Transparent Conductors and Printable Electronics Focus Topic
Room: 102 B - Session TC+EM+TF-WeM

Oxide and Flexible Electronics
Moderator: G. Exarhos, Pacific Northwest National Laboratory, L.M. Porter, Carnegie Mellon University

8:00am **TC+EM+TF-WeM1 Characterization of Thermal Plasma....**, ***M. Kinsler***, *K. Teh, R. Harrison*, San Francisco State University

A low-vacuum thermal plasma system is designed and developed to enable plasma-enhanced chemical vapor deposition and rapid plasma annealing of metal oxide thin films within the same system. Using this system, we have successfully synthesized optically transparent and electrically conductive, nanocrystalline zinc oxide (ZnO) thin films, with average grain sizes of between 75 nm and 150 nm at substrate temperatures ranging from 550C to 600C. Prior to synthesis, argon and oxygen are first introduced into the synthesis vessel, consisting of a quartz tube positioned in the center of an inductive copper coil, at 42 sccm and 0.07 sccm, respectively, with a background vacuum level of 1.15 PSIA. During synthesis, pure solid zinc precursor is melted and ionized by thermal plasma, and reacted with oxygen to form ZnO which is deposited on the substrate. Keeping the vessel pressure and substrate temperature constant, the growth rate of the ZnO films is approximately 15 nm/min. Using the same system, the ZnO-coated substrate can next be mounted on a different fixture and be annealed by thermal plasma at temperatures from 300C to 800C (0.25 to 0.38 T_m of ZnO) in a pure argon environment at 1.15 PSIA background pressure. Comparing the as-synthesized and annealed samples using techniques such as scanning electron microscopy (SEM), x-ray diffraction (XRD), UV-Vis spectroscopy, and four-point probe sheet resistance measurements, we observed improvements in the properties of the post-annealed ZnO films in the following ways: 1) ZnO grain size increased from approximately 50 nm to 100 nm, 2) the number of grains decreased and hence the number of grain boundaries decreased, 3) grain morphology became smoother possibly indicating less internal strain, and 4) sheet resistance of the film decreased. We hypothesize the improved electrical properties are attributed to the reduction in both grain boundaries and internal stress--both of which are known to reduce electron mobility. Synthesizing and annealing metal oxides, such as ZnO, in the same system would reduce overall turnaround time as moving samples between systems is avoided. Ultimately, this method could pave the way for the production of high-quality, optically transparent, and electrically conductive metal oxide semiconductor thin films in a single, rapid operation within a low-cost, small-footprint benchtop system.

8:20am **TC+EM+TF-WeM2 Effects of High Pressure on InGaZnO Thin Film**, ***S.H. Yoon***, *Y.J. Tak, D.H. Yoon, U.H. Choi, H.J. Kim*, Yonsei University, Republic of Korea

Since Hosono et al presented amorphous oxide semiconductor (AOS) thin film transistor (TFTs) in 2004, AOS TFTs have been attracting attention from many researchers for a decade [1]. AOS TFTs have high enough mobility for organic light emitting diodes, and high resolution display. One of the technologies for improving electrical characteristics is high pressure annealing [2,3]. We studied pressure effects on AOS TFTs without additional annealing process. We applied pressure on inverted staggered InGaZnO (IGZO) TFTs. IGZO layer (50nm) was deposited by sputtering. SiO_2 layer (200 nm) was deposited by plasma enhanced chemical vapor deposition (PECVD) as a gate insulator and an etch stop layer, respectively. MoW (200 nm) was deposited by sputtering as a gate metal, and Mo was deposited by sputtering as source/drain metal. Applied gas was N_2, and applied pressures varied 1MPa, 3 MPa, and 5 MPa for 2 hours, respectively. Figure 1 shows transfer curves on different pressure, and mobility and sub-threshold swing were improved. References:

[1] K. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano, and H. Hosono, Nature **432**, 488-492 (2004).

[2] K.H. Ji, J.-I. Kim, H.Y. Jung, S.Y. Park, R. Choi, U.K. Kim, C.S. Hwang, D. Lee, H. Hwang, and J.K. Jeong, Appl. Phys. Lett. **98**, 103509 (2011).

[3] R.S. Rim, W.H. Jeong, D.L. Kim, H.S. Lim, K.M. Kim, and H.J. Kim, J. Mater. Chem. **22**, 12491-12497 (2012).

8:40am **TC+EM+TF-WeM3 Surface Chemistry of Amorphous $InGaZnO_4$ Films**, *B. Flynn*, Oregon State University, *S.A. Thevuthasan*, Pacific Northwest National Laboratory, *H. Bluhm*, Lawrence Berkeley National Laboratory, ***G.S. Herman***, Oregon State University

Thin film transistors (TFT) utilizing amorphous $InGaZnO_4$ (a-IGZO) have multiple applications in high performance electronic devices, from flat-panel displays and integrated circuits to non-volatile memories. A-IGZO enables low processing temperatures, while retaining large electron mobilities, and low operation voltages and off currents. These stable carrier transport and electrical characteristics are crucial for many applications, and can be strongly affected by backchannel surface chemistry of a-IGZO TFTs. Understanding the chemistry of absorbed species and their effect on the electronic structure of a-IGZO is critical to improve the stability of these TFTs, while reactions at the metal/a-IGZO interface strongly influences switching characteristics of resistive random access memories. In this study we have characterized sputter-deposited thin films of a-IGZO using in-situ x-ray photoelectron spectroscopy (XPS). Both standard Al Ka and synchrotron-based radiation were used to investigate chemical changes at the a-IGZO surface. We have observed surface segregation and desorption of oxygen containing impurities for anneals up to 300 °C in ultra-high vacuum (UHV). The O 1s spectra were very sensitive to the local chemistries at the surface, and we used these spectra to characterize the interaction of molecular oxygen and water with well-defined a-IGZO surfaces for a wide range of temperatures and exposures. It was found that water adsorbs both molecularly and dissociatively at temperatures below 200 K, with corresponding downward band bending of ~0.15 eV for >20 Langmuir exposures. Oxygen did not appreciably affect the XPS spectra for the temperatures and exposures studied. We have also characterized the initial growth of platinum metal films on a-IGZO. The XPS characterization of chemical state differences of the elements and band bending due to surface effects will be discussed along with the film processing conditions.

