Thursday Morning, September 25, 2025

Plasma Science and Technology
Room 201 ABCD W - Session PS1-ThM

Plasma Diagnostics

Moderators: Thierry Chevolleau, CEA-LETI, France, **Pingshan Luan**, TEL Technology Center America

8:00am **PS1-ThM-1 Floating Probe-Based Plasma Potential Measurement in Low-Temperature Radio Frequency Inductively Coupled Plasma***, **Isak Lee**, Chulhee Cho, Inho Seong, Wonnyoung Jeong, Minsu Choi, Byeongyeop Choi, Jami MD Ehsanul Haque, Seonghyun Seo, Woobeen Lee, Dongki Lee, Wongyun Park, Jinhyeok Jang, Shinjae You,* Chungnam National University, Republic of Korea

Accurate measurement of plasma potential is essential for understanding sheath structures and particle dynamics. Among the available methods, the floating probe offers a simple approach but tends to underestimate the actual plasma potential due to electron flux from the plasma. To address this, we developed a modified floating probe that minimizes electron flux, enabling more accurate measurement of the plasma potential. The effectiveness of this technique was assessed by comparing the measured potentials with those obtained from a Langmuir probe. To evaluate their applicability, floating potentials were systematically measured under various conditions—including pressure, RF power, and probe configurations—and their variations were analyzed. As a result, we observed that reducing electron flux led the floating potential to approach the actual plasma potential. This study introduces a simplified and robust diagnostic method for plasma potential measurement, with high applicability to various plasma processing systems and low-temperature plasma research.

8:15am **PS1-ThM-2 Global Model Enabled Quantitative Diagnosis of Reactive Species in a Plasma Chamber Using RGA***, **Seonghyun Seo**, Wonnyoung Jeong,* Chungnam National University, Republic of Korea*; Sijun Kim,* Laboratoire de Physique des Plasma (LPP)CNRS, Republic of Korea*; Youngseok Lee, Chulhee Cho, Inho Seong, Minsu Choi, Byeongyeop Choi,* Chungnam National University, Republic of Korea*; Jami Md Ehsanul Haque,* Chungnam National University, Bangladesh*; Woobeen Lee, Isak Lee, Dongki Lee, Shinjae You,* Chungnam National University, Republic of Korea

As plasma etching technologies become increasingly constrained with the advancement of high-aspect-ratio and high-precision patterning techniques such as atomic layer etching (ALE) and high aspect ratio contact (HARC) etching, the need for accurate control and quantitative analysis of reactive species within the process chamber has become increasingly important. Among the diagnostic tools used to analyze reactive species in the chamber, the residual gas analyzer (RGA) is widely adopted due to its accessibility, but its use has been largely limited to qualitative analysis.

This study proposes a diagnostic method to quantify radical densities by applying global modeling to RGA measurements. First, a Langmuir probe was inserted into the ionizer of the RGA to experimentally measure the electron density and electron energy distribution. These data were used as inputs for the global model to calculate electron-neutral collision rate coefficients for the radical species.

Then, to convert the measured RGA signals into absolute radical densities, we experimentally determined the mass-dependent transmission probability through a quadrupole mass filter, which reflects how the detection efficiency varies with species mass. By incorporating this transmission function along with previously obtained electron-related parameters, a global model was constructed to determine radical densities from the RGA signals.

To verify the reliability of the proposed method, it was compared with existing diagnostic approaches for quantifying radical species in plasma processes. Additional validation was carried out by evaluating the applicability of the global model under varying process conditions, including RF power and chamber pressure. This study demonstrates that reactive species in plasma environments can be quantitatively analyzed using the proposed RGA-based method.

8:30am **PS1-ThM-3 Absolute Atomic Density Measurements in Hydrogen- and Oxygen-Containing Plasmas for Atomic-Scale Processing***, **Jente Wubs**, Thomas van den Biggelaar, Marnix van Gurp, Erwin Kessels,* Eindhoven University of Technology, Netherlands*; Jordyn Polito, James Ellis, Harm Knoops,* Oxford Instruments Plasma Technology, UK **INVITED**

Hydrogen- and oxygen-containing plasmas are often used in atomic-scale processing technologies such as atomic layer deposition (ALD) and etching (ALE). Examples include the deposition of oxide layers and the etching of nitrides. To accelerate process development and optimization, physical analysis of the plasma is essential. In particular, measurements of key radicals – such as hydrogen and oxygen atoms – are required, as these radicals are known to affect on-wafer outcomes during ALD and ALE processes. Knowledge of their densities (and, ideally, their spatial and temporal distributions) is therefore of major importance, not only to understand the plasma chemistry pathways driving these processes, but also to identify relevant plasma regimes for achieving optimal processing conditions.

