Plasma Science and Technology
Room 213B - Session PS2-WeM

Plasma Sources

Moderator: J. Caughman, Oak Ridge National Laboratory

8:20am **PS2-WeM1 Langmuir Probe Measurements of Change in Plasma Parameters with Change in Chamber Geometry in Electronegative Plasmas***, **S.P. Sant**, E.A. Joseph, B.S. Zhou, L.J. Overzet, M.J. Goeckner,* University of Texas at Dallas

The affect of chamber geometry on the characteristic behavior of two electronegative gases commonly used in the processing industry, namely CF@sub 4@ and O@sub 2@ were studied. The chamber used is the modified Gaseous Electronics Conference (mGEC) reference cell. The mGEC was designed to allow rapid changes to its geometrical structure and wall materials, allowing us to closely inspect various plasma-wall interactions. A Langmuir probe was used to obtain axial and radial measurements of ion density, electron density, plasma potential, electron temperature and floating potentials. These parameters were measured for a combination of two different source â?" chuck gaps (4 cm and 9.8 cm) and chamber diameters (20 cm and 64 cm). It is observed for both gases, that the electron temperature ranges from ~ 5 eV to ~ 1 eV as we move from the center towards the walls in the 64 cm diameter case with the narrow gap. For wider gap the peak temperatures are ~ 30% lower for O@sub 2@ case only, while they remain approximately the same for CF@sub 4@. In comparison, the plasma density drops by a factor of 2 in the center (1.5 E 11 to 0.8 E 11) with decrease in gap, but the center density remains fairly constant independent of chamber diameter. In general, it is observed that the experimental values vary with change in gap (coil to chuck distance), but remain fairly constant with change in chamber diameter. This work is supported by a grant from NSF/DOE, CTS â?" 0078669.

8:40am **PS2-WeM2 Modeling of a Commercial Dual Frequency Magnetically Enhanced Capacitively Coupled Plasma Reactor with Rotating Static Magnetic Field***, **T. Panagopoulos**,* Applied Materials, Inc.*; A.M. Paterson, J.P. Holland,* Applied Materials Inc.

Magnetically enhanced reactive ion etching (MERIE) reactors have recently been modeled for 200mm wafer processing chambers with single frequency and uniform static magnetic field. An extension of this work is presented for a commercial 300mm dual frequency MERIE reactor with rotating static magnetic field for an argon discharge. The magnetic field is modeled in the 3D space (CFD-ACE) and it is used as an input in a 2D computational model (HPEM). The different moments of the static magnetic field are solved independently and the species spatial profiles are compared for different magnetic field intensities and operating pressures. The use of magnetic field results in more confinement of the ion density within the area of the two electrodes. This confinement is more effective for lower pressures (10s of mTorrs) and tends to confine the plasma at the wafer center. On the other hand, when the pressure increases to a few hundreds of mTorrs, the plasma density is confined close to wafer edge. The density profiles are affected by the time averaged ionization source by bulk electrons. When no magnetic field is applied in the chamber, the ionization source is located near the wafer edge and in the middle of the inter-electrode spacing. As the magnetic field increases in a high pressure regime, the ionization sources move closer to the bottom electrode, and for even higher magnetic field (~100G) most of the ionization takes place at the edge of the bottom electrode with a lessened contribution from the top electrode. For lower operating pressures (~30 mTorr), the ionization patterns are different with a substantial contribution from the top electrode and bulk of the plasma, for average magnetic fields. In a similar way the dc bias is affected by the operating pressure regime; it becomes less negative as the magnetic field increases at low pressures, while it becomes more negative for the high pressure regime. Experimental wafer results agree with the simulation trends.

9:00am **PS2-WeM3 Control of Uniformity in Multifrequency Capacitively Coupled Plasmas Considering Edge Effects@footnote 1@***, **J. Lu**, M.J. Kushner,* University of Illinois at Urbana-Champaign

Multifrequency capacitively coupled plasmas are finding increasing use in etching and deposition applications. The optimization of ion flux uniformity is known to be a sensitive function of the edge electrical boundary condition embodied in the shape, permittivity and conductivity of the guard (or focus) ring. To investigate these geometrical and electrical effects, a 2-dimensional plasma hydrodynamics model has been developed which uses an unstructured numerical mesh. This meshing capability enables fine resolution of the substrate structures. The dependence of the ion flux uniformity on the electrical boundary condition using single and dual frequency operation (10s MHz and a few MHz with frequencies on one electrode or separate electrodes) will be discussed for process conditions of 10s mTorr in electropositive (Ar) and electronegative (Ar/fluorocarbon, Ar/O@sub 2@) mixtures. @FootnoteText@ @footnote 1@ Work supported by SRC and NSF.

