Monday Afternoon, November 2, 1998

Plasma Science and Technology Division Room 318/319/320 - Session PS2-MoA

Diagnostics I

Moderator: M.L. Brake, University of Michigan

2:00pm PS2-MoA1 Density Measurements of Cf@sub x@ in a GEC Reference Cell by Infrared Absorption, *I.C. Abraham¹*, *R.C. Woods*, University of Wisconsin, Madison; *G.A. Hebner*, Sandia National Laboratories

Tunable diode laser absorption measurements in the region around 1250 cm@super -1@ were used to determine line integrated CF, CF@sub 2@, and CF@sub 3@ densities in a GEC reference cell, modified for inductively coupled plasma operation. A quartz ring was also installed around the source region to stabilize and confine the plasma and to make the plasma chemistry more like that in industrial etch tools. The experimental layout involved a two pass arrangement, with the path including both the plasma and the space outside the glow region, in a plane just above the wafer surface. Two gas chemistries, C@sub 2@F@sub 6@ and CHF@sub 3@, and two wafer surfaces, bare silicon and blanket photoresist, were investigated. A range of pressure and power conditions, from 5 to 20 mTorr and from 100 to 300 W, respectively, was employed. The concentration of undissociated C@sub 2@F@sub 6@ in the C@sub 2@F@sub 6@ plasma was also measured. An intense spectrum of COF@sub 2@ can be detected in an O@sub 2@ cleaning plasma. The time evolution of CF, CF@sub 2@, and CF@sub 3@ in a C@sub 2@F@sub 6@ plasma was monitored, starting from a clean chamber and continuing for much longer than an etch cycle. The data should provide important benchmarks for models of oxide etching in inductively coupled plasma tools. This project was funded by SEMATECH under contract no. 38010430.

2:20pm PS2-MoA2 Un-Collided Beam Mass Spectrometric Measurements in C@sub 2@F@sub 6@ and CHF@sub 3@ Dielectric Etch Discharges, J. RaviPrakash, The Pennsylvania State University, U.S.A; R.C. McGrath, The Pennsylvania State University; G.A. Hebner, Sandia National Laboratories

Relative concentrations of reactive ions, neutral radicals and etch/resist products in dielectric etch chemistries have been measured using an uncollided beam mass spectrometer (Hiden EQP). Measurements were made in C@sub 2@F@sub 6@ and CHF@sub 3@ discharges produced in an inductively coupled research reactor operating with power densities, pressures, gas compositions and wafer materials typical of those found in etch processing tools. For C@sub 2@F@sub 6@ discharges we find that CF@sub 3@@super +@ is consistently the dominant fluorocarbon ion present, in agreement with published cross sections for dissociative ionization. Significant concentrations of CF@super +@, CF@sub 2@@super +@, and C@sub 2@F@sub 5@@super +@ are also observed. We will report on differences observed between our measurements of fractional yields for these reaction products and those expected from published dissociative ionization cross sections. Notable changes have been observed in concentrations of C@sub x@F@sub y@ species and of SiF@sub x@ etch products in the presence of photoresist. In CHF@sub 3@ discharges the dominant ion species are CF@sub 3@@super +@ and CHF@sub 2@@super +@. Smaller concentrations of CF@sub 2@@super +@, CF@super +@ and HF@super +@ are also observed. For each of the etch chemistries investigated, variation of species concentrations with changing power (100-400 W) and pressure (5-40 mTorr) were measured. We will report on discharge conditions which produce the maximum reactive ion species production within the processing reactor volume.

