Plasma Science and Technology Division
Room: 201 - Session PS-ThA

Plasma Diagnostics, Sensors and Control II
Moderator: J.-P. Booth, CNRS/Ecole Polytechnique, France

2:00pm **PS-ThA1 Characterization of Atomic Oxygen Emission by PROES and Ion-Flux Measurement in an ECR Plasma Etcher**, ***V. Milosavljevic***, Dublin City University, Ireland and University of Belgrade, Serbia, *B. Dolinaj, D. Gahan*, Impedans Ltd., Ireland, *N. Macgarailt*, Dublin City University, Ireland, *MB. Hopkins*, Impedans Ltd., Ireland, *S. Daniels*, Dublin City University, Ireland

For many years, optical emission spectroscopy (OES) has been successfully used for the measurement and control of plasma products in industrial plasma reactors. We have extended this technique using phase resolved optical emission spectroscopy (PROES), in a industrial electron cyclotron resonance (ECR) plasma etcher.

Experiments were conducted in a pure argon discharge with a SiO2 wafer on the biased electrode. Argon ion bombardment of the wafer liberates oxygen atoms to the discharge. Therefore, oxygen is only present at the beginning of a discharge in solid state, i.e. in the SiO2 lattice. The ECR etcher used in this experimental study has a 2.45 GHz microwave generator with a maximum power of 2kW, variable magnetic field of up 90 mT and 2MHz RF bias with maximum power of 250 W. The SiO2 wafer is mechanically clamped to the chuck to which the RF bias is applied.

In order to study the behavior of oxygen in the sheath region above the wafer an iCCD camera and high resolution spectrograph are employed and the iCCD camera is gated with respect to the 2MHz RF bias frequency. The production of oxygen is mostly due to RF voltage oscillation across the wafer induced by argon ion bombardment of its surface. The atomic oxygen spectral line intensity, from the 777 triplet, is monitored with respect to phase of the RF bias. Ion energy distribution functions, at the wafer surface, are measured using a floating retarding field energy analyzer (RFEA). The floating RFEA is is placed on the rf biased wafer surface and signal cabling is taken out through the reactor vacuum pump tunnel. This prevents the need for any modification to the reactor configuration. The RFEA sensor is 7 cm in diameter and the wafer on which it sits is 200 mm in diameter resulting in significant exposure of the wafer to ion bombardment. Phase resolved measurements are made using the iCCD camera which is operated with a repetition rate of 2 MHz synchronously (triggered) with the RF bias. The integration gate of 3.90625 ns is locked to a fixed phase position within the RF cycle (500 ns). This gives exactly 128 intervals over the 2Pi RF cycle. A variable delay between the fixed phase and the gate allows one to cover the complete RF cycle. We record strong correlation between the ion-flux and the PROES data.

This work was a partly funded by SFI under the Precision project.

2:20pm **PS-ThA2 Optical Diagnostics of Electron Energy Distributions in Low Temperature Plasmas**, ***J. Boffard***, *L.E. Aneskavich, R.O. Jung, C.C. Lin, A.E. Wendt*, University of Wisconsin-Madison

Passive, non-invasive optical emission measurements provide a means of probing important plasma parameters without introducing contaminants into plasma systems.* Due to the dominant role of electron-impact collisions in gas-phase reactions, our investigation focuses on characterization of the electron energy distribution function (EEDF). In particular, we highlight the ability to observe EEDFs under non-equilibrium conditions in which the EEDF deviates from the Maxwell-Boltzmann form. The energy dependence of the EEDF, which varies with plasma generation method and operating conditions, has significant implications for gas phase reaction rates and is thus critical to the predictive control of plasma process outcomes. EEDFs are determined using measurements of argon emission intensities in the 650-1150 nm wavelength range and measured metastable and resonance level concentrations, in conjunction with a radiation model that includes contributions from often neglected but critical processes such as radiation trapping and electron-impact excitation from metastable and resonance levels. Results using argon emission spectra will be presented for an inductively-coupled plasma (ICP) over a wide range of operating conditions (pressure, RF power, Ar/Ne/N_2 gas mixtures), which show a depletion of the EEDF relative to the Maxwell-Boltzmann form at higher electron energies, in good agreement with measurements made with Langmuir probes and predictions of a global discharge model. These results are consistent with predictions of electron kinetics and can be explained in terms of reduced life times for energetic electrons due to wall losses and inelastic collisions. For Ne/Ar plasmas, analysis of neon emission spectra in addition to the argon analysis provides enhanced sensitivity to the presence of high-energy electrons. This example highlights the potential utility of this method as a tool for probing kinetics of many types of low-temperature plasma systems, which are typically characterized by non-Maxwellian EEDFs.