9:20am **PS2-WeM4 Potentials and Fields in a 300-mm Dual-Frequency Capacitively Coupled Plasma Reactor***, **P.A. Miller**, E.V. Barnat, G.A. Hebner,* Sandia National Laboratories*; A.M. Paterson, J.P. Holland, T. Lill,* Applied Materials

Dual-frequency capacitively coupled plasma reactors provide separate control over plasma generation and ion extraction. Usually, a vhf power supply (source) is used to generate and sustain the plasma and an hf power supply (bias) is used to extract ions. At present there is debate over the optimum choices for the two operating frequencies, and whether they should be applied to one or two electrodes. Higher frequencies facilitate plasma generation with mild and controllable dissociation of feed-gas molecules, but the attendant shorter wavelengths cause concern over spatial variations in plasma properties. Regardless of frequency choices, electrical nonlinearity of plasma sheaths causes harmonic generation and mixing of source and bias frequencies. These processes, and the resulting spectrum of frequencies, are as much dependent on electrical characteristics of matching networks as on the plasma sheath properties. We investigated such electrical effects in a 300-mm Applied-Materials plasma reactor. Data were taken for 13.56-MHz bias frequency (chuck) and for source frequencies from 30 to 160 MHz (upper electrode). An rf-magnetic-field probe (B-dot loop) was used to measure the radial variation of fields inside the plasma. We will describe the results of this work. This work was supported by Applied Materials and Sandia National Laboratories, a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

9:40am **PS2-WeM5 Time and Position Resolved Characterization of ICP and Double-ICP Sources***, **P. Awakowicz**,* Ruhr-Universität Bochum, Germany **INVITED**

Inductively coupled rf sources are important tools in semiconductor plasma processing. In recent years, these tools also have been investigated for medical applications like plasma sterilisation and surface modification of polymers. This is the reason why a double ICP source has been developed. In order to characterize these different plasma sources, Langmuir probe measurements, energy-resolved mass spectrometry, optical emission spectroscopy and plasma modelling have been applied to different ICP sources. For time resolved measurements, Langmuir probe and mass spectrometer were synchronized. Time and position dependent profiles provide a deeper insight into physics of these source and provide additional parameters like puls frequency and duty cycle for adjusting new or improved processes.

10:20am **PS2-WeM7 Comparison of Fluorocarbon Gases and NF3 for Plasma Chamber Cleaning with Transformer-Coupled, Toroidal Source***, **B. Bai**, H.H. Sawin,* Massachusetts Institute of Technology*; L. Gary, M. Mocella,* DuPont Electronic Gases

In recent years, remote chamber cleaning has begun to replace in situ chamber cleaning for Chemical Vapor Deposition (CVD), due to the lower occurrence of chamber wall erosion and lower perfluorocompound (PFC) gas emission. We have tested a high-power transformer-coupled toroidal plasma source typically used with NF3 to produce fluorine atoms for chamber cleaning. The ASTRONex unit couples high power levels (<10 kW) into the feed gases, leading to high neutral temperatures (as high as 6000K) under conditions that produce relatively low electron temperatures. These condition produce very high degrees of dissociation of not only NF3, but also for fluorocarbon compounds â?" contrary to what has been seen in lower power and/or microwave units for remote chamber cleaning. In this work, a systematic comparison has been made among various fluorocarbon compounds (with added O2) including CF4, C2F6, C3F8, and C4F8, along with NF3. Trends in cleaning rates, which are significantly different from earlier studies in other units, will be described. Tool emission studies with Fourier Transformed Infrared Spectroscopy (FTIR), along with analysis of the cleaned surfaces via X-ray Photoelectron Spectroscopy (XPS) and Atomic Force Microscopy (AFM), will also be presented. Plasma parameters were also measured to better understand the kinetics in the source.

Neutral gas temperatures were obtained by fitting rovibrational bands of diatomic species like CO, CF or added N2. Electron temperature and electron density were determined by the atomic argon spectrum, while the atomic concentrations of fluorine and oxygen species in the plasma source were measured by advanced actinometry. For these two optical emission spectroscopy measurements, a full consideration of optical cascading and radiation trapping was necessary due to the high source pressure (~1 torr).

10:40am **PS2-WeM8 Scaling of Low-pressure Ionized Metal PVD Reactors@footnote 1@***, **V. Vyas**, M.J. Kushner,* University of Illinois at Urbana-Champaign

Ionized metal physical vapor deposition (IMPVD) at sub-mTorr pressures is used to deposit diffusion barriers and seed layers onto high aspect ratio trenches. At these pressures, conventional fluid or hybrid simulations are of questionable validity as transport is highly non-equilibrium and a kinetic approach may be warranted. In this work, a Monte Carlo simulation for ion and neutral transport (IMCS) has been developed and integrated into a 2-dimensional plasma equipment model to improve our capabilities to address lower pressures. The ion velocity distributions obtained from the IMCS are used to obtain transport coefficients for use in heavy particle momentum and energy conservation equations, thereby extending their validity to lower pressures. Hollow Cathode Magnetron (HCM) plasma sources for Cu deposition have been investigated using the model while varying power, pressure and source geometry. The consequences of varying these parameters on the uniformity of reactant fluxes, and their energy and angular distributions on the substrate will be reported. Comparisons will be made to experiments for plasma properties and deposition profiles. @FootnoteText@ @footnote 1@ Work supported by SRC and NSF.