2:40pm PS2-MoA3 Modeling High-Density Plasma Etching of Aluminum and Photoresist@footnote 1@, P. Ho, E. Meeks, A. Ting, S.J. Choi, Sandia National Laboratories

A plasma-etch mechanism has been developed to describe the high-density plasma etching of aluminum in BCl@sub 3@/Cl@sub 2@/Ar mixtures. Results of extensive validation comparisons with experimental data are shown for several different reactor models employing the aluminum-etch mechanism. Comparisons are made to diagnostic measurements of the gas-phase, including electron density, electron temperature, Cl@super -@ density, and relative radical densities, as well as to ion-flux and wafer-etch data from a commercial reactor. The reactor models employed include a well mixed reactor model and a 2-D axisymmetric plasma-flow model that can handle several, detailed surface-chemistry descriptions for different

plasma-materials interfaces in the reactor. The gas-phase plasma chemistry mechanism includes dissociation, ionization, and excitation of etch products to accurately capture macroscopic loading effects. The gas-phase chemistry and aluminum-etch mechanisms provide very good quantitative agreement between the models and the wide collection of observations and measurements available in this study. Simulation results from the 2-D model predict well the measured radial uniformity for blanket-aluminum etching. In addition to the aluminum-etch mechanism, a simple description of photoresist etching is introduced, which reproduces most of the observed trends for blanket photoresist etching in the BCl@sub 3@/Cl@sub 2@/Ar plasmas. @FootnoteText@ @footnote 1@This work was supported by a Cooperative Research and Development Agreement between SEMATECH and Sandia National Laboratories. 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

3:00pm PS2-MoA4 Studies of Ion Bombardment in Plasma Cleaning and Etching Gases, J.K. Olthoff, Y. Wang, National Institute of Standards and Technology

Ion-energy distributions and relative ion fluxes have been measured in a variety of plasma etching and cleaning gases, and their mixtures, at the grounded electrode of a high density inductively-coupled plasma (ICP) reactor. The gases studied include pure CF@sub 4@ and C@sub 2@F@sub 6@, along with the following mixtures: CF@sub 4@ + Ar, CF@sub 4@ + Ar + O@sub 2@, C@sub 2@F@sub 6@ + O@sub 2@, and SF@sub 6@ + Ar. All ions exhibited fairly simple ion-energy distributions that were indicative of the plasma potential. For pure CF@sub 4@, the two dominant ions observed were CF@sub 3@@super +@ and CF@super +@, but 3 other ions exhibited intensitites that were within a factor of 3 of the dominant ions. Similar behavior was observed in CF@sub 4@ + Ar mixtures with the addition of a significant flux of Ar@super +@ ions. For CF@sub 4@ + Ar + O@sub 2@ mixtures, 9 different ions exhibited fluxes whose magnitudes were within a factor of 2 of each other, thus indicating the complexity of the plasma-surface interactions in multi-component gases. In pure C@sub 2@F@sub 6@, CF@sub 3@@super +@ was the dominant ion, with only minor contributions observed from other ions. In mixtures of C@sub 2@F@sub 6@ and O@sub 2@, a host of other ions are formed, but the dominant ions are either CF@sub 3@@super +@ or O@sub 2@@super +@, depending upon the mixture. In SF@sub 6@ + Ar mixtures, all of the SF@sub x@@super +@ ions are observed, with the lower mass ions exhibiting larger intensities.

3:20pm PS2-MoA5 Diode Laser Measurements of CF@sub x@ and CO Radicals in an Inductively Coupled GEC Reference Cell, G.P. Deering, W.L. Perry, H.M. Anderson, University of New Mexico

Diode laser absorption measurements have been made on CF. CF@sub 2@ and CO radicals in an inductively coupled GEC reference cell. The GEC reference cell was modified with a quartz confinement ring around the source region to stabilize the plasma. Optical emission and Langmuir probe studies indicated this modification resulted in fluorocarbon discharges with a plasma chemistry similar to that found in commercial etch tools. The experiments in this study focused on radical concentrations found in the reactor under typical high density plasma etching conditions. At 300 W source power, 100 W bias power and 10 mTorr C@sub 2@F@sub 6@ pressure in the GEC cell, etching proceeded at about 5000 A/min. A range of source power and bias power conditions, from 100 to 400 W and from 0 to 130 W, respectively, was employed. The time evolution of CF, CF@sub 2@ and CO in a C@sub 2@F@sub 6@ plasma was monitored during an approximate 2 minute etch cycle. Chamber cleanliness and bias was found to exert a strong influence on radical densities. The data is expected to provide an important database for models of oxide etching in inductively coupled plasma tools. This project was funded by SEMATECH.

