Plasma Science and Technology Division
Room: 201 - Session PS2-TuA

Plasma Diagnostics, Sensors and Control I
Moderator: V. Nagorny, Mattson Technology, Inc.

2:00pm **PS2-TuA1 Prediction of Ion Sheath Shape and Ion Trajectory during Plasma Etching Processing using On-Wafer Monitoring Technique**, ***R. Araki****, K. Miwa, T. Kubota,* Tohoku University, Japan*, T. Iwasaki, K. Ono,* Mizuho Information & Research Institute, Inc., Japan*, S. Samukawa*, Tohoku University, Japan

Precise plasma processes are indispensable for the fabrication of ULSI and MEMS devices. Some MEMS devices have larger scaled 3D structures comparable to the ion sheath thickness on the surface in plasma processing. In such cases, because of distortion of sheath shape due to the MEMS structure, ions trajectory are distorted to the surface and it causes etched shape anomaly. In order to solve these problems, we are developing a system to measure sheath thickness and to predict sheath shape, ion trajectory, and etched shape by fusion of a new on-wafer monitoring data and computer simulation. Our newly developed on-wafer sheath shape sensor can measure the surface potential and ion saturation current at wafer surface. Based on these results, the sheath thickness, shape, and ion trajectory were calculated by using our developed simulation. In this study, we could measure the sheath thickness, and then calculate the sheath shape deformation around a structure having large step in the case of using SF6 inductively coupled plasma. We found that the sheath thickness was about 1 mm and ion trajectory was bent near the large steps on the wafer surface. This result was completely corresponding to the actual etching pattern profile near a structure having large step. It is suggested that our proposed fusion system of on-wafer monitoring data and computer simulation is very effective to predict real etched shape during plasma etching processes.

2:20pm **PS2-TuA2 Measuring Electron Density, Electron Temperature, and Plasma Potential with RF Frequency Probes**, ***D.R. Boris****, R.F. Fernsler, S.G. Walton*, Naval Research Laboratory (NRL)

Plasma density measurements are an essential tool in understanding and controlling processing plasmas across a wide range of applications. Charge collection probes (Langmuir probes) are of limited utility in depositing plasmas, high pressure applications or in processes that require the use of reactive gases, as these environments result in unreliable data acquisition. Plasma frequency probes are an attractive alternative to Langmuir probes in such applications since they do not suffer significant performance degradation in these environments. This work presents frequency probes measurements of plasma density over a range of 10^9 to 10^{12} cm^{-3} in a variety of processing plasma chemistries (N_2, CH_4, NH_3, O_2 and SF_6). In addition to electron density measurements frequency probes are also useful for measuring plasma potential, electron temperature, and electron energy distribution functions in the gas chemistries mentioned above.

2:40pm **PS2-TuA3 Effects of Wire Thickness, Neutral Pressure and Gas Composititon on the Inflection Point Technique**, ***B. Dechawatanapisal****, N. Hershkowitz, J.P. Sheehan, CS. Yip*, University of Wisconsin-Madison

The inflection point technique in the limit of zero emission determines the plasma potential by fitting a straight line to the graph of the emission current versus the inflection point of the emissive probe I-V traces. The plasma potential is determined by extrapolating the line to the limit of zero emission. The effects of wire thickness, gas composition, neutral pressure and position on the technique were investigated. Experiments were performed in a multi-dipole filament discharge. Wire thicknesses of 0.013, 0.025, 0.05 and 0.1mm were studied. Experiments were done in Argon, Xenon and Helium plasmas with neutral pressures ranging from 0.5mTorr to 3mTorr. Measurements were performed from the bulk of the plasma to its sheath edge near a 10cm diameter negatively biased plate.

This work is supported by U.S. DOE under the Grant and Contract Nos. DE-FG02-97ER54437 and No. DE FG02- 03ER54728, DE SC0001939 and by the National Science Foundation Grants under the Grant and Contract Nos. CBET-0903832, and No. CBET-0903783.

