Plasma Science and Technology
Room 311 - Session PS2-ThA

Dielectrics I
Moderator: J.L. Cecchi, University of New Mexico

2:00pm **PS2-ThA1 Ion Energy Control for Enhanced Plasma Etch Selectivity***, **Y. Andrew**, E. Ko, J. Machima, S.-B. Wang, A.E. Wendt,* University of Wisconsin, Madison

Ion energy distribution (IED) control@footnote1@ at the substrate during plasma etching has been examined for improvements in SiO@sub 2@/Si and SiO@sub 2@/photoresist etch selectivity. The IED is controlled using a tailored bias voltage waveform applied to the substrate in place of the conventional RF sinusoidal waveform. A periodic waveform consisting of a voltage ramp in combination with a short pulse produces a plasma sheath in front of the wafer with nearly time-invariant voltage, leading to a nearly monoenergetic ion flux at the substrate, as compared to the relatively broad IED typically produced by a sinusoidal waveform. A 13.56 MHz helicon etching tool, equipped with a substrate bias power supply capable of producing the tailored substrate bias waveform, has been used to etch blanket films of photoresist, Si and SiO@sub 2@ using sinusoidal and tailored bias voltage waveforms. Etch rates of the blanket films are measured in situ using laser interferometry. Results to be presented show improved selectivity with the tailored waveform and a broadened process window for selective etching of SiO@sub 2@ over silicon in fluorocarbon-based plasmas, and etch rate vs. ion energy data suggest physical mechanisms. Selective etching of SiO@sub 2@ over photoresist is also examined, as it is very desirable to reduce the demand for thick photoresist and the challenge it presents to lithography technology. Substantial improvements in SiO@sub 2@/photoresist selectivity are expected. @FootnoteText@@footnote 1@S. B. Wang and A.E. Wendt, "Control of ion-energy distribution at substrates during plasma processing" to be published, J. Appl. Phys., June 1999.

2:20pm **PS2-ThA2 Temperature and Bias Effects in ICP Etching of Silicon Dioxide***, **M.J. Cooke**, G. Hassall,* Oxford Instruments Plasma Technology Ltd., UK

Silicon dioxide etching has been evaluated in a new induction-coupled plasma (ICP) source (designated ICP380), with particular attention to the sources of nonuniformity in etching 200 mm wafers. The contributions of the ICP source, the rf bias to the wafer, and the gas flow distribution to uniform etching are examined experimentally, supported by simple models. The implications for the design of etching hardware and for the protocols to achieve reproducible processes are considered. The rate of polymer deposition and etching in fluorocarbon plasmas has been measured as a function of the ion impact energy and the temperature of the substrate, using interferometry and direct film thickness measurements. This has been related to the etch profile evolution for 10 micron deep trenches in thick silicon dioxide layers. It is shown that substrate temperature control is a necessary part of profile control, even for etches which are normally considered to be regulated by ion bombardment.

2:40pm **PS2-ThA3 Control of Incident Fluxes and Surface Reactions in the Etching of Dielectric Materials***, **T. Tatsumi**, M. Matsui, K. Kinoshita, S. Kobayashi, M. Sekine,* Association of Super-Advanced Electronics Technologies (ASET), Japan

The relationship between SiO@sub 2@ etch rates and the incident flux of reactive species in dual-frequency (27/0.8 and 60/2 MHz) parallel-plate systems were evaluated by using various in-situ measurements tools, such as infrared IRLAS, QMS, and OES. The thickness of a C-F polymer layer on the etched SiO@sub 2@ surface was measured by XPS. The SiO@sub 2@ etch rate depends on both the total amount of F in the C-F reactive species and the ion energy at a reactive layer on the SiO@sub 2@ surface.@super 1@ The net energy supplied to the reactive layer depends on the total amount of ions, the acceleration energy of ions (assumed to be the peak-to-peak voltage, V@sub pp@), and the energy loss in the C-F polymer layer. The C-F polymer thickness increased when the incident flux of C-F species was relatively higher than the removal ability of C-F polymer, that mostly depends on oxygen flux. To vary the incident CF@sub x@ species, the C@sub 4@F@sub 8@ flow rate in the C@sub 4@F@sub 8@/Ar/O@sub 2@ was increased under 30mTorr of gas pressure and 1450 V of V@sub pp@. The ion flux was controlled by adjusting the RF powers. When we increased the ion flux from 3.0 x 10@super 16@ to 3.6 x 10@super 16@ cm@super -2@s@super -1@, the etch rate was increased because the energy on the reactive layer increased while the Si etch rate remained the same. Furthermore, the formation of the thick polymer (>1nm) started under higher C@sub 4@F@sub 8@ flow-rate conditions. This means the ability to remove excess C-F polymer on the etched surface was also improved. As a result the process-window of selective etching was increased. C@sub 5@F@sub 8@/Ar/O@sub 2@ gas chemistry was also evaluated in the same manner. An increase of C-concentration of the parent gas molecules induces the excess incidence of C atoms to the surface. As a result we mostly observed the C-F polymer deposition rate (not steady-state thickness) under high C@sub 5@F@sub 8@ flow-rate conditions. It is necessary to use the lower pressure or higher ion energy conditions to suppress the excess formation of the C-F polymer in the C@sub 5@F@sub 8@/Ar/O@sub 2@ process. @FootnoteText@ This work was supported by NEDO. @footnote 1@T.Tatsumi et al., J. Vac. Sci. Technol., A17 (1999) 1562.

