Plasma Science and Technology Division
Room 609 - Session PS-TuA

Plasma Diagnostics II

Moderator: M.G. Blain, Sandia National Laboratories

2:00pm **PS-TuA1 Infrared and Microwave Absorption Diagnostics of Plasmas for Silicon Oxide Etching and Deposition**, ***R.C. Woods,*** University of Wisconsin, Madison **INVITED**

Absorption spectroscopic diagnostics are non-invasive and provide absolute species concentrations, integrated along the radiation path. Infrared diode laser spectroscopy uses molecular vibration-rotational lines, while microwave spectroscopy looks at pure rotational lines of molecules. The sensitivity of both is high, and their high resolution permits unambiguous separation and identification of many species. We have recently used IR diode laser spectroscopy to measure CF, CF@sub 2@, and CF@sub 3@ absolute concentrations in an inductively coupled GEC etching reactor in G. Hebner's laboratory at Sandia N.L. The three species' densities were studied as functions of power and pressure in C@sub 2@F@sub 6@ and CF@sub 3@H discharges, over both blanket silicon and blanket photoresist wafers. A home built microwave spectroscopic diagnostic has similarly been used at Wisconsin to study concentrations of several species in ECR plasmas intended for deposition of silicon oxide or fluorinated silicon oxide. Gas mixtures studied are silane/oxygen and TEOS/oxygen, or these with admixture of SiF@sub 4@. Species detected by this technique include SiO, CF@sub 2@, SiF@sub 2@, SiF@super +@, and several TEOS oxidation products, e.g., methyl and ethyl alcohol, formaldehyde and acetaldehyde, and formic acid. Although in principle these two absorption spectroscopic techniques are very closely related, sometimes looking at the same molecules and even absorbing from the same quantum levels, each has its own advantages and limitations, and these will be briefly discussed here. This work was supported by National Science Foundation Grant #EEC-8721545 and by SEMATECH under contract no. 38010430.

2:40pm **PS-TuA3 Thomson Scattering with Gated Intensified CCD Detectors for Diagnostic of rf Discharge Plasmas**, ***S.A. Moshkalyov,*** *T. Morrow, C. Thompson, W. Graham,* Queen's University of Belfast, Northern Ireland, UK

Thomson scattering (TS) with high-repetition rate lasers has been recently introduced as a diagnostic of electron parameters (electron density and electron energy distribution function, EEDF) in low-temperature gas discharge plasmas. This method has some distinct advantages over other techniques (like electric probes) which are commonly used to measure electron parameters in gas discharges. This technique is non-intrusive, and the interpretation of data is straightforward. However, due to the small cross-section of light scattering by free electrons, TS signals are extremely low (~ 20-30 photoelectrons/pulse for an electron density of 10@super 11@ cm@super -3@). To improve signal-to-noise ratios, measurements are typically made by accumulating the signals over ~10@super 3@ laser pulses. In most TS experiments, single-channel photomultiplier tubes are used for the light detection. A further step in the diagnostic development is the use of multichannel detectors such as gated intensified CCD's which record the entire TS spectrum and thus reduce considerably the time needed for measurements of the electron parameters. In our experiments, TS system with 10 Hz YAG laser (0.5 J at 532 nm) and a low-noise ICCD detector is used for diagnostics of an inductively coupled RF discharge plasma in a GEC reference cell. Experiments were carried out in Ar plasma for low pressures (25-250 mTorr) and relatively low powers (30-70 W). Experiments have shown that high accuracy of EEDF measurements in an extended range of electron energies (up to 12-15 eV) can be achieved by accumulating TS signals in 500-2500 pulses, with overall measurement time as small as 2-10 minutes. For high argon pressures EEDF has shown to be close to Maxwellian, while for low pressures strong deviation from Maxwellian distribution has been observed. The study of the effect of other gases admixtures to Ar is now on the way.

