Monday Morning, November 2, 1998

Vacuum Metallurgy Division
Room 328 - Session VM+TF-MoM

Ionized-PVD: Processes, Properties, and Applications

Moderator: S.L. Rohde, University of Nebraska, Lincoln

8:20am **VM+TF-MoM1 Ionised PVD and Filtered Arc Deposition; Processes, Properties and Applications**, ***P.J. Martin***, *A. Bendavid,* CSIRO, Australia*; H. Takikawa,* Toyohashi University, Japan **INVITED**

Recent innovations in vacuum arc deposition have resulted in the development of the filtered arc source as a deposition tool for a range of technologically important materials. The vacuum arc was recognised early on as a potentially useful source of energetic, ionised material and a practical high rate method for depositing thin films with bulk properties and the deposition of new materials. The inherent problem of microdroplet contamination was overcome by several approaches, the toroidal magnetic duct being the most prevalent. The present state of the art of filtered arc deposition (FAD) is discussed in terms of the current understanding of the emitted fluxes, the properties of the materials deposited by these devices and new applications.

9:00am **VM+TF-MoM3 Transport of a Cathodic-Arc Plasma Through a Linear-Solenoid Macroparticle Filter**, ***B.P. Cluggish***, *B.P. Wood,* Los Alamos National Laboratory

A long standing problem in the use of cathodic arcs for deposition of coatings is the production of micron sized droplets, or "macroparticles," of the cathode material. These macroparticles hit and stick to the substrate, causing defects in the coating. One widely used method for "filtering out" the macroparticles is to guide the arc plasma through a solenoidal "magnetic duct" (a metal tube with an axial magnetic field.) The macroparticles travel in straight lines and thus hit and stick to the walls of the duct, rather than reaching the substrate. Unfortunately, most of the plasma ions are lost as well. For this reason, we are performing measurements to understand the transport of the plasma through a duct. The ion flux is found to decay exponentially along the length of the duct, and the magnetic field is crucial for reducing the ion losses. However, increasing the field strength above 50 G has no effect on the ion losses. Furthermore, unlike previous researchers @footnote 1@, we find that applying a positive voltage to the duct has little effect on the ion losses. We have developed a computer simulation which reproduces our results, and predicts that the injection conditions at the entrance to the duct are crucial in determining the ion losses. This work supported by the U.S. D.O.E. @FootnoteText@ @footnote 1@ A. Anders, S. Anders, and I. G. Brown, J. Appl. Phys., vol. 75, pp. 4900-4905, 1994

9:20am **VM+TF-MoM4 Characterization of Magnetron-Sputtered Partially Ionized Deposition as a Function of Metal and Gas Species**, ***M.M.C. Allain***, *D.B. Hayden, D.R. Juliano, D.N. Ruzic,* University of Illinois, Urbana-Champaign

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 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 attached to a pulley system that allows the ion and neutral deposition rates to be determined along the substrate plane. The ionization fraction of the flux incident onto the QCM can then be determined as a function of position. The ionization rate is a sensitive function of the metal's ionization potential (IP). The electron energy distribution in the plasma is affected by the metal being sputtered and the working gases' ionization and excitation potentials (EP). While keeping the magnetron power, rf coil power, target to substrate distance and pressure constant, the ionization fraction, as a function of position, has been measured. The electron temperature and density are measured using a Langmuir probe. The target metals analyzed in design of this experiment are aluminum(IP=5.98eV), copper(IP=7.72eV), and titanium(IP=6.82eV). The working gases will be krypton(IP=13.99eV, EP=1.702eV), argon(IP=15.76eV, EP=2.55eV), neon(IP=21.56eV, EP=3.52eV), and helium(IP=24.58eV, EP=5.36eV). An analytic model is compared to the experimental results.

9:40am **VM+TF-MoM5 Effects of Coil dc Potential on Ion Energy Distribution Measured by an Energy-resolved Mass Spectrometer in Ionized Physical Vapor Deposition**, ***E. Kusano***, *T. Kobayashi, N. Kikuchi, K. Fukushima, T. Saitoh, S. Saiki, H. Nanto, A. Kinbara,* Kanazawa Institute of Technology, Japan

In ionized physical vapor deposition, ion energy distribution is crucial to obtain films with desired properties. The energy distribution is supposed to be affected by the plasma potential that relates to the coil dc potential induced by an applied rf power. In this study, ion energy distribution of ionized Ti particles and Ar discharge gas has been measured by an energy-resolved mass spectrometer for various coil dc potential. The sputtering cathode used in the experiment was a conventional magnetron sputtering source with a Ti target (55mm@phi@). The cathode was coupled with an rf coil (60mm@phi@, made of Cu) generating an additional plasma in the region between the target and the substrate. The mass spectrometer was a Balzers PPM421 plasma monitor. The orifice to the ion optics was 0.1mm@phi@ and electrically grounded. The coil dc potential was controlled by changing the resistance of the resistor in the LCR circuit connecting the coil to the ground. The results showed that the energy of Ti@super +@ and Ar@super +@ was enhanced from a few eV to more than 100eV as a coil rf power increased from 0 to 200W for a constant cathode dc current. By changing the resistance of the LCR circuit, the peak of the energy spectra shifted from about 160eV for the resistance of 0@OMEGA@(the coil was grounded) to about 100eV for the resistance of 1k@OMEGA@. In addition, it was found that the total energy of Ti@super +@ or Ar@super +@ arriving to the spectrometer increased as the resistance decreased. The results suggest that the coil potential to the ground affect the plasma potential and thus the energy distribution of ions arriving to the electrically grounded substrate through the plasma sheath.

