Friday Morning, October 19, 2007

Thin Film

Room: 602/603 - Session TF1-FrM

Thin Films for Displays and Flexible Electronics

Moderator: M.A. Creatore, Eindhoven University of Technology, The Netherlands

8:00am **TF1-FrM1 Effects of Processing Parameters on Electroluminescence of RF Magnetron Sputter Deposited ZnS: ErF_3,** *D.M. DeVito, A.A Argun, E.S. Law,* University of Florida, *M. Puga-Lambers, M.R. Davidson,* Microfabritech, ***P.H. Holloway***, University of Florida

ZnS:ErF_3 alternating current thin film electroluminescent (ACTFEL) devices were fabricated by RF plasma magnetron sputtering. In a full factorial design-of-experiment study, increasing deposition temperature, duty cycle on the doped target and sputter gas pressure all resulted in increases in the 1.55 μm near infrared (NIR) electroluminescence (EL) irradiance at 20V above threshold (B_{20}). An increase in the EL threshold voltage (V_{th}) upon increasing the duty cycle of the undoped target was also observed. Post-deposition annealing of ACTFEL devices at 425°C for 1 hr improved the NIR EL irradiance by decreasing the F concentrations in the ZnS:Er films. The origins of these effects are discussed in terms of negative ion resputtering, surface mobility of sputtered species, crystallinity, and the effects of atomic concentration upon the EL and radiative relaxation processes. A maximum irradiance, B_{20}, of 147 μW/cm^2 is measured for the 1.55 μm NIR EL peak from a ZnS:Er ACTFEL devices produced using a deposition temperature of 150°C, a duty cycle of 75%, an argon sputtering gas pressure of 24 mTorr and post-deposition annealing at 425°C for 1 hour in nitrogen.

8:20am **TF1-FrM2 Local Compositional Environment of Er in ZnS:ErF3 Thin Film Electroluminescent Phosphors**, ***M.R. Davidson***, University of Florida, *S. Stoupin*, Illinois Institute of Technology, *D.M. DeVito*, Oak Ridge National Laboratory, *C. Segre*, Illinois Institute of Technology, *P.H. Holloway*, University of Florida

Phosphors are wide bandgap materials that contain luminescent dopants. Excitation of the dopant can result from electron-beams (cathodoluminescence), photons (photoluminescence) or even mechanical means (piezoluminescence). We have studied the local environment of the erbium (Er3+) luminescent centers in an electroluminescent (EL) ZnS:Er phosphor. The local Er environment is critical to the efficiency and, in some cases, the emission wavelength of the phosphor. Many dopants have radiative relaxation transitions that are quantum dynamically unallowed. While these transitions may be strictly unallowed in the isolated atom, in the phosphor lattice these radiative transitions typically take place with a low probability. The excited states, therefore, must be fairly long-lived in order to allow enough time for the slow radiative transition. Defects and their associated electronic states in the vicinity of the phosphor luminescent center can act to delocalize the excited states and thus provide more effective non-radiative relaxation paths. A detailed knowledge of the local chemical and structural environment is therefore necessary in order to model the quantum efficiency of the radiative relaxation. The dependence of the local composition and order in sputter deposited thin film ZnS:ErF3 electroluminescent (EL) has been investigated using EXAFS as a function of post-deposition anneal temperature. Previous results have shown that the intensity of the EL peaks in the near infrared (1.55 μm) and visible (520 nm) both increase as the anneal temperature is increased, with the NIR intensity maximizing at an anneal temperature of 425 °C . In the as-deposited films, the entire ZnS host lattice is distorted by the presence of the Er, relative to an undoped ZnS film. The long-range crystallinity improves with increasing annealing temperature, especially for 425°C < T < 475°C, the highest annealing temperature studied. The data show that the Er atoms in the as-deposited films have a maximum of one nearest neighbor S atoms, but are surrounded predominantly by F atoms (although the presence of O atoms cannot be ruled out based on EXAFS data). Upon annealing, the spacing of the S around this complex begins to collapse and at 425°C, there is a longer range order that appears.