9:00am **TC+EM+TF-WeM4 UV Radiation Effect on Electrical Characteristics of Passivated IGZO TFTs**, ***Y.J. Tak***, *D.H. Yoon, S.H. Yoon, U.H. Choi, H.J. Kim*, Yonsei University, Republic of Korea

Ultraviolet (UV) radiation effects have been intensively researched in oxide thin film transistors (TFTs). In general, UV radiation induces the increase of off-current and the existence of hump effect.[1] These changes of electrical properties in non-passivated oxide TFTs are almost recovered to original states.[2] However, back surface of oxide TFTs is sensitive to oxygen and humidity, passivation is key layer for stability and reliability on device. For this reason, we investigated the effects of post UV treatment on the SiO_2 passivated indium gallium zinc oxide (IGZO) TFTs, specifically by irradiating UV spectrum of different wavelength, intensity, and treatment time. We performed light treatment of wavelength of 365 nm and 185 nm. And then varied power intensities were performed 64.66 mW/cm^2, 0.9375 mW/cm^2 respectively. These UV experiments were carried out with various treatment time of 10 min, 20 min, 30 min, and 60 min. As a result, the increment of off-current was shown which was higher in 185 nm radiated one than that of 365 nm, and increase of the intensity and treatment time led to increase in off-current and hump effect. Also, these changes were not restored to its original state after relaxation period. The result of experiment indicated that SiO_2 passivated-TFTs need to block the UV radiation because of incompletely vanished hump effect that causes degardation on the devices.

9:20am **TC+EM+TF-WeM5 Processing Water-based TFT Materials**, ***D.A. Keszler***, Oregon State University **INVITED**

High-quality semiconductor and dielectric films can readily be deposited from aqueous solutions containing polynuclear metal nonoclusters. To support the continued development of the films and their use, new techniques have been developed to remove residual mobile ions associated with hydroxide. Examples of incorporation of the resulting films into TFTs and MIM devices will be described.

10:40am **TC+EM+TF-WeM9 Printed Circuits and Sensing Systems**, ***G.L. Whiting***, *T. Ng, D.E. Schwartz, B.J. Van Tassell*, Palo Alto Research Center, *A.M. Gaikwad*, University of California, Berkeley, *D.A. Steingart*, Princeton University, *J. Veres*, Palo Alto Research Center **INVITED**

Low-temperature processable, mechanically compliant materials and the use of printing as a manufacturing technique enables fabrication of flexible electronic systems over large areas at low-cost, potentially allowing for novel applications and more widespread use of such systems. In this report recent developments made in printed systems technology will be presented, including examples of printed complementary circuits, sensors and power sources fabricated using techniques such as ink-jet, screen and gravure printing; as well as integration of these devices into functional printed systems.

Circuits in this work are based on ink-jet printed complementary organic field-effect transistors (FETs), which benefit from simplified design in comparison with unipolar circuits. Design rules for these devices have been determined and models describing the characteristics of these FETs have been developed to aid in designing circuits that can tolerate variation in the performance of printed transistors. In addition to ink-jet, devices have also been fabricated using a gravure method, providing a potential route to large-scale production of printed electronics. Flexible, printed batteries suitable for driving these systems have also been developed and will be described.

11:40am **TC+EM+TF-WeM12 Low Temperature Integration of Metal Oxide Thin Films for Flexible Electronic Applications**, ***P. Joshi***, *M. Shao, K. Xiao, S. Killough, P. Kuruganti, C. Duty*, Oak Ridge National Laboratory

In the last few years, there has been growing interest in the development of flexible electronics to meet the manufacturing technology demands of higher functionality, reduced material usages and device dimensions, and lower consumption of products. Metal oxide thin films are attractive for multifunctional flexible system development due to their very low cost, tunable properties, and simple electronic interface. Low temperature processing of metal oxides thin films is critical to exploit their unique structural, optical, and electrical properties for a wide range of active and passive device applications, such as flat panel displays, organic electronics, RFIDs, antennas, inductors, capacitors, sensors, batteries and energy harvesting devices. In the present paper; we report on the pulse thermal processing (PTP) processing of metal oxide thin films integrated on flexible substrates. The PTP technique is being explored for the development of cost-effective, high yield, and high quality integrated thin films and devices on low temperature substrates. This technology offers the ability to expose large areas of material to an extremely high energy flux (up to 20 kW/cm^2) during a very short period of time (as low as 30 microseconds) meeting the demands of roll-to-roll manufacturing technology. The details of the PTP processing of metal oxide thin films with specific examples related to single and multilayer thin film structures incorporating ZnO and ITO thin films are presented in this paper. The influence of the low processing temperature (<100°C) on the thin film growth and properties has been investigated in terms of process-structure-property correlation study. The impact of the substrate on the thin film growth and properties has also been analyzed. The low thermal budget PTP processing significantly impacts the microstructural, optical, and electrical characteristics on low temperature flexible substrates. The combination of low temperature deposition techniques and low thermal budget PTP processing show promise for multifunctional thin film material and device integration for flexible electronics.

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