10:00am **VM+TF-MoM6 Modeling of Large Cluster Synthesis**, ***A. Hosseini-Tehrani***, *F.K. Urban III,* Florida International University

The original idea of the ionized cluster beam (ICB) thin film deposition technique was based upon producing, ionizing and accelerating beams of atoms clusters from vaporized material onto a substrate in a vacuum environment, using a supersonic jet source. Simulation of this process using classical nucleation theory and one dimensional gas flow equations will be presented. This approach is an extension of previous methods used for simulation of condensation of water vapor during supersonic expansion in nozzles and simulation mechanism of large clusters from vaporized solid materials. Zinc cluster sizes predicted by the model are in qualitative and quantitative agreement with our experimental results. Simulation results will be presented for different materials as well. Recently, other methods of synthesizing clusters and nanoparticles, using different types of cluster source, like magnetron sputtering mounted in a cooled chamber, have come under development. We are in the process of extending the model for the magnetron sputtering gas aggregation cluster source and will present new results for this process.

10:20am **VM+TF-MoM7 Combined Monte Carlo and Fluid Sputter Transport Model in an Ionized PVD System with Experimental Plasma Characterization**, ***D.R. Juliano***, *D.B. Hayden, M.M.C. Allain, D.N. Ruzic,* University of Illinois, Urbana

A code has been developed to model the transport of sputtered material in a modified industrial-scale magnetron. The device has a target diameter of 355 mm and was designed for 200 mm substrates. The chamber has been retrofitted with an auxilliary RF inductive plasma source located between the target and substrate. The source consists of a water-cooled copper coil immersed in the plasma, but with a diameter large enough to prevent shadowing of the substrate. The RF plasma, target sputter flux distribution, background gas conditions, and geometry are all inputs to the code. The plasma is characterized via a combination of a Langmuir probe apparatus and the results of a simple analytic model of the ICP system. A Monte Carlo routine in the code then tracks high energy atoms emerging from the target as they move through the chamber and undergo collisions with the electrons and background gas. The sputtered atoms are tracked by this routine whatever their electronic state (neutral, ion, excited). If the energy of a sputtered atom decreases to near-thermal levels, then it exits the Monte Carlo routine as is tracked with a simple diffusion model. In this way, all sputtered atoms are followed until they hit and stick to a surface, and the velocity distribution of the sputtered atom population (including state information) at each surface is calculated, especially the substrate. Through the use of this simulation the coil parameters and geometry can be tailored to maximize deposition rate and sputter flux uniformity.

10:40am **VM+TF-MoM8 Plasma Diagnostics of Magnetic Field Assisted Ionized Magnetron Sputtering*, J.H. Joo,*** Kunsan National University, Korea, South Korea

The effects of axial magnetic field generated by solenoid coil has been studied for controlling the capacitive coupling between RFI antenna and metallic chamber wall, which causes severe coil sputtering at high RFI power levels. From OES results, at small magnetic flux density of 8G, RFI plasma showed sharp drop of plasma potential and reduced emission from Cu coil. Also visually the RFI plasma was confined within the RFI coil area. We compared two types of coil materials, metallic and ceramic coated. The plasma potential varied very much with materials and RFI power, which will affect the incomming ion's energy distribution. Also pulsing the sputtering power was studied to control average electron temperature of the RFI plasma, where electrons are easily quenched by heavily sputtered metals. As time dependent measuring of the plasma parameters is not readily available, some metallic films were deposited with different duties and the resulting film properties were measured. There was a big difference in preferred orientations of the grown Ag films. And the effects of ceramic coating on the RFI antenna will be addressed in the view point of plasma diagnostics, electron temperatures, electron densities, plasma potentials, contaminations and the change when it is coated by sputtered metals. Also the impedance characteristics of the RFI plasma were measured by RFZ-60 impedance analyser to study the type of coupling in mixed plasmas of DC magnetron and RFI plasma.

