Plasma Science and Technology
Room 314 - Session PS-TuM

Plasma Diagnostics: Processing

Moderator: H. Sugai, Nagoya University, Japan

8:20am **PS-TuM1 Attractive Interactions Between Negatively Charged Dust Particles in a Plasma***, **G.A. Hebner**, M.E. Riley,* Sandia National Laboratories

Plasma dust particle interactions, charges, and screening lengths are derived from measurements of time-dependent particle positions in a simplified geometry. The magnitude and structure of the ion wakefield potential below a negatively-charged dust particle levitated in the plasma sheath region were measured as functions of the pressure and interparticle spacing. Attractive and repulsive components of the interaction force were extracted from a trajectory analysis of low-energy dust collisions between different mass particles in a well-defined electrostatic potential that constrained the dynamics of the collisions to be one dimensional. Typical peak attractions varied between 60 and 230 fN while the peak particle-particle repulsion was on the order of 60 fN. Random thermal motion of the particles contributed to observable rates for transitions between different equilibrium configurations of vertically separated particles. We also observed a slight potential barrier that impeded the formation of vertically aligned pairs. The influence of nearest- and non-nearest-neighbor interactions on calculated particle parameters are examined using several methods. Implications for plasma / surface interactions and plasma dielectric charging will be discussed. This work was supported by the Division of Material Sciences, BES, Office of Science, U. S. Department of Energy 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.

8:40am **PS-TuM2 Measurement of Electrical Fields Around Dissimilar Materials Exposed to a Discharge***, **E.V. Barnat**, G.A. Hebner,* Sandia National Laboratories

The nature of a surface/plasma boundary can have an important impact on the processes that occur both in the plasma and on the bounding surface. In this work, fluorescence-dip spectroscopy is used to study the surface dependant sheath structure at the boundary of an argon glow discharge. The two laser technique monitors the variation in the fluorescence from an intermediate state caused by laser excitation from this intermediate state to Stark-shifted Rydberg levels sensitive to the electric fields present in the sheath. To demonstrate the effectiveness of the dip-spectroscopy technique, half of a conducting electrode is covered with an insulating surface and both spatially and temporally resolved measurements of the structure of the sheath are made around both the conducting and the non-conducting surfaces. The fields through the sheath above the two surfaces, the potential drops across the sheath, and the fields near the surface along the electrode are discussed for various discharge conditions. Future applications of fluorescence-dip spectroscopy will be discussed as well. @FootnoteText@ This work was supported by the Division of Material Sciences, BES, Office of Science, U. S. Department of Energy 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. .

9:00am **PS-TuM3 Plasma Processing Diagnostic Methods and Studies: A Historical Perspective***, **V.M. Donnelly**[1]*, University of Houston **INVITED**

In the late 1970's, plasma etching emerged as a breakthrough method for pattern transfer in silicon integrated circuits. Soon after, it became apparent that, to further develop this technology, it was important to understand the mechanisms responsible for anisotropic plasma etching. Researchers in industry, national laboratories and universities began applying well established diagnostic techniques, and inventing new methods, for elucidating the chemical and physical processes underlying plasma etching, as well as plasma assisted deposition. Experiments were designed to either measure parameters of the plasma (species concentrations and velocities), or to simulate plasma-surface interactions under less complex conditions (high-vacuum / beam experiments, discharge flow tubes, etc). This talk will review the history of diagnostic methods for plasma processing. An admittedly incomplete survey of plasma diagnostic techniques will begin with several methods that greatly predate the microelectronics era. Electrical, optical and beam methods will be discussed and selected key experiments will be highlighted.

9:40am **PS-TuM5 Absolute SiCl@sub X@ Densities in Silicon Gate Etching Plasmas Determined by Broad Band UV Absorption***, **M. Kogelschatz**,* CNRS/LSP, France*; G. Cunge,* CNRS/LTM, France*; N. Sadeghi,* CNRS/LSP, France*; O. Joubert, L. Vallier,* CNRS/LTM, France

Broad band UV absorption spectroscopy has been used to measure the absolute gas phase concentration of SiCl@sub X@ and SiF@sub X@ etch products (X = 0-2) during silicon gate etching in high density HBr/Cl@sub 2@/O@sub 2@ plasmas and their mixture with fluorocarbon gases. The silicon atom concentration in the ground and metastable states has also been measured. To convert the absorption rates to the Si atom density, the instrumental width of the monochromator had to be taken into account. Typical concentrations of etch products are about 10@super 11@cm@super -3@, and their behavior with the plasma conditions (RF power, O@sub 2@ gas flow) will be discussed. Vibrationnally resolved absorption spectra of SiCl@sub 2@ and SiBr, observed for the first time in etching plasmas, will also be presented. However, due to the lack of absorption cross sections, the absolute concentration of SiBr can not be deduced. A particular emphasize will be given on correlation between these etch products and the composition of the films deposited on the plasma chamber walls. This composition was determined from the analysis by OES and mass spectrometry of products introduced in the gas phase of a weak Ar-SF6 plasma from the chamber walls. The deposit of the silicon oxychloride layers on the walls is at the origin of process drifts as it changes the chemical composition of the surfaces exposed to the plasma. A large change of the recombination rate of Cl atoms as a function of the reactor walls composition has been observed by measuring the variation of the Cl/Cl@sub 2@ concentration ratio in the gas phase, as well as the absolute Cl@sub 2@ concentration by UV absorption.

