Plasma Science and Technology
Room 311 - Session PS-MoM
Plasma-Surface Interactions I
Moderator: E.R. Fisher, Colorado State University

8:20am **PS-MoM1 Plasma-Assisted Etching Processes for Dielectric Materials: Technological Challenges and Elementary Processes on Planar Surfaces and in Microstructures*, G.S. Oehrlein,*** University of Maryland **INVITED**

Low pressure discharges are used for pattern transfer into dielectric layers in integrated circuit production, e.g. for etching of vias and trenches in the formation of multi-level interconnection schemes. The dielectric materials range from conventional SiO@sub 2@ and different spin-on glass films, organic insulators to porous materials. The control of plasma-surface interactions is a prerequisite for successful pattern transfer into the dielectric materials. We will review the challenges that exist for several prototypical pattern transfer applications, the dominant plasma-surface interaction mechanisms, and the technological solutions that have been demonstrated.

9:00am **PS-MoM3 Observation of Surface Reaction Layers formed in Highly Selective SiO@sub 2@ Etch Process*, M. Matsui,*** *T. Tatsumi, M. Sekine,* Association of Super-Advanced Electronics Technologies (ASET), Japan

We characterized the surface reaction layers formed by a fluorocarbon plasma for SiO@sub 2@ selective etching over Si and Si@sub 3@N@sub 4@, in order to understand the etch mechanism and to develop a process and tool for future ULSI processing. Specimens were etched using C@sub 4@F@sub 8@/Ar/O@sub 2@ plasma in a dual-frequency (27/0.8MHz) parallel-plate RIE system. The relationship between ion energy (assumed to be equal to peak to peak voltage (V@sub pp@) of rf bais) and the thickness and composition of the surface reaction layers were quantitatively analyzed using X-ray photoelectron spectroscopy (XPS) and transmission electron microscopy (TEM). The CF polymer layer and the SiF@sub x@O@sub y@ layer on the substrates were observed. We found that the etch rate is strongly affected by the ion energy and the thickness of the CF film on etched materials. In a highly selective etch process, the thickness of the CF layer on the SiO@sub 2@ surface is below 1 nm, while those on the Si@sub 3@N@sub 4@ and Si substrates are about 5-6 nm. The difference in the CF layer thickness on each material should be an origin of the selectivity. Both TEM and XPS observations revealed that reaction layers (2-4 nm) were formed at the interface between the CF layer and Si, Si@sub 3@N@sub 4@. The XPS analysis showed the composition of the reaction layer was SiF@sub x@O@sub y@. This SiF@sub x@O@sub y@ layers were thicker when the ion energy was high and the CF film was thin, i.e. a high etch rate condition for Si and Si@sub 3@N@sub 4@. SiF@sub x@O@sub y@ is thought to be an intermediary product of the Si@sub 3@N@sub 4@ and Si etching. In a highly selective etch process, CF film are so thin that ion energy is not reduced when ions pass through the film on SiO@sub 2@. On the other hand, at the surface of Si@sub 3@N@sub 4@ and Si, thicker CF film were formed and reduced the etch rate, resulted in thin SiF@sub x@O@sub y@ layer formation. @FootnoteText@ This work was supported by NEDO.

9:20am **PS-MoM4 Early-stage Modification of SiO@sub 2@ Surface in Fluorocarbon Plasma for Selective Etching Over Si*, K. Ishikawa*,** *M. Sekine,* Association of Super-Advanced Electronics Technologies (ASET), Japan

