Transparent Conductors and Printable Electronics Focus Topic
Room: 106 - Session TC+AS+EM-ThM

Transparent / Printable Electronics Part 1

Moderator: R. Haasch, University of Illinois at Urbana Champaign

8:00am **TC+AS+EM-ThM1 Growth Characteristic and Films Properties of Ga doped ZnO (GZO) by Low Temperature Atomic Layer Deposition**, ***T.W. Nam***, *JM. Kim, W.S. Lee, H. Kim*, Yonsei University, Republic of Korea

Atomic layer deposition (ALD) has great benefits over other deposition techniques since its growth mechanism controlled by a self-limited surface reaction exhibits excellent conformality, large area uniformity, and atomic scale thickness controllability. In particular, ALD becomes increasingly more promising thin film deposition method for future flexible electronics. Recently, there have been many research efforts on the investigation of doped ZnO for transparent conducting oxides (TCOs) due to their higher mobility than that of undoped ZnO. Ga doped ZnO (GZO) is one of the promising material for substitution of ZnO. As a representative TCO for applications to the transparent thin film transistor (TTFT) or flexible electronic, GZO thin films by PVD or CVD have been extensively studied. Nevertheless studies on GZO films grown by ALD at low temperature condition which can be applied to flexible devices were still not carried out as far as we know in spite of its potential importance. Hence, for this study, we investigated the growth characteristics and film properties of low temperature ALD (LT-ALD) GZO films by varying deposition method. Field emission scanning electron microscopy (FE-SEM) observation of the GZO films deposited on 5:1 via patterns showed that the film has excellent conformality with over 95 % coverage even at room temperature growth. Additionally, the chemical and microstructural analysis was studied by various analytical techniques including X-ray photoelectron spectroscopy (XPS), X-ray diffraction (XRD) and atomic force microscope (AFM). Also spectrophotometer was used to measure a transmittance of the film and showed high transmittance that could be applicable to transparent devices.

8:20am **TC+AS+EM-ThM2 Enhancement of C-Axis Orientation of Ga-doped ZnO Films Deposited on Unintentionally Heated Glass Substrates using Nanosheet Seed Layers**, ***H. Makino***, Kochi Univ. of Tech., Japan, *T. Shibata*, NIMS, Japan, *N. Yamamoto*, Kochi Univ. of Tech., Japan, *T. Sasaki*, NIMS, Japan, *T. Yamamoto*, Kochi Univ. of Tech., Japan

Ga-doped ZnO (GZO) film is one of promising candidates as substitute for ITO transparent electrodes in optoelectronic devices. Control of structural properties, especially c-axis orientation, is crucial issue to improve electrical properties of polycrystalline GZO films on glass or plastic substrates [1]. Recently, nanosheet seed layers were proposed to control crystal orientation of oxide films on amorphous substrates [2]. In this study, we employed a seed layer of tungsten oxide nanosheets with two-dimensional hexagonal lattice structure for deposition of GZO thin films on unintentionally heated glass substrates.

The nanosheets were assembled on glass substrates by Langmuir-Blodgett method. The GZO films with thickness of 100 nm were deposited by an ion-plating with direct current arc discharge on unintentionally heated glass substrates with and without the nanosheet seed layers.

The crystal structural properties were characterized by x-ray diffraction measurements. The c-axis orientation of the GZO films was drastically enhanced by the nanosheet seed layers. The intensity of (002) diffraction peak of GZO films deposited with the seed layers was about 40 times as strong as that deposited without the seed layers. The degree of c-axis orientation was evaluated by the (002) x-ray rocking curve (XRC). The full-width half-maximum of XRC of the GZO films on the nanosheet seed layers was 2.6 °, which is even lower than that of GZO films deposited on bare glass substrate at 200 °C.

The electrical properties were characterized by Hall effect measurements at room temperature. The GZO films deposited on the nanosheet seed layers showed the resistivity of 2.9 x10^{-4} Ωcm with the Hall mobility of 24 cm^2/Vs and the carrier concentration of 9.0×10^{20} cm^{-3}. On the other hand, the GZO film deposited without the nanosheet seed layers showed the resistivity of 5.0 x10^{-4} Ωcm with the Hall mobility of 17 cm^2/Vs and the carrier concentration of 7.2×10^{20} cm^{-3}. Both the Hall mobility and the carrier concentration were improved by the nanosheet seed layers.

