Plasma Science
Room 104 - Session PS-FrM
Diagnostics III

Moderator: M.C.M. van de Sanden, Eindhoven University of Technology, The Netherlands

8:20am **PS-FrM1 Optical Diagnostics of Charged Particles in Processing Plasmas*, A. Kono,*** Nagoya University, Japan **INVITED**

Behaviors of electrons and negative ions in low-pressure high-density inductively coupled plasmas have been studied using non-intrusive optical diagnostic techniques. An efficient multichannel laser Thomson scattering measurement system, which is highly resistant to Rayleigh scattering interference, was developed and used to study electron energy distribution functions (EEDFs). In measurements of C@sub 4@F@sub 8@/Ar plasma at a total pressure of 25 mTorr, non-Maxwellian EEDFs were observed, in contrast to Maxwellian EEDF observed for pure Ar plasma. A particle simulation suggests that the observed EEDFs result from local electron heating and subsequent cooling of electrons by inelastic collisions in the non-heating region. Laser photodetachment technique in combination with millimeter-wave Fabry-Perot resonance technique was used to study negative ion density. Measurements of CF@sub 4@/, C@sub 4@F@sub 8@/, SF@sub 6@/, and NF@sub 3@/Ar plasmas at 25 mTorr show that at an Ar dilution ratio as high as 95% and at electron densities around 10@super 11@ cm@super -3@, the negative ion density is higher than or nearly as high as the electron density. This indicates that in high-density C@sub 4@F@sub 8@, SF@sub 6@, and NF@sub 3@ plasmas electron attachment occurs as effectively as in low-density plasmas with low dissociation degrees of the feedstock gases; on the other hand, in high-density CF@sub 4@ plasma, electron attachment takes place much more effectively than in low-density plasma, suggesting that dissociation of CF@sub 4@ results in production of highly electron-attaching species.

9:00am **PS-FrM3 Measurements of the Spatiotemporal Variation of Ion Flux in Plasma Etching Reactors*, T.-W. Kim,*** *S.J. Ullal, E.S. Aydil,* University of California, Santa Barbara

Variation of the ion flux and its spatial distribution across the wafer is critical in plasma etching: ion flux uniformity at the wafer determines the uniformity of etching. Most ion flux uniformity measurements to date have concentrated on studying the radial uniformity on a plane above the wafer. There are very few ion flux measurements on the plane of the wafer, especially in two dimensions. We have designed, built, and used planar Langmuir probes and probe arrays consisting of 10-30 probes on 75 mm and 200 mm diameter wafers to measure the variation of ion bombardment flux and its spatiotemporal distribution at the plane of the wafer in two different inductively coupled plasma reactors. Two-dimensional variation of the ion flux as a function of radial and angular positions on the plane of the wafer was mapped by interpolating between the probes. We demonstrate the uitility of these probes in studying factors that affect the ion flux and its uniformity including instabilities in an Ar discharge and effects of etching products in Cl@sub 2@ etching of Si. For example, in one of the reactors in Ar plasma at high pressure, a region of high ion flux ("hot spot") developes at the edge of the wafer at seemingly random positions and this "hot spot" rotates and moves around the edge on a time scale that depends on the plasma conditions. During etching of Si in a chlorine plasma, ion flux increases as a function of exposure time to the chlorine discharge and saturates on a time scale that is on the order of a few minutes. Through other diagnostic methods, this reproducible transient in the ion flux is related to the release of etching reaction products such as SiCl@sub x@ and subsequent deposition of a silicon oxychloride film on the reactor walls. Removal of this film from the wall with an SF@sub 6@ discharge resets the reactor walls back to a reproducible condition and returns the ion flux to the same level as at the beginning of the etching process.

