Plasma Science and Technology
Room 302 - Session PS+TF-ThA

Emerging Plasma Applications

Moderator: H. Barankova, Uppsala University, Sweden

2:00pm **PS+TF-ThA1 Emerging Plasma Deposition Applications**, ***D.P. Monaghan***, Gencoa, UK **INVITED**

Vacuum plasma deposition has been the mainstay of the thin film industry since its inception. In particular magnetron sputter based processes have come to the forefront due to the inherent stability and scalability of the technique. However, the method has to constantly re-invent itself in order to provide better solution for the ever-changing world of micro-electronics and consumer products. New generations of products are also being created that rely partly or completely on new sputter based processes. This in turn can require radical changes to the usual production methods. The presentation will highlight the state-of-the art in sputter technology and in particular a number of areas that will drive further market expansion and technical advancement in the field. Some examples will include thin film batteries where virtually every feature relies upon sputtered layers of a low or high tech. nature. Due to the miniature and highly efficient nature of the product, it opens up the possibility of providing "power" to many new product classes and new devices. Thin film solar cells that have the ability to create efficient conversion of energy via a low cost and lightweight structure may lead to a reduction of societies dependence upon fossil fuels. The introduction of vertical magnetic recording comes ever closer if longitudinal recording is limited to <200 Gbit/in2. Vertical recording can potentially achieve terabyte recording density, but places much higher demands on the process equipment and magnetron source technology. Another high growth area is display technology. The emergence of high definition large area LCD displays puts a corresponding demand upon the digital video disk storage capacity. New disk formats such have Blu-ray have been shown to offer up to 3x the storage capacity. In addition the possibility of a high and low video formats on a single disk means the creation of two separate recording media in a single production process.

2:40pm **PS+TF-ThA3 Investigating the Plasma-Propellant Interaction through Experimental Modeling**, ***R. Valliere***, *R. Blumenthal,* Auburn University

There has been a significant interest in the use of plasmas to ignite propellants in large bore artillery. A short, reproducible ignition delay and a reduced temperature dependence are the most important advantages of plasma ignition over conventional ignition. Using the experimental modeling method, pioneered by Winters and Coburn,@footnote 1@ the erosion rates of sprayed-on films of RDX and HMX have been investigated in inert and reactive plasmas, as a function of sample bias in order to isolate the ion and electron bombardment and chemical effects on the erosion rate. No significant erosion rate was observed in argon plasmas with zero or positive bias, indicating that erosion by electron bombardment alone is not significant. Under ion bombardment conditions, large negative bias, only a slow erosion rate (presumably due to sputtering) was observed. Erosion in hydrogen plasmas is quite different. The minimum erosion rate, observed at positive and zero sample biases, was ~100x the maximum rate observed in negative-biased argon plasmas. Under negative bias the erosion rate increased as a much as 20-fold, depending on a combination of ion current and sample bias. All observed erosion rates obey pseudo-first order kinetics. The fact that the erosion rates in the hydrogen plasmas are all much greater than the rates of the argon plasmas, even at large negative bias, indicates a strong chemical component to the erosion process. The bias and current dependence of the erosion rate in hydrogen plasmas indicate a synergistic effect between ions and reactive neutrals. The kinetics of erosion for the individual species and the synergistic effects between them will be presented. @FootnoteText@ @footnote 1@ H.F. Winters, and J.W. Coburn, JVSTB @bold 3(5)@, 1376 (1985).

3:00pm **PS+TF-ThA4 PECVD of SiO@sub 2@ Thin Film from Electron-Beam Generated Plasmas**, ***D. Leonhardt***, *S.G. Walton,* US Naval Research Laboratory

The deposition of thin films of SiO@sub 2@ is an integral part of flexible displays/electronics, medical implant bio-functionalization, as well as a robust barrier layer ideal for space applications. In all of these applications, the SiO@sub 2@ layer must be uniform and defect free over large areas. Typical plasma-based deposition technologies that are presently used have limitations in both the quality of material being deposited and the uniformity over large (square meter) areas. NRL has used electron beam-generated plasmas to produce a variety of SiO@sub x@ films, with the focus on PECVD processes for temperature sensitive substrates that are scalable to large areas. Mixtures of TEOS or HMDSO with Ar/O@sub 2@ based plasmas were used to grow films in modulated electron beam generated plasmas. The inherent low electron temperature of these plasmas results in low plasma fields and potentials, which in turn provide low energy (< 3 eV) ions to the substrate. The resultant film electrical, optical and chemical properties with respect to gas mixtures, substrate temperature and ion energy will be presented. The low ion energies were critical in producing films with lower defect densities than typical SiO@sub 2@ deposition processes. Using the ion energy as an additional process control 'knob' the film composition ranged from stoichiometric SiO@sub 2@ to heavily hydrolyzed. Fluxes to the substrate determined by mass spectrometry measurements will be correlated to these process variables and final film composition. Along with a highly tunable PECVD process, these plasmas offer tremendous scaling and uniformity capabilities that will also be discussed.