10:20am **PS-TuM7 In-situ Processing Memory Effects for Confined vs. Unconfined Plasmas***, **E.A. Hudson**, R. Annapragada, D. Keil, K. Takeshita,* Lam Research Corp.

In the fabrication of integrated circuits there is a growing trend towards performing several etch steps in a single pass through an etch tool. This in-situ processing approach reduces production costs and cycle times, but presents technical challenges because it requires the sequential use of very different plasma chemistries in the same reactor. An important example is the use of a polymerizing fluorocarbon-based plasma to etch patterns into silicon dioxide or organosilicate films, followed by oxidizing plasmas to remove the remaining photoresist film. Residual fluorocarbon polymer, left on chamber surfaces by the etch step, is attacked under oxidizing conditions, releasing fluorine-containing species which may have harmful effects on the wafer structures. This paper compares the "fluorine memory" effect for unconfined vs. mechanically confined capacitively-coupled RF discharges. Diagnostic measurements focused on plasma properties, chamber surface cleaning efficiency, and wafer-level results. Optical emission spectroscopy was used to detect atomic fluorine in the plasma during the photoresist strip step. Fluorine was found to persist much longer in the case of the unconfined plasma. The impact of residual byproducts at the wafer was evaluated from silicon dioxide loss and from changes in feature dimensions. Results indicate that use of a mechanically confined plasma greatly reduces "fluorine memory" effects during the photoresist strip step, compared to the unconfined configuration. This is attributed to the reduced gas residence time and more efficient cleaning of chamber surfaces in the confined configuration.

10:40am **PS-TuM8 Plasma Diagnostics and Thin Film Characterization in Dielectric Etching: Understanding the Role of Fluorine Chemistry***, **B. Ji**, S.A. Motika, P.R. Badowski, S. Dheandhanoo, E.J. Karwacki, J.R. Stets,* Air Products and Chemicals, Inc.*; C. Timmons, D.W. Hess,* Georgia Institute of Technology*; E.C. Benck,* National Institute of Standards and Technology*; Y. Ye,* Applied Materials, Inc.

Plasmas of fluorine-containing gases have for many years been utilized to etch dielectric materials such as silicon dioxide. Maintaining the balance between the anisotropic dielectric etch rate and formation of the protective passivation films on top of the photoresist surface and on the feature sidewalls is critical in assuring desired etch features and critical dimensions. In recent years, the semiconductor industry have adopted heavier molecular weight and lower fluorine to carbon ratio gases, such as c-C@sub 4@F@sub 8@, C@sub 5@F@sub 8@, and C@sub 4@F@sub 6@ for anisotropic dielectric etching. We performed a fundamentals study to

[1] **AVS 50th Anniversary Invited Speaker**

better understand the relationship between etch gas compounds and the species formed within both capacitively and inductively coupled plasmas. UV Absorption Spectroscopy, Sub-millimeter Wave Absorption Spectroscopy, Optical Emission Spectroscopy, Mass Spectrometry, and X-ray Photoelectron Spectroscopy were employed to evaluate the gas phase and surface chemistries of these three etching molecules.

11:00am **PS-TuM9 Loss Kinetics of CF@sub x@ Radicals and F Atoms in the Afterglow of Inductively Coupled Pulsed Plasmas*, X. Wu,*** *J.L. Cecchi,* University of New Mexico

We have studied the time evolution of the concentrations of CF, CF@sub 2@, and F in inductively coupled pulsed (ICP) plasmas after the termination of the discharge. The feed gases included CHF@sub 3@ and C@sub 2@F@sub 6@, with additions of H@sub 2@and O@sub 2@, to vary the amount of radicals and F produced in the discharge. Our observations were made over the pressure range from 10 to 60 mTorr and for inductively coupled powers of 300 to 900 W. Concentrations were determined by time-resolved wavelength modulated diode laser absorption spectroscopy for the radicals and by time-resolved actinometry for F. The latter measurements were facilitated by maintaining a small amount of power on the wafer chuck after the termination of the ICP power pulse. CF and F both exhibited first order exponential decays. The decay rates of CF increased with increasing pressure, suggesting the presence of gas phase loss processes in addition to losses at surfaces. The decay rates of CF varied linearly with F concentration, indicating that the gas phase reaction is likely due to the recombination with F atoms. CF@sub 2@ exhibited second-order decay. Possible mechanisms for this will be discussed.

