Transparent Conductors and Printable Electronics Focus Topic
Room: 7 - Session TC+EM+AS-WeA

Printable and Flexible Electronics
Moderator: G.S. Herman, Oregon State University

2:00pm **TC+EM+AS-WeA1 Metal Oxides and Organic Materials for Printed Electronics**, ***A. Facchetti***, Polyera Corp. and Northwestern U. **INVITED**

Printed electronics is a new technology envisioning the fabrication of electronic devices using printing methodologies instead of conventional photolitography employed in the silicon industry. Metal oxide- and organic-based materials will be key players for this technology. In this presentation I will discuss our latest results in developing new printable organic semiconductors Furthermore, I will describe amorphous and polycrystalline metal oxide formulations in which the corresponding films can be annealed at temperatures < 250 ºC. For instance, solution-processed amorphous tin-doped indium oxide (ITO) films for TFT fabrication at temperatures <250 °C can be achieved by controlling film precursor solution In^{+3} vs. Sn^{+4} molar ratio resulting in electron mobilities > 2 cm^2 $V^{-1}s^{-1}$ and ~ 20 cm^2 $V^{-1}s^{-1}$ for TFTs using SiO_2 and a self-assembled nanodielectric (SAND) as the gate dielectrics, respectively. Finally, a new general strategy for fabricating solution-processed metal oxide TFTs at dramatically lower temperatures (as low as 200 ° C for all TFT electrical components) using self-energy generating combustion chemistry will be presented. Our results show that by tuning the gate dielectric-semiconductor interface dramatically enhances performance, yielding In_2O_3, IZO, IZTO, and IGZO /amorphous alumina gate dielectric TFTs having electron mobilities of 40 cm^2/Vs and 13 cm^2/Vs at T_{anneal} = 250 ° C and 200 ° C, respectively.

2:40pm **TC+EM+AS-WeA3 Ion Dependence of Gate Dielectric Behavior of Beta-Aluminas in Transparent Oxide Field-Effect Transistors**, ***Y. Liu***, *B. Zhang, H.E. Katz*, Johns Hopkins University

Sodium beta-alumina (SBA) is an excellent gate dielectric material which can be used in low-voltage (2 V), solution-processed transparent oxide field-effect transistors (FETs). Sodium ions have been experimentally proved to be the origin of the high capacitance observed in SBA gate dielectric. With this discovery, the investigation of dielectric properties of alumina with the incorporation of other alkali metal ions (for example K^+, Li^+) becomes compelling.

High field-effect mobility (about 20 $cm^2 \cdot V^{-1} \cdot s^{-1}$), high saturation drain current (about 1 mA), and small subthreshold swing (about 200 mV/decade) were achieved in low-voltage (2 V), spin-coated zinc-tin-oxide (ZTO) FETs with potassium beta-alumina (PBA) and lithium beta-alumina (LBA) dielectrics. This proves that the incorporation of alkali metal ions in beta-aluminas is a general route to reduce operation voltage of transistors while achieve excellent electrical performance.

To investigate the effect of alkali metal ions on beta-alumina capacitance, beta-alumina Metal-Insulator-Metal (MIM) capacitors (PBA, LBA, and SBA) were analyzed in a frequency range from 100 Hz to 1 MHz. A tendency for beta-alumina capacitance to increase with increasing atomic number of alkali metal ions was observed. Besides, beta-alumina capacitance was found to decrease as temperature increases and LBA showed the strongest temperature dependence of capacitance. Moreover, capacitance of beta-aluminas with different thickness was measured and they were independent of thickness. With these results, electric double layer (EDL) structure was proposed as one way to explain the high capacitance of beta-alumina dielectrics. Ion exchange experiments showed significant diffusion of both lithium ion and potassium ion between PBA and $LiNO_3$ solution; however, a high concentration difference did not seem to cause obvious diffusion of either lithium ion or potassium ion between LBA and KNO_3 solution. This selective ion exchange behavior in beta-aluminas showed that the Al_2O_3 matrix structure would be affected by the alkali metal ions incorporated, and/or that Li ions are much more strongly bound. Thus, varying intercalated ion types and concentrations can be a means of tuning frequency-dependent capacitance of alumina films.

