Monday Evening Poster Sessions, November 2, 1998

Plasma Science and Technology Division
Room Hall A - Session PS-MoP

Plasma Science and Technology Poster Session

PS-MoP1 Plasma-CVD with a Pulsed DC Glow-Discharge: A Time Resolved Experimental Investigation@footnote 1@, ***T.A. Beer***, *J. Laimer, H. Störi,* Technische Universität Wien, Austria

Pulsed direct-current (d.c.) glow discharges are commonly used in systems for plasma-assisted chemical vapour deposition (PACVD). In the present work we investigate the development of plasmas relevant for the production of TiN coatings. A videocamera with gateable image-intensifier is used to study the spatial and temporal evolution of the development of the plasma. Additionally, we use a single electrostatic probe to determine a time resolved charged particle distribution. Measurements are performed on a commercially available Plasma-CVD. Different steel-cylinders have been used as substrates. The typical shutter-speed used in our experiments is 100 ns. The pictures taken were used to generate MPEGmovies@footnote 3@ showing the plasma developement. Our investigations reveal large differences between plasmas with and without TiCl@sub 4@. In the absence of TiCl@sub 4@, the plasma ignites within the first 500 ns. In the presence of TiCl@sub 4@, the formation of the plasma along the substrates occurs with a certain delay, which has also been reported by Mogensen@footnote 2@. Our experiments show that the plasma ignites at the beginning of each pulse at one spot, where a positive column is observed, and spreads from there across the substrate surface. The pattern of the spatialtemporal evolution is quite complex and the evolution of the negative glow depends on various parameter, including geometry. The observed delays in the plasma formation are in the range of 10 us to 130 us. Detailed investigations of the time-dependent density of electrons and negative ions with our Langmuirprobe-setup are still in progress, first measurements show a high concentration of negative ions in the afterglow. @FootnoteText@ @footnote 1@ Supported by the Austrian Science Foundation FWF under Project No. P10794 @footnote 2@ K Mogensen, C Mathiasen, S Eskildsen, H Stöori, Surf. Coat. Technol.(in press) @footnote 3@ http://www.iap.tuwien.ac.at/www/plasma/mp_plasma/

PS-MoP2 Comparison of Feature Profile Evolution for Halogen Plasma Etching of Silicon (100), *K.H.A. Bogart,* ***F.P. Klemens***, Bell Laboratories, Lucent Technologies*; J. Lane,* Massachusetts Institute of Technology*; M.V. Malyshev,* Bell Laboratories, Lucent Technologies and Princeton Univ.*; V.M. Donnelly, A. Kornblit, J.T.C. Lee,* Bell Laboratories, Lucent Technologies

Feature profile evolution during halogen plasma etching of silicon-based materials is affected by several contributions to the etch mechanism. These aspects, including isotropic chemical etching, broad ion angle distributions, ion scattering within a feature, and redeposition of etching products, can cause deviations from anisotropic etching such as bowed or undercut sidewalls and mictrotrench formation in trench bottoms. Different halogen source gases produce various feature profiles and likely affect changes in the mechanistic components of silicon (Si) etching. Crystalline silicon (100) wafers (p-type, 150 mm) and poly-crystalline silicon (poly-Si) deposited onto silicon dioxide (SiO@sub 2@) were etched in a transformer coupled plasma reactor at two applied rf powers (250, 500 W, bias = 150 W) with Cl@sub 2@, HBr and HCl plasmas. Both Si (100) and poly-Si were patterned with nested and isolated lines and trenches using a SiO@sub 2@ mask. Scanning electron microscopy (SEM) was used to identify feature morphology and make comparisons between different halogen sources. Cross sectional SEM micrographs showed that HBr plasmas produced features with vertical sidewalls and little or no microtrenching. Deviations from anisotropically etched profiles (bowed sidewalls and deep microtrenches) were most severe for wafers etched in Cl@sub 2@ plasmas. Line and trench features for wafers etched in HCl plasmas evolved hybrid profiles; microtrenching and sidewall bowing occurred, but to a lesser degree than for Cl@sub 2@ plasmas. These data indicate that the presence of hydrogen or the type of halogen species in the plasma plays a significant role in feature profile evolution.

