Plasma Science and Technology
Room 2009 - Session PS1-WeA

Plasma-Wall Interactions and Plasma Sources

Moderator: J.P. Booth, Lam Research Corporation

2:00pm **PS1-WeA1 Plasma-Wall Interactions in an Inductively Coupled Plasma Etching Reactor***, S. Ullal,* Lam Research Corporation **INVITED**

Wafer-to-wafer process reproducibility is one of the major concerns in plasma etching of thin films with high density inductively coupled reactors, which are widely used for integrated circuit manufacturing. These reactors are typically operated at low pressures, where the mean free path of species in the plasma is on the order of the reactor dimensions, and reactive radicals collide as often with the chamber walls as they do with each other in the gas phase. Thus, the plasma chamber walls play a crucial role in determining the discharge properties such as ion density, electron temperature, and species concentration. Often, a stack of thin films of different materials is etched sequentially using multiple gases in the same chamber. Chemicals used and/or produced during the etching of one film may adsorb or deposit on the walls of the reactor and alter the chemical reactivity of the walls. The changing wall conditions cause variations in the discharge properties directly affecting etching reproducibility. This problem of process sensitivity to the wall conditions has been known for a long time but its management has remained an art. This talk will review the advances made towards improving the understanding of plasma-wall interactions using various plasma diagnostic techniques as applied to specific chemistries used for plasma etching proceses used in integrated circuit manufacturing.

2:40pm **PS1-WeA3 Impact of Chamber Walls on Radical Densities in Cl@sub 2@ ICP Plasmas***, G. Cunge,* CNRS-LTM, France*; N. Sadeghi,* CNRS, France*; R. Ramos,* Freescale Semiconductor Inc., France*; O. Joubert,* CNRS-LTM, France

The radical densities in low pressure high-density discharges are controlled mainly by chemical reactions occurring at the reactor walls. This sensitivity of halogen-based plasmas to the chamber walls conditions is known for long time and is at the origin of process drifts. By using laser absorption at 355 nm we have measured the absolute density of Cl@sub 2@ molecules in a typical Cl@sub 2@ plasma operating either in a clean reactor or in a reactor coated with a SiOCl, CCl@sub x@ or TiOCl@sub x@ layer. We report that under identical plasma operating conditions, the Cl@sub 2@ mole fraction in the plasma can vary from 0.1 to 0.6 depending on the chemical nature of the chamber wall coatings. We have then measured the time variation of Cl@sub 2@ and SiCl@sub x@ (x=0-2;4) etch products densities (by UV absorption and mass spectrometry (MS)) during silicon etching both in clean and SiOCl-coated reactor. From the Cl mass balance in the system and from MS measurements we concluded that several species are produced from the SiOCl-coated reactor walls, including heavy Si@sub x@O@sub y@Cl@sub z@ species (with x up to 4). Furthermore, it is obvious from these measurements that the quartz surface below the RF coil behaves differently than the other reactor walls surfaces, and plays an important role in controlling the plasma chemistry. As a matter of fact, due to electrostatic coupling, this part of the equipment is bombarded by more energetic ions than the floating walls of the chamber and is thus an efficient region of production (/loss) of reactive species. Furthermore, the sudden formation or disappearance of a thin conductive layer below the RF coil can lead to plasma instabilities by influencing the electromagnetic coupling between the RF coil and the plasma. The impact of these phenomenons on metal gate etching processes will be discussed in details.

3:00pm **PS1-WeA4 Influence of Bombarding Energy on Stabilization of Radical Density of Fluorocarbon Plasma***, K. Kumagai,* Chubu University, Japan*; T. Tatsumi, K. Oshima, K. Nagahata,* Sony Corporation, Japan*; K. Nakamura,* Chubu University, Japan

Fluorocarbon discharges have been widely used for etching processes of dielectric thin films for microfabrication. However, these have suffered from various problems, in particular, repeatability of the etching characteristics. The problem becomes recently severe due to narrow process margin for next generation ULSI devices. One of the major origins is plasma-surface interaction on polymer-deposited vessel wall, leading to significant time-variation of radical composition of the plasma. Alternating ion bombardment (AIB) method has been proposed to reduce such interactions by applying an RF bias to the chamber wall. We reports on suppression of the temporal density variation of fluorocarbon radicals caused by removal of the deposited polymer with ion bombardment as well as effects of ion bombarding energy on the density variation. 13.56 MHz inductively-coupled plasmas were produced in Ar-diluted C@sub 4@F@sub 8@ gases in a stainless steel chamber in which two semi-cylindrical electrodes were set. Oxygen plasma pretreatments were performed before each the discharge. A 400 kHz RF source served alternating negative bias to the electrodes, and the AIB could control the deposition rate of the polymer on the biased wall. When the polymer deposition was suppressed with the AIB, the radical density reached a steady state more quickly after the discharge initiation. However the rise time of the radical density was seriously influenced by the ion bombarding energy. Significant polymer deposition occurred at the wall at a too low ion bombarding energy. On the other hand, when the ion bombarding energy is too high for suppression of the polymer deposition, thickness of fluorocarbon reaction layer formed on the wall surface increased, resulting in longer time to be required to reach steady state surface conditions. Thus, there was an optimal ion bombarding energy for fast stabilization of the surface condition and the radical density.

