Thursday Afternoon, November 3, 2005

Thin Films
Room 306 - Session TF+EM-ThA
Transparent Conducting Oxides

Moderator: S. Gupta, The University of Alabama

2:00pm **TF+EM-ThA1 Transparent Conducting Oxides***, J.C.C. Fan,* Kopin Corporation **INVITED**

Transparent Conducting Oxides (TCO) have enormous practical applications in energy-conserving heat mirrors, in solar-energy collectors, solar photovolactic and in electronic devices such as liquid crystal displays and light-emitting diodes. These oxides which are transparent in the visible spectrum are yet electrically conducting have been around for many decades. The most popular ones are In2O3-doped with Sn, and SnO2-doped with Sb. These two classes of TCOs have been extensively researched for many years and their results and applications will be reviewed. In addition, there are newer TCOs in the fields, such as MoO3, ZnO, and others. Their status and potential will also be discussed.

3:00pm **TF+EM-ThA4 Study on Initial Growth Process of Transparent Conductive Oxide Films Deposited by dc Magnetron Sputtering***, Y. Sato, M. Taketomo, A. Miyamura, Y. Shigesato,* Aoyama Gakuin University, Japan

It has been noticed that surface defects such as spike or pinhole of transparent conductive oxide (TCO) films should cause the degradation on the performance of organic organic light emitting diode (OLED) displays as appearances of dark-spots. In order to improve their performances, the film surface morphology has been required to be extremely flat. Such surface morphology should be highly related to the initial growth processes of the thin film electrodes. In this study, we investigated the early stages of film growth of representative TCO films such as ITO (Tin doped Indium oxide), IZO (Indium Zinc oxide) and GZO (Gallium doped Zinc oxide) deposited by sputtering. These films with thickness of 5-200 nm were deposited on unheated non-alkali glass substrates by dc magnetron sputtering under a various total gas pressures of Ar/O@sub 2@ mixture gases. The surface morphology of the films was analyzed quantitatively by atomic force microscope (AFM). The average roughness (Ra) of ITO and GZO films with the nominal thickness of 5 nm, deposited under 1.0 Pa, reached maximum of 0.4 and 0.8 nm, respectively. Ra of the both films decreased and remained constant around 0.2 and 0.4 nm, respectively, with the farther increase in thickness larger than 25 nm. These trends implied that three dimensional (Volmer-Weber) growth occurs for the polycrystalline ITO or GZO films, i.e. after an initial nucleation, an island structure grew and coalesced with each other with increasing film thickness. This expectation is consistent with the electrical properties of these films. On the other hand, Ra for the amorphous IZO film remained constant with the increasing nominal thickness from 5 to 200 nm. It must be considered that a nucleation density of IZO film should be much higher than those of ITO or GZO films. This work was partially supported by a Grant-in-Aid for 21st COE Program from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of the Japanese Government.

3:20pm **TF+EM-ThA5 Transparent Conducting Oxide Deposition using Closed Field Reactive Magnetron Sputtering***, **J.M. Walls**, D.R. Gibson, I. Brinkley, E.M. Waddell,* Applied Multilayers Ltd, UK

Magnetron Sputtering has many advantages for the deposition of optical coating materials. The sputtering process is "cold", making it suitable for use on the widest range of substrates including damage sensitive polymers. This paper will describe a "Closed Field" reactive sputtering process that allows high quality, transparent conducting oxide (TCO) thin films to be deposited at high rates. In contrast to previous reactive dc sputtering strategies the Closed Field process does not require a separate energetic ion or plasma source. The Closed Field automatically creates a magnetic confinement that extends electron mean free paths and leads to high ion current densities (>1mA.cm@super -2@). The combination of high current densities with ion energies in the range 15eV to 30eV creates optimum thin film growth conditions. As a result the films are dense, spectrally stable and exceptionally smooth (rms roughness

3:40pm **TF+EM-ThA6 Effect of Dendrimer Underlayers on Sputtered Indium-Tin Oxide Thin Film Microstructure, Morphology, Optical and Electrical Properties***, **R. Thunuguntla**, S. Gupta, S. Street,* The University of Alabama*; D. Loy,* The Army/ASUFlexible Display Center

Minimization of surface roughness is extremely important for sputtered indium-tin oxide (ITO) films used for organic light-emitting diode (OLED) applications. One of the techniques used to achieve smooth ITO films is the optimization of process parameters together with injection of cesium vapor into the plasma -- the recently-introduced negative sputter ion beam or NSIB process.@footnote 1@ We have investigated an alternative simpler approach -- the application of dendrimer monolayers by dip- or spin-coating techniques prior to ITO sputter deposition at ambient temperatures. The ITO films have been characterized by X-ray diffraction (XRD) and atomic force microscopy (AFM), and the film microstructure and morphology have been correlated with the optical and electronic properties such as transmission, resistivity, mobility and carrier concentration. The presence of the dendrimer underlayer appears to mediate the film roughness by grain size reduction and improved adhesion. The greatest effect is seen in films sputtered at low powers. This is expected, since a high level of ion bombardment is expected to damage or destroy the dendrimer underlayer. The observed improvement is most encouraging for flexible display applications, where good film properties and low surface roughness are required at low deposition temperatures. @FootnoteText@ @footnote 1@ M. H. Sohn et al., J. Vac. Sci. Technol. A21(4), 1347 (2003).

4:00pm **TF+EM-ThA7 Ferromagnetic Behavior in Indium Oxide Based Transparent Semiconductors***, J. Moodera,* Massachusetts Institute of Technology **INVITED**

Ferromagnetic semiconductors are expected to provide smooth transition for spin injection and transport needed for spin based technology leading to multifunctional devices of the future. Although the field of dilute magnetic semiconductors has been explored for a long time, in recent years there is increased activity due to the significant increase in the ferromagnetic ordering temperature (T@sub c@) of Ga@sub 1-x@Mn@sub x@As system and in various doped oxide systems, despite the existing skepticism in the latter area. We have observed ferromagnetism well above room temperature in Mn doped indium-tin oxide (ITO), Cr doped indium oxide (IO) as well as Mn doped zinc oxide films by reactive evaporation as well as sputtering. Films grown on sapphire (0001) and on silicon show excellent magnetic behavior with a moment ranging from 1 to 5µ@sub B@ for low concentrations of the dopant. Mn doped ITO and Cr doped IO are highly transparent as well as conducting. The electrical conduction is n-type with a carrier concentration in the range of 10@super 18@ to 10@super 20@ cm@super -3@. The charge carriers are seen to be spin polarized shown by the presence of anomalous Hall effect, revealing the magnetic interaction between itinerant electrons and localized Mn or Cr spins. What is interesting in these compounds is that the charge carriers can be independently varied independent of the dopant by the oxygen or the tin concentration in this transparent semiconductor for its easy integration into magneto-optoelectronic devices. In this talk the status of the field will be reviewed and compared with our work. Work carried out in collaboration with John Philip and Nikoleta Theodoropoulou. Supported by the CMI funds at MIT and NSF funds.

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