Thin Films Division
Room 310 - Session TF-WeA
Advances in Sputtering
Moderator: S. Zarrabian, Optical Coatings Laboratories, Inc.

2:00pm **TF-WeA1 Preferential Sputtering Effects in Thin Film Processing***,* ***S. Berg****, I.V. Katardjiev,* Uppsala University, Sweden **INVITED**

Predicting the partial sputtering yield (number of sputtered atoms of one element per one incident ion) for the different constituents during sputtering from a multielemental surface is a rather difficult task. For an alloy bulk target where no diffusion takes place, however, it can at least be assumed that the ratio of the outsputtered elemental fluxes is exactly equal to the corresponding composition ratio of the target bulk. During bias sputter deposition from an alloy target, however, the composition of the deposited film may deviate strongly from the target composition due to preferential re-sputtering of one (or more) elements from the growing compound film. We will present a systematic study that serves to clearify how and why some atomic elements are preferentially sputtered from a multielement matrix. By using a Monte Carlo based computer simulation program (T-DYN) it is possible to simulate the evolving collision cascades in the bombarded material and thus study the sputtering process in its dynamics. The results from such computer simulations indicate that the partial sputtering yield of one element in a multielement matrix depends in a systematic way on the atomic density of the material, the atomic number of the atomic elements and the projected range of the incoming energetic ion. Furthermore, from this study we have found out that it is possible to "tune" the partial sputtering yield of one element in a multielement matrix. The "tuning" effect can be quite dramatic. Adding a few percent of e.g. W to a pure Al target may increase the Al sputtering yield by as much as 100% as compared to the sputtering yield of pure Al. Other interesting effects caused by "controlled preferential sputtering" will also be demonstrated.

2:40pm **TF-WeA3 Measurements and Modeling of Ti and Ta Sputtering as a Function of Target Microstructure and Temperature***,* ***J.P. Allain****, D.A. Alman, D.N. Ruzic,* University of Illinois, Urbana-Champaign

The angular distribution of sputtered material and the absolute sputtering yield of metal targets by argon ions at energies less than 1000 eV has been measured in previous work for a number of materials.@footnote 1@ The use of titanium and tantalum films are continually applied as effective underlayers for both barrier and enhanced metallization properties. This paper focuses on the influence of target microstructure and temperature on the sputtering and angular distribution yields. A Colutron ion gun is used to produce an ion beam which is decelerated near the target. The beam diameter near the target is modified so as to focus on a single grain. The beam diameter can also cover several grains including grain boundaries. Grain boundary density and orientation is studied on its effect on the distribution and yield. The diagnostics near the target can be rotated to intercept the sputtered flux. The diagnostics consist of a quartz crystal oscillator to measure total yield and a cylindrical pyrolytic graphite collector plate. The graphite plate is analyzed by an PHI Auger spectrometer to obtain areal densitites and thus the angular distributions. The target assembly is fixed and monitored by a thermocouple. A "cold finger" which can deliver liquid N2 is attached to the target. Modeling of the system is used by an enhanced version of VFTRIM3D, a code which includes fractal geometry and a non-binary collision model.@footnote 2@ @FootnoteText@ @footnote 1@W. Eckstein, C. Garcia-Rosales, J. Roth, W. Ottenberger, "Sputtering Data", pub. Max-Planck-Institut Fur Plasmaphysik, February 1993. @footnote 2@D.N. Ruzic, Nucl. Instrum. Methods B 47 (1990) 118.

3:00pm **TF-WeA4 Reactor-Scale Models for Rf-Diode Sputtering for GMR Thin-Film Growth***,* ***S. Desa****, S. Ghosal, R.L. Kosut, J.L. Ebert, A. Kozak, T.E. Abrahamson,* SC Solutions*; J.F. Groves, H.N.G. Wadley, D.W. Zou,* University of Virginia