3:00pm **PS-TuA4 Determination of Electron Temperatures and Species Concentrations During Aluminum Etching**, ***V.M. Donnelly,*** *M.V. Malyshev, S.W. Downey, J.I. Colonell, N. Layadi,* Bell Laboratories, Lucent Technologies

Electron temperatures (T@sub e@) and species concentrations were obtained in chlorine-containing, high-density, inductively coupled plasmas (Applied Materials decoupled plasma source (DPS) metal etcher), using trace rare gases optical emission spectroscopy (TRG-OES). Measurements were carried out as a function of total pressure, source power, fraction of BCl@sub 3@ added to Cl@sub 2@ and substrate material (SiO@sub 2@, Al, and photoresist). A small amount (1.7% each) of all five rare gases was added to the plasma and emission spectra were recorded. TRG-OES T@sub e@ s corresponding to the high energy tail of the electron energy distribution function were derived from the best match between the observed and computed rare gas emission intensities. At source and bias powers of 1000 and 100 W, TRG-OES T@sub e@ s in Cl@sub 2@/BCl@sub 3@/N@sub 2@/rare gas plasmas increased from 1.5 eV at 40 mTorr to 3.0 eV at 3 mTorr, in good agreement with values computed from a global model and somewhat lower (at higher pressures) than those measured with a Langmuir probe. Surprisingly little dependence of T@sub e@ on substrate material was found. Reduced plasma induced damage at higher pressures correlated with a drop in both T@sub e@ and plasma density, but appears to be due mostly to the lower T@sub e@. Cl@sub 2@, Cl, BCl@sub 2@, BCl, B, AlCl@sub 2@, AlCl, Al, N@sub 2@ and BN emissions were identified. Qualitative, and in some cases quantitative absolute number densities were obtained by dividing these emission intensities by that from Ar, or Xe, corrected for electron impact excitation from Xe metastables.

3:20pm **PS-TuA5 Peter Mark Memorial Award Address**, ***E.S. Aydil***[1], University of California, Santa Barbara **INVITED**

4:00pm **PS-TuA7 Cavity Ring Down Spectroscopy for the Detection of Hydrocarbon Radicals during a-C:H Deposition**, ***K.G.Y. Letourneur,*** *M.C.M. van de Sanden, R. Engeln, M.G.H. Boogaarts, D.C. Schram,* Eindhoven University of Technology, The Netherlands

Cavity Ring Down spectroscopy can be used in order to quantify the relative influence of radical species impinging on a growth surface. This enhanced absorption technique allows the determination of low species ground state densities as well as the evaluation of their rotational and vibrational temperature. It also allows for time and space resolved measurements. Cavity Ring Down spectroscopy has been applied during the deposition of hard hydrogenated amorphous carbon films obtained from a remote argon arc plasma in which acetylene is injected as carbon precursor. The C@sub 2@H@sub 2@ molecules are subsequently dissociated by argon ions and electrons, present in the plasma, producing hydrocarbon radicals (C@sub 2@H@super *@ and CH@super *@) responsible for deposition (rates up to 20 nm/s). However, hitherto, to the best of our knowledge, no direct detection of the ground state of those radicals has ever been reported in such environment. Detection of the ground state of the CH and C@sub 2@H radicals via CRD spectroscopy around 430 nm and 276 nm respectively are presented. Typical ground state densities of CH of around 10@super 17@ m@super -3@ are found. The results are used to develop a model for the deposition process of hydrogenated amorphous carbon from a remote plasma.

4:20pm **PS-TuA8 Characterization of Transformer Coupled Oxygen Plasmas by Trace Rare Gas-Optical Emission Spectroscopy and Langmuir Probe Analysis**, ***N.C.M. Fuller,*** Bell Laboratories, Lucent Technologies and Columbia University; *M.V. Malyshev, V.M. Donnelly,* Bell Laboratories, Lucent Technologies; *I.P. Herman,* Columbia University

Trace rare gas-optical emission spectroscopy (TRG-OES) and Langmuir probe analysis have been used to measure the electron temperature, T@sub e@, in a high-density inductively (transformer) coupled (TCP) 10 mTorr oxygen plasma as a function of the 13.56 MHz radio frequency (rf) power. Rare gas actinometry and modeling at 7774 and 8446 Å have been used to determine the absolute densities of ground state atomic and molecular oxygen and the O(@super 1@D), O(@super 1@S) and O@sub 2@(a @super 1@@delta@@sub g@) metastables in the plasma. In the bright (inductive) mode, T@sub e@ increases from 2.7 to 3.4 eV for the electrons sampled by the Langmuir probe and from 4.1 to 5.5 eV for the high energy electrons sensed by TRG-OES, as rf power is increased from 100 to 1046 W. In the dim (capacitive) mode, below 45 W, T@sub e@ increases from a few eV at very low rf power to ~ 6 eV at 45 W. T@sub e@ decreases from 4.5 ± 1.5 eV at ~ 45 W to ~ 3.3 ± 0.8 eV at ~ 100 W. The gas dissociation peaks at ~ 40% at the maximum rf power density of 5.7 Wcm@super -2@ (1046 W), for which the ground state atomic and molecular oxygen concentrations are 2.5 x 10@super 14@ cm@super -3@ and 3.9 x 10@super 13@cm @super -3@ respectively. At this power density, the densities of O(@super 1@D) and O(@super 1@S) are 2.0 x 10@super 13@ cm-3 and 4.5 x10@super 11@ cm-3 respectively and the metastables collectively account for ~ 8% of all neutral species. For this