3:40pm PS2-MoA6 Cavity Ring Down Spectroscopy on an expanding Ar/C@sub 2@H@sub 2@ Plasma, A.H.M. Smets, K.G.Y. Letourneur, M.G.H. Boogaarts, M.C.M. van de Sanden, D.C. Schram, Eindhoven University of Technology, The Netherlands

In this contribution we present the first results obtained from a cavity ring down spectroscopy (CRDS) setup for the detection of low density species in a plasma reactor. In this reactor research is carried out on the use of an expanding plasma beam produced by a cascaded arc for the fast deposition of thin films. In the plasma beam acetylene is dissociated in several radicals which will react at the substrate to form hydrogenated amorphous carbon (a-C:H) films. At the moment the C@sub 2@H radical is considered to be responsible for the diamondlike quality of the a-C:H films. The aim of this

Monday Afternoon, November 2, 1998

project is to measure radical densities (C@sub 2@H, CH and H(n=2)) by using CRDS technique. CRDS is an absolute absorption technique based upon the measurement of the rate of absorption of the light pulse confined in an optical cavity. The absolute density of the n = 2 state of atomic hydrogen has been measured in an Ar/C@sub 2@H@sub 2@ expanding deposition plasma. From the measured H(n=2) densities it can be concluded that the C@sub 2@H radical is produced dominantly in an expanding Ar/C@sub2@H@sub2@ plasma. The results obtained by CRDS measurements on radicals will be used to develop a model for the growth of a-C:H films.

4:00pm **PS2-MoA7 VUV-Visible Emission Spectroscopy Investigation of Frequency Effects in Low Pressure Plasmas, A.C. Fozza,** École Polytechnique, Canada; *M. Moisan,* Université de Montréal, Canada; *M.R. Wertheimer,* École Polytechnique, Canada

Low pressure (p@<=@10 Torr), high frequency (HF) plasmas have been used for many years in various processing steps in very-large scale integration (VLSI) manufacturing of integrated circuits, and are now increasingly used as an efficient method for surface modification of polymers. In order to optimize a particular plasma process, the operator can vary such "external" (operator-set) parameters as the HF power, pressure, feed gas composition, reactor geometry, excitation frequency, etc. In the present study, we focus on the effect of the excitation frequency, f, a parameter which has received relatively little attention in the literature over the years. The difficulties encountered in designing meaningful frequency - dependent experiments are the following: - varying f over a wide range requires that one change the reactor and/or the powerdelivery system, which usually calls for a change of the plasma volume; working at constant electron density, n@sub e@, or absorbed HF power density, P@sub a@, has frequently not been taken into consideration. These difficulties can be avoided by the use of surface wave discharges (SWD), which constitute the most thoroughly modeled type of HF plasmas. SWD plasma sources possess great flexibility: a very broad (continuous) range of excitation frequencies, wide ranges of operating pressures and plasma densities, and high coupling efficiency. In earlier experiments in these laboratories, we have examined f-dependence of plasma deposition and etching experiments.@footnote 1@ The present experiments have been designed to investigate f-dependence more "directly", by studying optical emission from pure gases or their mixtures, as recently reported for the case of 2.45 GHz excitation.@footnote 2@ The vacuum ultraviolet (VUV) to visible emission from SWD plasmas in pure hydrogen or 0.07 H@sub 2@/0.93 Ar mixture have been investigated over a broad range of excitation frequency (50@<=@ f @<=@ 200 MHz) using a spectrophotometer with a known (calibrated) transfer function. As in earlier experiments,@footnote 1@ we have been able to interpret the fdependence of emission intensity (atomic lines and molecular bands) in terms of changes of the electron energy distribution function. @FootnoteText@ @Footnote 1@ M. Moisan, C. Barbeau, R. Claude, C.M. Ferreira, J. Margot, J. Paraszczak, A.B. Sá, G. Sauvé, and M.R. Wertheimer, J. Vac. Sci. Technol. B9, 8 (1991). @Footnote 2@ A.C. Fozza, A. Kruse, A. Holländer, A. Ricard, and M.R. Wertheimer, J. Vac. Sci. Technol. A16, 72 (1998).