3:00pm **PS2-TuA4 A New Diagnostic Tool System of Radio-Frequency Plasmas by Employing Floating-Emissive Probe**, ***Y. Taniuchi****, M. Utsumi,* Tokai University, Japan*, M. Yanagisawa,* Landmark Technology Corporation, Japan*, H. Shindo*, Tokai University, Japan

A new diagnostic tool to measure plasma parameters as well as Electron Energy Distribution Function (EEDF) by a floating-emissive probe has been proposed[1], and a diagnostic system has been newly developed and applied to radio-frequency (RF) plasmas. It is generally difficult for a conventional probe method to measure EEDF in RF plasmas, because of the plasma potential fluctuation, particularly in the capacitive mode. The present method has an advantage that there is no need of an external compensation circuit and all measurements can be made in the floating condition. The method is based on measurement of the functional relationship between the floating potential change ΔV_F and the heating voltage V_H of emissive probe. If the plasma electrons are in Maxwellian, the equation can be obtained for the value of ΔV_F as a practical and useful formula.[1]

It is important to know that the value of ΔV_F contains information of electron energy distribution. In the experiment, the data of V_F and ΔV_F was measured in a 13.56 MHz RF plasma produced by single-loop antenna[2], as a function of V_H. In the conditions of high RF power, the plasma mode was ICP and the measured values of ΔV_F were in agreement with the theoretical value, stating that the plasma electron was in Maxwellian. The electron temperatures thus obtained were very consistent with those measured by Langmuir probe. The electron density was also obtained from the value of ΔV_F near the plasma space potential and they were consistent with Langmuir probe data. Consequently, by using a new diagnostic system one can obtain the electron temperature and density, the plasma space potential and floating potential, as well as the EEDF in the floating condition of the probe. It should be stressed that this is the first success of floating probe to be able to measure all plasma parameters. One can also expect that the present method is applied to plasmas which are produced in insulated vessels.

References:

[1] K.Kusaba and H.Shindo, Review of Scientific Instruments, **78**, 123503-1(2007).

[2] Y.Jinbo and H.Shindo, Applied Physics Express, **2**, 016001-1(2009).

4:00pm **PS2-TuA7 A Comparison of Emissive Probe Techniques for Electric Potential Measurements in a Complex Plasma**, ***J.P. Sheehan******, University of Wisconsin-Madison*, Y. Raitses,* Princeton Plasma Physics Laboratory*, N. Hershkowitz,* University of Wisconsin-Madison*, I. Kaganovich, N.J. Fisch*, Princeton Plasma Physics Laboratory

Accurate measurements of the plasma potential is a critical challenge especially for complex plasmas such as magnetized and flowing. We compare various emissive probe techniques for measurements of the plasma potential. The measurements were conducted in a low-pressure magnetized discharge of the Hall thruster. The thruster was operated with xenon gas in subkilowatt power range and the discharge voltage range of 200-450 V. The probe was placed at the channel exit where, the electron temperature is in the range of 10 to 60 eV and the plasma potential is in the range of 50 to 250 V. The floating point method is expected to give a value ~Te/e below the plasma potential. The experimental results are consistent with these expectations. Specifically, it is shown that the floating potential of the emissive probe is ~2Te/e below the plasma potential. It is observed that the separation technique varies wildly and does not give a good measure of the plasma potential.

This work was supported by US Department of Energy grants No. DE-AC02-09CH11466, No. DE-FG02-97ER54437, and No. 3001346357 and the Fusion Energy Sciences Fellowship Program administered by Oak Ridge Institute for Science and Education under a contract between the U.S. Department of Energy and the Oak Ridge Associated Universities.