[1] T. Yamada et al., J. Appl. Phys. 107, 123534 (2010). [2] T. Shibata et al., Adv. Mater. 20, 231 (2008).

8:40am **TC+AS+EM-ThM3 Multi-component Transparent Conducting Oxides: Progress in Materials Modeling**, ***S.-H. Wei***, National Renewable Energy Laboratory **INVITED**

Transparent conducting oxides (TCOs) play an essential role in modern optoelectronic devices through their combination of electrical conductivity and optical transparency. We review recent progress in our understanding of multi-component TCOs formed from solid solutions of ZnO, In2O3, Ga2O3 and Al2O3, with a particular emphasis on the contributions of materials modeling, primarily based on Density Functional Theory. In particular, we highlight three major results from our work: (i) the fundamental principles governing the crystal structures of multi-component oxide structures including (In2O3)(ZnO)n, named IZO, and (In2O3)m(Ga2O3)l(ZnO)n, named IGZO; (ii) the relationship between elemental composition and optical and electrical behavior; (iii) the origin of high-performance of amorphous oxide semiconductors. From these advances, the challenge of the rational design of novel electroceramic materials is discussed.

9:20am **TC+AS+EM-ThM5 Composition Control of Electron Beam Deposited Nb-TiO_2 Thin Films**, ***N.A. Beckers***, *R.T. Tucker*, University of Alberta, Canada, *M.D. Fleischauer*, NRC-National Institute for Nanotechnology, Canada, *M.J. Brett*, University of Alberta, Canada

Nb-doped TiO_2 has been identified as a potential indium-free transparent conductor, and has been fabricated by pulsed laser deposition and sputtering with good success.[1,2] Other deposition methods, such as electron beam evaporation, are of interest for this material but have had limited demonstration to date. It would be advantageous to be able to use electron beam evaporation because in addition to planar films, the collimated flux allows for structured thin films via glancing angle deposition (GLAD). Composition control is essential for doped functional materials, which is typically difficult to obtain through physical mixing of source materials. Here we show that using a sol gel approach to prepare the source materials provides a possible route to circumvent this issue. The facile, solution based sol gel process for the synthesis of ceramic and glassy materials allows for precise composition control by controlling the amounts and ratios of the metal oxide precursors. A sol gel methodology was used to prepare a series of Nb-doped TiO_2 deposition source materials with the following compositions: $Nb_{0.06}Ti_{0.94}O_2$, $Nb_{0.12}Ti_{0.88}O_2$, and $Nb_{0.24}Ti_{0.76}O_2$. We will show that XPS results confirm the composition of the electron beam deposited films and reflects the composition of the source materials. Premixed powders of Nb_2O_5 and TiO_2 do not show the same translation of composition as the sol-gel derived source material. Details on the effects of the post-deposition annealing environment on the thin film optical and electrical properties will also be presented.

References:

1. Yamada, N.; Hitosugi, T.; Hoang, N. L. H.; Furubayashi, Y.; Hirose, Y.; Konuma, S.; Shimada, T.; Hasegawa, T. *Thin Solid Films* **2008**, *516*, 5754-5757.

2. Ishida, T.; Okada, M.; Tsuchiya, T.; Murakami, T.; Nakano, M. *Thin Solid Films* **2011**, *519*, 1934-1942.

9:40am **TC+AS+EM-ThM6 Laboratory and Production-Scale Low-Temperature Transparent Conducting Oxide Deposition**, ***E. Ritz***, University of Illinois at Urbana Champaign, *G.B. Rayner*, Kurt J. Lesker Company, *D. Andruczyk*, University of Illinois at Urbana Champaign, *T. Dockstader*, Kurt J. Lesker Company, *D.N. Ruzic*, University of Illinois at Urbana Champaign

Transparent conducting oxides (TCOs) are a class of materials that are becoming increasingly ingrained in our daily lives due to their use in electronic displays and mobile devices. There is a strong need to develop an economical deposition technique that allows for high transparency films with high electrical conductivity while replacing costly materials such as Indium Tin Oxide (ITO) with alternatives such as Aluminum-doped Zinc Oxide (AZO). In addition, a low-temperature deposition method would allow creation of TCOs on flexible plastic substrates, such as polyethylene terephthalate (PET). By using a dual DC magnetron system with a secondary RF antenna running at 13.56 MHz, a process has been developed that can deposit TCO films without significantly heating the substrate while maintaining high transmission and electrical properties. This capability has been demonstrated on a small-scale experimental setup utilizing 3-inch diameter circular magnetrons as well as a prototype production-scale chamber operating with 18x3.5 inch rectangular mangetrons aimed at flexible photovoltaic manufacturing. Using an immersed inductive RF antenna, ionization fraction can be increased to over 80%, measured by a