Available diagnostic techniques for measuring the densities of plasma radicals include probe–based methods and optical techniques, with the latter having the advantage of being non-invasive. A popular technique in both research and industry is optical emission spectroscopy. However, although this technique is experimentally relatively straightforward, analyzing emission spectra to obtain information on ground-state densities requires collisional-radiative models, which are only valid under specified conditions. Alternatively, ground-state densities can also be measured directly with absorption-based techniques, thus avoiding the need for modeling excitation processes. However, atomic absorption transitions from the ground-state to higher-energy states mostly lie in the vacuum ultraviolet part of the spectrum. The technical difficulties associated with this spectral region can be circumnavigated by using a technique called two-photon absorption laser induced fluorescence (TALIF), which does not require vacuum conditions and allows for measurements with high spatial and temporal resolution. However, TALIF is rather expensive and experimentally challenging, as it involves a bulky laser system and a complex calibration procedure. It is therefore less suited for monitoring atomic densities in industrial settings. Nevertheless, owing to the good accuracy and unparalleled spatial resolution, TALIF measurements are still of immense value when studying industrial plasmas, as they are necessary for the validation of e.g. probe-based methods and plasma models.

This contribution provides an overview of several plasma diagnostic techniques for detecting radicals relevant to ALD and ALE processes. Results on the densities of key plasma species in a commercial plasma source used for atomic-scale processing will be presented as well.

9:00am **PS1-ThM-5 RF-Compensation-Free Langmuir Probe Technique via AC-Driven Biasing in a RF Plasma***, **Inho Seong**, Chulhee Cho, Wonnyoung Jeong, Sijun Kim,* Chungnam National University, Republic of Korea*; Minsu Choi,* Chungnam National Univerisity, Republic of Korea*; Byeongyeop Choi,* Chungnam Nation Univerisity, Republic of Korea*; Ehsanul Haque Jami,* Chungnam National University, Bangladesh*; Seonghyun Seo, Woobeen Lee, Isak Lee, Dongki Lee,* Chungnam National University, Republic of Korea*; Shinjae You,* Chungnam National Univerisity, Republic of Korea

Langmuir probe diagnostics in RF plasmas typically require filter to compensate for the RF fluctuations. This is commonly achieved by designing resonant filters that present high impedance at the fundamental frequency and its harmonics. However, fabricating such filters is often challenging due to the need for precise tuning and stability under plasma conditions, which can lead to increased system complexity. In this work, we present a novel method to perform Langmuir probe measurements without the need for conventional RF filters. By applying an AC-driven bias to the probe, we effectively suppress the influence of RF fluctuations, enabling direct plasma parameter measurements. We analyzed this novel technique and validated it through experiments, confirming the feasibility of simplified, filter-free probe diagnostics in a RF plasma.

9:15am **PS1-ThM-6 Space and Phase-Resolved Ion Velocity Distribution Function Measurements in Electron Beam Generated E × B Plasma***, **Sung Hyun Son**,* Princeton University*; Ivan Romadanov,* Princeton University Plasma Physics Lab*; Nirbhav Chopra,* Princeton University*; Yevgeny Raitses,* Princeton University Plasma Physics Lab

Electron beam (e-beam) generated plasmas with applied electric and magnetic (E × B) fields are promising for applications that require efficient generation of ions and radicals in low-pressure environments [1]. We report spatially and phase-resolved measurements of the ion velocity distribution function (IVDF) in this plasma source using a planar laser-induced fluorescence (PLIF) system. A continuous-wave tunable diode laser produces a laser sheet that irradiates the plasma, and the resulting fluorescence is captured by an intensified CCD (ICCD) camera. Fluorescence images recorded at varying laser wavelengths are converted into two-dimensional IVDFs using the Doppler shift principle [2]. The PLIF measurements are validated against a conventional single-point laser-induced fluorescence (LIF) method using photomultiplier tube (PMT)-based detection at various positions. The phase-resolving capability of the system is tested by oscillating the plasma between two nominal operating modes with distinct density profiles, with the ICCD camera triggered by the externally driven plasma oscillation. The resulting oscillations in fluorescence intensity show good agreement with plasma density variations measured by electrostatic probes, demonstrating the system's ability to resolve phase-dependent dynamics. The measured IVDFs reveal several signatures of ion dynamics in this plasma source that could influence its material processing characteristics. In particular, radially outflowing ions and anomalous ion heating in the plasma periphery, both anticipated by theoretical studies and potentially detrimental to gentle plasma processing [3], are observed and reported.

