Electronic Materials and Processing
Room 2001 - Session EM-ThM

Organic Electronic Materials and Devices
Moderator: D.J. Gundlach, NIST

8:00am **EM-ThM1 Organic Thin Film Transistors with an Organic/High-k Inorganic Bilayer Gate Dielectric Layer**, ***Y.G. Seol,*** Sungkyunkwan University, Korea*; S.S. Lee, J.H. Lee,* Hanyang University, Korea*; N.-E. Lee,* Sungkyunkwan University, Korea

To develop the high performance OTFT devices, low threshold voltage (V@sub T@), low-leakage current, high current on-off ratio, and channel mobility are needed. To achieve low V@sub T@ and low-leakage current level, use of thin high-k gate dielectrics is required. For this purpose, the organic/inorganic (high-k) bilayer gate dielectric layers were investigated in this work. Flexible organic thin film transistors were fabricated using pentacene as a semiconducting layer and electroplated nickel (Ni) as a gate electrode on polyimide substrate. Electroplated gate electrode formed on the plasma-treated polyimide substrate provides a good adhesion. First, poly(4-vinyl phenol) (PVP) as an organic gate dielectric layer was deposited by spin coating after Ni gate electrode formation. Ultra-thin (10 nm) HfO@sub 2@ as a high-k dielectric deposited by ALD (atomic layer deposition) on the spin-coated PVP layer. ALD of HfO@sub 2@ layer was carried out at the substrate temperature 220 ~ 240°C. Pentacene as a semiconductor layer was thermally evaporated on the gate dielectric layer using a shadow mask in vacuum chamber at the substrate temperature of 80°C and then the thermal evaporation of gold source and drain electrodes was followed. The OTFT devices with no ALD HfO@sub 2@ layer were also fabricated for comparison. The channel length varied from 10 to 110μm, and the channel width was 800μm. The measured I-V characteristics indicated the significant reduction in the leakage current for thinner PVP layer and improvement of current on-off ratio.

8:20am **EM-ThM2 Low Voltage Organic Field-Effect Transistors with High k Nanocomposite Dielectric Gate Insulator**, ***A. Rasul,*** *J. Zhang, D. Gamota,* Motorola Inc.*; C.G. Takoudis,* University of Illinois at Chicago

Solution processed nanocomposite dielectric material with a high dielectric constant was demonstrated as a gate insulator for organic electronics applications. A nanocomposite consisting of cross-linked Propylene Glycol Methyl Ether Acetate and Barium Titanate (BTO) nanoparticles was developed and utilized as the gate insulator. The high relative permittivity (k=35), bimodal nanocomposite utilized had two different filler particle sizes 200 nm and 1000 nm diameter particles. Bottom contact organic field-effect transistors (OFETs) were demonstrated using a combination of printing and spray coating technologies. A metal coated plastic film was used as the flexible gate substrate. An amorphous organic semiconductor was utilized as the active layer. OFETs with the solution processed nanocomposite dielectric had a high field-induced current and a low threshold voltage and thus a low operating voltage due to the high capacitance gate insulator. We review the characteristics of the nanocomposite material and discuss the processing and performance of the printed organic devices. To the knowledge of the authors, this nanocomposite has the highest reported dielectric constant of a solution processed gate insulating material for an OFET worldwide.

8:40am **EM-ThM3 New Materials and Processes for Organic Transistors, Inorganic Transistors, and Printed Electronics**, ***T.J. Marks,*** Northwestern University **INVITED**

Materials chemists are exceptionally skilled at designing and constructing individual molecules with the goal of imbuing them with defined chemical and physical properties. However, the task of rationally assembling them into organized, functional supramolecular structures with precise, nanometer-level control is a daunting challenge. In this lecture, approaches to addressing this problem are described in which the ultimate goal is the fabrication of organic electronic circuit by printing techniques. Issues here concern not only the rational design of high-mobility p- and n-type organic semiconductors, but also dielectrics with ultra-high capacitance, low leakage, and high breakdown fields.

