Thursday Morning, November 5, 1998

Plasma Science and Technology Division
Room 318/319/320 - Session PS-ThM

Plasma Applications in Copper Metallization

Moderator: D.B. Graves, University of California, Berkeley

8:20am **PS-ThM1 Plasma Processes for Copper Dual Damascene Interconnect in Advanced CMOS Technologies*, J.E. Heidenreich,*** *D. Edelstein, R. Goldblatt, W. Cote, C. Uzoh,* IBM - Semiconductor R & D Center*; T. McDevitt, A. Stamper,* IBM Microelectronics*; A.H. Simon,* IBM - Semiconductor R & D Center*; J. Dukovic,* IBM T.J. Watson Research Center*; R. Wachnik, H. Rathore,* IBM - Semiconductor R & D Center*; S. Luce, J. Slattery,* IBM Microelectronics*; J. Ryan,* IBM - Semiconductor Research and Development Center **INVITED**

IBM has announced the implementation of Copper interconnect for a sub-0.25µm CMOS technology.@footnote 1@ This technology uses up to 6 levels of Copper wiring with a minimum metal contacted pitch of 0.63µm. Copper metalization offers the advantages of upto 40% reduction in wire resistance, increased allowable current density, and increase scalability, relative to Ti/Al(Cu) wiring which is commonly used in semiconductor applications. This technology was produced using a Dual Damascene integration scheme that dramatically reduces the number of steps necessary to build wiring levels. The industry, as a whole is moving toward both Copper metalization and Dual Damascene integration for reduced cost and increased performance. This talk will review the characteristics of this technology, and the results of our reliability evaluation. It will also focus on some of the special plasma processing challenges and opportunities that arise with the use of Dual damascene and Copper. @FootnoteText@ @footnote 1@D. Edelstein et al., Proc. IEEE IEDM, 773 (1997).

9:00am **PS-ThM3 Low k Dielectric Etching in High Density Plasmas*, O. Joubert,*** France Telecom CNET/DTM/TFM, France*; L. Vallier, P. Czuprynski,* France Telecom CNET, France

Dielectric etching remains one of the most challenging etching process for ultra large scale integration (ULSI) technology. The need to move to the so-called low k dielectric materials open a all new area of investigation. Among different options, one is to use polymers as low k dielectric. Opening high aspect ratio contact holes in polymer type materials can be as challenging as opening high aspect ratio contact holes in SiO@sub 2@. In this paper we have been studying the etching of high aspect ratio contact holes (higher than 5) in polymers. Studies were performed in a high density helicon source using various chemistries and plasma operating conditions. The etching was controlled using real time ellipsometry and optical emission techniques. First, oxygen plasmas were tentatively used to open high aspect ration contact holes. In all the plasma operating conditions used (low density and high density regimes and always at very high chuck bias power), undercut due to spontaneous etching reactions between the polymer and oxygen atoms present in the discharge or profile deformation such as bowing were observed. Other chemistries such as H@sub 2@/N@sub 2@ gas mixtures where spontaneous etching reactions between the polymer and reactive species are less important were also investigated. Oxygen based chemistries such as O@sub 2@/CO, O@sub 2@/CH@sub 4@, O@sub 2@/SO@sub 2@ allowing passivation layers to be formed on the polymer sidewalls of the contact were investigated. The best contact hole profiles were obtained using O@sub 2@/SO@sub 2@ gas mixtures where sulfur deposition on the polymer sidewalls strongly minimizes spontaneous etching reactions. On the other hand, some sulfur-based species are left behind which can react with air moisture possibly inducing metal corrosion during the subsequent interconnect formation. In situ anticorrosion treatments were performed to remove sulfur based species. The anticorrosion efficiency was evaluated by measuring the sulfur concentration on all the contact hole surfaces before and after anticorrosion treatment using chemical topography analyses by x ray photoelectron spectroscopy (XPS). @FootnoteText@ This work has been carried out within the GRESSI consortium between CEA-LETI and France Telecom-CNET.

