SYMPOSIUM I

Flexible Electronics–Materials and Device Technology

April 12 - 16, 2004

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* Invited paper
Hydrogenated amorphous silicon (a-Si:H) and nano- or polycrystalline silicon (µc-Si, poly-Si) are the semiconductors used for large-area electronics. They are applied to thin-film solar cells, active matrix liquid crystal displays (AMLCDs), optical scanners, and radiation imaging arrays. The tutorial describes materials growth and preparation, basic device properties, device physics, and applications. Attention is given to state-of-the-art, low-temperature processing. Special emphasis will be on the relation between material properties and device performance. Existing and emerging applications will be presented and discussed.

**Instructors:**
Siegfried Wagner, Princeton University
Jaon Pedro Conde, Instituto Superior Técnico, Lisbon, Portugal

**TUTORIAL**
A/I: Thin-Film Silicon Materials and Devices for Large-Area Electronics
Monday April 12, 2004
8:30 AM - 4:30 PM
Room 2001 (Moscone West)

8:30 AM **11.1**
*Strategies for Commercializing Flexible Displays.* Kimberly Allen, iSuppli/Stanford Resources, Santa Clara, California.

Flexible displays are a common suggested application for flexible electronics. These devices have fascinated people for decades, and the first attractive-looking demonstrations have recently become possible. How will the market evolve? At this early stage, the most useful information is of a strategic nature, allowing companies to plan their R&D resources appropriately. This presentation covers technology and manufacturing development, key challenges, favorable applications for flexible displays, and a forecast of the market size through 2010.

9:00 AM **11.2**

Organic light emitting devices (OLEDs) on flexible substrates offer advantages in weight and ruggedness for display applications while also enabling new products such as roll-up displays. For more ambitious applications such as room lighting, however, the OLED panel will likely be at least a square meter in area and plastic or thin metal foil substrate is a clear necessity if we are to achieve an "organic light" for "smart" surfaces, drives the interest in and development of this technology. While displays, smart cards, and RF tags all benefit from OLED on flexible substrates, existing technology suffers from a significant performance penalty. Specifically, the temperatures required for fabrication of high quality TFTs are incompatible with the flexible substrates of choice. The dominant approach currently is based on either amorphous silicon or organic TFTs, which are expected to provide cost effective manufacturing, but are severely limited in applications that can be addressed because of the low mobility of the devices. To overcome this limitation, a variety of novel materials and/or processes are beginning to be explored. The common element is that the semiconductor material is either processed off-line or with in situ fabrication methods. The desired result is nanostructured material with properties that rival those of single crystal. Various approaches currently in development will be presented and their progress reviewed. At the extreme, one can envision a future where macroelectronics plays a major role in the electronic systems landscape. While the disparity in performance between existing (and future) Si technology would seem to make this unlikely, the extreme cost pressure being experienced by the worldwide IC industry at least raises the question of alternative approaches. If OLED device performance can improve significantly at the same time the promise of low cost manufacturing can be realized, then perhaps "macroelectronics" can find a role beyond displays.

10:30 AM **11.4**
*Low Temperature Poly-Si TFT Technology.* Takashi Noguchi, SAIT & SKK Univ., Suwon, South Korea.

Low temperature poly-Si TFT technology is reviewed and is discussed from a view point of device, fabrication process and its possibility as a FPD (Flat Panel Display) application. After the appearance of effective crystallizing technique of SPC (Solid Phase Crystallization) or ELC (Excimer Laser Crystallization) using UV (Ultra-Violet) beam, the electronic properties of poly-Si thin-film relating to the high crystallinity of large grain size was improved drastically, and the process temperature for the TFT fabrication was reduced below 600°C down to 400°C. So far, improvement of device characteristic of poly-Si TFT such as an enhancement of carrier mobility or a reduction of leakage current has been studied intensively for the application to FPD on glass or on stainless steel substrates. Also, extensive study is being done in order to realize a further functional SOG (System on Glass). By reducing the total process temperature as low as 300°C or below and by modifying the device structure design, O-LED (Organic LED) FPD addressed by uniform poly-Si TFTs mounted on flexible plastic substrate with high reflectivity and very light-weight such as PES (Poly-Ether-Sulfone) or PET (Poly-Ethylene-Telephthalate) etc is expected. By establishing a reliable low-temperature fabrication process on an arbitrary and flexible substrates by considering their chemical and thermal endurance, the poly-Si TFT has a possibility to develop as a smart SOP (System on Panel) or to rather unique applications beyond the conventional Si LSI in the ubiquitous IT (Information Technology) era.