3:20pm **PS+TF-ThA5 Nanoparticles and Nanocoatings from Plasmas: Old Problems with a New Twist**, ***K.P. Giapis***, California Institute of Technology **INVITED**

The formation of particles in processing plasmas has generally been related to contamination and lower yields and is considered undesirable. However, nanometer-size particles can have unusual properties, very different from those of bulk materials, which makes them attractive for nanotechnology applications. We have explored the formation of Si nanoparticles in continuous-flow atmospheric-pressure dc microdischarges confined in capillary tubes. The intensity and size of these discharges permits the rapid decomposition of silane, leading to nucleation and growth of 1-3 nm Si particles, whose growth is abruptly terminated as they exit the microreactor. Narrow size distributions are obtained as inferred from classification and imaging. Particles of both charge polarities are detected with similar size distribution but 2X more positively charged particles. As-grown Si particles luminesce in the blue (420nm) with a quantum efficiency of 30% and may find applications in imaging and Si-based optoelectronics. The microdischarge synthesis route is generic to any gas-phase precursor and has been also used to grow Ge and Fe nanoparticles of 1-3 nm in size in benchtop setups. Nanowires and nanotubes are promising as nanoprobes, provided they can be coated with insulating materials followed up by tip end exposure and functionalization. We have used inductively-coupled plasmas to deposit conformal fluorocarbon coatings of a few nm thickness on carbon nanotubes. The coatings provide good insulation while they improve the rigidity of the nanotubes for surface imaging. We will present results from probe immersion experiments in Hg and water. Plasmas provide a versatile way to deposit a wide variety of extremely thin coatings to enable passivation, isolation, or functionalization at the nanoscale.

4:00pm **PS+TF-ThA7 Effect of Substrate Material on Properties of TiN Films Deposited in the Hybrid Plasma Reactor**, ***L. Bardos***, *H. Barankova, L.-E. Gustavsson,* Uppsala University, Sweden

Parameters of TiN films deposited in the hybrid hollow cathode and microwave ECR plasma reactor can be strongly affected by the substrate material. Differences have been found between films grown on Si substrates and steel substrates, as well as between steel substrates from martensite and austenite steels. Temperature measurements by simple probes made from different materials with surfaces covered by wafers from Si or from steel confirmed substantial differences depending on individual materials. These differences can be explained by material-dependent absorptions of the microwave power as well as by enhanced particle bombardment of ferromagnetic substrates connected with deformation of the magnetic field in the hybrid plasma reactor. The effect of surface bombardment has been confirmed by voltage current measurements using electrically biased probes. The results correspond well with properties of the obtained TiN films. Observed effects could be of more general importance, e.g. for microwave ECR plasmas, magnetron sputtering as well as for most magnetized plasma systems.

4:20pm **PS+TF-ThA8 Synthesis of Aligned Carbon Nanotubes by RF-Plasma-Assisted DC Plasma Chemical Vapor Deposition**, ***Y. Hayashi***, *T. Fukumura,* Kyoto Institute of Technology, Japan; *R. Utsunomiya,* Nissin Electric Co. Ltd., Japan

Aligned carbon nanotubes (CNTs) grown on a substrate are expected to be applied to the electron emitters of a field emission display. Plasma-enhanced chemical vapor deposition (plasma CVD) enables highly aligned growth of multi-walled CNTs by drawing them toward plasma in the sheath electric field.@footnote 1@ However the problem of aligned CNT growth by plasma CVD is large-area growth. We have developed a new method of large-area growth of CNTs under stable DC plasma sustainment without arcing by the assistance of RF plasma. Plates of RF electrode, a grounded electrode, and DC cathode were placed parallel in this order in a vacuum chamber. The grounded electrode was gridded so as to pass a part of the RF generated plasma into the space of DC discharge. Iron substrates were placed on the cathode electrode. 13.56 MHz RF power of 500 W was induced to the RF electrode and negative bias of 325 V was induced to the cathode electrode. 20 % methane diluted in hydrogen was introduced into the chamber with the operating pressure of 1000 Pa during the growth of CNTs. Well-aligned carbon fibers were observed by scanning electron microscopy and about 50 concentric layers of graphite with hollows were observed by transmission electron microscopy. These results confirm that CNTs can be synthesized by this method. DC discharge current was 0.7 A at the discharge voltage of 325 V under the assistance of 500 W RF-plasma, while it was 0.57 A without RF-plasma. The decrease of discharge impedance caused the stable sustainment of DC glow discharge without arcing. It is concluded that the large-area growth of well-aligned CNTs under the stable sustainment of DC glow discharge can be carried out by RF-Plasma-Assisted DC Plasma CVD. @FootnoteText@ @footnote 1@Y. Hayashi, T. Negishi and S. Nishino, J. Vac. Sci. Technol. A19, 1796(2001).