9:20am **PS-ThM4 High Density Plasma Patterning of Organic Low Dielectric Constant Materials*, T.E.F.M. Standaert,*** *P.J. Matsuo, S.D. Allen,* State University of New York, Albany*; K.H.J.M. Robben,* Eindhoven University of Technology, The Netherlands*; G.S. Oehrlein,* State University of New York, Albany*; J.G. Langan, W.R. Entley,* Air Products and Chemicals, Inc.*; R. Gutmann, T.M. Lu,* Rensselaer Polytechnic Institute

We have studied the etching of several organic low dielectric constant materials in a Transformer Coupled Plasma (TCP) source employing in-situ diagnostics, such as ellipsometry, x-ray photoelectron spectroscopy (XPS), and optical emission spectroscopy (OES). Dielectrics of particular interest are Polyarylene ether (PAE-2) and Parylene-N. Etched microstructures were examined by scanning electron microscopy (SEM). Successful pattern transfer into these organic dielectrics has been demonstrated using an Ar/O@sub 2@ chemistry and a SiO@sub 2@ hard mask. A systematic study has revealed how the erosion of the sidewall can be controlled as a function of the oxygen radical and ion flux. Following the dielectric etch, characterization of the surface residues and modifications were performed. The efficiency with which the original underlayer surface can be recovered was also investigated.

9:40am **PS-ThM5 Plasma Deposition of Low-Dielectric-Constant Fluorinated Amorphous Carbon Interlayer Dielectrics*, K. Endo,*** NEC Corporation, Japan **INVITED**

As LSI circuits continue to shrink, delay time of wiring caused by parasitic capacitance of interconnects becomes more important and further reduction becomes more difficult. Low-dielectric-constant (low-k) interlayer dielectrics (IL D) and low resistively wiring metals are now promising for reducing the RC delay of interconnects. Polymers are promisin g low-k materials. However, poor adhesion with Si substrates, poor thermal stability, and production difficulties have h indered their use in microelectronics. On the other hand, plasma-enhanced chemical vapor deposition (PE-CVD) of polymer films has many advantages that overcome these problems. Recently, a use of low-k fluorinated amorphous carbon (a-C:F) fi lms, that have both crosslinked and PTFE (polytetrafluoroethylene)-like structures, has proposed.@footnote 1@ Now, a cla ss of materials is widely investigated using PE-CVD. Around 400°C thermal stability and the dielectric constant o f 2.3-2.7 are realized by controlling the fluorine concentration in the films. For an easier integration, a-C:F film is covered with SiO@sub 2@ that protect the a-C:F film during processing. Si-rich SiO@sub 2@ glue layer is used to maintain adhesion strength between them. Also, excellent gap filling was realized by u sing a biasing PE-CVD technique. The fabrication of globally planarized 3-lebel Al interconnect using a-C:F ILD achieved 50% reduction in capacitance. Now, a combination of Cu and low-k materials is most promising for the further reduction in RC delay. Also, lower deposition temperature of Cu is appropriate for the low-k materials that are typically less the rmally stable than SiO@sub 2@ films. The a-C:F deposition technology can also be applied to Cu wiring system. A damascen e structure with Cu wiring and a-C:F ILD was successfully fabricated and no reaction between Cu and fluorine was observe d. @FootnoteText@ @footnote 1@K. Endo, MRS Bulletin 22, 55 (1997).

10:20am **PS-ThM7 Sources of Asymmetry in Ionized Metal PVD Reactors@footnote 1@*, J. Lu,*** *M.J. Kushner,* University of Illinois, Urbana-Champaign