11:00 AM **11.5**

Nanostructured materials and related technologies for large area, flexible, TFT-based electronics for potential high performance applications will be discussed. While not comparable in performance to conventional devices and circuits, attributes such as distributed (pervasive) electronics, reduced system weight/cost, and flexible form factor still offer integration into "smart" surfaces, drives the interest in and development of this technology. While displays, smart cards, and RF tags all benefit from TFT on flexible substrates, existing technology suffers from a significant performance penalty. Specifically, the temperatures required for fabrication of high quality TFTs are incompatible with the flexible substrates of choice. The dominant approach currently is based on either amorphous silicon or organic TFTs, which are expected to provide cost effective manufacturing, but are severely limited in applications that can be addressed because of the low mobility of the devices. To overcome this limitation, a variety of novel materials and/or processes are beginning to be explored. The common element is that the semiconductor material is either processed off-line or with in situ fabrication methods. The desired result is nanostructured material with properties that rival those of single crystal. Various approaches currently in development will be presented and their progress reviewed. At the extreme, one can envision a future where macroelectronics plays a major role in the electronic systems landscape. While the disparity in performance between existing (and future) Si technology would seem to make this unlikely, the extreme cost pressure being experienced by the worldwide IC industry at least raises the question of alternative approaches. If OLED device performance can improve significantly at the same time the promise of low cost manufacturing can be realized, then perhaps "macroelectronics" can find a role beyond displays.
In recent years, polycrystalline silicon thin-film transistors (polysil-TFTs) have been extensively investigated for applications in large-area electronics, especially for switching devices or peripheral driving circuits in active matrix liquid crystal display (AMLCD). In order to realize low-cost AMLCD with integrated peripheral circuits, it is essential to reduce the maximum process temperature for high-performance TFTs. Two annealing steps are adopted in the fabrication process of TFT device: one is channel-region annealing and the other is post-implantation annealing. Active region composed of amorphous silicon (a-Si) was crystallized by femto-second laser annealing (FLA) using Ti:sapphire lasers. Non-thermal melting on transparent a-Si to polysil was induced by the intense peak power of infrared ultrafast laser pulses which leads nonlinear photo energy absorption and generation of very dense photoexcited plasma. FLA annealing is a promising method also has higher breakdown voltage compared to the furnace annealing because the process time of FLA method is much shorter than furnace annealing method.

**A Simple Explanation on the Crystallization Kinetics of a CW Laser Crystallization of a-Si**

Recently, a CW laser crystallization of amorphous silicon using DPSS laser, so called CLC, has been reported as an alternative method to get a high-quality poly-Si on glass substrate. In this method, a-Si is crystallized by the scanning of CW laser and the large (long) grains are obtained along the laser scanning direction under adequate scanning speed and laser power. Not only the electric characteristics of CLC poly-Si TFT shows nearly same as that of MOSFET on SOI wafers, but also CLC has several advantages such as simple, easy and low cost process compared to the conventional sequential lateral solidification (SLS) using an excimer laser. Although there are some papers regarding electrical and structural characteristics of poly-Si, little has been known about the crystallization kinetics. We have studied CLC of various-shape patterned a-Si on glass substrate with changing thickness of a-Si film, scanning speed and laser power. Although there are many parameters for the crystallization as referred above, microstructures of the various samples are similar. The crystallized region is composed of small (edge of the pattern), large and very large grains (center of the pattern), we called it \( \text{SequentialLateralCrystallization region} \) with peculiar area distribution inside the pattern. This phenomenon can be explained as the positional difference between the heating and cooling rate of a-Si film inside the pattern during CLC. This difference decides the thermal distribution of a-Si inside the pattern, and finally the grain size is decided by the thermal distribution. By the combination of our concept for thermal distribution and the well-established ELC kinetics, the crystallization kinetics of CLC can be understood. We will give an explanation on the CLC kinetics with a simple model at the symposium.

**A Novel Femto-second Laser Annealing for TFT Device**

In this paper, we report on the fabrication of hydrogenated amorphous silicon (a-Si:H) vertical thin film transistors (VTFs) with nanometer-scale channel length, \( L = 100nm \), using conventional planar TFT processing technology. The device is a fully self-aligned structure and horizontal channel structure realized through optimization of photoetch processes. The VTF process design presented here is unique in that it has a strategic arrangement of the drain, gate, and source electrodes in such a way that the critical dimensions of the VTF are defined only by the inter-electrode spacing. This yields the smallest possible TFT size for any given photo-etching resolution. Presently, we can demonstrate VTFs with critical dimensions of 5-μm square area using standard 5-μm lithography to yield high ON-OFF current ratio (\( 10^5 \)) with low leakage current (\( V_{GS} = 1.0V \)). Extension of this design to active-matrix backplanes with competitive pixel sizes and fill factor (or aperture ratio) will be presented, along with a discussion of the contemporary performance barriers and avenues for improvement.
Long ago silicon migrated long ago to unconventional substrates. Amorphous silicon is mostly made of steel, other semiconducting polymers, and a-Si thin film transistors are made on glass. The tremendous technology base of silicon stimulates continued experimentation with silicon on unconventional substrates. FASCINATING results can be obtained that way. Many macroscopic concepts rely on flexible, shaped, or even elastic electronic surfaces. Integrating Si TFTs with the appropriate substrates raises many process issues. They stem largely from the fact that flexible substrates are so different from crystalline silicon and glass, for which the integrated circuit processes have been developed. The physical properties of the substrate define many process conditions. Most important is the maximum process temperature, which imposes the selection of suitable materials and design constraints for substrate passivation, planarization, and film adhesion also directly flow from the choice of substrate. Often these three functions are coupled. The choice is critical to the building of a thin film silicon structure on a flexible substrate. Dimensional instability and differential thermal expansion likewise shape process conditions. Shrinkage and warping calls for pre-process bake. Layers must be made to adhere strongly to the substrate, but also cause thermal contraction. Electronics that just need to flex can be made on substrates that remain fully coated with a passivation layer during the entire fabrication process. To the process steps this layer makes the substrate forever look like the passivating material. Fortunately SiNx and SiO2 work well as adhesion and passivating layers, and allow using standard silicon fabrication processes. Electronic surfaces that can be shaped or deformed reversibly provide another much bigger process challenge. At last the fabrication process itself, the flexible substrate must be exposed, which means that the passivation layer must be stripped. Because the properties of the substrate can be vastly different from those of silicon TFT materials, from that point of view, the processing of the substrate, patternning techniques and metalization procedures must be employed. I will illustrate these processing issues with specific examples.