9:20am **PS-FrM4 Time-resolved Radical Measurements in a Remote Silane Plasma Using the Cavity Ringdown Absorption Technique*, J.P.M. Hoefnagels,*** *A.E.E. Stevens,* Eindhoven University of Technology, The Netherlands*; W.M.M. Kessels, D.C. Schram,* Eindhoven University of Technology, The Netherlands, Netherlands*; M.C.M. van de Sanden,* Eindhoven University of Technology, The Netherlands

The highly sensitive cavity ringdown spectroscopy technique (CRDS) has been used for the determination of the density and plasma chemistry of SiH@sub x@ radicals in our remote silane plasma, which is used for high rate deposition of a-Si:H and µc-Si:H. Recently, a new CRDS based technique has been developed for measuring time-resolved radical densities (@tau@-CRDS) to obtain further insight into the dynamics of SiH@sub x@ radicals and to study the interaction of these radicals with the depositing surface. In @tau@-CRDS, the plasma is modulated and the corresponding response of the SiH@sub x@ radical density is monitored by sampling the SiH@sub x@ density at various times. For this measurement, a "state of the art" data acquisition system (100 MHz, 12 bit) has been developed such that single CRDS transients can be handled up to a repetition rate of 2 kHz. It will be shown that single transient handling improves the signal-to-noise ratio drastically, even for conventional CRDS measurements. The modulation of the plasma is done by application of pulsed rf power to the substrate holder in addition to the regularly operating remote plasma. This creates only a minor additional SiH@sub x@ radical density. In this way, gas phase and surface reactivities of the species are obtained under steady state plasma operation conditions. The feasibility of the @tau@-CRDS technique has been proven on SiH radicals probing the A@super 2@@DELTA@<-X@super 2@@PI@ electronic transition at ~413 nm. By using different modulation frequencies the measurements have also revealed that a previously unidentified broadband absorption on this wavelength is due to a rather unreactive species created in the silane plasma. Furthermore, @tau@-CRDS measurements on Si and SiH@sub 3@ will be presented and the gas phase and surface reactivity of these species will be discussed on the basis of a model.

9:40am **PS-FrM5 Temporally Resolved Measurement of Electron Temperature, Relative Electron Density, and Atomic Fluorine Density during Fluorocarbon/Rare-gas Plasma Etching of SiO@sub 2@, using Optical Emission Spectroscopy*, M.J. Schabel,*** Bell Laboratories, Lucent Technologies*; V.M. Donnelly, W.W. Tai, A. Kornblit,* Agere Systems

Measuring the time-resolved behavior of processing plasmas is important for determining process end-points, tool health and process faults. One commonly used approach is to monitor the optical emission for changes that correlate conditions. Recently, we have demonstrated that the plasma emission may also be used to characterize the time-averaged behavior of fundamental plasma properties, including electron temperature (T@sub e@), relative electron density (n@sub e@) and fluorine atom concentration (n@sub F@), through the application of advanced optical emission spectroscopy. Here we have used trace rare gas optical emission spectroscopy and rare gas actinometry to measure T@sub e@, n@sub e@, and n@sub F@ at ~2 second increments in an inductively-coupled commercial plasma reactor. The temporal behavior was evaluated over a complete plasma process cycle, which included plasma strike, stabilization, chamber seasoning, silicon dioxide etch, and an oxygen chamber clean and photoresist strip. Run to run repeatability of T@sub e@, n@sub e@, n@sub F@, and O-atom density was evaluated for each step in the cycle. T@sub e@ was found to be repeatable to within ± 0.5 eV for constant step conditions. The silicon dioxide etch step, comprised of C@sub 2@F@sub 6@, C@sub 4@F@sub 8@, a carrier gas, and a trace rare gas mixture (equal parts He, Ne, Ar, Kr, and Xe), was evaluated over variations in pressure (10-90 mTorr), flowrate (120-600 sccm), and carrier gas composition (0-100% Ar, balance Ne). Corresponding measurements of etch rates and sidewall angles were found to range between 2-12 kÅ/min and 85-90°, respectively. Correlations between plasma operating conditions, fundamental plasma parameters, and etch performance will be presented.

10:00am **PS-FrM6 Characterization of Mass-Filtered CF@sub x@@super +@ Ion Beams for Surface Studies of Etching*, M.J. Gordon,*** California Institute of Technology*; K.P. Giapis,* California Institute of Technology, U. S. A.