Ionized metal physical vapor deposition (IMPVD) can produce highly ionized metal fluxes for use in filling high-aspect-ratio vias and trenches in microelectronic devices. A typical IMPVD reactor uses inductively coupled plasma (ICP) excitation in conjunction with a dc or rf magnetron. Directionality, uniformity, and high deposition rate are the most desired properties in the deposition process. One factor that significantly affects the cited properties is the symmetry of excitation and sputtering in the IMPVD reactor. Asymmetries may be caused by nonuniform erosion of the target, asymmetric gas injection and/or pumping, or non-uniformities in the inductively coupled field due, for example, to transmission line effects. These asymmetric processes couple nonlinearly with each other. In this paper, sources of asymmetry in metal deposition will be numerically investigated. The computational tool used in this study is the three-dimensional Hybrid Plasma Equipment Model (HPEM), in which a Monte Carlo sputter model is coupled self-consistently to the plasma simulation. The reactor being modeled uses an external coil (made possible by a Faraday shield). Typical operating conditions are 10 mTorr gas pressure, 1kW ICP power, and 13.6MHz frequency. The uniformity of the ion flux and ionization fraction for Cu and Al IMPVD systems will be discussed as a function of aspect ratio, target geometry and antenna design.

@FootnoteText@ @footnote 1@Work supported by SRC, Materials Research Corporation, and NSF.

10:40am **PS-ThM8 Simulations for Process Optimization Issues in Ionized Metal PVD**, ***P.L.G. Ventzek***, *M. Hartig, V. Arunachalam, D.G. Coronell, D. Denning,* Motorola Inc.

Magnetron plasma sources for ionized metal plasma physical vapor deposition (IMP-PVD) are being exploited for metal deposition in semiconductor device manufacturing applications because of their ability to lay down films with the required step coverage at high rates and reasonable uniformity. Challenges exist to extend the technology to ever more aggressive features with tighter tolerances on process parameters (e.g. uniformity). Despite their importance, multidimensional numerical models that treat the plasma dynamics in IMP chambers are relatively rare. This is possibly due to the difficulty in considering the complex magnet arrangements that characterize these systems. In this paper, we will present results obtained using the Hybrid Plasma Equipment Model (HPEM)@footnote 1@ and MAXWELL3D@footnote 2@ to simulate the behavior of a generic IMP source for metal deposition. This generic source employs internal coils to ionize metal sputtered from a target in a dc magnetron. As is typical, the dc magnetron structure is azimuthally asymmetric and will consist of concentric spirals of oppositely oriented permanent magnets. A special feature of the model is that energy and angle dependencies in the sputter yield are considered and that we have developed a methodology for looking at 3- dimensional effects.@footnote 3@ First we will present design-of-experiment studies of various process parameters and magnet configurations. In general, reasonable agreement has been found between ion fluxes to the target and experimentally determined erosion profiles. Second we will illustrate how various process parameters affect across wafer thickness uniformity, compositional uniformity and step coverage. @FootnoteText@ @Footnote 1@M. Grapperhaus et al., J. Appl. Phys., 83, 39 (1998) @Footnote 2@Ansoft Corp. @Footnote 3@see AVS paper by J. Kress et al.

11:00am **PS-ThM9 Modeling of IMP Copper for Electroplating Seed Layer Application**, ***H.M. Zhang***, *I. Hashim, P.J. Ding, B. Chin, J.C. Forster,* Applied Materials

Copper is being considered for semiconductor metallization because of its better conductivity, and higher electromigration resistance compared to aluminum. Current trends suggest that electroplating will be the primary choice for copper deposition in sub-0.25 μm generations because of its relatively low cost, high deposition rates, and ease of filling high aspect ratio features. However a conducting seed layer is required prior to electroplating. Ion-metal-plasma (IMP) deposition of copper has been demonstrated to provide a good seed layer for aspect ratios up to 4.5 :1.@footnote 1@ To meet the challenges of filling even higher aspect ratio features, a better understanding of both the electroplating and IMP process is required. In this paper, we will focus on extending the limits of the IMP copper deposition process by using simulations. A 2-dimensional hybrid plasma equipment model (HPEM),@footnote 2@ developed at the University of Illinois, is used to model the IMP Cu system. Simulation results of the deposition rate show good agreement with experimental data. The ionization ratio of copper can be increased by increasing the RF power or the process pressure. TEM analysis of IMP copper deposition into high aspect ratio features show a significant improvement of the step coverage at higher pressures. A good correlation was obtained between ionization fraction predicted by simulation and experimentally obtained bottom coverage measurements. This study will show that with proper optimization, the application of IMP Cu to the deposition of seed layers for electroplating can be extended to future generation and geometries. @FootnoteText@ @footnote 1@I. Hashim et al, Abstract submitted for VLSI Multilevel Interconnection Conference, 1998. @footnote 2@M. Grapperhaus and M.J. Kushner, J. Applied Physics., 81, 569 (1997)

