Thin Films Division
Room 615 - Session TF-MoA
Fundamentals and Applications of Ionized PVD
Moderator: F.K. Urban III, Florida International University

2:00pm **TF-MoA1 Plasma Interaction Effects in Ion-Beam Assisted Pulsed Laser Deposition of Al-O-N Films***, **A.A. Voevodin**, J.G. Jones, J.S. Zabinski,* Air Force Research Laboratory

Interactions between plasmas produced by a nitrogen ion-beam source and pulsed laser ablation of Al@sub 2@O@sub 3@ were studied. Plasma fluxes from both sources intersected on the substrate surface in a typical arrangement for ion-beam assisted pulsed laser deposition (AIPLD). The study was focused on the detection of temporal and spatial plasma distributions, excitation states, and chemical reactions in the substrate vicinity, which were not present when operating each of the plasma sources separately. Plasma emission imaging and spectroscopy analyses using an ICCD camera and a spectrometer were used to investigate plasma development and chemistry in real time using the initial laser pulse for synchronization. In the study, the N@sub 2@ background pressure was varied in the range from 0.08 to 4 Pa and X-ray photoelectron spectroscopy was performed for Al-O-N films. Film elemental compositions were correlated with plasma chemistry. Two significant plasma interaction effects were discovered. One resulted in a considerable activation of N and O and formation of NO in a near substrate region, which then reacted with Al to from Al-O-N. A maximum plasma excitation was observed at reduced 0.1-0.2 Pa N@sub 2@ pressures and provided the highest amount of N in the films. Above 1 Pa of N@sub 2@, the Al-O-N films had lower nitrogen content, even though more nitrogen was available for the deposition. Another interaction effect was observed in the 2-4 Pa pressure region, when formation of short lived plasma channels connecting ion-beam and laser ablated plasmas were detected. These channels resulted in plasma bending and shifting from the substrate surface, affecting film composition and influencing ion beam current extracted from an ion beam-source. The study suggested that the interaction of ion-beam and laser ablation plumes in IAPLD might considerably affect plasma chemistry, excitation stages, and spatial distribution, providing new opportunities for the control of resulting film properties. @FootnoteText@ Key words: ion-beam assisted pulsed laser deposition, plasma chemistry, Al@sub 2@O@sub 3@ ablation, aluminiumoxynitride.

2:20pm **TF-MoA2 Time-of-Flight Measurements of Sputtered Species using Novel Pulsed High Plasma Density Magnetron Discharge***, **K. Macák**, V. Kouznetsov, J.M. Schneider, U. Helmersson,* Linköping University, Sweden*; I. Petrov,* University of Illinois, Urbana

Time resolved plasma probe measurements of a novel high power density pulsed plasma discharge are presented. Extreme peak power densities in the pulse (on the order of several kW.cm@super -2@) result in a very dense plasma with ionic flux densities of up to 1 A.cm@super -2@ at source-to-substrate distances of several cm and at a pressure of 0.13 Pa. The pulse duration was ~50 µs with a pulse repetition frequency of 50 Hz. The plasma consists of metallic and inert gas ions, as determined from time resolved Langmuir probe measurements and in situ optical emission spectroscopy data. The influence from the process parameters on the temporal development of the ionic fluxes is discussed. Deconvolution of metal ion probe current pulse waveform allowed for the calculation of the average ion energy. The ionized portion of sputtered metal flux was found to have an average energy of 2.6 eV in the absence of gas scattering. The obtained energies of the arriving metal ions conform with the collisional cascade sputtering theory. The degree of ionization of the sputtered metal flux at a pressure of 0.13 Pa was found to be 40±20 % by comparing the total flux of deposited atoms with the charge transferred by metal ions in the pulse.

2:40pm **TF-MoA3 Modeling of I-PVD Systems for TiN Film Deposition in Inductively Coupled Plasmas***, **M. Li**,* University of California at Berkeley, CANADA*; D.B. Graves,* University of California at Berkeley

TiN films are widely used as a diffusion barrier for aluminum, tungsten as well as copper in VLSI fabrication. Recently, ionized metal physical vapor deposition, or IPVD, has been used for TiN film deposition. However, this reactive sputtering process is relatively poorly understood. In this work, a two dimensional hybrid model, including a Monte Carlo treatment of fast sputtered atoms from the target and a fluid plasma simulation, is developed to study TiN film deposition in IPVD tools. The model includes a site balance surface model to describe the film deposition and target sputtering processes. Important issues such as neutral gas heating and rarefaction, the uniformity of film deposition across the wafer, and the film deposition characteristics have been investigated. In particular, the model predicts that the titanium species profiles and target shape are major factors in film deposition and computational uniformity at the substrate. The simulation results have been compared to the available experimental measurements.

