

## Electronic Materials and Processing Room 309 - Session EM-FrM

### Organic Electronic Devices

Moderator: A. Kahn, Princeton University

#### 8:20am EM-FrM1 Charge Transport in Amorphous Organic Semiconductors : Can We Describe a Wide Variety of Devices by a Single Model?, *Y. Roichman*, Princeton University **INVITED**

During the last years we witnessed an improvement of organic electronic devices and emergence of new devices, as a homogenous PN junction. At the same time the theory of charge transport in organic semiconductors was reexamined, with an emphasis on application to devices realistic operation condition. In this talk I will review the recent experimental evidences and advances in theory of charge transport in amorphous organic semiconductors. I will demonstrate that taking into account non-linear effects and a reasonable shape density of states the electronic behavior different devices (PN homogenous diode, PV cell and FET) that operate at different conditions can be explained by a single theoretical model. The differences between the major theoretical approaches will be briefly discussed as well.

#### 9:00am EM-FrM3 Physical Mechanisms in Programmable Nanoscale Organic Nonvolatile Memory Devices, *T. Graves-Abe, J.C. Sturm*, Princeton University

Great interest in novel, low-cost memory technologies has led to the development of a number of promising approaches based on organic thin films. @footnote 1@ We have recently reported memory devices based on 10-nm self-assembled films of 11-mercaptoundecanoic acid (MUA) sandwiched between gold electrodes. @footnote 2@ Devices can be placed into a high-conductance "ON" state by 3- to 4-V pulses and returned to a low-conductance "OFF" state with higher-voltage pulses. Devices have a number of desirable characteristics, including durability (more than 10@super 4@ write/erase cycles without degrading), nonvolatile memory states, fast programming times (<micro@s), and large current densities (up to 10@super 5@ A/cm@super 2@ at 1 V) to minimize resistance-capacitance delays in large memory arrays for fast access times. Models based on charge-trapping or conducting-path formation have been proposed to describe similar results in other thin films, @footnote 3@ although in practice it is difficult to distinguish between the models. In this work, we report strong evidence that the programmable conductance of our devices is due to the formation and destruction of conductive paths. This evidence includes: i) the presence of multiple step-like increases in current during the transition from OFF to ON states, which are attributed to the formation of a small number (<10) of conducting paths leading to the ON state, ii) the exponential reduction in the time required to form these conductive paths with increased electric field, consistent with the field-assisted diffusion of metal ions into the organic layer to form the paths, iii) the dependence of electrical characteristics on choice of electrode material, and iv) the extremely thin nature of the films. @FootnoteText@ @footnote 1@ Y. Yang et al, MRS Bull. 29, 833 (2004). @footnote 2@ T. Graves-Abe and J. C. Sturm, Mat. Res. Soc. Symp. San Fran., CA, April 2005. @footnote 3@ G. Dearnaley et al, Rep. Prog. Phys. 33, 1129 (1970).

#### 9:20am EM-FrM4 Effect of Poly (3-hexylthiophene) Film Thickness on Organic Thin Film Transistor Properties, *H. Jia, S. Gowrisanker, G.K. Pant, R.M. Wallace, B.E. Gnade*, University of Texas at Dallas

We present the effect of poly (3-hexylthiophene) thickness on the performance of OTFTs. When the poly (3-hexylthiophen) film thickness varies from 3.8nm to 23.8nm, the drain current and the saturation mobility increase with the thickness because of the higher channel conductance. In contrast, the on/off ratio decreases with P3HT film thickness, primarily because of the higher off current. Gate leakage also becomes higher when the film thickness increases, also contributing to a lower on/off ratio. The threshold voltage is more sensitive to dielectric surface treatment than to the thickness of P3HT film thickness. The mobility increases and then saturates with gate voltage. For devices from thick P3HT films, increasing gate voltage further after saturation decreases the mobility. Short channel effects are observed for channel lengths of @<= 5 μm. We also present the channel length dependence of threshold voltage and mobility. The drive current, on/off ratio, and mobility of P3HT devices should be optimized based on the specific application. @Footnote Text@ @footnote 1@ Jiyoul Lee, Kibum Kim, Jae Hoon Kim, Seongil Im, Duk-Young Jung, Appl.

Phys. Lett. 82, 4169 (2003) @footnote 2@ Satoshi Hoshino, Toshihide Kamata, and Kiyoshi Yase, J. Appl. Phys. 6028 (2002) @footnote 3@ R. Schroeder, L. A. Majewski, and M. Grell, Appl. Phys. Lett. 83, 3201 (2003) @footnote 4@ Manabu Kiguchi, Manabu Nakayama, Kohei Fujiwara, Keiji Ueno, Toshihiro Shimada and Koichiro Saiki, Jpn. J. Appl. Phys. 42, L1408(2003)