4:20pm **PS2-MoA8 Plasma Sheath Electric Field Strengths Above a Grooved Electrode in a Parallel-Plate Radio Frequency Discharge**, *U. Czarnetzki*, Universitaet GH Essen, Germany; G.A. Hebner, Sandia National Laboratories; *D. Luggenholscher*, *H.F. Dobele*, Universitaet GH Essen, Germany; *M.E. Riley*, Sandia National Laboratories

During plasma etching of microelectronic structures, the direction and energy of the ions that strike the surface has a major influence on the characteristics of the etch profile. In an ideal case, the sheath electric field vector will be perfectly perpendicular to the surface so that ions accelerated from the bulk plasma above the wafer will strike the wafer surface at normal incidence. In reality, the wafer surface is a multidimensional surface with several layers of subsurface dielectric that can significantly modify the electric field direction and ion trajectories. To examine the details of the spatial distribution of the electric field strength in the sheath region above an electrode with surface structure, and to provide data to validate recent advances in multidimensional sheath models, we have measured sheath electric fields above a structured electrode. The magnitude of the sheath electric field above a grooved electrode was measured using a novel, two color, laser induced fluorescence technique. Spatially resolved electric fields in the sheath region were determined by mapping the field induced Stark splitting of the n = 14 level in atomic hydrogen. Measured electric field values are in good agreement with calculated values. This work was performed at the

University of Essen. GAH thanks the Deutsche Forschungsgemeinschaft for a travel grant in the frame of the SFB 191. GAH and MER were supported by the United States Department of Energy (DE-AC04-94AL85000). Expert technical support by Rainer Fuhrer is gratefully acknowledged.

4:40pm PS2-MoA9 Ultrahigh Frequency vs. Inductively-Coupled Chlorine Plasmas: Comparisons of Cl and Cl@sub 2@ Concentrations and Electron Temperatures Measured by Trace Rare Gases Optical Emission Spectroscopy, V.M. Donnelly, M.V. Malyshev*, Bell Laboratories, Lucent Technologies; S. Samukawa, NEC Corporation, Japan

Using trace rare gas optical emission spectroscopy, Cl and Cl @sub 2@ number densities (n@sub Cl@ and n@sub Cl2@) and electron temperatures (T@sub e@) were measured for two source configurations of high-density chlorine plasmas. In one configuration, the reactor was outfitted with a spoke antenna, operated at a resonant ultrahigh frequency (UHF) of 500 MHz. Alternatively, the same reactor was configured with a single loop, inductively coupled plasma (ICP) source operated at a radio frequency of 13.56 MHz. Optical emission from trace amounts (1% each) of rare gases added to the main Cl@sub 2@ feed gas were recorded as a function of power and pressure, during slow etching of the SiO@sub 2@coated Si wafer. Modeling was used to derive T@sub e@ from these data. Additional emission from Cl@sub 2@ (at 305.0 nm) and Cl (numerous lines between 700 and 900 nm), normalized to the appropriate emission from the rare gases (i.e. actinometry) was used to obtain n@sub Cl@ and n@sub Cl2@. In the ICP, T@sub e@ decreased monotonically from 5.5 to 1.2 eV as a function of increasing pressure between 1 and 20 mTorr. Conversely, with the UHF configuration, T@sub e@ was 3.3 eV, independent of pressure between 1 and 7 mTorr, and then decreased to 1.7 eV as pressure was increased to 27 mTorr. At the same input power (1000W), both sources resulted in electron densities of 1 x 10@super 11@cm@super -3@ at 3.5 mTorr, yet the UHF plasma was much less dissociated (30%) than the ICP (70%). This is attributed to differences in the electron energy distributions in the two plasmas, especially at low pressure, caused by differences in energy transfer from the E-field to the electrons, through collisions with the gas. @FootnoteText@ *Also at Princeton University