11:00am **VM+TF-MoM9 Study of Thin Films Deposited from a Copper Beam Formed in an Argon Atmosphere Capable of Condensing Nanoparticles*, F.K. Urban,*** *A. Khabari, A. Housseini-Tehrani, P. Griffiths, G. Fernandez,* Florida International University

Although thin films formed from beams of nanoparticles or clusters have been discussed since the early 1970s, the question of the usefulness of this method has remained open as few films of any significant thickness have been formed to date. Early attempts did not condense, could only condense a few "high vapor pressure" solids, or were so low rate as to make growth too slow to be of use. A new deposition system has been designed and built here along the lines of those of Averback and Haberland, as they appear to have the most promise. The new system was specifically designed for high rate with a high throughput intermediate pressure pump and 2 kW capable sputter source. Preliminary films of copper deposited onto single crystal silicon substrates show a small beam divergence of less than 1 degree total. The beam is highly non-uniform with maximum intensity on-axis, which drops rapidly to zero within less than 10 mm off axis. Deposits have been made using a 1 Torr Argon + Helium sputtering and condensation atmosphere followed by nozzle aperture extraction. Films are affected by the amount of He and by cooling of the sputter chamber walls using liquid nitrogen. Nothing appears (detectable optically) on the substrate using Ar and no cooling and increases in both factors result in films of generally increased thickness. Optically transparent films of copper have been deposited but are not yet understood. SEM, TEM, and AFM results of Cu and other films will be presented.

11:20am **VM+TF-MoM10 Novel (111)-Textured AlCu Growth by Ionized Metal Plasma (IMP) Ti Underlayer*, J.-B. Lai,*** *L.-J. Chen,* National Tsing-Hua University, Republic of China*; C.-S. Liu,* Taiwan Semiconductor Manufacturing Company, Republic of China

(111)-textured AlCu is well known to possess better electromigration resistance than those of (200) and random orientations. In general, stronger (111)-textured AlCu can be obtained with the deposition of Ti underlayer compared with AlCu deposited directly on oxide or TiN underlayer. The improved texture is attributed to the small lattice mismatch between (0002)Ti and (111)AlCu. In this paper, (111)-textured AlCu (0.5 at. %) enhanced by Ti had been investigated using Auger electron spectroscopy, x-ray diffraction, transmission electron microscope, high-resolution transmission electron microscope, four-point-probe and EM test. Using thicker ion metal plasma (IMP) sputtered titanium underlayer was found to enhance the stronger growth of (111)-textured AlCu compared to conventional and collimated Ti films because of stronger (0002) textured-Ti was formed and hence the growth of (111)-textured AlCu was facilitated. However, TiAl@sub 3@, about 50 µm@OMEGA@-cm in resistivity, was found in the samples annealed at 400 °C. As the samples were annealed at 450 °C, a continuous but not smooth TiAl@sub 3@ precipitate layer was observed. If the precipitates of TiAl@sub 3@ were discontinuous and restricted to grain boundaries, the (111)-textured Al was destroyed and local joule heating caused the early failure of AlCu line. TiN, as a barrier layer, can retard the growth of TiAl@sub 3@. In our study, TiN/IMP-Ti was also found to enhance the stronger tendency of the growth of (111)-textured AlCu than TiN/collimated-Ti and TiN/conventional-Ti. The growth of (111)-textured TiN was enhanced by (0002)Ti. AlCu/TiN/IMP-Ti samples were observed to possess longer EM lifetime compared with those of AlCu/TiN/collimated-Ti (or conventional-Ti).

11:40am **VM+TF-MoM11 Plasma Polymerization of Fluorine Alloyed Amorphous Carbon Coatings*, A. Vanhulsel,*** *J.-P. Celis,* KU Leuven, Belgium*; E. Dekempeneer, J. Smeets,* VITO, Belgium

This paper reports on the deposition conditions and characterization of plasma polymerized fluorocarbon coatings grown by an inductively coupled r.f. plasma (ICP) source, using CH@sub 4@ and CF@sub 4@ as precursor gases. SiH@sub 4@, H@sub 2@or Ar were further added to the plasma to investigate their influence on the coating properties. The coatings were characterized by XPS to determine the surface and bulk composition and combined with FTIR-spectroscopy to reveal the structure of the coatings. The mechanical properties (hardness and Young's modulus) were measured by nano-indentation. The surface energy was obtained by contact angle measurements with 2 different liquids. By varying the deposition conditions, we were able to deposit coatings with surface energies as low as 14 mN/m. With the appropriate feed gases and process parameters it is possible to adjust separately the polar and dispersive part of the surface energy. A low polar component of the surface energy corresponds to a high fluorine ,CF@sub 3@and CF@sub 2@ content at the surface of the coatings. The wetting behaviour of the coatings against water is mainly dependent on the polar component. The maximum contact angle achieved was 113°. By adding H@sub 2@ to the plasma, it is possible to minimize the polar component and maximize the dispersive component of the surface energy to obtain a relatively hard (3 GPa) coating with a hydrophobic nature (contact angle (H@sub 2@O) = 90°). The fluorocarbon coatings deposited in this system are not sensitive to atmospheric aging.

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