To understand the surface reaction mechanism that governs SiO@sub 2@ etch performance, we studied the surface evolution, starting at the very beginning of the etching process. We also studied the way in which fluorocarbon (CF) polymer reaches a steady-state at a specific thickness. For this purpose, we prepared a modified GEC reference cell and optical apparatus for in-situ time-resolved infrared attenuated total reflection (IR-ATR) spectroscopy with a germanium (Ge) substrate. The SiO@sub 2@ film was formed by plasma oxidation of Si sputtered on a Ge substrate. We made the SiO@sub 2@ film about 10 nm thick because, according to Fresnel's formula, the CF peak height is linearly proportional to CF film thickness when the underlying SiO@sub 2@ is less than a few hundred nm thick. While the SiO@sub 2@ film was being etched in Ar-diluted C@sub 4@F@sub 8@ plasma, we took spectra every two seconds. A peak, located at 1230 cm@super -1@, due to C-F stretching absorption and a trough, at about 1100 cm@super -1@, due to Si-O stretching absorption, were observed. Observations proved difficult due to an overlap between the two components. By decomposing the spectra, we obtained the separated intensities of the CF and SiO@sub 2@ films. The time-dependence observations were fitted to a model, which enabled us identify the factors that enhance and inhibit CF film growth during SiO@sub 2@ etching. @FootnoteText@ This work was supported by NEDO.

9:40am **PS-MoM5 Silicon Etch Yields and Etching Chemistry in F@sub 2@, Cl@sub 2@, Br@sub 2@, and HBr High Density Plasmas*, S.A. Vitale*[1],** *H.H. Sawin,* Massachusetts Institute of Technology

Etch yields of silicon in F@sub 2@, Cl@sub 2@, Br@sub 2@, and HBr high density plasmas have been measured as a function of ion bombardment energy, ion bombardment angle, and plasma composition. This information forms a database of experimental values needed for feature profile evolution modeling. For all plasma chemistries, the etch yield increases with the square root of ion energy. Pure Cl@sub 2@ and pure HBr plasmas have very similar etch yields. Silicon etch rates are lower in HBr plasmas than in Cl@sub 2@ plasmas due to lower ion fluxes, not lower etch yields. The dependence of the etch yield on ion bombardment angle is significantly different for Cl@sub 2@ and HBr plasmas. The etch yield in Cl@sub 2@ plasmas decreases rapidly for ion angles above 60° (measured form the surface normal), which results in significant ion scattering from the sidewalls, causing the sidewall bowing and microtrenching seen when patterning polysilicon with Cl@sub 2@ plasmas. The etch yield in HBr plasmas decreases more gradually with ion angle, resulting in less ion reflection from feature sidewalls and could explain the lack of sidewall bowing and microtrenching seen when patterning polysilicon with HBr plasmas. HBr plasmas have higher etch yields than Br@sub 2@ plasmas due to: 1) the higher volatility of SiH@sub x@Br@sub y@ products compared to SiBr@sub 4@, and 2) extra Si surface coverage by small H atoms. As the temperature of the silicon increases, the etch yield in HBr plasmas decreases, due to reduced surface coverage by adsorbed Br and H atoms.

10:00am **PS-MoM6 Studies on SiF@sub x@ Radicals in Fluorosilane Plasmas Used for Silicon Etching and Deposition*, K.L. Williams*,** *E.R. Fisher,* Colorado State University

Fluorosilane plasmas have been used in the microelectronics industry for etching of Si/SiO@sub 2@ and for deposition of fluorinated silicon alloys, such as a-Si:H,F. Specifically, fluorinated a-Si films are used in the fabrication of solar cells, photoreceptors, and thin film transistors. In spite of high quality film production, there is still controversy over the mechanistic aspects of deposition processes. Moreover, fundamental chemical and physical information on plasma species such as SiF@sub x@ radicals is not available. The surface reactivity of SiF and SiF@sub 2@ radicals during plasma processing of silicon-containing substrates using the Imaging of Radicals Interacting with Surfaces (IRIS) technique is reported. The molecular beam sources are 100% SiF@sub 4@, 90/10 SiF@sub 4@/H@sub 2@, and 50/50 SiF@sub 4@/H@sub 2@ plasmas. SiF and SiF@sub 2@ have been studied as a function of applied rf power (20, 40, 80, and 170 W) in each of these plasma molecular beams. Initial reactivity measurements of SiF on a Si substrate demonstrate that applied rf power has a significant effect on SiF scatter, which ranges from S = 0.05 at 20 W to S = 0.70 at 170 W. A S < 1 indicates that there is surface loss of SiF. Several possible mechanisms exist which may explain surface loss of SiF . These possible mechanisms will be discussed along with IRIS results for both SiF@sub 2@ and SiF scatter. Furthermore, IRIS results can be correlated with data from film characterization by Fourier transform infrared spectroscopy (FTIR) and profilometry of films deposited under various plasma parameters (applied rf power and % H@sub 2@ addition).