PS-MoP3 Plasma Damage in Metal Etch Processes Using an Oxide Hardmask, ***J.I. Colonell***, *N.A. Ciampa,* Bell Laboratories, Lucent Technologies, US*; M.V. Malyshev,* Princeton University*; V.M. Donnelly, J.T.C. Lee,* Bell Laboratories, Lucent Technologies*; C.P. Chang, K.P. Cheung, W.Y.C. Lai, C.T. Liu, C.S. Pai, H.M. Vaidya,* Bell Laboratories, Lucent Technologies, US

Plasma damage in metal etch remains a serious problem in ULSI fabrication, and is expected to become more severe as gate oxide thickness is scaled. One proposed solution is to use an oxide hardmask, rather than a photoresist mask, to pattern the metal. Metal to oxide etch selectivities of 8:1 are achievable, so the mask thickness can be reduced from 1 µm to 1500 Å, thus reducing the aspect ratio for 0.4 µm spaces from ~4 to ~2 or lower. This change should reduce damage by reducing electron shading and aspect ratio dependent etching. However, metal etch processes using hardmask generally require low pressure conditions (2 to 5 mTorr, compared to 10 to 20 mTorr for a typical photoresist process) which lead to higher plasma densities and electron temperatures. We have measured plasma damage due to metal etch in a commercial, high density, inductively coupled reactor on 0.25 µm technology CMOS capacitor and transistor testers, with oxide thicknesses from 50 Å down to 25 Å. The effect of source power (from 300 W to 600W) and process pressure (3 mTorr to 7 mTorr) on the damage will also be discussed.

PS-MoP4 2DINESE - Topography Simulation Software for Process Modeling and Optimization, ***I.V. Katardjiev***, Uppsala University, Sweden*; G. Carter,* Salford University, United Kingdom, U.K.*; S. Berg,* Uppsala University, Sweden

2DINESE@footnote 1@ is a powerful two-dimensional topography simulation program designed specifically for process simulation in IC R&D and manufacturing. It can simulate virtually all erosion and deposition processes currently employed in IC manufacturing - Reactive Ion Etching, Ion Beam Etching, Plasma etching, wet chemical etching, various PVD and CVD methods, multilevel metalization, to name a few. 2DINESE is built on a robust numerical implementation of the Theory of Surface Evolution, based on the generalized Huygens Principle of Wavefront propagation in anisotropic media. The basic points of this theory will be presented and its numerical implementation briefly discussed. Ample simulation examples will also be presented as well as a demonstration of the program will be given. @FootnoteText@ @footnote 1@ 2DINESE is freely available for academic use.

PS-MoP5 A Comparison of Oxide Damage in MOS Capacitors in Plasma Cleaning Applications, *X.M. Tang,* College of William and Mary*;* ***Q. Wang***, Keithley Instruments*; D.M. Manos,* College of William and Mary

This paper reports a study of a comparison of damage produced by three different sources for photoresist dry-cleaning and removal. The sources include a CW 1kW, 13.6 MHz TCP plasma source, a pulsed TCP source capable of operation at variable frequency and duty cycle, and a source creating a directed stream of energetic (1-10 eV) neutral oxygen atoms. By judicious choice of conditions among these three sources, it is possible to identify the relative contributions to gate oxide damage from ions, electrons, neutrals, and photons. Damage from contamination by deposition of wall materials or other impurities were also included in these studies. Test structures included MOS capacitors consisting of (Al/100 Angstoms of SiO2/Si). Source parameters were varied including pressure, RF power, gas composition, pulse length, and, in the case of neutral stream cleaning, reflected neutral energy and flux. Ion fluxes were estimated from measured plasma parameters and by calorimeter probe methods. Pre-exposure and post-exposure damage levels, under these variations of conditions, were measured using simulataneous high frequency and low frequency C-V and i-V techniques.Results are compared to damage assessments and to models which have previously been reported. Results showed less gate oxide damage in the neutral stream cleaning source. Residue removal and correlative surface damage from impurity effects are assessed by studies using XPS, STM, and Auger spectroscopy. Simulation models are used to correlate the process damage to the plasma discharge parameters.

