Plasma Science and Technology Division
Room A106 - Session PS2+AS+SS-ThM

Plasma-Surface Interactions I

Moderators: Lei Liu, Lam Research Corporation, **Pingshan Luan**, TEL Technology Center America

11:00am **PS2+AS+SS-ThM-10 Remote Plasma-Activated and Electron Beam-Induced Etching of Ruthenium and Its Comparison to Tantalum***, Yudong Li*[1]*,* University of Maryland College Park*; C. Preischl, M. Budach, H. Marbach, D. Rhinow,* Carl Zeiss SMT, Germany*; G. Oehrlein,* University of Maryland College Park

Refractory metals are of importance in microfabrication, which necessitates patterning of these materials. One issue is to reduce near-surface modifications of materials during processing, which is often due to ion bombardment and atomic mixing. Recently, we have developed a novel technique of combining electron beam (ebeam) and remote plasma (RP) for materials processing [1, 2]. Material damage is significantly reduced since energetic ion bombardment is prevented. The RP generates reactive neutral precursors and the ebeam provides energy deposition to enable further precursor-materials interactions.

Here we investigate the effects of ebeam and RP on Ru and Ta with the goal of selective etching. The simultaneous irradiation of ebeam and RP with Ar and O_2 as the feed gas induces Ru etching. The Ru ER increases with emission current, electron energy, and O_2 flow rate, while it shows less dependence on RP power. A pretreatment step by ebeam/RP or RP only with $Ar/O_2/CF_4$ significantly enhances the subsequent Ru ER induced by ebeam/RP with Ar/O_2. This effect is likely associated with the reactor wall passivation by the introduction of CF_4 through RP, which reduces recombination of O atoms on reactor surfaces. For Ta, RP with fluorine-rich $Ar/O_2/CF_4$ induces Ta etching at a high rate. If instead an O_2-rich gas mixture is used, we observe Ta oxidation. The RP sustains the spontaneous Ta etching by generating F which interacts with Ta and forms volatile tantalum fluoride. Contrary to the Ru metal, where the ebeam induces etching, the ebeam is found to promote oxidation of Ta. The opposite roles of ebeam on Ru and Ta and the sensitive dependence on CF_4 flow rate of Ta etching provides the opportunity to achieve Ru over Ta etching selectivity.

We gratefully acknowledge the financial support of this work by Carl Zeiss SMT GmbH

References:

1. Lin, K.-Y., et al., SiO2 etching and surface evolution using combined exposure to CF4/O2 remote plasma and electron beam. Journal of Vacuum Science & Technology A, 2022. 40(6).

2. Lin, K.-Y., et al., *Electron beam-induced etching of SiO2, Si3N4, and poly-Si assisted by CF4/O2 remote plasma.* Journal of Vacuum Science & Technology A, 2022. **41**(1).

11:20am **PS2+AS+SS-ThM-11 Plasma Surface Ionization Wave Interaction with Single Channel Structures***, Joshua Morsell, S. Shannon,* North Carolina State University

The interaction of atmospheric pressure plasma jets (APPJ) with materials has found promising applications in the fields of plasma medicine, catalysis, and material treatment. One area of interest is the surface ionization waves (SIW) present in these plasmas. SIWs interactions with complex interfaces is critical to these applications and require further study. A complex interface is any target with non-uniform electrical properties and/or non-planar surface morphology. The focus of this work is to study how surface ionization waves interact with single channel structures in dielectric media. The results show that the fraction of the SIW that escapes the channel is dependent on both driving voltage and channel width.

The plasma source in this study is an APPJ powered by a nanosecond DC pulse of positive polarity with helium as the working gas as used in [J. Morsell et al., J. Phys D: Appl. Phys. 56 (2023), 145201]. Voltage and current data are collected via integrated current and high voltage probes at the source head. Time resolved ICCD imaging is used to image SIW propagation. The single channel targets consist of a 25 x 50 mm glass slide which has had a single channel etched across its minor axis. There are six total channel samples with different widths and depths. These samples are mounted to a target stage, which has another glass slide with an optically transparent conductor acting as a ground plane allowing imaging through the substrate. SIW velocities in the system have been measured. The first is the SIW velocity within the channel, the second is the radial velocity of the portion of the SIW that escapes the channel. Both velocities increase with increasing voltage but show no significant trends with channel geometry. Velocity magnitudes for radial surface waves are 40-70 km/s and in-channel velocities are determined to be 60-130 km/s. Total light emission from the discharge is used to determine the fraction of the SIW escaping the channel. There exists a strong dependence of SIW portioning with channel geometry and driving voltage. As voltage increases the SIW is less confined and the fraction of the SIW escaping the channel increases. As channel width increases less of the SIW is allowed to escape the channel. No conclusive trends are observed with respect to channel depth. Observation also reveals that the fraction of the escaping SIW relates to the sample area exposed to the discharge. A smaller area of the substrate is exposed to the SIW for low voltages and large geometry channels.

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11:40am **PS2+AS+SS-ThM-12 Plasma-wall Interactions: Implications for Advanced Chamber Materials Requirements***, John Daugherty,* Lam Research Corporation **INVITED**

In semiconductor device fabrication, plasma-assisted processes dominate both the deposition and etching of materials.Over 50 years of successive technology nodes have motivated innovations and continuous improvements in plasma reactor technology, and the semiconductor industry now employs a sophisticated portfolio of plasma reactors that use a wide variety of chemistry and operating approaches. Today, many aspects of the fabrication process must achieve process variations of ~1% and often must contribute particle contamination of less than one particle per wafer pass.Despite dramatic improvement in reactor design and in chamber materials, it remains challenging to achieve current variation requirements because plasma reactors still suffer from process drift, molecular contamination, and particulate contamination that originate from plasma-modification of the chamber materials. The first consideration in choosing a chamber material is the expected maximum ion bombardment energy.The plasma conditions within a single chamber are quite nonuniform, and the ion energy may fall into several ranges. Some parts experience <20 eV ions, and while these parts can be engineered for very long lifetime, challenges remain in meeting performance requirements.Other parts experience ion energies >100 eV (sometimes >1 keV in etch processes).These parts are almost always cost-sensitive consumables. There is an intermediate range of ~50 to 100 eV where there is considerable materials design complexity because of the desire to maintain process stability for thousands of wafers while operating very near the energy thresholds for ion-enhanced chemical modification of the wall material. Another design consideration is that the chamber materials must withstand a repeating sequence of multiple chemistries and plasma conditions followed by *in situ* plasma cleans using still different chemistry.The variety of chemically reactive molecules and free radicals include mixtures containing multiple halogens, hydrogen, oxygen, and depositing species from fluorocarbons, hydrocarbons, complex deposition precursors, and etch products. Recently we have adapted sophisticated materials metrology to examine the materials modifications that occur throughout the lifecycle of real production parts. We have also performed control experiments that allow us to infer the dominant plasma processes that cause the materials modifications we observe on production parts used in various applications.The implications for what types of materials are suitable for different parts of a plasma reactor are explored in this presentation.

[1] **PSTD Coburn & Winters Student Award Finalist**

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