4:40pm **PS+TF-ThA9 In Situ Oxidation and Plasma Studies for Magnetic Tunnel Junctions: The Mechanism of Plasma Oxidation of Ultra-Thin Aluminum Films Unraveled***, M.C.M. Van De Sanden,* Eindhoven University of Technology, The Netherlands*; K. Knechten,* Oce Technology, The Netherlands*; B. Koopmans, H.J.M. Swagten, W.J.M. de Jonge,* Eindhoven University of Technology, The Netherlands

Plasma oxidation of thin aluminum films is a commonly used technique to form thin aluminum oxide barriers for application in magnetic tunnel junctions (typically 1 nm). In this technique a glow discharge in oxygen (P = 5-12 W, p = 5-40 Pa) is used to oxidize ultra thin sputtered aluminum films. In comparison with thermal oxidation the process is faster and provides high values of tunneling magnetoresistance (TMR) but at the cost of higher resistance-area products (RxA). However, whereas thermal oxidation of thin aluminum films is well understood in terms of the original model of Cabrera, where the oxidation rate is limited by field-assisted thermal 'hops' of aluminum ions into the oxide, the detailed mechanism of plasma oxidation of thin aluminum films is still unknown. To unravel the mechanism in situ measurements of the oxidation rate and plasma parameters such as the ion and oxygen density are performed. The oxidation rate is determined from single wavelength ellipsometry. From these measurements we have concluded that not one single particle in the plasma is responsible for the increase in oxidation rate observed. A clear correlation of the oxidation rate with the ion flux towards the sample is observed. In addition the oxidation rate is also correlated with the atomic oxygen density in the gas. These results can be explained within a modified Cabrera model of oxidation in which the oxidation temperature is locally enhanced due to the thermal spike of an impinging ion. Additionally, due to the presence of atomic oxygen in the plasma, the field over the oxide during oxidation is enhanced by the increased adsorption of atomic oxygen on the oxide surface. Including both effects in an adjusted equation for the oxidation rate provides a good agreement between model and experiments. The model provides new insights into plasma based oxidation of ultra thin films and offers oppertunities to further control the quality of the tunnel barrier.

5:00pm **PS+TF-ThA10 High Density Plasma Processing of Si Nanocrystal Embedded SiO@sub x@ Thin Films***, P.C. Joshi,* SHARP Labs of America, Inc., US*; T.K. Li, W. Gao, Y. Ono, A.T. Voutsas, J.W. Hartzell, S.T. Hsu,* SHARP Labs of America, Inc.

The optical properties of Si nanocrystals are of interest for efficient and low cost integrated optoelectronic applications. The fabrication of novel optoelectronic devices, exploiting the unique optical properties of Si nanocrystals, requires thin films with high PL/EL quantum efficiency. One approach that is being actively pursued for optoelectronic devices is the fabrication of Si nanocrystal embedded SiO@sub x@ thin films. The development of stable and reliable optical devices requires thin films with high concentration and uniform distribution of Si nanocrystals with controlled particle size. In this paper, we report on the high-density plasma processing of Si nanocrystal embedded SiO@sub x@ thin films. The high-density plasma technique is characterized by low plasma potential, high plasma density, and independent control of plasma energy and density; which provide unique process possibilities and control. The high plasma concentration and low plasma potential of the HDP process are attractive for the generation of Si nanocrystals while minimizing the plasma induced bulk and interfacial damage. We have been successful in controlling the optical properties SiO@sub x@ thin films and the wavelength of the emitted PL signal over a wide range exploiting the unique characteristics of the high-density PECVD technique. The present paper describes a correlation between the optical properties and the PL characteristics of the SiO@sub x@ thin films deposited in the temperature range of 25-300 °C. The high-density plasma deposited SiO@sub x@ films have shown PL signal even in the as-deposited state while subsequent annealing (900-1100 °C) has resulted in significant enhancement of the PL intensity. The present results demonstrate the potential of the high-density PECVD technique for the low temperature processing of the Si nanocrystal embedded SiO@sub x@ thin films with controlled physical and optical characteristics for novel optoelectronic applications.

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