PS-MoP6 Etching and Cleaning using a Pulsed ICP Plasma, ***D.M. Manos***, *X.M. Tang,* College of William and Mary

In this paper, we report studies of a pulsed ICP plasma using mixtures of argon, oxygen, water, hydrogen, and CF4 for removal of photoresist and cleaning and etching of SiO2. This paper reports measurements of the spatial and time-resolved electron temperature, plasma density, and measurements of the relative density of reactive species using optical emission spectrometry. Relative contributions of particle fluxes arising

from ion vs. neutral species are estimated from measurement using heat flux and momentum sensors. The rf antenna power was monitored with current and voltage probes for 2 kW operation into dummy loads and into etching plasmas. Etching and cleaning rates were measured as a function of rf power, pulse frequency, duty cycle, gas composition, using SEM, AFM and a quartz microbalance. The modulation frequency and duty cycle were varied to optimize cleaning and etching efficiency. Experimental results are compared to a globally averaged model published by Ashida et. al.@footnote 1@ and to particle-in-cell simulations performed in this work, using MAGIC.@footnote 2@ @FootnoteText@ @footnote 1@S. Ashida, et. al., J. Vac. Sci. Techol., A13, 2498, (1995) @footnote 2@B. Goplen, et. al., "Magic Users Manual", MRC/WDC-R-409, August 1997

PS-MoP7 Increase of Etch Resistance of Deep UV Photoresist by Implantation, ***K.K. Ong***, Nanyang Technological University, Singapore*; C.P. Soo,* National University of Singapore, Singapore*; M.H. Fan,* Chartered Semiconductor Manufacturing Ltd., Singapore*; A.J. Bourdillon,* National University of Singapore, Singapore*; M.H. Liang,* Nanyang Technological University, Singapore*; L.H. Chan,* Chartered Semiconductor Manufacturing Ltd, Singapore, Republic of Singapore

As device dimension shrinks, there is a need to use deep UV lithography to define sub-quarter micron features. However, most of the novel photoresists used in deep UV lithography generally face a problem: low etch resistance. In this study, implantation of various kinds of dopant into the resist layer was the approach to increase etch resistance. The first approach was that implantation of dopant into the resist formed a carbonized layer at the surface. The carbonized layer formed at the surface could be clearly observed on the cross SEM micrographs. This might increase the etch resistance by the assumption that the etch resistance is proportional to the C/H ratio of the resist (made by Wilson et al.). The etch rate of the treated resist was extracted from detailed experiment. Generally for both B and P implantation, the carbonized layer was thicker with increase implantation voltage. The thickness could reach to the range of around 0.5 μm. This enables a thinner resist (probably at 0.6-0.7 μm) used in the lithography, which enhance the resolution and the depth of focus. Secondly, implantation of Si into the resist might form the silylated resist which normally bears a higher etch resistance. Besides that, implantation of B or P into the oxide substrate increased the oxide etch rate greatly with respect to the above resist layer. The greater difference in the etch rate of the resist and oxide substrate gave a better etch selectivity.