3:00 PM *12.4/A3.4


For fabrication of flexible electronic devices, SUFTLA technology and a micro liquid process, in which an inkjet printing is included, are very promising. We have already developed several flexible devices using these technology in Seiko Epson Corporation. They not only enable us to fabricate devices, but also give us a versatile means for a flexible production system. SUFTLA, which stands for *Surface Fee Technology by Laser Annesting/ablation*, is a technology that enables TIFs and TIF devices to be transferred from the original substrate to a new substrate by using the laser to form an exafoliation layer sandwiched between the TIF and the original substrate. The advantage of this technology over a direct fabrication of TIF on a plastic substrate is that the well-matured conventional TFT fabrication technology can be utilized. Therefore, proper and reliability of TIFs can be guaranteed. It has been demonstrated that the TIF properties don't change before and after the transfer process. We have successfully developed an flexible AM-LCD (AM-organic liquid crystal display) and AM-OLED (AM-organic EL display) by using active matrix poly SiTFT backplanes with integrated drivers transferred onto plastic substrates. Micro Liquid Process (MLP) is a process which includes an inkjet technology as an important component. MLP is defined as using a functional liquid material as a starting one and a direct patterning method to form a patterned solid film with accurate dimension. Candidate liquid materials include liquid metals, liquid semiconductors, liquid ceramics and organic materials in liquid form. Development of organic materials is most recently explored, and then followed by organic inorganic materials. In the MLP, including an inkjet, the process is divided into three major steps; (1) inkjet process, which enables to make the detailed pattern and mechanical positions it accurately on the substrate; (2) self-assembling of the droplet by surface energy, which enable a further accurate patterning than the mechanical one and (3) solid thin film forming by moving a monolayer of substrate which is caused by evaporation of a solvent. As applications of MLP, we have developed a color filter for LCD, organic EL display, organic TIFs and a micro lens for VCSEL (vertical cavity surface emitting laser) by using organic materials, metal bus lines for a plasma display were directly inkjet printed using a silver liquid metal and an PZT pizo element was also directly patterned by inkjet so as to form epitaxial growth. Direct patterning of morganic films is very encouraging for flexible electronics devices. I confirm SUFTLA and Micro Liquid Process are very useful both for flexible devices and a flexible production system. If combined each other, advantage would be enhanced to the nth degree.

4:00 PM 12.7/A3.7

Temperature Dependent Carrier Transport in Single Crystalline Si TIFs inside a Location-Controlled Grain. Yulaika Ruan, Ryoichi Ishihara, and C.I.M. Beenakker; ECTM/DIMES, Delft University of Technology, Delft, Delft, zuid-holland, Netherlands.

Precise location-control of a grain in excimer-laser crystallization process allows us to eliminate the grain boundaries from active area of thin film transistor, i.e. single-crystalline Si TIFs (c-Si) TIFs fabricated inside a location-controlled grain by μ-Czochralski process [1] showed a high field effect mobility of 450 cm/Vs and low-leakage current of 10^-10 A. [2] The high performance of c-Si TIFs will allow us to design system circuits as well as driver circuits with display, i.e., system on glass. In present work, to understand mechanism of carrier transport of the c-Si TIFs in detail, the temperature dependence of V characteristics of c-Si TIFs fabricated inside a location-controlled grain by μ-Czochralski (grain-filter) process were studied. The n-channel TIFs used in this study were fabricated with μ-Czochralski process [1] as follows. A grid of cavity (grain-filter) (size 100 nm) was made in SiO2 by photolithography. Subsequently, a 300 nm thick a-Si was deposited by LPCVD using silane at 545°C and fills the grain-filter. The samples heated at 450°C were crystallized with XeCl excimer-laser with various energy densities. TFTs having W/L of 3.2/21/288 μm, were fabricated inside a grain with top gate, self-align structure having LPCVD SiO2 (120 nm) as a gate insulator. NBTI characterization was performed. Temperature dependent V characteristics of TFTs were measured for gate voltage Vgs ranging from -10 to 10 V at a drain voltage of 0.2 V. Activation energies Ea were calculated from an Arrhenius plot by means of current obtained at -12°, 77°, 127° and 177°C. At ON-state (Vgs=10V), the Ea drops to negative value (-0.01 eV), which is distinct from a typical poly-Si TFT. The value indicates that bulk trap states density is very low and TIF behaves like single-crystalline MOSFETs. This was varied for a wide range of laser energy densities. With a low laser energy density, the Ea in OFF-state (Vgs=10V) was calculated to be 0.02 eV, which indicates that the leakage current is thermally generated at mid-gap states. In contrast, for a high laser energy density, the Ea in OFF-state (Vgs=10V) was nearly constant at 0.7 eV. This suggests that the defects creating mid-gap states, e.g., random grain boundaries, were diminished, as a result of the high laser energy density and hence a long melt duration. Leakage current is dominated rather by trap states located in the band tail, which may be caused by remaining coherent grain boundaries in the location-controlled grain. [1] P.C.Van der Wilt, B.D.van Dijk, G.J.Bertens;R.Ishihara and C.I.M. Beenakker, formation of location-controlled grain by I'-Czochralski (grain-filter) process, Proc. of SPIE, Vol. 5004 (2003) Pg.10-19

4:15 PM 12.8/A3.8

Elastic integrated circuits on elastomeric skin. Stephanie Perichon Lacroix and Sigurd Wagner; Electrical Engineering, Princeton University, Princeton, New Jersey.

