Plasma Science and Technology Division
Room B117-119 - Session PS2-ThA

Plasma Modeling and Characterization

Moderators: Catherine Labelle, Intel Corporation, **Du Zhang**, TEL Technology Center America

2:20pm **PS2-ThA-1 Control of the Ion Angle and Energy Distribution by an Embedded Electrode in a Focus Ring for a Capacitively Coupled Rf Plasma***, **Seoi Choi**, H. Lee,* Pusan National University, Republic of Korea

With the recent advancements in semiconductor processes reaching the nanoscale, research is underway to enhance the uniformity of plasma in plasma etching reactors. The non-uniformity of the etch process is noticeable at the edge of the wafer due to inhomogeneous electrical characteristics. We investigate a mechanism to control the plasma sheath above the wafer edge for a uniform etching process over the dielectric focus ring by changing the electric field and ion flux uniformly across the wafer surface using a two-dimensional particle-in-cell simulation parallelized with a GPU. An appropriate waveform on the electrode inserted inside the focus ring changes the sheath oscillation and ion flux to improve the ion energy and angular distributions (IEADs) to achieve a better etch rate.

2:40pm **PS2-ThA-2 Plasma Etch Chemistries for High Aspect Ratio Application with Low Emission***, **Phong Nguyen**, C. Jennings, S. Biltek, N. Stafford,* Air Liquide

In recent years, several countries and semiconductor manufacturing companies have announced targets for net-zero carbon emission by 2050. Plasma etch processes are responsible for a high percentage of emission for chip manufacturing especially in high aspect ratio (HAR) dielectric etch. Such an etch process involves employment of high global warming potential (GWP) fluorocarbon gasses such as C4F8, CH2F2. In the past decades, Air Liquide R&D has developed multiple alternative chemistries in HAR applications with very low GWP. However, while the gas entering the plasma etch chamber may be high or low GWP, it is difficult to predict the emission gases post plasma due to the complexities of the breakdown and recombination processes within the plasma.

In this study, we demonstrate that the plasma etch chamber emission gas stream can be analyzed and quantified by Fourier Transform Infrared Spectroscopy (FTIR). Complementary to FTIR analysis, Quadrupole Mass Spectrometry (QMS), a powerful tool, is implemented to help identify emission species in the chamber via studying positive ion fragments present inside the plasma. In addition, these Air Liquide novel chemistries have shown improved etch performance with lower CO2 equivalent emission as compared to that of current baseline in HAR etch processes.

3:00pm **PS2-ThA-3 Two and Three-Dimensional Kinetic Modeling of Capacitively Coupled Plasma Discharge in Cylindrical and Cartesian Geometry***, **Willca Villafana**, A. Powis,* Princeton University Plasma Physics Lab*; S. Rauf,* Applied Materials*; I. Kaganovich,* Princeton University Plasma Physics Lab

In a Capacitively Coupled Plasma (CCP) discharge, the processing rates and uniformity of the wafer depend on key parameters such as the ion flux, ion energy distribution function (IEDF), and plasma homogeneity. The non-Maxwellian nature of the IEDF requires a kinetic treatment, which can be achieved with Particle-In-Cell (PIC) simulations.

In this work, we develop a procedure to control the plasma uniformity and its dynamics using a weak magnetic field with a 2D cylindrical axisymmetric model. The present investigation takes leverage of PIC modeling and uses the explicit EDIPIC-2D code [1]. A detailed analysis of the sheath structure, the ion flux, and IEDF at the wafer will be performed. Additionally, we will also report recent examples and progress regarding 3D PIC modeling using the in-house LTP-PIC code [2].

[1] https://github.com/PrincetonUniversity/EDIPIC-2D

[2] T. Charoy, et al, “2D axial-azimuthal particle-in-cell benchmark for low-temperature partially magnetized plasmas,” Plasma Sources Sci. Technol. **28**(10), 105010 (2019).

Acknowledgments:

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3:20pm **PS2-ThA-4 Effect of Feed Gas Content and Substrate Temperature on RIE of SiN_x with $Ar/C_4F_6/O_2$ Plasma***, **Xue Wang**,* Colorado School of Mines, USA*; R. Gasvoda,* Lam Research Corporation, Tualatin*; E. Hudson, P. Kumar,* Lam Research Corporation, Fremont*; S. Agarwal,* Colorado School of Mines

Effect of feed gas content and substrate temperature on RIE of SiN_x with $Ar/C_4F_6/O_2$ plasma

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In reactive ion etching (RIE) with fluorocarbon-based plasmas, the etch selectivity of SiO_2 relative to SiN_x is controlled by tuning the F to C ratio in fluorocarbon feed gas, and by tuning the ion energy. Previously, we showed that the substrate temperature is one potential process knob to control the etch selectivity for SiO_2 over SiN_x during C_4F_6/Ar plasma RIE. Our *in situ* optical diagnostics show that increasing the substrate temperature during RIE of SiN_x from 70 to 120 °C creates an etch-stop layer and lowers the etch rate of SiN_x, with no noticeable effect over the same temperature range during RIE of SiO_2. *In situ* infrared spectroscopy and *ex situ* X-ray photoelectron spectroscopy (XPS) show that the fluorocarbon layer on the SiN_x surface is more defluorinated at 120 °C, likely forming a graphitic etch stop layer which lowers the etch rate.