Many ion beam systems used to probe plasma-surface interactions during etching are unable to deliver the tunable energy and high particle flux conditions that are typical of realistic processing plasmas. Some of the problems include inefficient ion production, space charge spreading of the beam resulting in very low fluxes, and a fixed plasma potential that requires the sample to be offset from ground in order to vary the beam energy. Furthermore, mass-filtering of the ion beam is required if the reaction dynamics of specific plasma species are to be understood. To create an improved ion source for etching studies, we have developed a mass-filtered ion beam system based on extraction of ions from an inductively coupled plasma (ICP) discharge. In our system, ions are extracted from an ICP discharge (13.56 MHz) using an accel-decel lens arrangement and injected into a transport line floating at -15 kV. The ion beam is mass filtered at high voltage using a magnetic sector, focused, and then decelerated to impinge on a grounded sample. Similar to biasing a wafer, capacitively coupled RF (15-30 MHz) from an auxiliary electrode is used to vary the ICP plasma potential and hence, vary the ion beam energy. Mass-filtered ion currents after focusing that approach 1 mA/cm@super 2@ can be obtained due to high ion densities in the ICP and beam transport at high voltage to avoid space charge spreading. This talk will focus on ion source design and beam characterization experiments for CF@sub x@@super +@ species extracted from ICP etching plasmas. The dependence of CF@sub 2@@super +@/CF@sub 3@@super +@ beam currents and ion energy distribution functions (IEDF's) on plasma pressure (1-10 mT) and RF inductive power (50-500W) were measured using a hemispherical energy analyzer located downstream of the sector magnet. In addition, the effect of capacitive RF bias power and frequency (15-30 MHz) on the plasma potential was investigated by monitoring the shift in the beam IEDF.

10:20am **PS-FrM7 Ion Energy Measurements in a Pulsed Plasma with a High-resolution, Submicron, Retarding Field Analyzer**, ***M.G. Blain**, M.J. Sowa, R.L. Jarecki,* Sandia National Laboratories

A silicon wafer-based, submicron, high-resolution, retarding field analyzer (RFA)@footnote 1@ was used to measure ion energy distributions in an inductively coupled plasma where the source power was pulsed on and off. Experiments were conducted in argon at pressures from 1.5 - 40 mTorr, with various source rf powers, for periods of 10-40 µsec with duty factors from 20%-80%. In contrast to the single peak obtained with continuous Ar plasmas, distinct high and low ion energy peaks were frequently observable in the pulsed plasmas. These distinct peaks can be attributed to contributions from a high T@sub e@ inductively-powered plasma, and a low T@sub e@ afterglow, respectively. A simulation based on the global plasma model of Ashida, et al.@footnote 2@ was able to capture the qualitative trends in the pulsed data, confirming this interpretation. Additional pulsed experiments were performed with 0-100% O@sub 2@/Ar mixtures, as well as various Cl@sub 2@/Ar mixtures. Oxygen addition, in particular, produces an increased spread between the high and low energy peaks, perhaps due to depletion of electron density by attachment during the afterglow.@footnote 3@ @FootnoteText@ @footnote 1@M.G. Blain, J.E. Stevens, J.R. Woodworth, Appl. Phys. Lett., v.75, n.25, p.3923, 1999. @footnote 2@S. Ashida, C. Lee, and M. A. Lieberman, J. Vac. Sci. Technol. A, v.13, n.5, p.2498, 1995. @footnote 3@Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

11:00am **PS-FrM9 Characteristics of the LAPPS Ion Flux to an RF Biased Surface**, ***D.D. Blackwell**, S.G. Walton, D. Leonhardt, D.P. Murphy, R.F. Fernsler, R.A. Meger,* US Naval Research Laboratory

The ion flux properties are possibly the most critical parameters in a process plasma. Every industrial plasma process, from sputtering to deposition, is highly dependent on the density, energy, and composition of the ions. At NRL, we have been experimenting with electron-beam produced plasmas as an alternative to radiofrequency (RF) driven discharges. The most promising of these sources is the hollow cathode driven Large Area Plasma Processing System. This source is designed to produce large area (> 1 m@super 2@), high density, uniform sheets of plasma. In this presentation we will show measurements of the ion energy distribution function (IEDF) from continuous and pulsed electron beam plasmas produced in 20-30 wide, 1 cm thick sheets by a 2 kV hollow cathode. The IEDF is obtained using a gridded energy analyzer incorporated into a RF biasable stage. The surface flux and IEDF in the presence of large RF voltages applied to the stage will be presented. We will also be comparing the IEDF's taken in a pulsed system and a continuous current system during the "beam on" and afterglow periods to observe their temporal evolution. Typical operating conditions are 15-20 millitorr of argon, oxygen, or nitrogen, and 150-200 Gauss magnetic field.

Author Index

Bold page numbers indicate presenter