3:00pm **PS2-ThA4 Reaction Mechanisms and SiO@sub 2@ Profile Evolution in Fluorocarbon Plasmas: Bowing and Tapering@footnote 1@***, **D. Zhang**,* University of Illinois at Urbana-Champaign*; C. Cui,* Applied Materials, Inc.*; M.J. Kushner,* University of Illinois at Urbana-Champaign

The rate and quality of fluorocarbon plasma etching of dielectrics is largely determined by a balance between deposition of polymer and ion activated chemical or physical sputtering. The proper balance results in selectivity and sidewall passivation producing straight walled features. The scaling of SiO@sub 2@ etching in fluorocarbon plasmas was numerically investigated using the Hybrid Plasma Equipment Model and the Monte Carlo Feature Profile Model (MCFPM). Algorithms were added to Surface Kinetics Module to account for multiple polymer layers, delivery of activation energy through polymer layers and ion activated polymer deposition. The MCFPM was also improved by including these processes. Reaction mechanisms were developed in which deposition of C@sub n@F@sub m@ radicals, either direct or ion activated, produces a polymer layer. At the interface of the polymer layer and SiO@sub 2@, a C@sub n@F@sub m@-SiO@sub 2@ complex is formed which, in the presence of fluorination by F atoms diffusing and ion energy delivery through polymer layers, produces etching in a 2 step process. Selectivity to Si results from lack of consumption of the polymer layer. SiO@sub 2@ etch rates increase with increasing bias at low biases due to increased activation energy delivered through a thinner passivation layer. Etch rates saturate at high biases due to polymer starvation. Comparisons to experiments showed that etch profiles transitioned from bowed to tapered as the passivation flux to ion flux ratio increased. This transition is delayed to higher passivation flux to ion flux ratios by increasing the bias. In general, loss of critical dimension correlated with a reduction in etch rate due to the thickening of passivation layers. For this reason, saturation of the etch rate due to polymer starvation also improved maintenance of the critical dimension. @FootnoteText@ @footnote 1@Work supported by AMAT, LAM, SRC and NSF.

3:20pm **PS2-ThA5 Etching Mechanism of Silicon Nitride Film in Self-aligned Contact Etching Process***, **M. Ito**, S. Senda, K. Kamiya, M. Hori, T. Goto,* Nagoya University, Japan

For a contact hole etching process, the high etching selectivity of SiO@sub 2@ over Si@sub 3@N@sub 4@ as well as Si is required. In order to clarify the etching mechanism of Si@sub 3@N@sub 4@ film in H@sub 2@ diluted C@sub 4@F@sub 8@/Ar electron cyclotron resonance plasmas, we have investigated the mixing-layer in Si@sub 3@N@sub 4@ films using in-situ X-ray photoemission spectroscopy and in-situ Fourier transform-infrared reflection absorption spectroscopy. From etching results and C-N bonding compositions in the mixing layer as a function of H@sub 2@ dilution ratio, the intensities of C-N sp@super 2@ bonds are considered to have a relation with the etching rate of Si@sub 3@N@sub 4@. On the other hand, C-N sp@super 1@ bonds were not observed at all in the films. Moreover, to clarify the H@sub 2@ dilution effect, we have observed the surface reaction during H@sub 2@ plasma annealing after etching Si@sub 3@N@sub 4@ films under C@sub 4@F@sub 8@/Ar plasma condition. It was found that intensities of C-N sp@super 2@ bonds as well as sp@super 3@ bonds decreased while Si-N bonds increased with the annealing time. Therefore, C-N sp@super 2@ bonds as well as C-N sp@super 3@ bonds are suggested to be etched through the formation of byproduct such as HCN and to be broken to form Si-N bonds through the recombination of the dangling bonds such as -N and -Si. This fact suggests that the restriction of reaction of C-N sp@super 2@ bonds and C-N sp@super 3@ bonds with H or F atoms is a key factor for achieving higher selective etching of SiO@sub 2@ over Si@sub 3@N@sub 4@.