gridded energy analyzer, and plasma density increased by an order of magnitude from 10^{10} cm^{-3} to 10^{11} cm^{-3}, as measured by Langmuir probe. The secondary plasma deposits energy in the film without heating the substrate above 100°C while still achieving film resistivity on the order of 10^{-3}-10^{-4} Ohm-cm (measured by four-point probe method) and transparency of greater than 90% in the visible wavelengths (measured by spectrophotometry.) Adjusting the RF power (0-1000W) and the oxygen content (0-5%) in the plasma enables the ability to tune the film transparency and conductivity to desired levels. Crystal formation of films analyzed by x-ray diffraction (XRD) and elemental composition determined by x-ray photoelectron spectroscopy (XPS).

10:40am **TC+AS+EM-ThM9 Optical and Electronic Properties of Photonic Crystal Based Transparent Conductors**, ***S. Narayanan***, *M. Bockstaller, L. Porter*, Carnegie Mellon University

Transparent conductors are becoming ubiquitous in a host of civil and military applications, including transparent electrical contacts in solar cells and LEDs, heated glass for aircraft and automobile windows, and electrochromic devices and smart windows. However, finding abundant materials with optimal electrical and optical properties and that can be produced economically is a particular challenge. Moreover, limited supply and large demand, of late, for indium has inspired focused research on finding alternatives to ITO as a transparent conductor. We report here a novel approach to control optical properties such as absorption, transmission and reflection in multilayered structures (based on [1-2]) with absorbing components. Appropriate combination of materials could, among others, allow for applications like transparent electrodes, transparent electromagnetic shielding, flexible transparent conductors, etc. Through this study, we have demonstrated the validity of this approach using a few different materials combinations including polymer/metal and metal/ceramic systems. In these realizations the approach was shown to increase the transparency in the visible frequency range by ~ 3 orders of magnitude as compared to the reference materials. For example, transmittances of 30-50% of incident light in the visible region were measured for films containing a polymer (polystyrene – PS) and an amount of metal (gold – Au) that was 3-4 times as thick as its skin depth (~ 40-50 nm). We have also found compatibility between the observed experimental results and numerical simulations. Apart from enhanced optical transmittance, resisitivity values of ~ 10^{-4} Ωcm (comparable to Au films having ~ 10^{-5} Ωcm) have also been discovered in structures having insulating components. Our ongoing and future work is focused on alternative structures to enhance conductivity in the transverse direction as well as incorporate flexibility in the same. **References:** [1] M. Scalora *et al.*, *J. Appl. Phys.* **83** 5 (1998) 2377-2383 [2] M. Scalora, M. J. Bloemer, C. M. Bowden, *Optics and Photonics News* **10** 9 (1999) 24-27

11:00am **TC+AS+EM-ThM10 Effect of Plasma Treatment and Annealing on the Electrical Properties of Spin-Coated Colloidal ITO Films**, ***S.M. Joshi***, *G.W. Book, R.A. Gerhardt*, Georgia Institute of Technology

Colloidal ITO based inks may be an attractive route to direct writing transparent circuits and also be useful for the fabrication of transparent conductive ITO films on complex shaped substrates. The presence of stabilizing ligands and minimal contact between the ITO nanoparticles in the deposited films can be a challenge in obtaining the optimum electrical properties. This study investigates the effect of plasma treatment and annealing on the electrical properties of colloidal ITO films. Crystalline colloidal ITO nanoparticles were synthesized in-house by a non-aqueous technique. The solutions were spin coated onto glass and quartz substrates and their electrical and optical properties were evaluated. All films were found to be completely transparent, while the as-deposited films had resistivities more than 10^{8} ohm-cm. Plasma treatments were shown to be effective in removing residual organics in the films, and even without annealing, some recipes were able to reduce the film resistivity by more than four orders of magnitude. Plasma treatments, when done in combination with annealing, resulted in films with resistivities less than 1 ohm-cm.