This paper describes the development of a physical model for the Rf-diode sputtering of GMR thin-films. The model consists of: (1) a CFD finite element model for the velocity and pressure distribution of the Argon (Ar) gas flow in the chamber, (2) a steady-state plasma model for the flux and energy of Ar ions striking the target and the substrate, (3) a molecular dynamics (MD) sputtering model for the energy distribution, angle distribution, and yield of the Copper (Cu) atoms sputtered from the target by the Ar ions, and (4) a Direct Simulation Monte Carlo (DSMC) model for the transport of Cu atoms through the low-pressure argon gas to the deposition substrate. The individual models for gas flow, plasma discharge, Cu sputtering, and DSMC-based Cu atom transport are then integrated to create a detailed, steady-state, input-output model capable of predicting thin-film deposition-rate and uniformity as a function of the process input variables: power, pressure, gas temperature and electrode spacing. (Deposition and uniformity in turn define well-known device characteristics such as H@sub sat@ and GMR ratio.) The paper also describes the development of an approximate input-output model whose CPU time is several orders-of-magnitude faster than that of the detailed model. Both models were refined and validated against experimental data obtained from an actual GMR chamber.

3:20pm **TF-WeA5 Using Pulsed DC Power for Reactive Sputtering of Al@sub 2@O@sub 3@***,* ***A. Belkind****, A. Freilich,* Stevens Institute of Technology*; R. Scholl,* Advanced Energy Industries

Implementation of reactive sputtering of dielectrics such as Al@sub 2@O@sub 3@ by the use of steady DC power is obstructed by arcing. The arcing appears to be due to breakdown of the dielectric (oxide) films that grow on the metal target surface and which accumulate positive charges on their surfaces due to ion bombardment. The arcing can be greatly alleviated when pulsed DC power is applied. By pulsed DC power we mean that the power is applied for a short "on" period, and then removed for a short "off" period. During the "off" period the plasma can discharge the surfaces, provided certain conditions are met. The dependence of adequate discharging, and thus arc prevention, on the duration of the "on" and "off" periods is examined. In addition, the dynamics of plasma density loss in the "off" period and its re-establishment in the initial part of the "on" period are discussed. Reactive sputtering takes place only during the "on" period, and part of this period is lost for effective sputtering due to the necessity for full plasma re-establishment. This produces a dependence of the deposition rate on both the duty cycle and the frequency of pulsing, but not on the power. This dependence is examined and the power efficiencies of AC and pulsed power DC reactive sputtering are compared and speculation made as to the differences in results published between single and dual cathode systems.

3:40pm **TF-WeA6 Suppression of Hillocks and Whiskers on Al Films Deposited onto a Glass***,* ***H. Saka****, Y. Suzuki,* Nagoya University, Japan*; H. Takatsuji, K Tsujimoto,* IBM, Japan*; K. Kuroda,* Nagoya University, Japan*; S. Tsuji,* IBM, Japan

A new technique to suppress formation of hillocks and whiskers on an Al film deposited onto a glass substrate has been developed. First, an Al film was deposited on a LCD-grade glass substrate by industrially conventional dc magnetron sputtering. Heating this films above 573K resulted in formation of a number of hillocks and whiskers. Onto this Al film another layer of Al film was deposited by rf magnetron sputtering. When the thickness of the second Al layer is very thin, many hillocks and whiskers are formed on heating. However, when the thickness of the second Al layer is around 40nm, the formation of both hillocks and whiskers are completely suppressed. Cross-sectional TEM observation revealed that the second layer of Al deposited by rf sputtering is amorphous. The sheet resistance of the second layer was measured by van der Pauw method to be 3.5 x 10@super-6@ ohm cm.

4:00pm **TF-WeA7 Substrate Bombardment and Heating in Dual Magnetron Sputtering Using Mid-Frequency AC***,* ***J. Plaisted****,* Kinneo*; G.W. McDonough, G.A. Roche,* Advanced Energy

Dual magnetron sputtering (DMS) using mid-frequency AC has become a popular method for the reactive deposition of dielectrics. However, several studies have reported higher levels of substrate bombardment and heating with the use of this technique. In an effort to determine the cause, we separated the effects of plasma ignition from those of the anode arrangement. The anode arrangement employed in mid-frequency DMS was duplicated in DC operation using a pair of opposed magnetrons powered by a floating output generator. Values of the substrate self-bias, ion current, and temperature were compared to those obtained from running the sources with 40 kHz AC and standard DC techniques. Results indicate that a large fraction of the energetic species found in mid-frequency DMS can be explained by a restriction of the anode surfaces to the paired magnetrons.