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2:40pm **PS-ThA3 Two Dimensional Laser-Collision Induced Fluorescence Measurements in Low Pressure Plasmas**, ***E.V. Barnat***, Sandia National Laboratories **INVITED**

Laser-collision induced fluorescence (LCIF) is utilized to produce two-dimensional maps of electron densities and electron temperatures in helium plasmas. In this presentation, the basics of the technique are discussed and means of implementing the technique are described. To correlate the measured intensities of light emitted from the various probed states to electron densities and temperatures, a collisional-radiative model (CRM) is employed. Comparison of predictions made by this CRM to measured LCIF emanating from well characterized plasma constitutes as the calibration process of the LCIF technique. After describing the development and implementation of the LCIF technique, application of the technique to temporally and structurally interesting plasmas are discussed. Examples include ion sheaths, electron sheaths that form around biased electrodes immersed in a plasma. Also discussed are striated structures formed in a pulsed positive column. Transient evolution of these systems is discussed and future extensions of the LCIF technique are considered. "This work was supported by the Department of Energy Office of Fusion Energy Science Contract DE-SC0001939".

3:40pm **PS-ThA6 Controlled Electron Beam Excitation Method to Study Process Chemistries**, ***P.L.S. Thamban***, *G. Padron-Wells*, University of Texas at Dallas, *J. Hosch*, Verity Instruments Incorporated, *M.J. Goeckner*, University of Texas at Dallas

We describe a method to conduct optical emission spectroscopy (OES) measurements, electron beam excitation, that can be adopted to study and quantify process chemistry species. Our method and experiment, designed to be incorporated as a diagnostic system in process tools, relies on extracting electron beam from an inductively coupled plasma. First we will present and discuss results that show electron energy dependent cross section measurements in gas mixtures specifically Fluorocarbon process chemistries. Energy dependent optical excitation cross sections of Fluorine, Oxygen and ionic species as measured with this method will be presented. The controllable excitation method and its applications to quantitative measurements of species in process chamber/exhaust will then be presented. Comparative measurements of species densities as measured with Fourier Transform Infrared Spectroscopy (FTIR) and e-beam excitation will be presented. This project is funded by NSF-Grant (CBET-0922962) and Verity Instruments.

4:00pm **PS-ThA7 Experimental Implementation of Robust Multivariable Real-time Feedback Control Design for RIE Plasma Processing System**, ***Y. Zhang***, *B.J. Keville, A. Holohan, S. Daniels*, NCPST Dublin City University, Ireland

A robust multivariable real-time feedback control strategy for improving output characteristics of a reactive ion etching (RIE) plasma system is presented. Semiconductor fabrication is one of the major applications of low-pressure plasmas. During the course of manufacturing of semiconductor devices, it is often necessary to etch dielectric and/or metal layers to provide features in the layers for subsequent semiconductor processing steps. Reducing process variation is becoming ever more critical and challenging due to shrinking IC device feature dimensions and an increase in wafer size. Developments in process control are struggling to keep pace with these more stringent demands due to the fact that most semiconductor manufacturing tools are run in open loop mode. In this case, key plasma parameters such as ion flux and radical densities at the substrate surface are sensitive to drift in tool subsystems, changes in wall condition and wafer loading, for example. Disturbances to key plasma parameters may affect process metrics such as etch depth and anisotropy and result in a significant degradation in device yield and performance.

In this paper, we report the development of a robust multivariable, real-time feedback controller for the improvement of process repeatability and reproducibility of a RIE tool. Key plasma variables are sensed and their responses to the process inputs are identified experimentally. A MIMO controller then is developed and implemented to control these variables. *H-infinity* control theory and software are used for a systematic tuning procedure. This controller can effectively reduce cross-coupling effects and cope with parameter uncertainties and external disturbances in real-time in order to achieve robustness and optimal performance of the multivariable system.