11:20am **TC+AS+EM-ThM11 Hybrid Organic/Inorganic Materials and Devices for Flexible Electronics Applications**, ***M.A. Quevedo-Lopez***, *J.I. Mejia, A. Salas-Villasenor, A. Carrillo-Castillo, B.E. Gnade,* University of Texas at Dallas, *D. Allee*, Arizona State University **INVITED**

The field of flexible electronics has expanded tremendously over the past few years. Similar to what happened in silicon integrated circuit technology 40 years ago; flexible electronics are now at a point where system design and process integration will drive the technology. Flexible electronics will likely push the limits of material performance, process integration, circuit design, and system integration to demonstrate the full potential of flexible electronics. In general, key components for any flexible electronic application include thin film transistors. In order to be competitive with state-of-the-art a:Si:H thin film transistors, any other thin film transistor technology must show reproducible transistor parameters such as mobility, threshold voltage, drive current and reliability.

A grand challenge in flexible, thin-film-transistor (TFT) circuitry is the development of complementary metal oxide semiconductor (CMOS) circuits. Although flexible digital circuits, flexible sensors, flexible batteries and solar cells have already been demonstrated, the missing technology piece that must be developed is flexible analog circuitry. For example, an operational amplifier will enable the interface to most sensors and actuators, significantly expanding the functionality of flexible electronic systems. In this paper, we will present n- and p-type chalcogenide-based materials that can be used as the building blocks for analog CMOS-based circuits. In particular, we will introduce the use of chemical bath deposition as an alternative to deposit these materials and will discuss the correlation between device characteristics and materials properties. Photolithography-based chalcogenide-based TFTs processed by chemical bath deposition achieved mobilities in the order of 10-25 cm2/V-s. In addition, we demonstrate hybrid CMOS for a:Si-Pentacence, CdS-Pentacene and CdS-TIPS Pentacene.

We also present the impact of semiconductor thickness, gate dielectrics and contact in device performance. In addition, NAND, NOR and Inverters are demonstrated using chalcogenide-based materials integrated with either a-Si or pentacene. Device processing is carried out at a maximum processing temperature of 110oC, which is compatible with most plastic substrates.

Transparent Conductors and Printable Electronics Focus Topic
Room: 106 - Session TC+EM+NS-ThA

Transparent / Printable Electronics Part 2
Moderator: S. Durbin, University at Buffalo

2:00pm **TC+EM+NS-ThA1 ZnO-based Schottky Diodes and Their Utilization in Transparent Electronics**, ***H. von Wenckstern***, Universität Leipzig, Germany **INVITED**

Transparent conducting oxides (TCO) have found application as electrode in emerging markets like that of thin films solar cells or flat panel displays. For this passive functionality the TCO material must combine high transparency preferentially over a wide spectral range and high conductivity. In the last years active transparent devices like photodetectors, transistors or a complete transparent circuitry are envisioned and rely on semiconducting properties of the material. Besides a precise control of the doping level in the active part of devices the creation of space charge regions by rectifying contacts is a prerequisite for active devices. In the emerging field of transparent electronics, only metal-insulator-semiconductor field-effect transistors (MISFETs) were considered so far. In this contribution transparent, high-performance MESFETs, inverters etc. based on ZnO and related ternaries are presented. We discuss design prospects as well as limitations regarding device performance, reliability and stability.

The influence of the contact metal and dielectric passivation layers on the properties of ZnO Schottky diode, used as gate electrode within the MESFETs, as well as sources of non-idealities will be highlighted.

2:40pm **TC+EM+NS-ThA3 Photoresponse of Amorphous In-Ga-Zn-O / Pt Schottky Junction**, ***D.H. Lee***, *K. Nomura, T. Kamiya, H. Hosono*, Tokyo Institute of Technology, Japan

Amorphous oxide semiconductors (AOSs) are expected as an alternative to amorphous/poly-Si for thin-film transistors (TFTs) in next-generation flat-panel displays (FPDs) because AOS TFTs have many advantages such as large field-effect mobilities (>10 $cm^2(Vs)^{-1}$) and low-temperature process [1]. For more advancing AOS optoelectronic technology, it is important to develop more various devices other than TFTs, and to study some remaining issues such as operation characteristics of AOS devices under light illumination.