3:00pm **TF-MoA4 Origin and Evolution of Sculptured Thin Films***, **R. Messier**, V.C. Venugopal, P.D. Sunal, H. Maeda,* Penn State University **INVITED**

Sculptured thin films (STFs) are columnar thin films prepared by directed vapor deposition under low adatom mobility conditions. Since the columns grow in the direction of the incoming vapor, and this column direction can be changed instantaneously, a new class of thin films can be engineered in which the STF nanostructural shapes can be sculptured into useful morphologies such as helices, matchsticks, chevrons, and periodically bent nematics. Wide variations in the exact STF shapes, as well as combinations of these morphologies, are possible through simple rotations of the substrate around two canonical axes. Potential applications include optical retardation layers for use in optical storage and communications systems, optical sensors for fluids of biological, chemical or nuclear significance, templates for biomaterials growth, and low-pemittivity materials for microelectronics. For normal angle deposition the columns generally expand and compete for growth evolution, thereby resulting in a cauliflower-like morphology. This is due to an in-plane, isotropic, atomic self-shadowing mechanism. Fortuitously, for large oblique angle deposition conditions („ 40š vapor incidence angle with respect to the substrate normal), typical for STF preparation, the columns become slanted, separated, and cylindrical due to an anisotropy in the self-shadowing process. Thus, the columns have a constant cross-section with film evolution - a requirement for many practical applications. It has been found experimentally, however, that under conditions of rapid or abrupt rotation of the substrate during oblique angle deposition, the columns expand, a situation which could limit their utility. In order to control STF morphology in the broadest sense, it is necessary to understand the details of the atomic clustering and growth competition process. In this paper a fundamental and yet practical approach will be presented for classifying the atomic self-shadowing processes in STF growth based upon previous experience in morphology evolution modeling and experiments. Recent experiments in STF growth include systematic changes in column growth rate / substrate rotation rate, use of textured substrates, and variations of low energy ion bombardment.

3:40pm **TF-MoA6 Ionized Physical Vapor Deposition (PVD) using Hollow-Cathode Magnetron (HCM) Source for Advanced Metallization***, **E. Klawuhn**, G.C. D'Couto, K.A. Ashtiani, P. Rymer, M.A. Biberger, K.B. Levy,* Novellus Systems, Inc.

Ionized Physical-Vapor Deposition (I-PVD) has been recognized as the technology of choice for extending the application of PVD processes to < 0.25 µm device geometries. However, due to the complexity of the conventional RF I-PVD, these sources are not in widespread manufacturing use. The Hollow-Cathode Magnetron (HCM) source is a new and promising technology that maintains the simplicity of the PVD technology and combines it with a very high-density diffused plasma (> 10@super 12@ #/cm@super 3@) for efficient ionization of sputtered metals. The HCM is based on the principle of charged particle magnetic mirror applied to an inverted cup shaped target. As such, it does not require any additional RF or microwave sources for generation of metal ions. The HCM source was used for deposition of Ti(N), Ta(N), and Cu films. Excellent bottom coverage (20 % for Cu, 40% for Ta and 30 % for Ti) in narrow, high aspect ratio vias (0.25µm, 5:1 AR) was obtained without the application of RF bias to the wafer. Since reactive processes were run in a non-poisoned mode, both TiN and TaN films had the same step coverage as Ti and Ta films, respectively. The TiN film resistivity is of the order of 30 µ@ohm@-cm (for a 1000 Å film) and close to the theoretical bulk resistivity of 18 µ@ohm@-cm. The HCM films have strong crystallographic orientation, and for Ti, TiN, Ta, and Cu respectively. RF bias was utilized to increase the bottom coverage and the sidewall coverage of the films, thus extending the technology to higher aspect ratios. In addition, RF bias was used to modify film properties such as grain size, grain orientation, and film texture. In this paper, the HCM theory of operation will be reviewed and results will be presented for the application of this source for deposition of Ti(N), Ta(N), and Cu films. In addition, the effects of RF bias on step coverage and film properties will be discussed.

4:00pm **TF-MoA7 Gas Phase Dynamics of Copper Ionized Metal Plasmas***,* ***Y. Andrew****, I.C. Abraham, Z. Lu, T.G. Snodgrass, A.E. Wendt, J.H. Booske,* University of Wisconsin, Madison*; P.L.G. Ventzek, S. Rauf,* Motorola