Elastic integrated circuits are essential for robotic sensor skin that can stretch, wrinkle or shrink while transmitting data to embedded sensors. In this paper, we demonstrate the first stretchable integrated circuits made of thin film transistors (TFTs) on elastomeric membranes, and interconnected with stretchable gold conductors. We have fabricated gold interconnects on thin film transistors, fabricated on plastic foil with the gold conductors on the elastomer membrane to form active load inverter circuits. We describe the complete fabrication process, including the fabrication of microscopic electrical contacts on elastomeric substrates. We also present the electrical performance of the inverter circuits prior to, during, and after 3D mechanical stretching.

4:30 PM *12.9/A3.9


Cluster tool (or multi-chamber) systems are generally used in the production of amorphous silicon thin film transistors, solar cells, etc.
In this, each process chamber (e.g. PECVD for SiNx, intrinsic and doped amorphous silicon, sputter deposition techniques for metallization and ITO) is physically separated from others via gate valves in order to avoid cross contamination, which is crucial in obtaining optimal performance of an electronic device. The planar substrate is transported via a robotic arm from one chamber to another. Flexible amorphous silicon single-crystal solar cells are produced using a roll to roll approach. In this, a large roll of material (e.g. a mile long) is transported through the various process zones; an attempt is made to minimize the cross contamination, between the doping and the intrinsic process regions, via the inclusion of slits, gas curtains, differential pumping etc. As is inevitable, cross contamination of the intrinsic layer due to Phosphorous and Boron persists thus preventing an optimal performance of the resulting device. We present a new type of system architecture [1] to fabricate thin film silicon devices, such as TFT's on to flexible substrates, which uses the inherent advantages of the cluster tool. In this, a large quantity of the deposited material is retained within the cassette which includes a reed to reel operation. As in the current cluster tools for planar substrates, the cassette is transported to a process chamber using a robotic arm; within the process zone (e.g. SiNx using the PECVD technique), the cassette is engaged to motors to move the flexible material in a reel-to-reel operation. When the entire roll in the cassette has been processed, it is disengaged from the motors and transported into other chambers for further processing (e.g. intrinsic or doped amorphous silicon, sputter depositing depositions of metals, or ITO). We also discuss the use of the pulsed PECVD deposition technique, which allows an increase in the electron density during the 'ON' cycle, thus allowing the deposition rate of amorphous silicon to exceed 10Å/s in the 'OFF' cycle by the ions responsible for dust formation in the plasma are neutralized. We show that high quality micro- (or nano) crystalline Silicon can be produced using a modified pulsed PECVD technique. In particular, at a deposition temperature as low as 120 °C, materials result with a grain size of 200 Å, low O concentration and a minority carrier diffusion length of 1.2 µm resulting in a solar cell conversion efficiency of 8% for single junction p-i-n device. The technique allows that the structure of the films can be altered from 110 to 220 cm²/mV ster which has implications for fabricating nc-Si TFT's with high field effect mobility, especially on low cost flexible substrates. (1) US patent 

**SESSION 13: Flexible Si TFT Circuits**

**Chair:** Jin Jang  
**Wednesday Morning, April 14, 2004**  
**Room 2018 (Moscone West)**

**8:30 AM • 13.1 Amorphous Silicon AMOLED Display Backplanes on Flexible Substrates.** Arokia Nathan, Denis Striakhilev, Peyman Servati, Kapil Sakariya, Czang-Hee Lee, Anil Kumar and Andrei Sazonov; Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, Canada.

Amorphous silicon (a-Si) technology is an attractive candidate for active-matrix OLED displays because of its maturity and low-cost. Even though a-Si and poly-Si transistors are somewhat limited in terms of mobility and stability of operation, innovative threshold-voltage-shift compensated pixel circuits [1,2] are making it possible to construct active-matrix OLED prototypes with a-Si TFT processes optimized for device performance. In addition, there has been a dramatic progress in efficiency of OLED materials over past few years [3] enabling lower drive current requirements, which relaxes the constraints on a-Si TFT's. Making the a-Si TFT process compatible to plastic substrates requires a reduction of process temperature from 300 Celsius to 150 Celsius or below, which tends to compromise the quality of thin-film materials and device performance. Hence, optimizing the TFT process for high device performance with limited thermal budget is a necessary step towards flexible AM-OLEDs with a-Si backplanes. We have developed and extensively characterized low temperature a-Si TFT processes for plastic substrates [4]. Our TFTs on plastic substrate have effective mobility of 0.8 cm²/Vs, threshold voltage of 0.5 V, leakage current which is similar to good quality devices on glass fabricated at higher temperatures. Highly stable threshold-voltage-shift-compensated a-Si TFT pixel driver circuits have been fabricated on plastic substrates. The performance of pixel circuits is examined in terms of current driving ability, linearity, dynamic range and transient response, and more importantly, long term stability. Initial tests of circuit degradation behavior over extended time period showed stable drive currents. We will present the long-term circuit stability of our circuits along with a systematic comparison of stability and lifetime of voltage- and current-programmed circuits. [1] A. Nathan, D. Striakhilev, P. Servati, K. Sakariya, A. Kumar, K.S. Karim, A. Sazonov, Proc. MRS, vol. 769, p.29, 2003. [2] K. Sakariya, P. Servati, D. Striakhilev, A. Nathan, Proc Electrodiplay, Nice, p.699, 2002. [3] M. Hack et al., Journal of SID, v. 9, p. 191, 2001. [4] D. Striakhilev, A. Sazonov, A. Nathan, J. Vac. Sci. Tech. A20, p.1087, 2002.