PS-MoP8 An Integrated Surface Kinetics-Plasma Equipment Model for Etching and Deposition: Effects of Bias on Wall Reactions@footnote 1@, ***D. Zhang***, *M.J. Kushner,* University of Illinois, Urbana-Champaign

In high plasma density, low pressure etching tools, heavy particle reactions which occur at the walls are equally, if not more important, than heavy particle reactions which occur in the gas phase. To self consistently address these reactions, as well as to address reactions mechanisms occuring on the wafer, a Surface Kinetics Module (SKM) has been developed for the Hybrid Plasma Equipment Model (HPEM). The SKM is a surface site balance model which is employed at every mesh-point at the border between the plasma and surfaces. During each iteration of the HPEM, the fluxes and energies of species from the plasma to selected surfaces are used as input to a set of differential equations encompassing the surface reaction mechanism. The SKM then solves for the steady state values of surface coverages, processing rate (etching or deposition), and the species/fluxes leaving the the surface to the plasma. These values are then used to update the flux-in/flux-out boundary conditions which are used in the plasma portion of the HPEM. The SKM has been employed to investigate reaction mechanisms in Inductively Coupled Plasma (ICP) etching (oxide and poly-Si) systems with an rf biased substrate. With increasing rf biasing, the sheath voltage at surfaces other than the wafer also increase, thereby increasing the rate of sputtering of passivating species. These species return to the plasma, thereby increasing their flux to the wafer. The goal of the investigation is to determine whether the variation of these wall sputtering processes with rf bias amplitude is sufficient to significantly perturb the etching rate on the wafer. @FootnoteText@ @footnote 1@Work supported by SRC and NSF.

PS-MoP9 Investigations of Oxide Etching Using Validated Plasma Models, ***J.E. Johannes***, *T.J. Bartel, M. Gallis, E. Meeks,* Sandia National Laboratories

Future technology, 0.25 micron and below, will require continued use of high density plasma (HDP) etch reactors to perform dielectric etch of fine-line, high aspect ratio features using fluorocarbon gases. Applying plasma models to better understand and design this process is difficult due to the lack of chemical information. By coupling fundemental chemical data, diagnostic data, and reactor scale models a validated plasma mechanism and model can be developed for predictive HDP simulations. A three step process will be defined for developing predictive HDP models. This study will focus specifically on a C@sub 2@F@sub 6@ plasma for oxide etch, although the strategy can be applied to other lasma systems. First, a preliminary mechanism is developed using existing cross sections and beam studies from the literature. A sensitivity analysis is then used to reduce the number of reactions and species in a preliminary C@sub 2@F@sub 6@ mechanism to generate a 'manangable' chemistry set for 2-D/3-D simulations. Phase two of this process is mechanism and model validation; this step is required to have confidence in the model. O-D and 2-D simulations are compared to available C2F6 plasma data, from both experimental and commercial reactors, to suggest improvements in the chemistry models and to validate the plasma models. A wide range of data comparisons used for mechanism development and validation will be presented for this study including: spatially resolved langmuir probe data, laser induced fluoresence (LIF) data, diode laser absorption data, Hiden probe data and oxide etch rates. A suite of four different codes will be used: 1.) Aurora, a well stirred reactor model, 2.) MPRES, a 2-D finite element plasma model , 3.) Icarus, a 2-D Direct Simulation Monte Carlo (DSMC) plasma code and 4.) Pegasus, a 3-D version of Icarus. The final step in the process is to apply the validated mechanism to investigate commercial processes. The validated mechanism will be applied in the DSMC codes to study the effects of etch rate and uniformity as a function of gas injection and flow rate in a commercial HDP. In addition, Icarus/Pegasus simulations will be performed to investigate 300 mm scale-up issues.

PS-MoP10 Model for Etch Depth of Contact Hole, ***B. Abraham-Shrauner***, Washington University