10:20am **PS-MoM7 Ion Energy Distributions at the RF-Biased Electrode in an Inductively-Driven Discharge*, I.C. Abraham*,** *J.R. Woodworth, M.E. Riley, P.A. Miller,* Sandia National Laboratories

We report the energy distributions of ions striking an rf-biased electrode in discharges in an inductively-driven Gaseous Electronics Conference Reference cell. The rf-bias and inductive power supplies were phase locked to a 13.56 MHz oscillator. Using a mass-and-energy sensitive ion analyzer we examined the ion energy spectra for ions of a variety of masses in discharges containing mixtures of the noble gases Ar, Ne, and Xe. The ions were sampled thru a pinhole in the rf-biased lower electrode. Oscillations of the plasma potential and the rf-bias waveforms on the driven electrode were directly measured to compare to the ion energy spectra. The ion energy distributions, which had a single peak and a width of 3.5 eV (FWHM) when the electrode was not biased, split into double peaked

[1] **PSTD Coburn-Winters Student Award Finalist**

distributions as rf-bias was applied to the electrode. Lighter ions consistently had larger splittings in their energy distributions, with the largest splittings being in rough agreement with the rf potential difference between the plasma and the biased electrode. The influence of ICP coil power, rf-bias power, and pressure were investigated. Measurements of plasma densities and temperatures as well as comparisons to model ion energy distributions will be presented. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-ACO4-94AL85000.

10:40am **PS-MoM8 The Influence of High Density Plasma on TiN Films Deposited by Ionized Physical Vapor Deposition***, **D. Mao**, J.A. Hopwood, K. Tao,* Northeastern University

The deposition of adhesion layers, diffusion barriers, and seed layers into high-aspect-ratio features is a critical technology for next-generation integrated circuit interconnects.@footnote 1@ One promising method of fabricating high-aspect ratio vias is ionized physical vapor deposition(I-PVD). Titanium nitride films were prepared by I-PVD in a gas mixture of argon and nitrogen. To understand the deposition mechanisms, optical emission spectroscopy analysis, Langmuir probes, and quadrapole mass spectrometry(QMS) were utilized to characterize the plasma. From the results of QMS, the dissociation of N@sub 2@ is as high as 50% for low N@sub 2@ partial pressure(~1.5mtorr), but decreases to 15% at 3.5mtorr. The properties of the TiN@sub x@ films were investigated by Rutherford backscattering, scanning electron microscopy(SEM), stress measurement, and electrical resistivity measurement. The ability of I-PVD to deposit titanium nitride at the bottom of narrow, deep vias and trenches was characterized by cross sectional SEM. The resistivity was found to increase as the N@sub 2@ partial pressure increases. The stress was found to increase from 1 GPa to 7 GPa as the bias voltage changes from -20V to -50V. The effect of nitrogen on the degree of ionization of sputtered titanium will also be discussed. The effect of dissociation of nitrogen and ion density on the characteristics of the TiN@sub x@ film will be presented by comparison with standard sputtering. @FootnoteText@ @footnote 1@ J. Hopwood, 'Ionized physical vapor deposition of integrated circuit interconnects', J. Physics of Plasmas, Vol. 5, pp 1624 (1998)

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