9:40am EM-FrM5 Vapor and Solution Deposited Organic Thin Film Semiconductor Transistors, *T.N. Jackson*, Penn State University **INVITED**  
Organic thin film transistor (OTFT) device performance now rivals or exceeds that of a-Si:H devices, and low OTFT process temperatures allow fabrication on a range of surfaces including cloth, paper, or polymeric substrates. However, it is still unclear whether OTFTs will find significant commercial application. To do so, OTFTs must demonstrate characteristics that differentiate them from other device technologies, especially a-Si:H TFTs. Potential advantages for OTFTs include the possibility of device and system fabrication on substrates not readily accessible to a-Si:H devices and also reduced cost manufacturing. For practical device and system use, OTFTs must demonstrate the uniformity, reproducibility, reliability, and integration with other devices, needed for realistic applications. As a candidate application we have considered the integration of vapor-deposited OTFTs with organic light emitting diodes (OLEDs). Working with Kodak we have fabricated small test displays that allow us to investigate device characteristics and passivation and isolation requirements for integrating these organic devices. Solution-deposited organic semiconductors may offer important advantages for low-cost processing. However, solution processed semiconductors typically lack the molecular-level order which may be important for good carrier transport and large field-effect transistor mobility. Working with J. Anthony (University of Kentucky) we have investigated functionalized pentacenes and pentacene derivatives. These materials use bulky molecular side groups to control molecular packing and allow solubility in a range of common solvents. Surprisingly, solution-deposited films of some of these materials show good molecular ordering and using these materials we have been able to fabricate OTFTs with mobility > 1.5 cm@super 2@/V-s.

#### 10:20am EM-FrM7 Optical and Electrical Properties of a New N-type Semiconductor: N, N@super '@-bis (3-phenoxy-3-phenoxy-phenoxy)-1,4,5,8-naphthalenetetracarboxylic diimide, *D.X. Yang, R.P. Shrestha*, University of North Carolina-Chapel Hill; *T.J. Dingemans*, Delft University of Technology, The Netherlands; *E.T. Samulski, E.A. Irene*, University of North Carolina-Chapel Hill

Optical properties of N, N@super '@-bis (3-phenoxy-3-phenoxy-phenoxy)-1,4,5,8-naphthalenetetracarboxylic diimide (NDA-n2) thin film, a N-type organic semiconductor, were investigated using optical transmission and spectroscopic ellipsometry (SE) in the visible-near uv optical range. The dispersion in refractive index and extinction coefficient along with anisotropy, surface roughness and annealing results are reported. An oscillator model with one Tauc-Lorentzian oscillator and four Gaussian oscillators was proposed to describe the dielectric function of NDA-n2. Vacuum annealing of the thin film was performed and monitored using in-situ SE. The films we stable up to 150 °C and no optical anisotropy was found for the films. Capacitance versus voltage (C-V) and current versus voltage (I-V) measurements were performed on capacitor and thin film transistor (TFT) structures, respectively. The C-V results indicate a value of about 3.4 for the static dielectric constant. The I-V yields TFT transfer characteristics that are used to optimize the film formation process and device performance of the thin film semiconductor for TFT@super '@s. The mobility of NDA-n2 was obtained from I-V results in a TFT structure.

#### 10:40am EM-FrM8 Growth and Chemical Structure of Crystalline Rubrene Films, *G. Witte, D. Kaefer, Ch. Woell*, Ruhr-University Bochum, Germany

Rubrene single crystals have recently been demonstrated to exhibit remarkably high charge carrier mobilities@footnote 1@ which favors the use of this organic semiconductor material for molecular electronics applications e.g. organic field effect transistors. In contrast to other oligomer semiconductors such as pentacene the growth of crystalline thin films, however, has not been achieved for rubrene. Using x-ray absorption spectroscopy (NEXAFS) we have analyzed the initial stage of film growth on various substrates and demonstrate the importance of molecular conformation which involves a loss of chirality in case of rubrene. Whereas organic molecular beam deposition at room temperature only leads to rather amorphous layers, dendritic films are obtained at high substrate temperatures but the size of the crystallites is mainly limited by competing dewetting and desorption. An improved crystallite growth is achieved by using a modified "hot wall"-type deposition cell which allows operation

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under UHV-conditions but at much higher vapor pressure. Moreover, by combining AFM and SEM with XPS and LDI-TOF mass spectroscopy the morphology of the films and the amount of rubrene-peroxide formed upon exposure to air was characterized. Large differences in the corresponding rubrene-peroxide concentrations and their depth profiles were found for the various films and crystals which is of great importance for applications in molecular electronics. @FootnoteText@@footnote 1@ V.C. Sundar et al. Science 303, 1644 (2004).

11:00am **EM-FrM9 Pentacene Wetting Layer Formation on SiO<sub>2</sub> Substrate**, C. Kim, D. Jeon, Seoul National University, South Korea

We have applied in-situ ellipsometry to study the growth of pentacene film on the SiO<sub>2</sub> surface. As soon as the evaporation began, the intensity of ellipsometry spectrum decreased. Atomic force microscopy (AFM) images of the early stage of growth, however, did not show any pentacene-related morphology. The pentacene islands in the first layer appeared after a continued deposition. The immediate change of ellipsometry spectrum with the onset of deposition indicates that pentacene molecules accumulate on the SiO<sub>2</sub> surface from the beginning. However, the flat AFM image of the early stage indicates that pentacene initially forms an amorphous wetting layer before crystalline islands appear. The roughness of the SiO<sub>2</sub> surface decreased with the pentacene deposition, which is another indication of the amorphous wetting layer. Pentacene is known to form a wetting layer on a clean metal or semiconductor substrate. In other words, pentacene reacts with the surface before a crystalline film forms. Our result shows that pentacene forms a wetting layer on an inert substrate as well. The existence of an amorphous layer on an insulating substrate should affect the performance of the pentacene devices. To show this we will also present the result from the electrostatic force microscopy of the pentacene film. This work was supported by the Nano Systems Institute at Seoul National University.

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