In this study, we fabricated good and stable metal-AOS Schottky contacts made of amorphous In-Ga-Zn-O (a-IGZO) and bottom Pt electrodes at temperatures below 200°C even though it is generally difficult to make high performance oxide Schottky junctions [2]. It was found that the a-IGZO/Pt Schottky contacts have an ideality factor n ~ 1.1 and a Schottky barrier height ϕ_b ~ 0.9 eV, which were evaluated from their J-V curves using the thermionic emission model. From C-V results, the Schottky junctions operate at the full-depletion condition, whose C corresponds to the geometrical capacitance of the a-IGZO layer, and relative permittivity ε_s of a-IGZO was obtained approximately 13. However, the results of temperature dependences of J-V characteristics were unexplained if we take a simple uniform Schottky barrier model; we found that the barrier potential fluctuations model [3] explained them well, and the mean barrier height $\phi_{b,m}$ of 1.2 eV and the net electron affinity χ_s of a-IGZO of 4.2 eV were obtained. On the other hand, the Schottky contacts showed very small open circuit voltages (V_{OC}'s) < 0.1 V under 100 $mWcm^{-2}$ AM1.5 light illumination, which are far smaller than the built-in potential (V_{bi} ~ 0.4 eV) estimated from the C-V measurements in dark. We also observed that V_{OC} decays with time after starting the light illumination. We will discuss the mechanism of the small V_{OC} based on these results.

[1] T. Kamiya et. al. *Sci. Technol. Adv. Mater.* **11** 044305 (2010).

[2] K. Ip et al., J. Cryst. Growth **287,** 149 (2006).

[3] J. H. Werner and H. H. Güttler, J. Appl. Phys. **69**, 1522 (1991).

3:00pm **TC+EM+NS-ThA4 Novel Metal-organic Precursors for Printed Electronics - Synthesis, Implementation, and Properties**, ***J.A. Belot***, *R.A. Potash, R.D. McCullough, K.A. Singh, L. Porter*, Carnegie Mellon University

Printed electronics is a rapidly growing industry and within this emerging field there are three required material categories critical to fabricating active and passive circuitry – insulators (dielectrics), semiconductors (polymers), and conductors (metals). The increased interest in printable electronics as alternatives to silicon-based technologies is fueled by the promise of large-area, flexible, and ultra-low-cost devices. To enable the growing demands of printing processes this work develops metal-containing inks for the deposition of the coinage metals - copper, silver, and gold. These metals are chip components ranging from interconnects to source and drain contacts in organic field effect transistors. The liquid ink approach is based on fundamental advances in coordination chemistry to fabricate discrete metal complexes that can be heated or irradiated to yield metallic films. Ultimately inkjet printing technologies were employed to deposit these metal inks in specific, predetermined patterns that were directly transformed into active and passive devices. The versatility of this approach holds the possibility of printing any metallic design and pattern on virtually any type of substrate.

3:40pm **TC+EM+NS-ThA6 A New Application for a-IGZO TFTs: An Addressable Microfluidic Electrowetting Channel Device**, ***J. Noh***, *J.H. Noh*, University of Tennessee, *E. Kreit, J. Heikenfeld*, University of Cincinnati, *P.D. Rack*, University of Tennessee

An electrowetting (EW) microfluidic platform designed for control and transport of aqueous and polar species has been fabricated on passive electrodes as well as an active matrix thin film transistor (TFT) array. To drive the EW devices we integrated the micro fluidic platform on a base-plane of transparent TFTs. Specifically, we have used an InGaZnO (IGZO) active layer for the TFT device which has superior performance and offers the benefit of transparent devices for biological and display applications. The TFTs are fabricated with a bottom-gate staggered structure with Cr gate and SiO2 gate dielectrics deposited via plasma enhanced chemical vapor deposition (PECVD). The a-IGZO semiconducting active layers are deposited using rf magnetron sputtering in a reactive Ar-O2 atmosphere. Finally, source and drain electrodes are formed by e-beam evaporating Ti/Au. Finally the device is annealed in an N2ambient for electrical activation. For the EW device integration, Al electrodes are have been deposited various passivation layers. Subsequently a top dielectric and a hydrophobic Fluoropel layer are applied. In this presentation we will review the process flow and will discuss the materials integration issues of EW device and its effect on the TFT performance. We will illustrate the EW characteristics based on standard planar electrowetting on dielectric (EWOD) platforms and compare them to a new concept we have termed the "Laplace Barrier" which includes post arrays and enhances electrowetting characteristics.