[1] Zhao F, Raitses Y, Yang X, Tan A, Tully C.G. 2021 High hydrogen coverage on graphene via low temperature plasma with applied magnetic field *Carbon* 177: 244-251

[2] Severn G D, Edrich D A and McWilliams R 1998 Argon ion laser-induced fluorescence with diode lasers *Rev. Sci. Instrum.* 69 10–5

[3] Chopra N S, Romadanov I and Raitses Y 2024 Production of warm ions in electron beam generated E × B plasma *Appl. Phys. Lett.* 124064101

9:30am **PS1-ThM-7 Short Duty Cycle Pulsing of an RF Driven ICP with Electronegative Gases***, **Banks Peete**, Carl Smith,* North Carolina State University*; James Prager, Paul Melnik, Tim Ziemba,* Eagle Harbor Technologies*; Sung-Young Yoon, Meehyun Lim, Sungyeol Kim,* Samsung Electronics, Republic of Korea*; John Mattingly, Steve Shannon,* North Carolina State University

Many common gases used for plasma enhanced processes in semiconductor manufacturing have electronegative properties; the gas molecules will attach free electrons in a plasma to form negatively charged ions. These gases are a vital presence in etching processes because of their ability to form certain reactive species. However, electron attachment can form plasma instabilities that vary in amplitude and frequency based upon the power delivery design, power density, and gas composition. These instabilities disrupt power delivery, leading to challenges in consistency for industrial applications. Power delivery networks that do not rely on traditional impedance matching have been studied previously to demonstrate expanded process capabilities for pulsed RF power delivery, most notably through reduced power delivery latency and more rapid electron-ion pair production. This work expands the study to evaluate the performance of a matchless RF power delivery network with regard to electron-ion pair production, plus power delivery latency and stability when used with an electronegative plasma. The ability to quickly apply RF power with minimal delay, enabled by the matchless pulser, allows the RF to be turned on and off before the instabilities can fully manifest while still producing a controllable peak electron density over a short pulse cycle time. Thus, the plasma avoids the onset of the instability in electron density and temperature that is characteristic of electron attachment instabilities in electronegative plasmas by achieving the desired peak density on a time scale faster than the onset of the instability. This can expand the stable operating space for industrial plasmas reducing the reliance on very specific gas mixture, pressure, and power parameters where the instability does not occur.

This work is supported by a grant from the Samsung Mechatronics Research Division, Suwon, Republic of Korea.

9:45am **PS1-ThM-8 Probing Microwave-Driven Plasmas: Impact of N_2 Addition in Ar/N_2 Plasma***, **Nafisa Tabassum**,* North Carolina State University*; Abdullah Zafar, Timothy Chen, Kelvin Chan,* Applied Materials*; Steven Shannon,* North Carolina State University

A microwave-driven plasma operating at 2.45 GHz is investigated by means of optical emission spectroscopy, laser absorption spectroscopy, laser induced fluorescence, probe diagnostics, and plasma simulation package Zapdos. A mixture of Ar/N_2 is used as the operational gas with N_2 partial pressure varied from 0 % to 25 % of total gas pressure. The effect of N_2 partial pressure, gas pressure, and delivered power density are investigated in the range of 70 mTorr - 1 Torr and 0.25-1.25 W/cm^3 . Electron density, electron temperature and plasma potential were measured using a single Langmuir probe. Imaging of the plasma using an ICCD camera was used to estimate the physical extent of the plasma. Relative concentrations of molecular nitrogen N_2 , ionized molecular nitrogen N_2^+ and atomic nitrogen N were obtained through optical emission actinometry as a function of pressure and delivered power density. The following lines are used in this study: N_2 : $C^3\Pi_u \rightarrow B^3\Pi_g$ at λ = 337.1 nm, N_2^+ : $B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$ at λ = 391.0 nm, N: $3p^4S_{3/2}^0 \rightarrow 3s\,^4P_{5/2}$ at λ = 746.8 nm, and Ar: $2p_1 \rightarrow 1s_2$ at λ = 750.4 nm. . The transition between the under-dense and over-dense operating regimes, influenced by variations in the delivered power density, gas pressure, and N_2 partial pressure has been mapped to these plasma generated species. This study identifies hysteresis effects during changes in delivered power densities and pressure near the critical power, P_c, for transition from the under-dense to over-dense condition. In particular, the critical power required for this transition decreases with increasing pressure. This hysteresis behavior is further confirmed through observations of plasma diameter variations under different pressure and power density conditions. The influence of the partial pressure of N_2 in Ar – N_2 plasma on the mode transition and hysteresis is investigated. This study explores how plasma-generated species form, their roles in ionization pathways within a multi-species gas mixture, and how these factors affect the transition from under-dense to over-dense regimes. These dynamics, in turn, influence the critical power required for the transition and the spatial distribution of the plasma-generated species.

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