8:40am **TF1-FrM3 Fabrication and Characterization of Indium Zinc Oxide-Based Thin Film Transistors**, ***D.C. Paine***, Brown University **INVITED**

Active electronics implemented on cheap flexible polymer substrates offer the promise of novel display technologies, wearable electronics, large area memory, and a multitude of other, as-yet-unthought-of, applications that require low cost and high volume manufacturing. Thin film transistors (TFT's) fabricated on temperature-sensitive plastic substrates at low temperatures are the key to this technology. TFT's that use metal (In, Zn, Sn, Ga) oxide channels offer both high mobility (relative to amorphous Si) and the advantage of optical transparency in the visible regime. We report on the fabrication and performance of amorphous oxide transparent thin film transistors that use dc-magnetron sputter techniques to deposit IZO (In2O3-10wt%ZnO) at low oxygen potential (0vol%O2) for the source, drain, and gate-contact metallization and, at higher oxygen partial pressures (10 vol%O2), for the semi-conducting channel. The devices in this study were processed at room temperature except for a single 280°C PECVD deposition step to deposit a 230 nm-thick SiOx gate dielectric. The devices are optically transparent and operate in depletion mode with a threshold voltage of -5 V, mobility of 15 cm2/Vsec, an on-off ratio of >10E6 and, a sub-threshold slope of 1.2 V/decade. We show that control of oxygen in the sputter gas (0 to 30 vol %) during IZO deposition allows control of carrier density.

9:20am **TF1-FrM5 Near IR Electroluminescent Studies Of ZnS Photonic Crystal**, ***E.S. Law***, *P.H. Holloway*, University of Florida, *N. Shepherd*, North Texas State University

The effects of a photonic crystal (PC) structure on outcoupling of light from an alternating current thin film electroluminescent (ACTFEL) device are being studied. The ACTFEL device consists of a thin film of ZnS doped with erbium sputter deposited onto an aluminum-titanium-oxide (ATO) thin insulating layer on an indium-tin-oxide (ITO) transparent conducting electrode on a glass substrate. Al top electrodes are vapor deposited onto the ZnS:Er phosphor, and light is emitted through the glass substrate. ZnS:Er has strong emissions in the near IR at 1550nm, but it has been shown that much of this light is lost laterally to total internal reflection and absorption. The PC structure allows light from these lost modes to be transferred to modes that outcouple from the device. The data show that a triangular array of circles of radius and lattice spacing of 264nm and 660nm, respectively, in the ZnS:Er layer of the ACTFEL device allow coupling of horizontal modes to vertical modes. The sensitivity of this coupling to the dimensions of the PC will be reported. The PC was created with electron-beam lithography using a PMMA resist over the ZnS:Er layer of the ACTFEL device. An Ar ion etch was used to etch the triangular array of holes into the ZnS:Er layer. FOx® flowable silicon oxide was spin coated into the holes to act as the contrasting dielectric layer to the ZnS:Er layer which enables the PC effect. Finally an aluminum electrode was vapor deposited on the backside of the device. The emissions of ACTFEL devices were analyzed using an optical spectrometer. A sevenfold increase in the vertical modes of 1550nm light emission was observed from a device with a PC structure.

9:40am **TF1-FrM6 Conformal CVD of MgO from Mg(H3BNMe2BH3)2 and Water: A New Process for Dielectric Barrier Layers in Plasma Display Panels**, *Y. Yang*, ***D.Y. Kim***, *G.S. Girolami, J.R. Abelson*, University of Illinois at Urbana-Champaign

MgO is an attractive material for use as a dielectric barrier layer: it is a refractory oxide with a high melting point (2852 °C), high dielectric constant (9.8), wide bandgap (7.2 eV), and high secondary electron emission coefficient. These properties, combined with a good resistance to plasma erosion, make it suitable for use in AC plasma display panels, with the potential to significantly lower the firing voltage. Chemical vapor deposition affords simplicity, high deposition rate, and the ability to produce conformal coatings in deep features such as cylindrical vias. However, previous efforts to deposit MgO by CVD have not been satisfactory due to low deposition rate (~ nm/min), high deposition temperature (> 400 °C), or the presence of carbon or halogen impurities. Such issues derive from the lack of a suitable Mg-containing precursor molecule. We recently developed a completely new type of Mg precursor, bis(N,N,-dimethyldiboranamido)magnesium, here termed Mg(DMDBA)2. The vapor pressure of this precursor at room temperature is remarkably high, ~ 0.8 Torr, such that no carrier gas or heated delivery lines are required. The precursor is thermally stable but reacts readily with water to produce MgO films at temperatures as low as 225 °C. The high vapor pressure of the precursor allows us to achieve extreme conformality, e.g. a completely uniform film on a trench with depth/width ratio of 35:1, or a very rapid growth, e.g. deposition rate of a few hundred nm/min, or any compromise in between. We will present the CVD kinetics and the microstructure, crystallinity, electrical, and optical properties of MgO films grown from Mg(DMDBA)2 and H2O. Films grown at T > 500 °C on Si(100) or glass substrates are crystalline with a (002) texture; films grown at T > 400 °C are columnar; and films grown a lower temperatures are dense and smooth. The refractive index is 1.69-1.72 and the dielectric