4:00pm **TC+EM+NS-ThA7 Amorphous Oxide Semiconductor Thin-Film Transistors**, ***J.F. Wager***, *K. Hoshino*, Oregon State University, *B. Yeh, R.L. Hoffman*, Hewlett-Packard Company **INVITED**

Amorphous oxide semiconductor (AOS) thin-film transistors (TFTs) are transitioning towards commercialization for active-matrix liquid crystal display flat-panel display backplane applications. They also appear to be well-positioned to meet the more demanding challenges associated with active-matrix organic light-emitting device backplanes. Additionally, AOS TFTs offer an attractive approach to printed electronics. The primary focus of this talk will be to discus our novel approach to top-side passivation of bottom-gate indium gallium zinc oxide (IGZO) and zinc tin oxide (ZTO) AOS TFTs. Device performance between passivated and unpassivated AOS TFTs will be compared. Passivation mechanisms will be considered in the context of induced-gap state and device physics electrostatic modeling.

4:40pm **TC+EM+NS-ThA9 Why Optimum Oxygen Pressure Range Exists for Fabricating Amorphous In-Ga-Zn-O Thin-Film Transistor and How it Should be Optimized**, ***K. Ide***, *K. Nomura, T. Kamiya, H. Hosono*, Tokyo Institute of Technology, Japan

Amorphous oxide semiconductors (AOSs) represented by amorphous In-Ga-Zn-O (a-IGZO) are expected for large-area high-performance flexible electronic devices, because AOSs have large electron mobilities greater than 10 $cm^2(Vs)^{-1}$ even if fabricated at room temperature (RT). In particular, a-IGZO has good controllablities of carrier concentration, and their thin-film transistors (TFTs) exhibit superior properties including long-term stability.

In this study, we investigated effects of oxidation on operation characteristics of a-IGZO TFTs. Bottom gate, top-contact a-IGZO TFTs were fabricated on SiO_2/c-Si substrates by RF magnetron sputtering. Sputtering conditions were the RF power of 70 W and the total pressure of 0.55Pa. Two oxidation treatments were examined; (i) ozone annealing and (ii) varying a mixing gas ratio of Ar : O_2 from 18 : 2 to 19.8 : 0.2 in standard cc per minute (sccm) during the channel deposition.

For the ozone annealed TFTs, annealing at ≤ 250°C produced good TFTs, while those annealed at 300°C caused large hysteresis and S slope. After applying a high V_{GS} larger than 40 V, the transfer characteristics showed the large V_{th} of 40V and the small hysteresis. Trap state around Fermi level of

the large S state and the large V_{th} state were ~$4x10^{17}$ and ~$1x10^{17}$ $cm^{-3}eV^{-1}$, which were estimated by C-V analysis. The large V_{th} state is very stable in the dark, but the TFT recovers to the initial large S state by light illumination. The photoresponse measurements revealed that deep trap states were formed at 2.3 eV below the conduction band minimum by applying a high V_{GS}. Thermal desorption spectra showed that weakly-bonded excess oxygens were incorporated in the a-IGZO layer. From these results, we built a subgap DOS model of the trap states of the excess oxygens. We also confirmed similar behaviors in a-IGZO TFTs fabricated in high oxygen pressure conditions.

This study reveals that the control of oxygen stoichiometry is important for obtaining good performance and stability of AOS TFTs.

5:00pm **TC+EM+NS-ThA10 Effects of Low-Temperature Annealing and Deep Traps in Operation Characteristics of Amorphous In-Ga-Zn-O Thin-Film Transistors**, ***T. Kamiya***, *Y. Kikuchi, K. Ide, K. Nomura, H. Hosono*, Tokyo Institute of Technology, Japan

Amorphous oxide semiconductors (AOSs) represented by a-In-Ga-Zn-O (a-IGZO) are expected for channel materials in thin-film transistors (TFTs) for next-generation flat-panel displays such as jumbo-size / fast / ultrahigh-resolution liquid-crystal displays and organic light-emitting diode displays. These are also expected for flexible electronics devices because they may be fabricated on unheated substrates, and thus produce flexible displays and circuits on inexpensive plastic substrates such as PET. On the other hand, it is known that, although room-temperature fabrication is possible for AOS TFTs, post-deposition thermal annealing at ≥300°C is better employed to obtain good stability. To employ this technology to the flexible electronics, the annealing temperature should be lowered to 200°C or far below. We reported that wet O_2 annealing produces the best performance TFTs when annealed at ≥300°C, while it caused serious negative threshold voltage (V_{th}) shift at ≤200C. In this paper, we report the origin of the negative V_{th} shift by employing photoresponse spectroscopy of TFT characteristics. It revealed that the near-valence band maximum (VBM) states are reduced significantly even by the low-temperature 200C annealing, and implied that the negative V_{th} shift originates from free electrons released by annihilation of the near-VBM states.