In this work, we explore the substrate temperature dependence on RIE of SiN_x as a function of O_2 dilution of a C_4F_6/Ar plasma. Using *in situ* four-wavelength ellipsometry, we measured the steady-state etch rate of SiN_x over 200 s. In our experiments, we varied the O_2 to C_4F_6 flow ratio over the range of 0.29 to 1.75. Consistent with previous studies, the etch rate of SiN_x increased with increasing O_2 to C_4F_6 flow ratio in the feed gas at both substrate temperature of 70 and 120 °C. High-resolution spectra of the C 1s and F 1s regions were measured for SiN_x surfaces after 200 s of RIE with *ex situ* XPS for O_2 to C_4F_6 flow rate ratios of 0.29, 0.75, and 1.75. Analysis of the XPS data shows that addition of O_2 results in a thinner CF_x layer, which enhances the etch rate of SiN_x. More interestingly, we found that the etch rate of SiN_x is higher at 120 °C than that at 70 °C at low O_2 to C_4F_6 ratios (< 1.25). This temperature dependence flips for O_2 to C_4F_6 ratios >1.25. We speculate the thickness of CF_x layer and mixing layer are influenced by the substrate temperature, which leads to this temperature dependent etch behavior.

Oral Presentation Requested

3:40pm **PS2-ThA-5 Characterization of Ion and Reactive Species in Perfluorocarbon Gas ($C_4H_2F_6$-Z) Plasma for Mitigating Global Warming Potential***, **Minsu Choi**,* Chungnam National University (CNU), Republic of Korea*; Y. Lee,* Institute of Quantum Systems (IQS), Chungnam National University (CNU), Republic of Korea*; C. Cho,* Chungnam National University (CNU), Republic of Korea*; S. Kim,* Institute of Quantum Systems (IQS), Chungnam National University (CNU), Republic of Korea*; I. Seong, W. Jeong, B. Choi, S. Seo,* Chungnam National University (CNU), Republic of Korea*; Y. Seol,* Institute of Quantum Systems (IQS), Chungnam National University (CNU), Republic of Korea*; H. Tak,* Sungkyunkwan University (SKKU), Republic of Korea*; G. Yeom,* Sungkyunkwan University (SKKU), SKKU Advanced Institute of Nano Technology (SAINT), Republic of Korea*; S. You,* Institute of Quantum Systems (IQS), Chungnam National University (CNU), Republic of Korea

In semiconductor and display manufacturing, Perfluorocarbon (PFC) gases are widely used for cleaning post-etching and deposition. With the adoption of advanced patterning like Double Patterning Tech (DPT) and Quadruple Patterning Tech (QPT), PFC gas consumption is rising. However, PFC gases are chemically stable, leading to a high Global Warming Potential (GWP). Reducing PFC gas emissions is essential due to their long-lasting global climate impact.

Transitioning to alternative gases requires understanding ion and active species distribution and plasma density, critical factors dependent on the plasma source. This study focuses on the comprehensive characterization of ion and active species in C4H2F6-Z gas and compares it to the conventional process gas, CHF3. Additionally, an essential plasma parameter, plasma density, is measured using a cut-off probe. Experiments in uniform chambers with Capacitively Coupled Plasma (CCP) and Inductively Coupled

Plasma (ICP) sources reveal changes in ion and active species with power, pressure, gas ratio, and pulsing frequency.

Comparative data between the conventional and new gases are discussed. This research contributes to the development of alternative precursors to reduce the impact of global warming.

4:00pm **PS2-ThA-6 Cryogenic Aspect Ratio Etching of SiO_2 at $CF_4/H_2/Ar$ Plasma in a Cryogenic Reactive Ion Etch System***, **Hee Tae Kwon**, I. Bang, J. Kim, H. Kim, S. Lim, S. Kim, S. Jo, J. Kim, W. Kim, G. Shin, G. Kwon,* Kwangwoon University, Republic of Korea

In the manufacturing processes of 3D NAND, the high aspect ratio contact (HARC) etching process, which is one of the most critical steps, has encountered a significant challenge. HARC, typically performed at room temperature, has become increasingly difficult to achieve the desired high aspect ratio while maintaining high productivity. This challenge is expected to become harder when considering devices with highly stacked alternating layers of silicon-containing materials, such as SiO_2 and SiN. Therefore, cryogenic HARC technology has emerged as a promising solution to overcome this challenge, as it offers advantages in terms of productivity and better etch profile. Consequently, we conducted cryogenic aspect ratio etching of SiO_2 at $CF_4/H_2/Ar$ plasma in a cryogenic reactive ion etch system. Overall, our results revealed that cryogenic aspect ratio etching of SiO_2 showed a higher etch rate and a higher aspect ratio under the experimental conditions. With these conditions, we conducted the cryogenic aspect ratio contact etching of SiO_2 for the comparison with the etching of SiO_2 at RT as well.

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