9:20am **EM-ThM5 Organic Thin-Film Transistors with Novel SAM-Modified Dielectrics**, ***I.G. Hill,*** *M. McDowell,* Dalhousie University, Canada*; J.E. McDermott, S.L. Bernasek, J. Schwartz,* Princeton University

Pentacene organic thin-film transistors (OTFTs) exhibit charge carrier mobilities very similar to their amorphous silicon counterparts. Several impediments remain, however, which hinder their use in consumer electronic devices, including long-term stability and poor sub-threshold performance. While the implications of the former are obvious, those of the latter are subtler. The sub-threshold slope (a measure of the sharpness of the off-to-on transition) and the threshold voltage impact the total voltage swing which must be applied to the device gate to switch between the on and off states, and thus dictate power supply requirements and power dissipation. Pentacene devices utilizing bare silicon dioxide as a gate dielectric exhibit poor sub-threshold slopes (several volts/decade) and, typically, large positive threshold voltages. Both effects can be attributed to a high dielectric/semiconductor interfacial charge trap density. We have investigated the use of phosphonate-linked self-assembled monolayers (SAMs) to modify the electronic structure to the dielectric/pentacene interface. The SAM molecules were chosen to present a surface for pentacene growth which resembled an existing organic semiconductor layer, thus reducing the density of interfacial defects and charge trapping sites. Devices incorporating these SAMs have demonstrated near-zero threshold voltages and sub-threshold slopes less than 200 meV/decade of current, which is only 3x the thermodynamically allowed limit.

9:40am **EM-ThM6 Growth of Pentacene Films: Influence of Substrates**, ***G. Witte,*** *D. Kaefer, Ch. Woell,* Ruhr-University Bochum, Germany

In recent years organic semiconductors have gained wide-spread attention due to their promising potential as active materials for organic electronic applications. Of particular interest among such materials are oligoacenes, such as pentacene, because of their ability to form crystalline phases which reveal remarkable high carrier mobilities. In view of the interrelation between intermolecular packing and electronic properties a precise control of the molecular packing and orientation in thin (poly-) crystalline films is of vital interest especially for devices such as OFETs where high charge carrier mobilities are required. Here we report the result of a comprehensive growth study of thin pentacene films deposited by OMBD under vacuum conditions onto various metal surfaces. By combining different microscopy techniques including STM, AFM, SEM with X-ray absorption spectroscopy (NEXAFS) the evolution of such organic films has been analyzed as a function of thickness and deposition parameters (rate and temperature). We demonstrate that the resulting molecular orientation and the film morphology depend critically on the roughness and chemical termination of the substrate whereas growth rate and substrate temperature mainly affects the grain size. Dewetting phenomena which usually dominate the morphology of pentacene films on clean metal substrates can be suppressed by first coating the substrate with self-assembled monolayers (SAMs) which leads to rather smooth films. Possible driving forces for the appearance of the various film structures and strategies for a rational control of the microstructure of such organic films are discussed.

10:00am **EM-ThM7 In-Plane Anisotropy of Pentacene Crystals on Surface Alignment Layers and its Influence on Photovoltaic and Thin-Film Transistor Device Characteristics**, ***A. Amassian,*** *A.C. Mayer, A. Kazimirov, D.-M. Smiglies, G.G. Malliaras,* Cornell University