5:20pm **TC+EM+NS-ThA11 β-alumina (SBA): A Promising High Dielectric Constant Gate Material for Solution Processed, Transparent and Low Voltage Transistor Devices**, ***B. Zhang***, *Y. Liu, H. Katz*, Johns Hopkins University

β-alumina (SBA) has been discovered as a promising high dielectric constant gate material for solution processed, transparent and low voltage transistor devices. Some experimental evidence indicates that the mobile Na ion within two spinel blocks made by Al and O is responsible for the high dielectric constant. Transistors (W/L ratio 10) using SBA as gate layer and zinc tin oxide (ZTO) as active layer only need 2V to obtain 0.7mA output current. SBA material is compatible with organic semiconductors such as PQT12 and pentacene as well. Some key issues regarding using SBA for real applications, such as device stability in the ambient atmosphere, response under high frequency, and threshold voltage shift under gate bias have also been studied. It is found that encapsulating the device with CYTOP fluorinated polymer is an effective way to increase the operational stability of the devices in the ambient environment.

Transparent Conductors and Printable Electronics Focus Topic
Room: East Exhibit Hall - Session TC-ThP

Transparent Conductors and Printable Electronics Poster Session

TC-ThP1 A Combinatorial Thin Film Sputtering Approach of the Synthesis and Characterization of Al_2O_3-TiO_2 High-k Dielectrics for Oxide TFT Application, ***J.H. Noh***, *J. Noh, P.D. Rack*, The University of Tennessee

For the last decade, oxide based thin-film transistors (TFTs) have been extensively investigated because of their transparency, high mobility, low process temperature which are expected to serve as the basis for new optoelectronic and flexible devices. However, most of the work on oxide TFTs still rely on conventional dielectrics from Si technology, such as plasma-enhanced chemical vapor deposited (PECVD) SiO_2 or SiN_x with process temperature of 250–300°C. For high performance, low-cost and flexible electronics, high-k dielectrics at low process temperatures are needed. rf sputtering is alternative process for low temperature dielectrics. Usually, the deposition rate with oxide target is very low, so it is not compatible for mass production. In order to overcome this problem, reactive sputtering is adapted in this study. Although oxide TFTs with low-temperature sputtered materials such as Al_2O3, HfO_2, Y_2O_3, Ta_2O_5 have already been reported in the literature, TFTs performance are worse than standard higher temperature dielectrics because of high interface trap density due to low temperature. In order to improve the TFT performance, high-k materials are preferable. However, most of the high-k materials show a polycrystalline structure and small bandgap, hence the leakage current is high and breakdown voltage is low. These problems can be overcome through a combination of high-k but low bandgap and low-k but large bandgap materials. In this study, TiO_2 is chosen as a high-k material because of very high dielectric constant of ~ 80, and Al_2O_3 is chosen as a low-k material because of large bandgap of 8.7 eV. For optimization of high dielectric constant and low leakage current, a combinatorial thin film sputtering approach is used for the synthesis and characterization of Al_2O_3-TiO_2 high-k dielectrics because a combinatorial thin film sputtering approach can yield a wide range of compositions via a single co-sputter deposition process. The composition ranges of the films are simulated using a co-sputtering simulation and compared favorably to compositions measured by the wavelength dispersive spectrometer (WDS). The TFTs are fabricated with a bottom-gate staggered structure using amorphous indium gallium zinc oxide (a-IGZO) and In_2O_3 as the semiconducting active layer. Standard I-V and C-V data on the dielectric multilayers will be compared as a function of composition and finally, the TFTs' performance will be presented according to the relative contents of TiO_2 and Al_2O_3.

TC-ThP2 Fabrication and Characterization of Sub-micron OTFT Using Ink Jet Combined Imprint Process, ***K. Kim***, *N. Kwon, I. Chung*, Sungkyunkwan Univ., Republic of Korea

We fabricated sub-micron organic thin film transistors on polyethersulphone (PES) substrate using ink jet printing combined with an imprint method. The channel lengths of OTFTs were in the range between 500 nm and 1 um. 6,13-bis(triisopropylsilylethynyl) (TIPS) pentacene was used as an active material and Polyvinyl alcohol (PVA) was chosen as a gate insulator. TIPS pentacene was printed by jetting onto the confined channels which were prepared using imprinting. The surface of confined channel was modified by UV irradiation in order to enhance the crystallinity of tips pentacene. The physical properties were analyzed using SPM, SEM, and XRD. The electrical properties were extracted from the transfer characteristics which were measured using Keithley-4200.