11:20am **PS-ThM10 Metal Flux Ionization Fraction in Copper Ionized Physical Vapor Deposition@footnote 1@**, *T.G. Snodgrass, J.E. Foster, S. Lu,* ***A.E. Wendt***, *J.H. Booske, J.L. Shohet,* University of Wisconsin, Madison

A characterization and modeling effort is directed at a more complete understanding of the potential and limitations of copper ionized physical vapor deposition (IPVD) for damascene processes. An rf inductively-coupled IPVD tool operating in argon includes a dc magnetron sputter source mounted in the top of an 18" D chamber. A 14'' D internal single-turn rf induction antenna is positioned between the magnetron and a 12" D substrate holder. Improved filling of high aspect-ratio features depends on the degree to which metal atoms are ionized as they pass through the rf plasma. To identify factors governing the "ionized flux fraction," measurements of metal properties have been made in the gas phase and at the substrate. Optical spectroscopy and Langmuir probes measure gas phase concentrations of neutral and ionized copper, and an improved quartz crystal microbalance@footnote 2@ is used to determine both neutral and ion fluxes at the substrate. The sputter rate from the target as well as the deposition rate radial profile at the substrate location have been characterized in detail. Results with and without the rf plasma show that the rf induction plasma has the primary effect of increasing the ionized metal flux and has only a minor effect on the flux of neutral copper. Selfsputtering of the internal rf antenna has also been examined, and methods to control it will be presented. A model has been constructed that, along with the measurements described, provides a physical explanation of the IPVD operating characteristics. @FootnoteText@ @footnote 1@This work supported by NSF grant #EEC8721545 @footnote 2@T. G. Snodgrass, W. Wang, J. H. Booske, A. E. Wendt, J. L. Shohet, submitted to Rev. Sci. Instr.

11:40am **PS-ThM11 Scattering and Sputtering Processes of Energetic Ar@super +@ and Cu@super +@ Ions on Cu Surfaces: Molecular Dynamics Simulations**, ***C.F. Abrams***, *D.B. Graves,* University of California, Berkeley

Two competing technologies, electroplating and ionized PVD, show promise in filling narrow, high aspect ratio trenches and vias with copper. While energetic metal and inert gas ions play central roles in IPVD, they are potentially no less important in plating due to the need to deposit a high-quality seed layer of metal on top of a thin barrier layer before plating from solution can proceed. Therefore, a better understanding of how energetic Ar@super +@ and Cu@super +@ ions interact with copper surfaces is crucial for further development of both technologies. We present results of molecular dynamics (MD) simulations of Ar@super +@ and Cu@super +@ ions impacting model Cu surfaces with a variety of impact energies (50 - 200 eV) and angles. We modeled Cu-Cu interactions using the EAM potential energy function (PEF) and Ar-Cu interactions using the ZBL PEF.@footnote 1@ We report the distributions in reflected angles and energies for these ions. We report both total and differential sputter yields with respect to angle of ejection, and compare our MD results to recent experimental findings.@footnote 2@ The effect of changing ion energy and angle on these quantities is discussed. For example, we observe that the sputter yield for Ar@super +@ on Cu decreases as the Ar@super +@ ion's incident angle is increased from 30@super o@ to 60@super o@ from normal. These results shed light on the dynamics of low energy ion/metal surface interactions and provide a useful database of events for profile evolution simulations of Cu seed layer deposition and trench/via fill. @FootnoteText@ @footnote 1@ K. Gartner et al., Nucl. Instr. Meth. Phys. Res. B 102, p183 (1995). @footnote 2@ C. Doughty, S. M. Gorbatkin, and L. A. Berry, J. Appl. Phys. 82, p1868 (1997)

Author Index

Bold page numbers indicate presenter