Plasma Science and Technology Division
Room A106 - Session PS-WeM

Exploring Boundaries of Plasma Science (ALL-INVITED SESSION)

Moderators: Michael Gordon, University of California at Santa Barbara, **Mingmei Wang**, Lam Research Corporation

8:00am **PS-WeM-1 Electron Beam Driven Plasmas: Development and Use for Ultra Low T_E Processing*, Scott Walton,*** Naval Research Laboratory **INVITED**

The advantages of plasma-based materials processing techniques are numerous. The capability to rapidly and uniformly modify large areas (> 10^3 cm^2) with high precision is one reason plasmas are widely used in the materials and surface engineering communities. However, with the ever-evolving demand for new materials and single nanometer-scale device dimensions across a variety of applications, some of the limitations of conventional plasma sources are becoming apparent. The lack of process control and excessive ion energies in the development of atomic layer processing strategies are examples.

The Naval Research Laboratory (NRL) has developed a processing system based on an electron beam-generated plasma. Unlike conventional discharges produced by electric fields (DC, RF, microwave, etc.), ionization is driven by a high-energy (~ keV) electron beam, an approach that can overcome many of the problems associated with conventional plasma processing systems. Electron beam-generated plasmas are generally characterized by high charged particle densities (10^{10}- 10^{12} cm^{-3}), low electron temperatures (0.3 - 1.0 eV), and in reactive gas backgrounds, a relatively low radical production rate compared to discharges. These characteristics allow the ability to precisely control the flux of charged and reactive neutrals as well as ion energy at adjacent surfaces. This provides the potential for controllably etching, depositing, and/or engineering the surface chemistry with monolayer precision.

An overview of NRL's research efforts in developing this technology will be presented, with a focus on source development and operation, plasma characterizations, and how the system can be advantageously applied to the processing of select materials. Examples include graphene, where erosion and damage is a major concern and the etching of semiconductor materials, such as Si, SiN and SiO_2, where the focus is on etch rates and selectivity at low ion energy. This work is supported by the Naval Research Laboratory base program.

8:40am **PS-WeM-3 My Path to AVS Fellow: Non-Volatile Memory Processing from Fundamental Understanding to the Promise of Atomic Layer Etching and Sustainable Etch Precursors*, Eric Joseph,*** IBM T. J. Watson Research Center **INVITED**

Non-volatile memory technologies such as phase change memory (PCM) and magnetoresistive memory (MRAM) have seen various levels of success in manufacturing over the past decade.Intel/Micron's Optane PCM memory and Everspin's MRAM are just a few examples of recent products, while in more recent research, these same materials are also being explored as accelerator technologies for AI hardware applications. However, to enable these memory technologies, a significant understanding of plasma processing is required to achieve high fidelity pattern transfer while maintaining device performance. In this talk I will walk through first data highlighting the challenges of material volatility for both PCM and MRAM etching and how process induced modification of the material leads to deleterious device performance.Furthermore, we will review the promise of atomic layer etching in enabling new avenues to address patterning issues for MRAM and PCM and demonstrate how ALE can lead to new opportunities for sustainable future non-volatile memory processing applications.

9:20am **PS-WeM-5 VHF Plasma Enhanced Atomic Layer Deposition of SiN_x using Aminosilane Precursors***, Y. Ji, S. Choi, J. Kang,* Sungkyunkwan University, Republic of Korea*; A. Ellingboe,* Dublin City University, Ireland*; C. Lee,* Merck Korea*; H. Chandra,* EMD Electronics*; **Geun Young Yeom,*** Sungkyunkwan University, Republic of Korea **INVITED**

In this study, we investigated the plasma enhanced atomic layer deposition (PEALD) of silicon nitride (SiN_x) using the VHF-CCP N_2 plasma and different aminosilane precursors at the process temperature range of 100–300 ^oC. The combinations of VHF-CCP plasma source instead of conventional HF-CCP plasma source and an adequate aminosilane precursor allowed a high growth rate and high quality films as well as excellent conformality close to 100% at substrate temperature of 300 ^oC. In addition, when external magnetic field was added during the VHF CCP N_2 plasma generation during the PEALD of SiN_x film, the magnetized VHF CCP N_2 plasma allowed better film quality and higher conformality at low temperature of 200 ^oC.

11:00am **PS-WeM-10 PSTD 2022 Young Investigator Awardee Talk: Plasma Processing Challenges for Emerging Memory Technology*, Luxherta Buzi*[1]*,*** IBM Research, T. J. Watson Research Center*; N. Marchack, S. Engelmann, R. Bruce,* IBM Research Division, T.J. Watson Research Center **INVITED**

Continuously shrinking feature size in patterning imposes non-volatile memory processing challenges, particularly for phase change memory (PCM) materials, where damage mitigation is imperative. Optimization of etch process and chemistry in minimizing or eliminating structural or compositional damage is key for the success of this technology. Use of halogens is often needed for a better profile control, reduce redeposition, selective metal etching etc., but it can cause structural damage and elemental depletion of PCM materials leading to an increase in the recrystallization time. Ion sputtering with inert gases on the other hand, can cause material re-deposition on the sidewall, poor profile control and worse etch selectivity.

In addition to ion bombardment which is typically responsible for physical sputtering and increased roughness, plasma can generate short wavelength irradiation due to electron-neutral collisions. UV/VUV photons emitted in a plasma can reach high fluxes and thus become important in terms of plasma-surface interaction processes. Elemental depth profiling with ion beam analysis and time resolved laser reflectivity was done to study the phase transition behavior of GST when exposed to different chemistries, temperatures, plasma duration, and various reactor configurations.

Surface oxidation of PCM materials can substantially alter switching properties therefore, in-situ plasma enhanced CVD encapsulation has been viewed as a favorable solution. It is imperative that RIE and encapsulation mitigate damage and oxidation of PCM material during integration. In-situ encapsulation of GST and tuning of plasma parameters, caused controlled SiN film deposition with simultaneous selective etching and damage removal from GeSbTe-based PCM materials.

11:40am **PS-WeM-12 How Can Machine Learning Help Process Development?*, Satoshi Hamaguchi,*** Osaka University, Japan **INVITED**

The recent development in data science and technology such as machine learning (ML) and artificial intelligence (AI) is now changing the way we perform various tasks, including research and development. Process development for semiconductor manufacturing is so complex that there is much room for improvement in its efficiency by ML and AI. Often one of the major problems in applying ML and AI for process development is the lack or insufficiency of experimental data. One possible remedy is to form "digital twins,"i.e., numerical simulation models of plasmas and plasma-interacting surfaces, and generate a large amount of data that can augment the shortage of experimental data. Even if the simulation results do not agree with experimental observations quantitatively, as long as the simulation data are correlated with experimental observations, such augmented data help us search optimal process conditions and perform a design of experiments. In this presentation, the recent development of data-driven plasma science [1] for low-temperature plasmas and their applications to material processing will be briefly reviewed. Then, more specifically, the prediction of sputtering yields/etch rates of materials by ion beams and the construction of plasma surrogate models will be discussed, which could allow real-time simulation of plasma processing systems for process control and fast survey of optimized process conditions.

[1] R. Anirudh, et al., "2022 Review of Data-Driven Plasma Science" IEEE Trans. Plasma Sci. (2023) to appear/ arXiv:2205.15832

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[1] **PSTD 2022 Young Investigator Awardee**

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