11:00am **PS2-WeM9 Production of Meter-scale High-density Microwave Plasmas for Giant Materials Processing***, **H. Sugai**, Y. Nojiri, T. Ishijima, E. Stamate,* Nagoya University, Japan

There has been a great need for meter-scale high-density plasma sources for manufacturing giant microelectronics devices such as liquid crystal display and solar cell. Capacitive discharges at frequencies in VHF range enable us to generate a medium-density meter-size plasma, however standing wave effect and edge effect significantly degrade the plasma uniformity. Here, we present a new technology for production of large-area uniform high-density plasmas based on surface wave excitation at 2.45 GHz. The critical challenges are (1) how to avoid huge atmospheric pressure acting on a dielectric window for microwave radiation, and (2) how to design an antenna-plasma coupling so as to attain the plasma uniformity over meter-size. The first issue is dodged by employment of a dielectric-filled waveguide and slot antennas, which are contained in a low-pressure plasma vessel. The second issue is solved by a careful design of slot antenna and by introduction of corrugated dielectric surface. Surface waves propagating along the interface between a dielectric plate and plasma are investigated in an analytical model and also in FDT simulation. The standing modes of surface waves at 2.45 GHz were successfully detected by a movable antenna, and the mode numbers are in good agreement with the wave theory. In the preliminary experiments using a large discharge vessel (length 1 m, width 0.3 m), we obtained the plasma density of ~5x10@super11@ cm@super-3@ with ~10 % uniformity at 2.5 kW in argon at 50 mTorr.

11:20am **PS2-WeM10 Extraction of a Directional Ion Beam with Controlled Energy Using a Pulsed Plasma***, **L. Xu**, V.M. Donnelly, D.J. Economou,* University of Houston

A 13.56MHz pulsed (typically 50µs ON/50µs OFF), capacitively coupled plasma reactor was developed to generate a nearly monoenergetic, directional ion beam. The DC bias on the target ranged from -150 to -270 volts depending on the input power and pressure. A Langmuir probe was employed to characterize the pulsed Ar plasma and a 3-grid ion energy analyzer was used to measure the ion energy distribution (IED). The EEDF during the power-ON fraction of the cycle was non-Maxwellian with a high energy tail, most likely due to secondary electrons emitted from the target. Beyond 4 µs into the power-OFF period, a Maxwellian EEDF was observed and the electron temperature (T@sub e@) decayed rapidly. The evolution of the EEDF during the power-OFF period was also used to verify the collapse of T@sub e@. After a specified delay in the power-OFF period, a positive voltage pulse was applied to a DC ring electrode surrounding the plasma to raise the plasma potential (V@sub p@) and "push" positive ions through a grounded grid out of the plasma. With the DC ring electrode voltage pulse on, a high-voltage shift of a Langmuir probe IV curve signified an increase of V@sub p@. With 50 V applied to the DC ring, the energy of the extracted ion beam peaked at 49.4 V, while the FWHM of the IED was 4.3 V, limited by the rise time of the homemade voltage pulse circuit. The ion beam is also expected to be very directional since the ion temperature depends on T@sub e@, which was very low during ion extraction. Finally, the sheath thickness during ion extraction was much larger than the holes of the grid, resulting in a vertical sheath electric field and minimal divergence of the ions as they traversed the grid holes. This was verified by a self-consistent PIC simulation. Work supported by NSF.

11:40am **PS2-WeM11 Particle-in-Cell Simulation of Ion Extraction Through a Grid***, **S.K. Nam**, V.M. Donnelly, D.J. Economou,* University of Houston

Ion extraction from a plasma through a grid finds applications in ion beam and neutral beam sources. The flux, energy and angular distributions of ions (or neutrals) extracted from the plasma are of primary importance in such applications. These quantities depend critically on the shape of the meniscus (plasma-sheath boundary) formed over the surface topography of the extraction grid. For example, when the sheath thickness is comparable to or smaller than the grid hole size, the sheath tends to conform to the surface topography of the grid (plasma molding) resulting in divergent beams. A self-consistent Particle-in-Cell (PIC) simulation of ion extraction from a plasma through a grid was developed. Emphasis was placed on extracting ions, which are as mono-energetic and as directional as possible. The effect of control parameters affecting the sheath thickness (plasma density, electron temperature, sheath potential) relative to the grid hole size (and aspect ratio) was studied. For a hole size of 0.5 mm, the FWHM of the ion angular spread was about 4, 10, and 20 degrees for sheath thickness of 4.3, 2.6, and 0.7 mm, respectively (sheath potential of 50 V, electron temperature 3 eV). Ion flux uniformity was very high for the thick sheath case (within a 3%) but degraded gradually for the thinner sheaths due to stronger ion divergence. Conditions which allowed the extraction of an ion beam with specified energy and angular spread were determined. The influence of hole-hole interaction was also studied. Work supported by the National Science Foundation.

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