Significant research effort has gone into understanding and controlling the growth of pentacene thin films, with the ultimate goal of enhancing charge transport by favouring 2D over 3D growth on surfaces. As pentacene behaves as a 2D powder on insulating surfaces, and electron transport is limited by charge trapping at grain boundaries, electron mobility can be further improved (in some directions) by orienting crystal growth using surface alignment layers. In this paper, we report on our recent efforts to induce in-plane anisotropy in pentacene crystals on a variety of mechanically rubbed surfaces, including conducting polymer (PEDOT:PSS) surfaces, high-k dielectrics (fluorinated ter-polymer) and various self-assembled monolayers (SAMs). In situ x-ray scattering measurements carried out at the Cornell high energy synchrotron source (CHESS) in a variety of measurement configurations show evidence of in-plane alignment in monolayer-thick pentacene films vacuum evaporated on some of these rubbed surfaces. Rubbing-induced preferential orientation of pentacene grains is shown to lead to an increase of the pentacene mobility by a factor of ~2.5 for current flow in the direction perpendicular to alignment in organic thin film transistor devices (OTFT).

10:20am **EM-ThM8 Metallic Thin Films of Molecular Metals**, *I. Malfant, K. Rivasseau, D. de Caro, L. Valade,* Laboratoire de Chimie de Coordination (CNRS), France*;* ***J. Fraxedas,*** Institut de Ciencia de Materials de Barcelona (ICMAB-CSIC), Spain

Intrinsically metallic molecular materials become in most cases activated semiconductors when prepared as thin films due to the formation of segregated domains, the so-called grains boundaries. The transport

properties of such polycrystalline films are thus determined by the morphology of the films. Needless to say that there is tremendous interest in circumventing the extrinsic effects of grain boundaries in order to exploit the intrinsic physical properties of the pristine materials when targeting technological applications. We show two examples of truly metallic organic thin films (thickness ca. 4 μm) grown by electrocrystallization on silicon wafers of TTF-based molecular metals, where TTF stands for tetrathiafulvalene. Our first example is TTF[Ni(dmit)@sub 2@]@sub 2@, dmit = dithiolethionedithiolate. The films show a reversible metal-insulator transition at 12 K.@footnote 1@ The second example concerns the single-component neutral molecular metal Ni(tmdt)@sub 2@, tmdt = trimethylenetetrathiafulvalenedithiolate. The films exhibit a room temperature conductivity of ca. 100 S/cm.@footnote 2@ We confirm that electrocrystallization is the technique of choice to obtain metallic films of single- and multi-component organic materials and we pursue the preparation of superconducting films. @FootnoteText@@footnote 1@D. de Caro, J. Fraxedas, C. Faulmann, I. Malfant, J. Milon, J.- F. Lamère, V. Collière, L. Valade, Adv. Mater. 16, 835-838 (2004) @footnote 2@I. Malfant, K. Rivasseau, J. Fraxedas, Ch. Faulmann, D. de Caro, L. Valade, L. Kaboub, Jean-Marc Fabre, F. Senocq, J. Am. Chem. Soc. 128, 5612-5613 (2006).

10:40am **EM-ThM9 Mobility Optimization Study of Organic Semiconductor Based Thin Film Transistors***, **R.P. Shrestha**, D. Yang,* University of North Carolina at Chapel Hill*; Y.X. Li,* Shandong University, China*; L. Yan, E.A. Irene,* University of North Carolina at Chapel Hill

Optical and electronic properties of two spin cast organic semiconductors N,N '- bis (3-phenoxy-3-phenoxy-phenoxy) -1,4,5,8-naphthalenetetracarboxylic diimide (NDA) and poly (o-methoxyaniline) POMA have been previously reported. In this study, the effect of various process changes (annealing, dielectric layer, device geometry) on the mobility of organic thin film transistors (OTFT) fabricated using NDA and POMA is explored. Low dielectric constant (K), non-polar dielectric materials improved charge mobility as did judicious annealing and bottom contact geometry. For example, the initial mobility of 10-3 cm2 V-1 s-1 for POMA can be improved by an order of magnitude by using polyethylene (PE) (low K) and degraded using polyvinylidene trifluoroethylene P(VDF-TrFe) (high K) dielectric layers. Similar results are reported for NDA OTFTs. Other performance parameters such has turn-on/off ratio and threshold voltages are also reported for the devices.

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