Plasma Science and Technology
Room 315 - Session PS2-FrM

Plasma Science

Moderators: Kenji Ishikawa, Nagoya University, Japan, **Thorsten Lill**, Lam Research Corporation

10:30am **PS2-FrM-10 Power- and Material-Dependent Wall Contamination from Plasma-Exposed Graphite**, ***Ana Clecia Alves Almeida***, *John Foster,* University of Michigan, Ann Arbor

Graphite beam targets, liners, and protective surfaces used in electric-propulsion vacuum facilities may become sources of wall contamination when exposed to energetic plasma conditions. This work compares contaminant generation and deposition from POCO graphite and Grafoil in an argon plasma over a range of operating powers. Chamber pressure, gas flow, current–voltage behavior, optical emission spectroscopy, and mass spectrometry are recorded during each exposure to characterize the electrical operating state and the gas-phase products released from the material. Glass witness plates positioned around the plasma collect transported material for subsequent scanning electron microscopy and energy-dispersive X-ray spectroscopy.

Preliminary measurements with POCO graphite show OH emission and correlated water-fragment signals, demonstrating that water retained by the carbon material is released and dissociated during plasma operation. The comparative campaign will determine how graphite structure and plasma power affect pressure transients, water-derived species, carbon-containing products, and the amount and distribution of deposited material. SEM will be used to examine film coverage and morphology, while EDS will assess carbon, oxygen, and other detectable constituents. Correlations between gas-phase diagnostics and witness-plate composition will be used to identify contamination pathways from the graphite source to surrounding surfaces.

These measurements address how carbon facility materials contribute to coatings on chamber walls, optical windows, electrical insulators, and plasma diagnostics. Such deposits may alter optical transmission, surface conductivity, secondary-electron emission, and plasma–wall interactions, thereby affecting the interpretation of electric-propulsion ground-test measurements.

10:45am **PS2-FrM-11 Separating Radical-Driven and pH-Dependent Pathways in Low-Temperature Plasma-Induced DNA Damage**, ***Hao Yu***, *Cecilia Julieta Garcia Villavicencio, Sylwia Ptasińska,* University of Notre Dame

Low-temperature plasma (LTP) damages DNA through reactive oxygen and nitrogen species (RONS) generated by plasma-liquid interactions, while concurrent acidification can further destabilize DNA [1,2]. Previous studies identified amino-acid-dependent protection and pH changes during plasma exposure [3,4]. Here, we used the quantification of multiple types of plasma-jet-induced DNA damage under additive-free conditions as the baseline and examined the effects of phosphate buffer and amino acids in aqueous plasmid DNA.

Plasmid DNA was irradiated using a helium atmospheric-pressure plasma jet. Single-strand breaks (SSBs), double-strand breaks (DSBs), and enzyme-sensitive sites were quantified by gel electrophoresis under additive-free conditions. In the modulation study, samples were irradiated with and without 10 mM phosphate buffer (PB) to maintain neutral pH or allow acidification, and tryptophan, tyrosine, and methionine (10–300 µM) were added as radical scavengers. Hydroxyl-radical competition was evaluated using a coumarin assay with dimethyl sulfoxide (DMSO) as a reference scavenger.

In the additive-free system, strand breaks dominated the detected damage, while enzyme-sensitive sites were observed at lower levels and DSB signals were weak [5]. Under the 10 kV and 1 kHz condition, the solution acidified during irradiation without PB, whereas PB maintained a near-neutral pH. The SSB yield was approximately 3.8 times higher without PB than with PB, indicating that acidification contributed to the measured damage. All three amino acids increased the fraction of undamaged supercoiled DNA in a concentration-dependent manner, both with and without PB. The three amino acids showed comparable protective effects at equivalent concentrations. At µM concentrations, the amino acids produced only minimal changes in pH. Separately, the coumarin–DMSO competition assay showed that radical scavenging reduced the hydroxyl radicals available to react with coumarin. Taken together, the results separate an acidification-dependent contribution from RONS-driven DNA damage and support radical scavenging as the main protective mechanism of amino acids at µM concentrations.

References: 1. P. J. Bruggeman et al., *Plasma Sources Sci. Technol.* **25**, 053002 (2016). 2. S. Ptasińska et al., *Phys. Chem. Chem. Phys.* **12**, 7779 (2010). 3. A. Stypczyńska et al., *Chem. Phys. Lett.* **500**, 313 (2010). 4. C. J. G. Villavicencio et al., *Molecules* **29**, 5889 (2024). 5. H. Yu et al., *Research Square*, rs-9645581/v1 (2026).

11:00am **PS2-FrM-12 Mechanism of Ammonium Salt Formation During Etching of Si_N_x in an HF Plasma**, ***Md Tanzid Hossain***, Colorado School of Mines, USA; *Xue Wang,* LAM Research; *Prabhat Kumar, Thorsten Lill, Mingmei Wang, Taner Ozel,* Lam Research; *Tae Won Kim,* LAM Research; *Harmeet Singh,* Lam Research; *Sumit Agarwal,* Colorado School of Mines, USA

During HF plasma etching of SiN_x, ammonium-containing salt layer forms that can strongly influence SiN_x etching. This layer has conventionally been treated as a single salt as ammonium fluorosilicate, $(NH_4)_2SiF_6$ (AFS), formed through reactions among the primary etch products SiF_4 and NH_3 and excess HF. Here, we use *in situ* attenuated-total-reflection Fourier-transform infrared spectroscopy to resolve the composition of this layer and determine how ion bombardment controls its formation and removal. SiN_x films were exposed to an inductively coupled HF plasma at 10 mTorr while the substrate bias was varied from the self-bias condition to −240 V. Ammonium-containing salts formed rapidly and persisted throughout etching. Under applied-bias conditions, the salt layer approached a steady state, consistent with continuous formation balanced by ion-assisted decomposition and removal. Under self-bias, the salt accumulated into a more continuous layer. Gaussian deconvolution of the NH_4^+ bending region and the distinct thermal decomposition behavior as shown in Fig. 1, indicates that NH_4F, NH_4HF_2, and AFS coexist rather than forming a single AFS salt. In addition, a SiF_5^- vibrational feature is consistent with the theoretically proposed NH_4SiF_5 intermediate, supporting a stepwise pathway toward AFS formation. Although the relative fractions cannot be quantified because the infrared absorption cross sections are unknown, X-ray diffraction indicates that AFS is the predominant crystalline salt phase. Hydrogen-rich SiN_x films produced greater salt accumulation and lower etch rates. Overall, these results support a stepwise ammonium-salt formation pathway initiated by the reaction of NH_3 with HF to form NH_4F, followed by further higher fluoride salts like NH_4HF_2 and reactions with Si-containing etch products that ultimately led to predominantly $(NH_4)_2SiF_6$.

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