**9:00 AM • 13.2 High-Performance Poly-Si and Single Crystal Silicon Thin Film Transistors on Plastic Substrates by Using Transfer Methods.** Wei Chih Peng, Ting Cheng Lin and YewChung Sermon Wu; Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu, Taiwan.

High performance thin-film transistors (TFTs) on plastic substrate had been studied in recent years. The shock-resistant and light-weight of plastic TFTs has much potential to replace conventional TFTs on glass. In this work, poly-Si and single crystal Si TFT devices on Si substrates were transferred onto a plastic substrate by a bonding and removing Si substrate process. No degradation of electrical characteristics was observed by this transfer method.


Uniformity of thin film transistor based on p-Si material crystallized by SLS technology was intensively investigated. SLS TFT shows quite good Vth uniformity except some bad TFTs. These bad TFTs showed high field effect mobility, specifically on low cost flexible substrates. (1) US patent 

**9:30 AM • 13.4 Organic Light-Emitting Devices for Large-Area Displays Driven by Amorphous Silicon.** Walter Ross, Siegfried Karg, Heike Riel, Timman A. Beiserlein, Santos Alvarado, Constance Rest, Marilyn Sousa, Thomas Brunschwiler and Peter Mueller; IBM Zurich Research Laboratory, Ruschlikon, Switzerland.

The application of organic light-emitting-devices (OLEDs) in active-matrix displays driven by amorphous silicon requires highly efficient light emission for all primary colors. We have developed a top-emitting OLED architecture which significantly enhances the external electroluminescence efficiency. This architecture allows the individual optimization of the electrical and the optical device characteristics. With an optimized set of red, green and blue OLEDs we achieved an efficiency of 22 cd/A (white average) and an excellent color purity covering more than 90% of the NTSC color triangle. The optical architecture developed not only promotes the light ouput and also provides a tolerable viewing angle and a high contrast ratio. Moreover, the operating voltage required for a current density of 10 mA/cm² is now higher than 5 V. Crucial for the excellent performance data achieved were a careful design of the electrical architecture, a right selection of materials, the proper engineering of injection barriers, and a thorough investigation of the charge transport and recombination properties of the OLEDs. This optimized OLED architecture was used in a collaboration with IDTech Corp. and CMO Corp. to fabricate a large-area (20-inch), high-resolution, full-color, amorphous silicon, active-matrix display 1 T. Tsujimura, et al.; A 20-inch OLED Display Driven by Super-Amorphous Silicon Technology. Proceedings SID, 2003, Vol. XXXIV, (2003) 6-9.

**SESSION 14: Organic TFTs I**

**Chair:** Norbert Frechauf  
**Wednesday Morning, April 14, 2004**  
**Room 2018 (Moscone West)**

**10:30 AM • 14.1 Organic Thin-Film Transistor on Plastic with Self-Organized Process.** Jin Jang, Sung Hwan Kim and Hye Young Choi; Advanced Display Research Center, Kyung Hee University, Seoul, South Korea.

Organic thin-film transistors (OTFTs) have been rapidly developed in the past few years. Especially, pentacene TFT has a field effect mobility of higher than 1 cm²/Vs. Therefore, OTFT has many applications requiring large-area coverage, structural flexibility and low cost. However, there are many issues in TFT process. One problem in fabricating organic transistor is difficult in patterning the
organic active layer using photolithography. While bulk pentacene is relatively insoluble and non-reactive in the typical solvents used in photolithography, the performance of pentacene TFT is dramatically degraded by exposure to solvents. In this work, we made an active island without using photolithography. Note that the conventional photolithography can not be used for OTFTs. The source-drain pentacene TFTs of two structures-top (inverted staggered) and bottom contacts (inverted coplanar). The bottom contact structure gives inferior performance to the top contact. By this reason, the top contact structure is widely studied. Shadow mask technique is generally used to define source and drain on pentacene film for TFT fabrication, but this is not a suitable structure for display manufacturing. Since no photolithography process can be performed after pentacene is deposited, bottom contact device is the only option for high-resolution fabrication. Therefore, we studied a bottom contact structure. We have studied bottom-gate organic thin-film transistors with a selectively grown pentacene thin-film structure. This organized in the TFT area by using an organic vapor phase deposition. The surface treatment was found to be very effective to have the active islands for display manufacturing. By using this self-organized technology, the organic thin-film transistors with a field-effect mobility of 0.41 cm²/Vs, a threshold voltage of -1 V, an ION/IOFF ratio of 10⁶ and off-current of less than 10 pA/µm have been demonstrated.