constant is 9.5, both of which are very close to the values for bulk MgO. The excellent CVD process characteristics and excellent film quality makes this an attractive new means to deposit the dielectric barrier layers in PDPs.

10:00am **TF1-FrM7 Other Impurity-co-doping Effect on the Stability of Resistivity in AZO and GZO Transparent Conducting Thin Films**, ***T. Kuboi***, *Y. Honma, T. Miyata, T. Minami*, Kanazawa Institute of Technology, Japan

It has been recently reported that the resistivity of Al-doped ZnO (AZO) and Ga-doped ZnO (GZO) transparent conducting thin films with a thickness below approximately 100 nm always increased when tested in heated high humidity environments. For the purpose of improving the resistivity stability in these films for use in heated moist environments, the effect of impurity-co-doping on the stability of resistivity was investigated for AZO and GZO transparent conducting thin films. The impurity (X)-co-doped AZO and GZO (AZO:X and GZO:X) transparent conducting thin films were prepared on glass substrates by dc (both with and without incorporated rf) magnetron sputtering, rf magnetron sputtering and pulsed laser deposition methods. AZO and GZO thin films co-doped with V or In were prepared with thicknesses in the range from approximately 20 to 200 nm at a temperature of 100-200^{o}C. The resulting thin films were investigated using micro-structural analyses such as EXAFS and TEM. The stability tests were conducted long term (up to 1000 h) in a high humidity environment (air at 90% relative humidity and 60^{o}C). It was found that the resistivity stability of AZO:V thin films was considerably improved by optimizing the content of co-doping V. In particular, AZO:V films with a thickness of 50 nm were stable enough to be acceptable for use in practical transparent electrode applications. In contrast, thin films with a thickness below approximately 30 nm were always unstable under the above test condition. The resistivity increase of films with a thickness below 30 nm is mainly attributable to carrier transport being dominated by the trapping of free electrons due to oxygen adsorption on the film surface rather than the grain boundary.

10:20am **TF1-FrM8 Sputtered In_2O_3 and ITO Thin Films Containing Zirconium**, ***T.A. Gessert***, National Renewable Energy Laboratory, *Y. Yoshida,* Colorado School of Mines, *T.J. Coutts*, National Renewable Energy Laboratory

The deposition of high-quality tin-doped In_2O_3 (ITO) films by vacuum sputtering is well established. Nevertheless, coating specialists are keenly aware that maintaining high electrical and optical quality in a production environment represents significant challenges. ITO films with high carrier concentration and mobility generally are produced using high substrate temperature (250-350°C) in an ambient where the oxygen partial pressure is controlled to yield a slight oxygen deficiency in the film. Unfortunately, if the sputter ambient becomes too oxygen deficient, the optical transparency of the film decreases. The challenge during ITO deposition is to incorporate enough oxygen to produce films with high transparency while retaining slight oxygen deficiency to yield optimum electrical properties. In a large-area production coating system, this critical oxygen partial pressure must be achieved not only across a large deposition area, but also take into account variations such as target use, seasonal changes, and maintenance activities. Our recent investigations have identified a method to produce ITO-like films that are less sensitive to variations in the oxygen-containing deposition ambient. We are studying the effect of adding small amounts of Zr to both In_2O_3 and ITO ceramic sputtering targets. These targets are then used to produce thin films on glass substrates by r.f. magnetron sputtering. Electrical (Hall) and optical (UV-Vis-NIR spectrophotometry) analysis of these films shows that high-quality Zr-doped In_2O_3 (IZrO target = 9 wt.% ZrO_2+ 91 wt.% In_2O_3) films can be produced at high substrate temperatures (250-350°C) without adding oxygen to the sputter ambient. This result is in contrast to films produced from typical ITO targets (ITO target = 9 wt.% SnO_2+ 91 wt.% In_2O_3), where deposition in pure Ar yields films with very poor optical transparency. Films produced using a target where a small amount of Zr is added to a standard ITO target (ITO:Zr target = 1 wt.% ZrO_2+ 9 wt.% SnO_2+ 90 wt.% In_2O_3) show that the Zr addition allows for a broader range of oxygen partial pressure during deposition. We believe these results may embody significant advantages for large-area ITO film production, and could point the way toward similar benefits in other TCOs such as those based on ZnO or SnO_2 This abstract is subject to government rights.