4:20pm **PS-ThA8 Real Time, Multivariable Control of an SF_6/O_2/Ar Plasma**, ***B.J. Keville***, *M.M. Turner*, Dublin City University, Ireland

Plasmas of sulphur hexafluoride, SF6, mixed with oxygen and argon have been used for silicon etching in microelectronics manufacturing. Fluorine atoms produced by dissociation of SF6 etch Si with very high rates. Lateral etching, which reduces feature anisotropy, may be inhibited by the formation of a silicon oxide passivating layer on feature sidewalls. It has been demonstrated experimentally that feature profile shape is determined to a large extent by the balance between O and F radical densities at the surface of the substrate. In general, etch recipes are specified in terms of inputs such as gas flow rates, RF power and pressure and processes are run 'open loop'. 'Chamber matching', which entails ex situ statistical analysis of metrics such as etch depth, uniformity, anisotropy and selectivity, is required to ensure that each chamber produces acceptable results. However, process reproducibility may be degraded due to real-time disturbances such as MFC and match network drift, wall seasoning and substrate loading. An alternative approach which would reduce the need for chamber matching and reduce process sensitivity to disturbances would be to specify a recipe in terms of plasma parameters such as O and F radical densities, and the fluxes and energies of ions at the wafer surface and to regulate these in real time by adjusting the inputs with a suitable real time control algorithm. This presentation describes how a real time, multivariable control algorithm for an SF_6/O_2/Ar plasma plasma may be designed with the aid of a control-oriented process model. The stability and efficacy of the control algorithm is demonstrated using a model of the process and a variety of simulated disturbances. Experimental implementation of the control algorithm on a laboratory capacitively coupled plasma is described.

4:40pm **PS-ThA9 Maxwell Demon and its Instabilities**, ***CS. Yip***, *N. Hershkowitz*, University of Wisconsin-Madison

Previous experiments[1] have shown that in a low pressure, low temperature plasma, positively biasing an array of thin wires can increase electron temperature by creating an angular momentum trap to absorb cold electrons. In this experiment, such a Maxwell demon device was reproduced by welding 0.025mm tungsten wires onto stainless steel shafts, which were then covered with ceramic. This device was used to more than double the plasma electron temperatures in a multi-dipole chamber operating in the mTorr regime. Moreover, the demon is observed to reduce the cold electron population in a plasma with a bi-Maxwellian electron distribution, leaving a single Maxwellian electron distribution. However, at high positive voltage, instabilities in the kHz range prevent acquisition of meaningful temperature data. The conditions of this instability are investigated by varying neutral pressure, plasma density and applied voltage up to 150V in an argon plasma.

References

[1] K. R. MacKenzie, R.J. Taylor, D. Cohn, E. Ault, and H. Ikezi. App. Phys. Lett. Vol. 18, #12, 1971.

5:00pm **PS-ThA10 Reliable Arc Detection and Arc Mitigation in RF Plasma Systems**, ***D. Coumou***, *R. Chouiery*, MKS, ENI Products

1. Introduction

Arc disturbances in an RF plasma source are typically short duration transients arising from discharges between the plasma and the electrode, the plasma and the chamber sidewall, or discharges within the plasma that are induced by the build-up of polymer structures. When these transients occur, a reliable means is necessary to detect the presence of the arc and to intercept the RF power delivery system to mitigate the arc event. We present a novel solution of arc detection using suitable tools from a communications equivalent paradigm that supersedes conventional heuristic methods. The proposed arc detection scheme is a quantitative approach measuring the relative arc energy of the plasma arc transient. A receiver operating characteristics (ROC) curve demonstrates the robust detection of arc transients relative to a ground truth source and yields insightful information contrasting the detection of arc disturbances in different RF sensing locations in the RF power delivery system. When an arc event is detected, arc mitigation is deployed based on suppressing the RF power with duration proportional to the detected arc energy. The rapid, and if necessary, repeated control of the RF source results in a reduction in the plasma potential to extinguish the arc source and alleviate subsequent damage. Results from PECVD and PVD tools corroborate the impact of this new scheme to significantly ameliorate thin-film manufacturing.

2. Brief Theory of Operation

A correlation function is applied to the voltage and current signals representative of the main-line electromagnetic fields sampled by an RF sensor. Analogous to a digital communication system deploying a correlation receiver, the voltage and current signals are digitally sampled, and the power between these signals is derived using well known properties of the correlation function. From the power measurement in the presence of a detected arc transient, arc energy is accumulated from fixed, non-overlapping correlation block functions. By measuring the amount of energy at the moment of detection, an RF counter mechanism is initiated by the RF power supply to reduce the plasma potential and suppress the arc source.

3. Results

Laboratory experiments are conducted and analytically summarized through an ROC curve to demonstrate the efficacy of our detection method by low false-positive occurrences. Field trials for PECVD and PVD tools outline the broad utilization of this arc detection and accompanying arc mitigation for all RF processes associated with photovoltaic device fabrication.

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