TC-ThP3 Study on Multiple Stacked 6,13-bis(triisopropylsilylethynyl) (TIPS) Pentacene for Improved Organic Thin Film Transistor, ***S. Lee***, Sungkyunkwan Univ. & Samsung Mobile Display, Republic of Korea, *J.J. Han, K. Kim, I.J. Bae, I. Chung*, Sungkyunkwan Univ., Republic of Korea

We found that the crystallization of TIPS pentacene thin film plays an important role in determining the electrical property of organic thin film transistor (OTFT). Ink jetted TIPS pentacene film reveals 2 different types of grains namely due to the coffee strain effect. The better electrical properties were obtained from the OTFTs with bigger grains that had been possible due to the multiple stacked TIPS pentacene layer. Poly-4-vinylphenol (PVP) was used as a gate insulator, and Au electrode was evaporated using a shadow mask. The channel lengths of OTFTs with the bottom gate structure were 20-50 um. The physical properties of the TIPS pentacene films were analyzed using optical microscope (OM), x-ray diffraction (XRD) and secondary electron microscopy (SEM). The electric characteristics of OTFT were obtained using Keithley- 4200.

TC-ThP4 Catalyst-assisted Pulsed Laser Deposition of Tin (IV) Oxide on Si Substrates: Growth Evolution of Low-dimensional Nanostructures, ***K.T. Leung***, University of Waterloo, Canada

Single-crystalline nanostructures of SnO_2 have been grown with the aid of size-controllable gold nanoisland catalysts supported on a Si substrate by using the Pulsed Laser Deposition (PLD) method. By changing the gas atmosphere and manipulating the deposition at a relatively low substrate temperature (500-700°C), we produce faceted nanobricks, nanograss, and nanoribbons on oxidized Si and cubic nanoparticles on H-terminated Si. Scanning electron microscopy clearly shows the faceted morphology of these one-dimensional and zero-dimensional nanostructures and suggests a vapour-solid and a vapour-liquid-solid growth mechanisms for nanoparticles and nanobricks and for nanograss and nanoribbons, respectively. X-ray diffraction results reveal the tetragonal crystalline phase of the SnO_2 nanostructures, and the relative intensity ratios obtained for different peaks further show a preferred growth orientation of (101) for the nanoparticles and nanobricks, and of (200) for the nanograss and nanoribbons. For nanograss and nanoribbons, transmission electron microscopy confirms the single-crystalline nature of these nanostructures, and the corresponding high-resolution and selected area electron diffraction data illustrate their different growth orientations that generally lead to the preferred growth directions as inferred from the corresponding X-ray diffraction data. We have also recently used Helium Ion Microscopy to elucidate not only the intricate surface details but also the growth evolution of these SnO_2 nanostructures. These results demonstrate the versatility of the catalyst-assisted PLD technique in depositing a variety of SnO_2 nanostructures, which can be easily optimized and/or modified by appropriate doping within the PLD method for producing desirable optoelectronic, magnetic, gas-sensing, and semiconducting properties for emerging applications.

TC-ThP5 From Discrete and Hollow Nanocavities to the Formation of Continuous Indium-Filled Indium Oxide Nanotubes, *M. Kumar*, South Dakota State University, *B.R. Mehta*, ***J.P. Singh***, Indian Institute of Technology-Delhi, India

The growth mechanism for single crystalline indium oxide nanotu be is still under debate in scientific community. The mechanism was proposed for the growth of nanotubes based on the growth parameters dependent morphological transformation from discrete and hollow nanocavities in nanowires to continuous indium-filled indium oxide nanotubes. The gas flow rate induced change in indium partial pressure and hence supersaturation during reaction of species on substrate decides the growth of two different nanostructures. We discussed a unified growth mechanism based on vapor-solid growth followed by the out diffusion or in-diffusion of metal indium depending on it's partial pressure during growth. The out diffusion of indium resulted discrete and hexagonal nanocavity enclosed with minimum surface energy planes, {111} while the higher partial pressure of indium support the merging of discreet nanocavities into continuous connecting and filled with In metal.

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