[1] **Peter Mark Memorial Award Winner**

power density, excitation of the metastables contribute ~ 44% and ~ 50% of the emission observed at 7774 and 8446 Å respectively, with the O(@super 1@D) metastable being the principal contributor. In the dim mode, the densities of O(@super 1@D) and O(@super 1@S) are three and five orders of magnitude smaller, respectively, than that of ground state atomic oxygen. Throughout the rf power range investigated, the density of O@sub 2@(a @super 1@@delta@@sub g@) is ~ one-third that of O(@super 1@D).

4:40pm **PS-TuA9 Diagnostics of Large-area Plasma Produced by Surface Waves on a Metal Wall with Periodicity**, ***T. Yamauchi***, *K. Aoki,* Toshiba Corporation, Japan; *H. Sugai,* Nagoya University, Japan

Surface-wave plasma is a promising next-generation plasma source since it readily yields a large-area high-density plasma at low pressures. In most cases, surface waves at 2.45GHz are excited along a dielectric wall, however, the use of a large-area dielectric wall often induces serious wall erosion and impurity release. To avoid such problems, the use of a metal wall with periodic structures which results in an increase in plasma density as well as an improvement in density uniformity is proposed in this paper. The top of the vacuum chamber consists of an Al plate(340mm diameter) comprising two quartz windows (20mm width) which also serve also serving as slot antennas. A periodic structure was installed on the Al plate. The experimental conditions are an Ar gas flow rate of 60sccm, a pressure from 30 to 70Pa and a microwave power of 2kW. We obtained the electron density of 10@super11@10@super12@cm@super-3@, which exceeds the cut off density (7.44 x10@super10@cm@super-3@)for 2.45GHz. The behavior of the ion saturation current, electron density and electric field intensity between two slots. Without the periodic structure the values show peaks under each slot antenna, thus indicating the influence of microwave radiation from the slot antennas themselves. Accordingly, it is revealed that the periodic structure on the metal wall is effective for generating a large-area surface-wave plasma.

5:00pm **PS-TuA10 UV Absorption Spectroscopy of Pulsed Fluorocarbon Plasmas**, ***B.A. Cruden***, *K.K. Gleason, H.H. Sawin,* Massachusetts Institute of Technology

Thin polytetrafluoroethylene(PTFE)-like films have been deposited in a pulsed capacitively coupled plasma from a variety of fluorocarbon precursors. It has been shown that pulsing of the plasma allows for composition control, giving reduced amounts of cross-linking and branching, and a higher CF@sub 2@ content. While some precursors, such as hexafluoropropylene oxide (HFPO), appear to deposit primarily in the off-time and is believed to be dominated by long-lived difluorocarbene species, other precursors, such as tetrafluoroethylene (TFE) show a linear dependence of deposition on duty cycle, suggesting deposition occurs primarily in the on-time period. To help elucidate the nature of the deposition processes and the differences between these precursors, UV absorption has been used to measure CF@sub 2@ concentrations quantitatively. In the plasmas examined here partial pressures of CF@sub 2@ are observed in the range of 5-15 mtorr for a 1 torr total pressure. Transients in concentration have been modelled by a elementary mole balance and effective reaction constants have been obtained. Optical emission spectroscopy and actinometry are also used to study the role of other species including O, F, CF and CF@sub 3@. XPS is used to study how the composition of the films varies with precursor and pulsing conditions, and can be related to the gas phase concentrations as measured by UV Absorption. Additionally, a quartz-crystal microbalance (QCM) has been used to measure deposition rates during the plasma on and off times.

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