A major goal of organic transistor development is to minimize the limitations in mobility caused by grain boundaries, both in sublimed and in solution-deposited films. Here we present data from devices prepared by the direct application of macroscopic single crystals to polymer dielectrics, discussing the insights gained from their examination as well as nonlinearities in the experiments. We then study the mechanism of deposition of semiconductor oligomer films from solution that also results in devices comprising macroscopic crystallites. Much higher mobilities are observed from these devices than previously observed from solution deposited molecular solid films. The role of mesophases, interfacial effects, and annealing in the deposition is discussed.

11:00 AM 14.3 Stability of Organic Thin Film Transistors. Jeong-In Han, Yong-Hoon Kim, Sung-Kyu Park, Dae-Gyu Moon and Won-Keun Kim, Information Display Research Center, Korea Electronics Technology Institute, Pyungtae, Kyunggi, South Korea.

Recently, the stability of organic thin-film transistors has become one of the most important issues in this area of research. In this report, we investigated the stability of polythiophene thin-film transistor (TFTs). Using poly (3-hexylthiophene) (P3HT) as active channel, electrical properties such as saturation field effect mobility, threshold voltage and on/off current ratio change significantly in ambient air and in solution-deposited films. Here we present data from devices that also results in devices comprising macroscopic crystallites. Much higher mobilities are observed from these devices than previously observed from solution deposited molecular solid films. The role of mesophases, interfacial effects, and annealing in the deposition is discussed.


Two different origins of the source/drain (S/D) series resistance (Rₛ) were found in bottom-contact (BC) pentacene thin-film transistors (TFTs): first, the mixed phase of pentacene grown in the blurred edge region of Au electrode and second, the semi-insulating region in a pentacene layer between Au and a carrier accumulating layer. It is known that the electric characteristics of organic TFTs with a short gate length are affected by Rs [Nechayov et al. Solid-State Electronics 47, 250 (2003)]. Kymissis et al. IEICE Trans. Electron Device 48, 1950 (2001)]. It is important for the improvement of TFT performance to clarify its origin. However, it has not been fully understood so far. We fabricated the TFTs (both BC and top-contact (TC)) with the Au-SiO₂ electrode patterned by lift-off process. This process normally requires an adhesion layer such as Ti or Cr underneath Au. Our subsequent measurements demonstrated that, though there existed no mixed phase region, Rs of the TFT area was reduced which suggests that a proper passivation layer is a major goal of organic transistor development is to minimize the limitations in mobility caused by grain boundaries, both in sublimed and in solution-deposited films. Here we present data from devices prepared by the direct application of macroscopic single crystals to polymer dielectrics, discussing the insights gained from their examination as well as nonlinearities in the experiments. We then study the mechanism of deposition of semiconductor oligomer films from solution that also results in devices comprising macroscopic crystallites. Much higher mobilities are observed from these devices than previously observed from solution deposited molecular solid films. The role of mesophases, interfacial effects, and annealing in the deposition is discussed.

11:45 AM 14.5 Temperature-Dependent Contact Resistances in High Quality Polymer Field-Effect Transistors. Douglas Natesan,1,2 Behrang H. Hamadian,1,3 Physics and Astronomy, Rice University, Houston, Texas; 1Electrical and Computer Engineering, Rice University, Houston, Texas.

We report measurements of the parasitic contact resistance and the true channel resistance in bottom contact poly-(3-hexylthiophene) (P3HT) field effect transistors with channel lengths from 400 nm up to 40 µm, from room temperature down to 77 K. For fixed gate voltage, the ratio of contact resistance to channel resistance approached a record 1 cm²/Vs at room temperature and high gate voltages.
Organic transistor based thin-film electronics. Ananth Dodabalapur, 1 ECE, UT-Austin, Austin, Texas; 2 ECE, UT-Austin, Austin, Texas.

This talk will review progress in realizing devices, circuits, and systems based on organic and polymer semiconductor based thin-film transistors. Such devices have been used to make large-scale circuits, display systems, chemical and biological sensors, and identification tags. However, challenges remain such as optimizing gate dielectric as well as fabrication processes that are suitable for low-cost manufacturing. The performance characteristics of organic TFTs places constraints on circuit speeds, but this is compensated for by ease of prototyping. This trade-off, as well as some unique properties such as chemical sensitivity, will influence the use of such transistors in commercial applications.

Four-probe electrical measurement on a dry-etched pentacene OTFT. Iwao Yagi1, Kazuhito Tsukagoshi1,2 and Yoshinobu Aoyagi1.

In organic thin-film transistor (OTFT), the interface at the channel/electrode could have a crucial influence on the device performance. Actually, large contact resistance was pointed out even in pentacene OTFT, which exhibited higher field-effect mobility among the OTFTs, from the analysis of the result of two-probe electrical measurement. To directly observe the effect of contact resistance, the total resistance should be divided into the contact resistance component and the channel resistance, thus a four-probe electrical measurement of the pentacene OTFT device is required.

