to performance degradation by decreasing the mobility of transistor and raising the threshold voltage and subthreshold swing. In this study, we developed a CuI/IGZO phototransistor capable of detecting light in the whole visible range by utilizing copper iodide (CuI), a p-type semiconductor material widely used in photodetectors, solar cells, and LEDs. As p-type CuI is spin-coated on the n-type IGZO layer, a pn junction and a type-II bandgap structure can be formed, which leads to an increase in the number of electrons and holes generated by light and enhances the photocurrent. Also, zinc (Zn) was additionally doped to prevent the degradation of performance of CuI TFTs due to the volatility of iodine, and enhance the on-off current ratio of the transistor. For the gate dielectric, spin-coated Al_2O_3 was employed instead of SiO_2, yielding better device stability. While the Al_2O_3 layer was not deposited by atomic layer deposition (ALD), it still provided sufficient insulating properties. Future work could incorporate ALD-based thin-film deposition to achieve improved thickness uniformity, interface control, and large-area process scalability. In fact, ALD has shown promise in uniformly doping IGZO and CuI thin films and controlling defects, suggesting that it can further enhance the responsivity and detectivity of CuI/IGZO phototransistors. The proposed device has great potential for applications in photo-memory and neuromorphic device, presenting innovative advancements in fields such as artificial intelligence, autonomous driving, and smart devices.

EM-TuP-5 Networking Density Effects on the Patterning Performance of Resists Deposited via Hybrid MLD*, **Long Viet Than**, Giulio D'Acunto, Stacey F Bent,* Stanford University

The implementation of extreme ultraviolet (EUV) lithography in semiconductor manufacturing promises to extend Moore's Law by enabling the patterning of sub-8 nm feature sizes. However, further device scaling is dependent on the implementation of EUV-tailored photoresists that meet requirements in sensitivity, resolution, and line edge roughness. With feature sizes approaching the nanometer scale, stochastic variation in the photoresist molecular structure also affects pattern quality, resulting in the need for new resist chemistries with uniform chemical distribution.

Metal-organic thin films deposited via hybrid molecular layer deposition (MLD) are a promising class of materials to address the challenges of designing new EUV-compatible resist chemistries, by incorporating EUV-absorbing metal centers into the polymer network while exhibiting Å-level thickness control and atomic-scale homogeneity. In this work, we investigated a series of hybrid MLD-derived aluminum alkoxide (alucone) resists, deposited via trimethylaluminum (TMA) and a series of alcohol counter-reactants (glycerol, ethylene glycol, and sequential dosing of methanol/ethylene glycol). This process yielded thin films that are chemically akin, as demonstrated by X-ray photoelectron spectroscopy (XPS), but exhibit notable differences in networking/crosslinking density. Electron beam lithography, an established proxy for EUV, was used to evaluate how these structural differences affect their patterning performance. All three alucone resists exhibited negative-tone patterning, attributed to the loss of organic ligands and to the formation of inorganic alumina. We found that decreasing the crosslinking density improves the resolution limit, ultimately achieving 14 nm lines in 1:1 line/space patterns with alucone containing methanol/ethylene glycol linkers. The variation observed between these hybrid materials underscore the importance of structure-property relationships for the rational design of metal-organic EUV resists.

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Park, Gi-Beom: EM-TuM-16, **1**
Park, Jin-Seong: EM-TuM-16, 1
Preischel, Florian: EM-TuP-2, 4
— R —
Reith, Heiko: EM-TuA-6, 3
— S —
Sohn, Woosuk: EM-TuP-4, **4**
Song, Jisheng: EM-TuM-14, 1
Sung, Hyunah: EM-TuA-3, 2
Sung, Hyunah Daniela: EM-TuA-5, 2
— T —
Than, Long Viet: EM-TuP-5, **4**
Tiwale, Nikhil: EM-TuA-3, 2; EM-TuA-5, 2
Tsapatsis, Michael: EM-TuM-12, 1
— V —
Veyan, Jean-Francois: EM-TuA-5, 2
— W —
Waltz, Kayley: EM-TuM-12, 1
— Y —
Yang, Fan: EM-TuM-14, **1**
Yang, Hae Lin: EM-TuM-16, 1