3:40pm **PS2-ThA6 High-performance Silicon Dioxide Etching for High-aspect Contact Holes*, S. Samukawa,*** NEC Corp., Japan **INVITED**

SiO@sub 2@ etching is done by using fluorocarbon gases to deposit a fluoropolymer on the underlying silicon. This deposit enhances the etching selectivity of SiO2 over silicon or silicon nitride. CF@sub 2@ radicals especially are used as the main gas precursor for polymer deposition. In a conventional gas plasma, however, the CF@sub 2@ radicals and other radicals (high-molecular-weight-radicals: C@sub x@F@sub y@) lead to the polymerization. This condition causes microloading and etching-stop in high-aspect-contact hole patterning due to the sidewall polymerization during SiO@sub 2@ etching processes. Conversely, by new fluorocarbon gas chemistries (C@sub 2@F@sub 4@/CF@sub 3@I), we achieved selective radical generation of CF2 and eliminated high-molecular-weight-radicals. Under this condition, microloading-free and etching-stop-free high-aspect-ratio-contact-holes patterning of SiO@sub 2@ was accomplished. Thus, the higher molecular weight radicals play an important role in the sidewall polymerization in contact holes because these radicals have a higher sticking coefficient than CF@sub 2@ radicals. Selective generation of CF@sub 2@ radicals and suppression of C@sub x@F@sub y@ radicals are thus necessary to eliminate the microloading and etching-stop when formation high-aspect-contact-ratio holes.

4:20pm **PS2-ThA8 Selective Etching of SiO@sub 2@ in High Density Fluorocarbon Plasmas for Applications in Micro-systems***, F. Gaboriau, M.-C. Peignon, G. Turban,* ***Ch. Cardinaud,*** CNRS-University of Nantes, France

In the recent years, plasma processes using high density sources have been extensively developed to meet the more and more stringent constraints required by integrated circuits fabrication. Among the various steps, dielectric etching is the more challenging as processes rely on polymerizing hydrofluorocarbon gases that produce simultaneously deposition and etching. It is thus difficult to achieve adequate SiO@sub 2@/mask etch selectivity and to continue etching in high aspect ratio features at the same time. Our aim is to develop new plasma processes concerning the oxide etching step for micro-machining device elaboration. Fabrication of MEMS (micro electro mechanical systems) and O-MEMS (optical MEMS) requires several conditions : i) a higher etch rate, ii) an extreme selectivity, iii) much longer etching processes. Previous studies have shown that adding methane to a fluorocarbon gas (CHF@sub 3@, C@sub 2@F@sub 6@, CF@sub 4@) yields to a significant improvement of the selectivity from 4 to 20 with no significant loss in the SiO@sub 2@ etch rate (300 nm/min). The present study using in-situ real time measurements by ellipsometry and quasi in-situ XPS analysis is focused on the influence of gas flow rate on the SiO@sub 2@ and Si (acting as a mask) etching using a mixture C@sub 2@F@sub 6@-CH@sub 4@. C@sub 2@F@sub 6@ was chosen due to a higher oxide etch rate compared to CHF@sub 3@ and CF@sub 4@. Increasing the gas flow rate when using pure C@sub 2@F@sub 6@ yields to an increase of both material etch rates ; the selectivity is thus unchanged and equal to 2. In contrast, using C@sub 2@F@sub 6@-CH@sub 4@ mixtures with 40% of methane leads to a significant improvement of the selectivity (from 4 to 15) when increasing total gas flow rate ; indeed, oxide etch rate shows the same behavior as before whereas silicon etch rate decreases when increasing gas flow rate. Besides, XPS analysis exhibits a dependence between the silicon etch rate and the fluorocarbon layer thickness pointing out that this overlayer controls the silicon etching. Influence of the gas flow rate on the gas phase is under study using mass spectrometry, optical emission spectroscopy and Langmuir probe ; these diagnostics will allow us to determine the ion flux on the surface and to correlate the different evolutions of plasma species with the etch rate evolution for a better understanding of SiO@sub 2@ and Si etch mechanisms.

5:00pm **PS2-ThA10 Trench Etch Processes for Dual Damascene Patterning of Low-k Dielectrics*, P. Jiang,*** *F.G. Celii, W.W. Dostalik, K.J. Newton,* Texas Instruments, Inc.*; H. Sakima,* Tokyo Electron America

The use of dual damascene patterning for integration of Cu with low-k dielectric films has introduced new challenges for plasma etch processes. With a via-first dual damascene approach, an important issue for trench etch is defect formation (i.e., oxide ridges) around vias which can degrade device reliability. The use of low-k films as the dielectric material adds additional complexity and more limitation on the etch process parameters. This paper discusses the development of etch processes that meet the special requirements for Cu/low-k dual damascene trench etch. All experiments were conducted in a medium-density TEL Dipole Ring Magnetron (DRM) system. The dielectric film used here was an organosilicate glass (OSG). Using C@sub 4@F@sub 8@/N@sub 2@/Ar chemistry, a trade-off was observed between etch rate and oxide ridge formation. The N@sub 2@/Ar ratio was found to be the key parameter in controlling the severity of the oxide ridges, but eliminating the ridges using the N@sub 2@/Ar ratio resulted in a low OSG etch rate and poor throughput. However, we will discuss an alternative method which achieves high OSG etch rate while maintaining CD control and ridge-free conditions. The effect of various process parameters on the OSG etch rate and ridge formation will be detailed. A comparison of experimental results against numerical simulations of C@sub 4@F@sub 8@-based bulk plasmas with varying gas flow ratios will also be reported.

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