Copper ionized metal plasmas are of interest for the Damascene process of interconnect fabrication, in which trench and via structures are filled with copper. Used to deposit seed layers for subsequent electroplating, ionized metal plasmas produce films with enhanced conformality compared to conventional physical vapor deposition (PVD) processes. Improved understanding of the performance potential and limitations of this process motivate this study to characterize discharge properties through experiment and simulation. We examine a system consisting of a DC powered 15 cm D copper sputter source and an RF induction plasma powered by a single turn 36 cm D loop antenna internal to the vacuum chamber, with an argon pressure of 10-50 mTorr. Measurements include plasma parameters, ion and neutral copper flux at the substrate, RF and DC potentials on the antenna and in the plasma, and spectroscopic measurements of ground state and metastable copper as well as argon metastable concentrations in the gas phase. The simulations have been done using the Hybrid Plasma Equipment Model, a comprehensive plasma equipment modeling tool developed at the University of Illinois. The plasma is treated as a fluid in this model except for thermal copper neutrals sputtered from the target, for which a Monte Carlo simulation is used. The extensive data set includes some surprising observations. For example, both experiment and simulation show that for some operating conditions, the copper metastable density is substantial compared to that of the ground state population. Measurements and simulation will also address electrical measurements on the system, including a substantial but unexpected DC self-bias voltage on the antenna. Finally, by comparing copper fluxes measured directly and computed from spectroscopically determined gas phase concentrations, we can infer the temperature of the copper in the gas phase, which is found to increase substantially with RF power to the plasma.

4:20pm **TF-MoA8 Effects of Copper Seedlayer Deposition Method for Electroplating***,* ***E.C. Cooney III****, D.C. Strippe, J.W. Korejwa,* IBM Microelectronics

We have investigated copper seedlayer deposition using both ionized PVD and collimation methods by depositing similar films into agressive dual damascene structures. Step coverage measurements using TEM indicated that ionized PVD seedlayers exhibited better bottom and sidewall coverage than collimated seedlayers. Subsequent electroplating of contact structures did not indicate differences in the quality of the filling when observed using SEM. However electrical testing of 68000 dual damascene via chains did show improved chain yield for the ionized PVD deposited films. Cross-sections of the chains revelaed small voids at the bottom of the vias deposited using collimated seedlayers while no voiding was observed for the ionized PVD copper films. Finally SEM examinations of unfilled dual damascene cross-sections indicated the ionized copper seedlayers to be rougher as compared to copper films sputtered using collimation.

4:40pm **TF-MoA9 Steel Coating by Self-induced Ion Plating, a New High Throughput Metallization Ion Plating Technique***,* ***P. Vanden Brande****, A. Weymeersch,* Cockerill Sambre - RDCS, Belgium

Ion plating techniques present major advantages for continuous steel coating in terms of throughput and product quality when compared respectively to sputtering and vacuum evaporation techniques. However, the ion plating systems available on the market today are still cumbersome and present technological difficulties for immediate implementation in high throughput air-to-air continuous steel coating plants. To address these difficulties we have developped a new ion plating technique referred to as self-induced ion plating in order to produce continuous coating on flat products. This technique is essentially based on the generation of a magnetron discharge in the sputtered and evaporated vapour produced by a tin cylindrical target. Very high deposition rates were achieved (220µm/min) with moderate values of the electrical mean power density (45W/cm@super 2@) applied to the tin target. The magnetron configuration used allowed the reduction of material side losses. This was achieved by reducing the metal escape zone area on the target side. Another feature of this technique is that the control of the heat transfer between the target and its backing plate allows the control of the target surface temperature and hence the control of the sputtered and evaporated material fractions.

5:00pm **TF-MoA10 Analysis of Mode Transistions in I-PVD and Conventional PVD Reactive Sputtering of Refractive Diffusion Barrier Materials***, D.R. Juliano, R. Ranjan, D.N. Ruzic,* ***J. Norman****,* University of Illinois, Urbana-Champaign

I-PVD techniques have shown to be effective for the deposition of contact, barrier, adhesion and seed layers. For copper metallization such layers include Ti, Ta, TiN and TaN. In conventional PVD processes, reactive sputtering techniques have shown two important deposition modes, namely, metallic and poison modes. In the metallic mode the nitration occurs on the substrate whereas in the poison mode it occurs on both the target and the substrate. There are advantages and disadvantages of each. Mode transitions are compared between I-PVD and conventional PVD sputtering processes. The analysis includes measurements of plasma temperature and density using Langmuir probe techniques, as well as ionization fractions and deposition rates. A dc planar magnetron with a 33-cm diameter target is coupled with a secondary plasma source to ionize the sputtered metal neutral flux to control the angular distribution of the flux arriving at the surface of the substrate. The secondary radio-frequency (rf) plasma is created between the sputtering target and the substrate by a multi-turn coil located in the vacuum chamber. The rf plasma increases the electron temperature and density, which results in significant ionization of the neutral metal flux from the sputtering target. By applying a small negative bias to the substrate, metal ions are drawn to the substrate at normal incidence. A gridded energy analyzer and a quartz crystal microbalance (QCM) are embedded in the substrate plane to allow the ion and neutral deposition rates to be determined.

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