4:20pm **TF-WeA8 A Novel Approach to Collimated Physical Vapor Deposition***, A.P. Paranjpe,* ***D. Heimanson****, J.C.S. Kools, P.V. Schwartz, K. Song, B. Bergner, S. McAllister,* CVC

In some applications of Physical Vapor Deposition (PVD), it is desirable to have the atoms arriving at the substrate at angles close to the normal (collimation). Applications of collimated PVD include filling of highaspect ratio vias, as used in multilevel IC metallization, or high resolution shadow masking as used in lift-off technology. Several approaches to collimation have been proposed in recent years: natural (or long throw) collimation, physical collimation, ion beam deposition ionized PVD and hollow cathode collimation. In this contribution, we introduce a novel approach to collimation. It is found experimentally that this approach leads to a strongly improved degree of collimation when compared to the conventional collimation methods. Contrary to ion beam deposition and ionized PVD, our approach allows to vary the kinetic energy of the sputtered atoms arriving at the substrate over a wide range. Simulations of the target-to-substrate atom transport using the Simbad package show that the improved collimation method leads to angular distributions with Full Widths at Half Maximum (FWHM) below 20 degrees.

4:40pm **TF-WeA9 Microcrystalline Silicon Thin Films Deposited By Low Temperature Reactive Magnetron Sputtering: The Effect Of Using Deuterium vs. Hydrogen***, **J.E. Gerbi**,* University of Illinois, Urbana-Champaign*; D.S. Kim,* SAIT, Korea*; G. Ben Amor,* Ecole Polytechnique, France*; J.R. Abelson,* University of Illinois, Urbana-Champaign

Microcrystalline silicon (uc-Si:H) thin films are of interest for macro-electronic technologies: they can serve as optical absorber or doped contact layers in solar cells, or as the nucleation layer in the direct deposition of polycrystalline silicon on glass for thin film transistors.@footnote 1@ The grain size, shape, and defect density significantly modify the electronic properties of uc-Si:H; therefore, it is highly desirable to control the film microstructure through the growth process. We previously showed that DC reactive magnetron sputtering (RMS) of a Si target produces uc-Si:H films when sufficient H@sub 2@ is added to the Ar working gas. In the sputtering plasma, H@sub 2+@ ions are accelerated towards the Si target and reflect as fast neutral H atoms, which impinge on the growing film and implant to a depth of ~ 50Å. This large flux of fast H atoms provides unique control over the nucleation and growth of the uc-Si:H phase.@footnote 2@ In this work, we explore the effects of using D@sub 2@ instead of H@sub 2@ to grow uc-Si:H films on glass at a substrate temperature of 230°C. The substitution of D@sub 2@ for H@sub 2@ lowers the partial pressure at which the microcrystalline regime is entered, and produces films with a higher degree of crystallinity throughout the entire pressure range investigated. Crystalline nucleation and the grain-size dependent electronic structure are observed in real time using spectroscopic ellipsometry. We report post-deposition TEM, Raman spectroscopy, and electrical characterizations. To explain the implantation-related isotope effect, we present binary collision (TRIM) simulations of the energy distribution, range, and recoil behaviors of the H vs. D neutral fluxes, and their resultant dynamic concentrations in the film. @FootnoteText@ @Footnote 1@Y. H. Yang and J. R. Abelson, Appl. Phys. Lett. 67, 3623 (1995). @Footnote 2@Y. H. Yang, M. Katiyar, N. Maley, and J. R. Abelson, Appl. Phys. Lett. 65(14), 1769 (1994).

5:00pm **TF-WeA10 Atomistic Simulations of the Sputter Deposition of Copper***, **W. Zou**, J.F. Groves, X.W. Zhou, H.N.G. Wadley,* University of Virginia

RF Diode sputter deposition is being explored for synthesizing metal and magnetic multilayer films. A discrete simulation Monte Carlo binary collision model has been developed to analyze the spatial uniformity and impact velocity of individual vapor atom with a substrate. The analysis began with the calculation of ion-impact with a metal target using Molecular Dynamics simulations. This provided both the initial energy distribution of vapor atom and its angular distribution immediately upon their sputter emission from the target. The model then used input conditions such as background pressure, temperature, gas type, and reactor geometry in combination with a discrete simulation Monte Carlo method to analyze vapor atom transport to the substrate. Results are shown of vapor atom deposition efficiency, the spatial distribution of the film thickness, the impacting atom energy and the impact angle distribution of the vapor atoms. These vapor transport model results provide a link between the microstructure of thin films and the deposition process conditions, and can be used for reactor design and control.

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