11:20am **PS-TuM10 Effect of an Applied-phase of Bias Pulse on a Charge Reduction on a SiO@sub 2@ Hole Exposed to Plasma Etching in a Two-frequency CCP*, T. Ohmori,*** *T.K. Goto, T. Makabe,* Keio University, Japan

In a top-down nano-meter scale etching, it will be essential to develop in-situ diagnostics for plasma damage in the interface under close and complementary cooperation between optical and electric procedure. In our previous paper@footnote 1@ we have applied an emission selected computerized tomography close to the wafer exposed to plasma etching, in order to investigate the polarity and the phase of high energy charged particles incident on the wafer deeply biased by a low frequency source in RIE. A reduction in charging voltage on a contact hole bottom of SiO@sub 2@ was measured in the pulsed plasma power source in the 2f-CCP in CF@sub 4@/Ar by using a dual measurement system consisting of a temporal emission CT and a contact hole charging. In the present work, detailed correlational results of the reduction in the charging voltage are shown as a function of phase and amplitude of the single bias pulse at 500 kHz. Discussion is focused both on the injection mechanism of energetic negative charges to the wafer and on the magnitude of the negative charges. As a result, during the off-period 10 µs of VHF power source it is confirmed in the present pulsed 2f-CCP system that:(1)the magnitude of the injected negative charge increases with increasing the threshold time of the single bias pulse, and at the same time a strong reduction in the charging voltage is performed, (2)secondary a strong negative self-bias-voltage is always kept to have an efficient RIE with energetic positive ions on the wafer except for the period of the single bias pulse. @FootnoteText@ @footnote 1@T.Ohmori, T.K.Goto, T.Kitajima, and T.Makabe, Proc.of Dry Process Symposium 165(2002)Tokyo, Appl.Phys.Lett.(submitted).

11:40am **PS-TuM11 Analysis of Downstream Etch Chemistry in Ion-Ion and Electron-Ion Cl2 Discharges*, A.K. Jindal,*** *A.J. Prengler, L.J. Overzet, M.J. Goeckner,* University of Texas at Dallas

It has been shown that ion-ion plasmas can significantly reduce substrate charging damage. This study clearly shows that ion-ion plasmas also influence the etch chemistry. This knowledge may facilitate improvements in plasma processing or environmental control. Here, we use FTIR spectroscopy to examine the volatile etch products downstream of the turbo pump resulting from the etching of C-Si, SiO2, and photoresist in electron-ion and ion-ion Cl2 discharges. RF power is either pulsed to produce ion-ion plasmas or continuous to produce electron-ion plasmas. An independently controlled chuck is rf biased to produce an alternating flux of negative and positive ions or a combination of electrons, negative ions, and positive ions at the substrate. Changes in etch chemistry are studied and compared as functions of biasing schemes and substrate chuck voltages. Continuous wave (electron-ion), asynchronous, and synchronous, biasing regimes are all subjected to peak to peak chuck biases of 25, 50, 75, and 100 V via a 300 kHz waveform. Asynchronous and synchronous (ion-ion) modes apply to 1 kHz, 50 percent duty ratio pulsed regimes of the discharge in which the former implies continuous biasing throughout the entire pulse cycle and the latter to only the afterglow, where an ion-ion plasma exists. Clear distinctions in etch chemistry are evident solely based upon the biasing scheme. For example, CO2 is observed for all chuck biases in both pulsed regimes during photoresist etch, but no signal is apparent at lower biases in the continuous mode. Not only is there an undeniable difference in etch chemistry, but we can affect our emission by varying the biasing scheme. This work was funded in part by a grant from NSF/DOE, contract number CTS-0078669 and a grant from NSF, contract number CTS-0079783.

Author Index

Bold page numbers indicate presenter

— A —
Annapragada, R.: PS-TuM7, 1
— B —
Badowski, P.R.: PS-TuM8, 1
Barnat, E.V.: PS-TuM2, **1**
Benck, E.C.: PS-TuM8, 1
— C —
Cecchi, J.L.: PS-TuM9, 2
Cunge, G.: PS-TuM5, 1
— D —
Dheandhanoo, S.: PS-TuM8, 1
Donnelly, V.M.: PS-TuM3, **1**
— G —
Goeckner, M.J.: PS-TuM11, 2
Goto, T.K.: PS-TuM10, 2
— H —
Hebner, G.A.: PS-TuM1, **1**; PS-TuM2, 1
Hess, D.W.: PS-TuM8, 1
Hudson, E.A.: PS-TuM7, **1**
— J —
Ji, B.: PS-TuM8, **1**
Jindal, A.K.: PS-TuM11, **2**
Joubert, O.: PS-TuM5, 1
— K —
Karwacki, E.J.: PS-TuM8, 1
Keil, D.: PS-TuM7, 1
Kogelschatz, M.: PS-TuM5, **1**
— M —
Makabe, T.: PS-TuM10, 2
Motika, S.A.: PS-TuM8, 1
— O —
Ohmori, T.: PS-TuM10, **2**
Overzet, L.J.: PS-TuM11, 2
— P —
Prengler, A.J.: PS-TuM11, 2
— R —
Riley, M.E.: PS-TuM1, 1
— S —
Sadeghi, N.: PS-TuM5, 1
Stets, J.R.: PS-TuM8, 1
— T —
Takeshita, K.: PS-TuM7, 1
Timmons, C.: PS-TuM8, 1
— V —
Vallier, L.: PS-TuM5, 1
— W —
Wu, X.: PS-TuM9, **2**
— Y —
Ye, Y.: PS-TuM8, 1