10:40am **TF1-FrM9 Electronic and Optical Properties of TiO2-based Transparent Conducting Oxide**, ***T. Hitosugi***, University of Tokyo, Japan, *N. Yamada, Y. Furubayashi, S. Nakao, Y. Hirose, A. Ueda,* Kanagawa Academy of Science and Technology (KAST), Japan, *T. Shimada, T. Hasegawa*, University of Tokyo, Japan

Anatase Nb-doped TiO_2 appears to be promising transparent conducting oxide (TCO) for use as a next generation transparent electrode.[1,2] We report on electric properties of transparent conducting anatase $Ti_{0.94}Nb_{0.06}O_2$ polycrystalline films on glass. The films deposited using pulsed laser deposition at substrate temperature of room temperature, with subsequent H_2-annealing at 500°C, showed resistivity of 4.5 x 10^{-4} Ωcm at room temperature, and optical transmittance of 60-80 % in the visible light region. These results indicate that anatase $Ti_{0.94}Nb_{0.06}O_2$ films have excellent potential for practical transparent conducting oxides.

[1]Furubayashi et al., Appl. Phys. Lett. 86, 252101 (2005).
[2]T. Hitosugi et al., Jpn. J. Appl. Phys. 44, L1063 (2005).

11:00am **TF1-FrM10 Reactive Sputtered SnO_2 as the Active Layer in Transparent Thin Film Transistors**, ***W.-Y. Chen***, *J.-S. Chen*, National Cheng Kung University, Taiwan

Thin film transistors (TFTs) are the fundamental driving circuits for flat panel displays. In combination with the 'transparent circuit technology', transparent TFTs can increase the brightness and decrease the power consumption of displays. Therefore, oxide semiconductors are investigated as a substitute for the conventional amorphous silicon on TFTs because of their high optical transparency. In this work, we investigate the possibility of using reactive sputtered tin oxide (SnO_2) as the active layer in transparent TFTs. The transmittance of as-deposited SnO_2 film can reach 90%. Hall measurement shows that the SnO_2 film has higher carrier mobility than amorphous silicon. By changing the Ar/O_2 flow ratio during sputtering, the resistivity as well as the carrier mobility of SnO_2 can be varied. With an adequate preparation condition, the reactive sputtered SnO_2 film can lead to good characteristics as the active n-channel layer in transparent TFTs.

11:20am **TF1-FrM11 Electron Field Emission Study of Reactive Sputter Deposited Palladium Oxide Thin Films**, ***C.-J. Huang***, *F.-M. Pan, T.-C. Tzeng, C.-H. Tsai*, National Chiao-Tung University, Taiwan

Palladium oxide (PdO) is a p-type semiconductor and has many technological applications, such as catalysis, photoelectrolysis, and sensors. Because it is thermally stable up to 800°C, at which the oxide decomposes, and has a relatively low work function (3.9 eV), PdO is a suitable material for field emission applications. It has been used as the electrode material in a surface conduction electron emitter display. In this study, PdO thin films 100 nm thick were prepared on the Pt bottom electrode by reactive sputter deposition and the field emission characteristics were studied. X-ray photoelectron spectroscopy (XPS) and X-ray diffraction (XRD) were used to characterize the chemical composition of the PdO thin film. Under certain deposition conditions, the PdO thin film exhibited a flake-like surface structure. The morphology of the deposited PdO thin film was highly dependent on the sputter deposition conditions, such as the gas flow ratio (Ar /O_2) and the substrate temperature. According to atomic force microscopy analysis, the PdO thin film deposited at 25°C had a root-mean-square (RMS) surface roughness of ~23 nm. The flake structure had a ridge angle smaller than 60° with a height ranging from ~30 nm to 100 nm. The sharp ridge angle can enhance the electric field at the local area around the ridge during the field emission operation. The field emission property of the PdO flake structure were studied using a simple diode configuration under a vacuum condition of ~10^{-6} torr, and the turn-on field was about 8.5 V/μm at the emission current density of 10 μA/cm^2.

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