A linear relation between the etch depth and the inverse diameter of a contact hole is derived approximately. The linear relation was found experimentally for contact holes etched in silicon dioxide and several models for it were computed.@super 1@ This linear relation can also be reexpressd as a function of time for which there is also data.@super 2@ The new feature is the application of Langmuir kinetics with synergistic etching of neutrals and the ions. The neutrals are modeled for molecular flow in a pipe with a sticking coefficient equal to one.@super 2@ This assumption is supported by a recent finding that the etching (nondepositive) neutrals are not adsorbed appreciably on top of the same neutrals on the passivated walls of contact holes etched in silicon dioxide.@super 3@ The ions are modeled simply by a vertical beam since the directed ion energy fluxes at the center of the contact hole fall off slowly with depth. The effect of the depositive neutrals on the etch depth relation is estimated. Etch rates for the neutrals and ions are computed from data.@super 1@ @FootnoteText@ @footnote 1@ 1. S. C. McNevin, M. Cerullo and J.T.C. Lee, Bull. Am. Phys. Soc. 42 1707 (1997). @footnote 2@ H. H@um u@bner and M. Engelhardt, J. Electrochem. Soc. 141, 2453 (1994). @footnote 3@ A. Misaka and K. Harafuji, IEEE Trans. Elect. Dev. 44, 751 (1997).

PS-MoP11 Oxide Etch Characteristics of Inductively Coupled Plasmas Using Multipole Magnets for the Fabrication of Optical Waveguides, ***K.J. An***, *D.H. Lee, G.B. Yoo,* SungKyunKwan University, Korea*; J.H. Joo,* Kunsan National University, Korea, South Korea*; G.Y. Yeom,* SungKyunKwan University, Korea

Dry etching of silicon oxide is one of the key steps not only in the silicon integrated circuit fabrication but also in other applications such as the fabrication of optical waveguides. In case of the fabrication of optical waveguides, dry etching characteristics of anisotropic etch profile, low sidewall roughness to reduce scattering loss, and high SiO@sub 2@ etch rates with high etch selectivities over mask materials easily to etch the films over 10μm thick are required In this study, glass etch characteristics of inductively coupled plasmas using multipole magnets were investigated. Various fluorocarbon gases and their combinations were used as etch gases. The10μm thick glass layer on silicon wafers used in this experiment was grown by plasma enhanced chemical vapor deposition. As the etch mask material, 3000Å thick Cr patterned using an Ar ion beam etching technique was used. To investigate the effects of multipole magnets on the characteristics of the plasmas and etch properties, ion density and F radical intensity were measured with and without the magnets along with etch rates, etch selectivities, and etch profiles. Also, we have analyzed the etched glass surface by x-ray photoelectron spectroscopy(XPS) to investigate the change of stoichiometry and binding states of the surface materials. When the glass was etched, the significant increase of etch rate, the increase of etch uniformity, and changes in the surface composition

were obtained with the magnets together with the increase of ion densities and radicals. Using CF@sub 4@, 1000watts of inductive power, 5mTorr of operation pressure, -100Volts of dc-self bias voltage, and with the magnets glass etch selectivity over Cr higher than 30 and glass etch rate over 4500Å/min with anisotropic etch profiles and smooth sidewalls of 10µm thick etched glass waveguides could be obtained.

PS-MoP12 Consequences of Photon Injection in an Inductively Coupled Plasma@footnote 1@, ***E.R. Keiter***, *M.J. Kushner,* University of Illinois, Urbana-Champaign

The plasma chemistry used for PECVD and etching are usually complex and consist of many different neutral and ionic species, only a subset of which may be desirable. Due to the nonselective excitation and dissociation typically obtained in plasmas, it can often often be difficult to simultaneously optimize all process variables. For example, a plasma with optimally high ion flux may have other plasma parameters that are detrimental to the process, such as a larger density of a polymerizing radical. By using an auxiliary source of excitation, such as a photon beam for photolysis or photoionization, it may be possible to simultaneously optimize multiple plasma parameters. In this paper we present results from a numerical study of an Inductively Coupled Plasma (ICP) system which includes an auxilliary photon source. The Hybrid Plasma Equipment Model (HPEM) has been modified to include a Monte Carlo Photon Beam (MCPB) module and is the simulation tool used in the study. Photons in the MCPB are represented as numerical particles, and photon absorption is described by using a variable particle weighting method. Photon reactions are specified in the same manner as other chemical processes. Source rates for charged and neutral species which result from photon absorption are generated by the MCPB and used by the fluid module of the HPEM. We will present the results from a parametric study of the effects of an external photon source on species densities and plasma parameters for a Cl@sub 2@ etching system and Ar/SiH@sub 4@ deposition system. @FootnoteText@ @footnote 1@Work supported by Applied Materials, SRC and NSF.