3:20pm **PS1-WeA5 Modeling of Seasoning of Reactors: Effects of Ion Energy Distributions to Chamber Walls****, A. Agarwal,* University of Illinois at Urbana-Champaign*; **M.J. Kushner**,* Iowa State University

Wafer to wafer process reproducibility during plasma etching often depends on the conditioning of the walls of the reactor. Deposition of passivation on chamber walls can change the reactive sticking coefficients for radicals, thereby changing the composition of the radical and ion flux to the substrate. Ion bombardment of the walls may affect the passivation coverage or production of etch influencing species through activation of sites or sputtering. As such the spatial distribution of ion energies on the walls and their evolution as the chamber seasons are important. These seasoning processes may occur during a single etching sequence or recipe due to there being incomplete initial seasoning or there being a change in radical fluxes to the walls. In this talk, the seasoning of plasma etching reactors will be discussed using results from a computational investigation. The Surface Chemistry Module and Sputter Module of the Hybrid Plasma Equipment Model were modified to obtain the ion energy distributions to all surfaces inside the reactor and to use them to calculate energy dependent surface reaction rates. Sputtered, energetic products from passivated side walls, and their transport to the wafer, were also accounted for using the same methodology as in magnetron sputtering. Results will be discussed for the seasoning of ICP reactors using Ar/Cl@sub 2@ gas mixtures; and CCP reactors using Ar/C@sub 4@F@sub 8@ mixtures. The consequences on reactive fluxes (magnitude and energy) to the substrate due to both wall sputtering and changes in reactive sticking coefficients will be presented. @FootnoteText@ *Work supported by Semiconductor Research Corp. and the National Science Foundation.

3:40pm **PS1-WeA6 Plasma Requirements from Dielectric Etch Systems for Advanced Materials***, D.J. Hoffman,* Applied Materials **INVITED**

As materials of dielectric etch migrate to meet the needs of the 32 nm node, the needs in ion energy, density, ion energy distribution, and electron energy are expected to shift and mandate modifications to tool design. Specifically, low-k dielectric with k-value below 2.5 created need dramatically different energy spectrum than a deep etch into a very hard material. Other functions, such as chamber cleaning, ultra soft etch, via etch, and trench necessitate using densities that range from low 10@super 10@ cm@super -3@ to high 10@super 10@ cm@super -3@, ion energies in the range of 50 V to thousands of volts, and energy spread of 20 to 80 %. In this paper we, examine how 3-frequency capacitive systems can produce the requisite plasma parameters. In each capacitive system, the ability to create density is controlled by a) characteristic impedance, which then determines the voltage at relevant power b) given the voltage of the system and the plasma intrinsic rectification- the division between sheath creation and density creation, and c) given ion energy transit times for a characteristic density and sheath voltage, ion energy spread. With the process need establishing plasma targets, we compare how various frequency ranges can be used to produce the desired plasma.

4:20pm **PS1-WeA8 Frequency Dependent Ion Kinetics in a 300 mm Dual-Frequency Capacitively Coupled Plasma Reactor***, **G.A. Hebner**, E.V. Barnat, P.A. Miller,* Sandia National Laboratories*; A.M. Paterson, J.P. Holland,* Applied Materials

Argon ion kinetics were measured in a dual frequency, capacitively coupled 300 mm chamber. Laser induced fluorescence measurements of the argon ion metastable lineshape yield information on the ion temperature, density and drift velocity. The spatially-resolved LIF technique is a nonperturbative probe to investigate energy deposition mechanisms, ion energy distribution functions, charge exchange reactions, neutral heating, and plasma potential gradients within the plasma. This talk will discuss ion characteristics for a single rf frequency drive (13, 60 and 160 MHz), combinations of rf drive frequencies, as well as scaling with pressure (10 to 70 mTorr) , rf power, and radial position. We find that the ion density increased linearly with rf power, as did the electron density, indicating the ion metastable state is formed from direct impact ionization. The ion temperature was on the order of 500 K. This is consistent with other measurements in capacitively coupled systems at 13 MHz but considerably less than values in inductively coupled systems (1000 to 9000 K). The lower ion temperature may reduce molecular decomposition. Radially resolved ion drift velocity measurements show the radial drift velocity can be lower at 60 MHZ than 13 MHz. Additional details will be discussed. 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 Energys National Nuclear Security Administration under contract DE-AC04-94AL85000.

4:40pm **PS1-WeA9 Spatial and Temporal Structure of a Sheath formed in a 300 mm, Dual-Frequency Capacitive Argon Discharge***, **E.V. Barnat**, G.A. Hebner, P.A. Miller,* Sandia National Laboratories*; A.M. Paterson, J.P. Holland,* Applied Materials

The spatial and temporal distributions of the electric fields of a sheath formed by a dual-frequency driven capacitive argon discharge are measured as functions of relative mixing between a low frequency current (13.56 MHz) and high frequency current (67.8 MHz). This is the first time a Stark effect based technique has been employed to measure sheaths of this nature. We find that for a given total input power, as the high frequency power increases, both the total voltage across the sheath and the thickness of the sheath decreases. We also find that the temporal evolution of the potential across the sheath as well as the sheath thickness contain both rf components and that the high frequency oscillations become more prominent with increased high frequency power. For insight, comparisons of the measured spatial and temporal profiles are made to computational models commonly employed in the literature. These models include the collisional rf sheath model of Lieberman@footnote 1@ and extended to dual frequencies by Robiche@footnote 2@ et al. Where possible, we compare on our measured trends to those predicted by the models, which in general, show good agreement. Included in the discussion are the effects the edge has on the distribution of the electric fields and the effects the driving frequency has on the field distribution across the wafer. @FootnoteText@ @footnote 1@ M.A.Liberman, IEEE Trans. Plasma Sci. 17, 338 (1989).@footnote 2@ J. Robiche, P. C. Boyle, M. M. Turner and A. R. Ellingboe, J. Phys. D: Appl. Phys 36, 1810 (2003).

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