To fabricate precisely patterned pentacene OTFT device for a four-probe electrical measurement, we proposed and developed a new dry-etching method for the pentacene thin-film. In this method, pulsed Nd:YAG laser irradiation in the wavelength of 355 nm was used to remove away the pentacene thin-film in the irradiated area. The sample for the four-probe measurement was fabricated with applying the etching process to the channel of a prefabricated pentacene OTFT on SiO2/Si substrate with multiple top contacts. The results of the four-probe measurements revealed that both the channel resistance and the contact resistance changed with applied gate voltage. When the gate voltage (Vg) of -80 V was applied, the contact resistance reduced to be smaller than 1% of the value at Vg=0 V, while the channel resistance reduced to be about 10%. This suggests that this large gate-dependent change in the contact resistance is dominant in the operation of the pentacene OTFT. In our presentation, we would like to present the details of the patterning processes and the experimental results in the four-probe electrical measurements of the pentacene OTFT devices.

Short Channel Effects in Regioregular Poly(thiophene) Thin Film Transistors. Michael L Chabinyc, Jeng-Ping Lu, Alberto Salleo 1,3, Steven Dale Theiss and Dennis Vogel. 1Electronic Materials Laboratory, Palo Alto Research Center, Palo Alto, California.

Semiconducting polymers are being considered as a replacement for amorphous silicon in thin film transistors (TFTs) in display backplanes. Understanding the electrical characteristics of polymeric TFTs is important in display backplanes, which are used in a variety of electronic devices, including televisions, mobile phones, and digital cameras.

We have investigated the performance of polymeric TFTs with channel lengths from 5 to 50 μm. The results show that the mobility of the polymeric TFTs is significantly affected by the gate dielectric material, with the highest mobilities achieved using PEDOT:PSS dielectric. The results also indicate that the mobility is highly dependent on the thickness of the gate dielectric and the gate dielectric constant.


We present the use of polymeric aperture masks in fabricating high performance pentacene-based integrated circuits patterned over areas as large as 15cm x 15cm on both glass and polymer substrates. Devices over the entire patterned area were fabricated and
Organic field-effect transistors with bending radius down to 1 mm: Tsuyoshi Sekitani1, Hiroshi Kawaguchi2, Takahiro Sakurai2 and Taka Sohmy3; 1Quantum-Phase Electronics Center, The University of Tokyo, Bunkyo-ku, Tokyo, Japan; 2Center of Collaborative Research, The University of Tokyo, Meguro-ku, Tokyo, Japan.

We have investigated the allowed bending radius of high-quality pentacene organic field-effect transistors (OFETs) manufactured on a plastic substrate, and found that the reduction of mobility due to the application of a bending stress with a radius of curvature (R) smaller than about 3 mm was only about 20%. This remained true even at R = 1 mm. We also studied the recovery performance after stressing OFETs. High-performance OFETs with a mobility of 0.3 cm2/Vs and an on/off current ratio of above 105 were obtained. A stress apparatus was used to apply a stress for the OFETs, and the gate electrode was formed by thermal evaporation of 5 nm Cr and 50 nm Au through a shadow mask on a 75 μm flexible polyimide-sheet plastic substrate. Then, a polyimide gate dielectric layer was formed by spin coating and a 30 nm thick pentacene film was deposited through a shadow mask. The 50 nm Au drain-source electrodes were formed using a shadow mask. The channel length and width of OFETs are normally 50 μm and 16 μm, respectively. The electrical properties of the OFETs were measured using a three-lead probe (Agilent Technologies 4156c Precision Semiconductor-Parameter Analyzer) while the OFETs were stressed using a stress apparatus. The apparatus consists of a cylinder of radius R variable from 50 to 1 mm, corresponding to an expansive strain in the plane. Systematic measurements focused on the three aspects: mobility, threshold voltage, and typical dc current-voltage characteristics. It should be noted that no significant change in performance has been found when bending the device down to a radius of R = 1 mm except for a slight decrease in the mobility. Additionally, there were no significant residual effects found after the removal of the bending stress. In the analysis of the mechanical flexibility, we demonstrated that our OFETs' electrical properties were fairly stable during the application of a bending stress. Our results can lead to a better understanding of the operation of OFETs under stress, and thereby help produce robust electronic devices that have a higher level of mechanically flexibility.

Comparison between organic transistors: effects of material properties and device geometry. Omella Sangiorgi1, Anna Bonfiglio1,2, Piero Cosseddu1, Fulvio Marchetti1, Ilario Manuzza1, Marco Bargiacchi2, Aldo di Carlo2 and Paolo Lugli3; 1Dept. of Electrical and Electronic Engineering and INFN, University of Cagliari, Cagliari, Italy; 2Centre S3 - INFN, National Institute of Physics, of Macerata, Italy; 3Dept. of Electronic Engineering and INFN, University of Roma "Tor Vergata", Roma, Italy.

Two identical structures of Pentacene thin film transistors have been investigated that differ only for the type of the insulator layer on which pentacene has been deposited during the same thermal evaporation process. One is made on a heavily doped silicon substrate with a silicon dioxide insulating layer, the other one made with an identical geometry, on a flexible insulating film that acts also as the mechanical support of the whole structure. The relevant differences observed in the electrical characteristics (both static and dynamic) demonstrate that - the substrate has a strong role in determining the mobility of the semiconductor. The recorded mobility is significantly different and AFM images were obtained, that confirm the role of grain size and orientation on the recorded mobility of pentacene. - the parasitic capacitance effects due to the structure (e.g. due to metal superpositions) strongly influence the dynamic behavior observed in electrical characteristics. The true role of the organic semiconductor in determining the dynamic parameters of the device can be only observed if the structure is free of such capacitance effects.
transistors and their fabrication is underway. Also realization of a simple circuit on PET substrates using the already fabricated poly-Ge transistors is in progress and will be reported.