PS-MoP14 Low-Temperature Helicon Assisted Reactive Evaporation of Sn-doped and Ge-doped Silica Films for Planar Waveguide Photonics, ***K.W. Gaff***, *A. Durandet, R.W. Boswell,* The Australian National University, Australia

Photosensitive silica films are a key technology in the development of silica based integrated optic devices. While the photosensitivity of silica glass doped with a variety of elements has been investigated for fibres, the development of photosensitive films for planar waveguides is still nascent. Previous research has concentrated on germanium doped silica films, often hydrogenated, and fabricated primarily by flame hydrolysis or PECVD, although ion-implantation techniques are also being researched. Fibre preform fabrication and flame hydrolysis silica film deposition normally involve temperatures around 1000°C, while temperatures during PECVD fabrication of silica films are typically 300-400°C. In the present work, we employ a unique process - helicon assisted reactive evaporation (HARE) - which combines three-crucible, electron-beam evaporation with a helicon source to generate a high density reactive plasma for thin oxide film deposition. The process enables deposition of hydrogen free, multi-component doped silica films at relatively low temperatures, typically between 100-150°C. Using this process, we were able to deposit tin-doped silica films. We compare the optical properties of the tin-doped films with those of germanium-doped films deposited using the same process and with germanium-doped films fabricated by the higher temperature processes.

PS-MoP15 In-situ Cleaning of GaAs and Al@sub x@Ga@sub 1-x@As Surfaces and Production of Ohmic Contacts Using an Atomic Hydrogen Source Based on a Reflected Arc Discharge, ***V.A. Kagadei,*** Research Institute of Semiconductor Devices, Russia; *D.I. Proskurovsky,* Institute of High Current Electronics, Russia

The existence of a thin-metal-film - semiconductor interface containing no contaminant is a necessary condition for the formation of high-quality ohmic contacts. Chemical treatment of the surface of a semiconductor is insufficient to provide an interface free from oxide. This is most pronounced for semiconductors showing high rates of oxidation of the surface, e.g., for Al@sub x@Ga@sub 1-x@As. A technology for production of ohmic contacts with n-type GaAs and n-type and p-type Al@sub x@Ga@sub 1-x@As has been proposed, such that the surface cleaning in a flow of atomic hydrogen (AH) and the deposition of a metal film are accomplished in a unified vacuum cycle. A feature of this technology is that the processes are conducted in a vacuum deposition system with a residual pressure of 3 10@super -6@ Torr for GaAs and (3-7) 10@super -7@ Torr for AlxGa1-xAs. The AH flow was produced by a reflected-arc-discharge-based source with a hollow cathode and a self-heating element. In the course of cleaning, the hydrogen pressure was 10@super -4@ Torr. The specimen temperature and the treatment time were varied in the range as follows: T = 100 - 400 C and t = 0.5 - 90 min. AuGe/GaAs interfaces have been produced with the contaminant content being below the sensitivity threshold of the method of Auger electron spectroscopy (AES). With some technological procedures having been executed, an AuGe/Al@sub 0.6@Ga@sub 0.4@As interface has been produced with the oxygen content less than 1% and the contents of other impurities below the AES sensitivity threshold. A comparative examination has been carried out for ohmic contacts produced using the technology proposed and the conventional technology based on "wet" chemical cleaning. The contacts produced by the proposed technology show a better morphology of the surface and of the contact area edge, high adhesion, and a low contact resistant; the process of their production features good reproducibility. Performance data of devices made using the new technology are reported. The technology developed is promising for production of shallow-lying contacts with GaAs and contacts with AlxGa1-xAs having a high Al content.

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