4:20pm **PS2-TuA8 Probe Diagnostics Instrument for Laboratory and Industrial RF Plasmas**, ***V. Godyak***, RF Plasma Consulting

Contemporary probe diagnostics of low pressure rf discharge non-Maxwellian plasmas implies the measurement of electron energy distribution function, EEDF and variety of plasma parameters found as the corresponding EEDF's integrals. There are four major problems in implementing of meaningful probe diagnostics in rf plasma reactors. They are: a) large frequency spectrum with significant amplitudes of the plasma rf potential corresponding to source and bias fundamental frequencies and

***** Coburn & Winters Student Award Finalist their harmonics; b) low frequency noise due to plasma instability and ripples in an rf power source, c) too high impedance between the plasma and grounded chamber due to limited surface of the chamber and its contamination or/and an artificial protective coating, and d) contamination of the probe surface with a low conductive layer of the reaction products. The probe characteristic distortion caused by these factors are hardly recognized when one just follows Langmuir procedure to infer plasma parameters assuming Maxwellian EEDF, since distorted and undistorted probe characteristics look similarly. But the problem becomes apparent after double differentiation of the distorted probe characteristics (to infer the EEDF) due to error augmentation inherent to differentiation procedure. A probe diagnostic system VGPS® [1], addressing the aforementioned problems has been designed and tested in the variety of rf plasmas in basic research experiment and in different rf plasma reactors. Examples of EEDF measurements with high energy resolution (small fraction of T_e) and large dynamic range (3-4 orders of magnitude) in laboratory and industrial rf plasmas, are given in this presentation.

4:40pm **PS2-TuA9 Ion Energy Distributions in Pulsed Plasmas with Synchronous DC Bias: Effect of Noble Gas**, ***W. Zhu***, *H. Shin, V.M. Donnelly, D.J. Economou*, University of Houston

Ion energy distributions (IED) on the substrate electrode were measured in a Faraday-shielded inductively coupled plasma. Narrow distributions with well-controlled ion energy were obtained by pulsing the plasma and applying a synchronous DC bias on a "boundary" electrode during the afterglow. The peak ion energy was controlled by the DC bias, as the plasma potential and the electron temperature decayed drastically in the afterglow. IED measurements were performed in Ar, Kr and Xe plasmas, using a retarding field energy analyzer. A Langmuir probe was also used to measure time- and space-resolved plasma density and electron temperature during a pulse as a function of power and pressure. The quasi-steady electron temperature (late in the active glow) followed the order Ar > Kr > Xe i.e., the gas with the highest ionization potential had the largest electron temperature. The opposite order of T_e (Xe > Kr > Ar) was observed in the afterglow, as the decaying electron temperature was controlled by diffusion cooling, and the diffusivity is lower for heavier gas. The full width at half maximum (FWHM) of the IEDs followed the order Xe>Kr>Ar. Higher electron temperature in the afterglow correlated with larger FWHM. The width of the IED could also be controlled by varying the pulsed plasma frequency and duty cycle, or the time window of the application of the DC bias during the afterglow. Small additions (up to 5% by volume) of chlorine gas resulted in IEDs that were similar to those in the corresponding pure noble gas plasma, except that the peak ion energy was lower by a few eV.

Work supported by the DoE Plasma Science Center and NSF.

5:00pm **PS2-TuA10 2011 AVS John A. Thornton Award Lecture - As Device Dimensions Continue to Shrink… A Journey Through Thirty Years of Plasma Etching Diagnostics and Mechanisms**, ***V.M. Donnelly****, University of Houston **INVITED**

With each new generation of integrated circuits and reduction in transistor and interconnect dimensions, plasma etching of fine features in silicon, aluminum and insulating thin films encounters new sets of challenges. Over the past thirty years, our understanding and control of plasma etching processes has greatly improved, due to the advances in diagnostic techniques and basic mechanistic studies, combined with advanced modeling methods. This talk will review studies, mostly from our laboratories, spanning this era with an emphasis on the connections between studies, the influence of other fields, and the interactions between collaborators and colleagues. Some old controversies will be revisited and perhaps revived.

***** John A. Thornton Memorial Award Winner

Authors Index

Bold page numbers indicate the presenter