3:00pm **TC+EM+AS-WeA4 Selection Rule of Preferred Doping Site for N-Type Transparent Conducting Oxides**, ***S.-H. Wei***, National Renewable Energy Laboatory, *C. Li, J.B. Li*, Institute of Semiconductor Physics, CAS, China

Traditionally, it is believed that the conduction band edges of d^0 or d^{10} oxides are derived mostly from cation *s* states, thus doping on anion sites is expected to cause less perturbation and produce shallow donor levels in these materials. Using first-principles calculations, we show that although this paradigm is applicable for more covalent oxides such as SnO_2 where F_O is a better n-type dopant than Sb_{Sn}, for more ionic oxides such as ZnO, the conduction band edge actually contains a considerable amount of O *s* orbitals, thus F_O in ZnO causes larger perturbation and consequently produces deeper donor levels than cation site doping such as Al_{Zn}. The rule that anion site doping is preferred for more covalent oxides and cation site doping is preferred for more ionic oxides for n-type metal oxides should be general and can be used to guide future study of and search for functional oxide materials.

4:00pm **TC+EM+AS-WeA7 Single-Walled Carbon Nanotube Aerogel Based Elastic Conductors**, *K.H. Kim, Y. Oh, I. Lee,* ***M.F. Islam***, Carnegie Mellon University **INVITED**

Flexible conductors of various shapes and sizes with high electrical stability under large elastic stretching and bending are of significant importance in diverse fields ranging from microelectronics to biological implants. A major roadblock in the development of flexible conductors is the disparity between elastomers and stiff conducting materials used in microelectronics. We have developed a novel scheme to create flexible conductors by completely backfilling a prefabricated conducting porous single wall carbon nanotube (SWCNT) three-dimensional network, called SWCNT aerogel, with an elastic polymer polydimethylsiloxane (PDMS). Our approach allowed us to control SWCNT dispersion quality, and tune shapes, sizes and thicknesses of the SWCNT-aerogel/PDMS composite films to make them transparent. The resistance of our stretchable conductors remains nearly unchanged under repeated stretch-release cycles up to a tensile strain of 100% and high bending strain. We believe that the simple but unique fabrication method can be combined with different types of elastic polymers for different electrical, mechanical or biological demands.

4:40pm **TC+EM+AS-WeA9 Networked Metal Nanowire-Polymer Composites for Flexible, Transparent and Conducting Devices**, *S. Narayanan, S. Fu, M.R. Bockstaller,* ***L.M. Porter***, Carnegie Mellon University

Transparent conductive metal oxides (TCOs) exhibit inherent disadvantages such as limited supply, brittle mechanical properties, expensive processing that present major barriers for the more widespread economic use in applications such as flexible transparent conductors A promising alternative route towards flexible, transparent conductive materials is based on silver nanowire network structures, which can be easily processed from solution. We report a systematic analysis of the effect of nanowire geometry and solution processing on the network characteristics of nanowire deposits, and the associated electronic and optical properties of silver nanowire-based transparent electrodes. Ag nanowire (of average diameter ~100 nm) films drop-cast from solution were shown to exhibit bulk-like electrical conductivity (~2-50 Ω/sq) and high transparency (~70-75%). The electrical properties of nanowire networks were found to be sensitive to geometric parameters of the wire assembly that can be interpreted by use of percolation theory. At concentrations below the percolation threshold the sheet resistance increases dramatically, effecting a marked deviation from bulk-like behavior [1]. The dispersion of Ag nanowires in a conducting medium, like that of a conducting polymer was found to significantly reduce nanowire aggregation and thus decrease the percolation threshold. Preliminary results of spun-cast films of composites of these nanowire networks with PEDOT:PSS show higher transmittances (~79-82%) with similar conductivities (~10-170 Ω/sq) combined with better film forming properties. The use of composites was found to bring about a consistent improvement in electrical conductivity with very little change in the transmittance. Samples prepared on flexible PET substrates showed no degradation in conductivity on flexing thereby showing ample promise for incorporating flexibility in such structures. Through analysis of microstructural characteristics of these films, a quantitative correlation of the density of nanowires with conductivity and transmittance will be presented. The advantages of using such a composite structure in reducing the percolation threshold will be discussed.

[1] Sukanta De *et al.* ACS Nano **4** 12 (2010) 7064-7072

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