5:00pm **PS2-MoA10 Spectroscopic Measurements in an Inductively Coupled RF Discharge in Hydrogen@footnote 1@**, *M.L. Huebschman*, *R.D. Bengtson, J.C. Wiley, J.G. Ekerdt,* University of Texas, Austin; *V. Bakshi,* International Sematech

Spatially resolved electron temperature profiles, T@sub e@(r,z), and plasma density profiles, n@sub e@(r, z) were measured with a multi-chord, multi-channel optical emission spectrometry in inductively coupled hydrogen plasmas over a range of RF power and pressure in a semiconductor growth and analysis chamber. The intensities from eighteen simultaneous chords viewing the plasma were measured for ten hydrogen Balmer lines. The calibrated intensities were Abel inverted to give local densities of the upperstate populations. Spatially resolved temperature profiles were obtained from the ratio of line intensities. Electron density profiles, n @sub e @(r.z) were determined from a collisional-radiative model@footnote 2@ using the electron temperature, pressure balance, and the populations of levels n = 3, 4, 5, and 6. Measurements were made with hydrogen pressures of 5 - 50 mTorr and with input powers from 50 -200 W. Measured density and temperature profiles will be compared with fluid models. There are clear indications of capacitive coupling in the profiles. These experiments and models are motivated by the desire to develop physically accurate computational models of a simple chemical system -hydrogen on silicon- in a simple geometry which could be verified by measurements. @FootnoteText@ @footnote 1@Research supported in part by the Texas Advanced Research Program. @footnote 2@L. C. Johnson and E. Hinnov, J. Quant. Spectrosc. Radiat. Transfer. Vol. 13, 333 (1973).

Author Index

-A-Abraham, I.C.: PS2-MoA1, 1 Anderson, H.M.: PS2-MoA5, 1 — B — Bakshi, V.: PS2-MoA10, 2 Bengtson, R.D.: PS2-MoA10, 2 Boogaarts, M.G.H.: PS2-MoA6, 1 -C-Choi, S.J.: PS2-MoA3, 1 Czarnetzki, U.: PS2-MoA8, 2 -D-Deering, G.P.: PS2-MoA5, 1 Dobele, H.F.: PS2-MoA8, 2 Donnelly, V.M.: PS2-MoA9, 2 — E — Ekerdt, J.G.: PS2-MoA10, 2 — F — Fozza, A.C.: PS2-MoA7, 2

Bold page numbers indicate presenter

— H — Hebner, G.A.: PS2-MoA1, 1; PS2-MoA2, 1; PS2-MoA8, 2 Ho, P.: PS2-MoA3, 1 Huebschman, M.L.: PS2-MoA10, 2 -L-Letourneur, K.G.Y.: PS2-MoA6, 1 Luggenholscher, D.: PS2-MoA8, 2 -M-Malyshev*, M.V.: PS2-MoA9, 2 McGrath, R.C.: PS2-MoA2, 1 Meeks, E.: PS2-MoA3, 1 Moisan, M.: PS2-MoA7, 2 -0-Olthoff, J.K.: PS2-MoA4, 1 — P — Perry, W.L.: PS2-MoA5, 1

— R — RaviPrakash, J.: PS2-MoA2, 1 Riley, M.E.: PS2-MoA8, 2 — S — Samukawa, S.: PS2-MoA9, 2 Schram, D.C.: PS2-MoA6, 1 Smets, A.H.M.: PS2-MoA6, 1 - T --Ting, A.: PS2-MoA3, 1 -vvan de Sanden, M.C.M.: PS2-MoA6, 1 -w-Wang, Y.: PS2-MoA4, 1 Wertheimer, M.R.: PS2-MoA7, 2 Wiley, J.C.: PS2-MoA10, 2 Woods, R.C.: PS2-MoA1, 1