16.3 Transparent Conductors for Flexible Displays: a Performance Study, Sonia Gregg and Jay S. Lewis; MCNC - Research & Development Institute, Research Triangle Park, North Carolina.

The development of a transparent conductor that can undergo small radius bending is of particular relevance for transparent film conductors used for flexible displays. For this reason, tin oxide (ITO) is traditionally used, but is known to be brittle and susceptible to fatigue failure at moderate radius of curvature. We developed test methodologies for electro-mechanical testing of thin film flexible substrates and performed a comparative study using a single ITO layer as benchmark. A cylindrical bending geometry with accurate radius determination was used and performance was investigated as function of high number of cycles (> 1000) for analysis in realistic conditions. The performance of the conductor thin film under bending depends on many parameters, such as substrate thickness, surface modification and neutral plane position. We have explored the properties of multilayer structures containing ITO and of alternative materials suitable to interconnect applications. We found that a judicious choice of layer thickness allows the use of silver sandwiched by ITO ("Dielectric-Metal-Dielectric" structure) to obtain a highly conducting transparent layer with promising bending properties. We will compare the performance of ITO, surface-modified ITO, conductive polymers, and MDM conductors in terms of conductivity, transparency, and performance under mechanical strain and mechanical cycling. This work was supported by the Army Research Laboratory (Contract No. DAAD17-01-C-0085).

16.4 Optical and electrical properties of ionic semiconductor CoOx, synthesized by electrodeposition, Longcheng Wang and Meng Tao; Nanofab Center, Univ. of Texas at Arlington, Arlington, Texas.

Ionic semiconductors offer unique advantages over covalent semiconductors. They can be synthesized by low-cost and low-temperature methods such as chemical bath deposition and electrochemical deposition. The non-directional nature of the ionic bonding reduces defects due to dangling bonds in covalent semiconductors. They are particularly suited for large-area and low-cost applications such as sensors, displays, LEDs, and flexible electronics. We have synthesized cobalt oxide films (CoOx) by using electrodeposition from cobalt nitrate (Co(NO3)2) and sodium nitrate (NaNO3). UV-Vis absorption was employed to characterize optical properties of the deposited films. The band gap from the optical absorption data was determined to be between 2.1-2.3 eV. Hall measurements were employed to characterize electrical properties of the deposited films, including conduction type, carrier concentration, and mobility. It was found that all the films were n-type with electron concentration on the order of 10^18 cm^-3 and electron mobility in the range of 160 cm^2/Vs. It was also found that the mobility decreases as the film thickness increases. The electrical properties of the conductive films compares favorably with amorphous and organic semiconductors. Supported by Petroleum Research Fund.

16.5 Abstract Withdrawn

16.6 Electrical characteristics of edge contact type cell for Phase change RAM, Min Soo Youm1,2, Sun II Shim1,2, Man Young Sung2,1, Korea Institute of Science and Technology, Seoul, South Korea; 2Korea University, Seoul, South Korea.

PRAM is a promising candidate for next generation memory because of many advantages such as high speed, low power, non-volatility, high density and low cost. PRAM operation relies on the phenomenon that chalcogenide-based materials, such as GeSbTe, can be reversibly switched from an amorphous phase to a crystalline phase by applying an external electric current. The electrical resistivity of the amorphous and crystalline phases differs by a factor of 10^6. However, there are still several problems to be solved before the commercialization of PRAM can be achieved; these include the high operation current (>1.3 mA), the slow set writing speed (>50 nsec), and the thermal fatigue of the phase change material. The operation current could be reduced to a few hundreds of mA for low-power high-density memory chip production. In this paper, PRAM cell, which has a small and reproducible contact area was fabricated and electrically characterized. The fabricated PRAM cell has improved thermal environment. Normally, contact area is determined by photolithography in the bottom contact type structure. But in the case of edge contact type structure like this, it is determined not only by the photolithography but also by the thickness of bottom electrode.

16.7 The Electronic Circuit Composition and Structure of String for A Novel Braid Electronics-Systems by Kunihiko-Structure, Shigekazu Kuniyoshi and Kunichi Tanaka, Electronics & Mechanical Engineering, Chiba University, Chiba, Japan.

A new integrated circuit concept that forms electronic equipment by the braid structure using the flexible fiber that has equipped the field effect transistor, the solar cell, the light emitting diode, the wiring pattern, etc. is proposed. In this report, the structure of the filamentous body as a basic structure of the braid with various electronic functions was examined. A plastic optical fiber, the glass fiber, and the insulating thin metal line which is enough flexible to construct the kunihiko-structure are used as a base substance of the string for braid. The braid structure described here is constituted by the two sets of two strings that are mutually intertwined and parallel to two planes that lie at right angles. The part where the string crosses each other is used as an electric connection in the new integrated circuit. The field effect transistor and the solar cell formed on a pillar-like fiber are arranged symmetrically with the front reverse side. In order to amplify circuit composition, an active element such as field effect transistors, the electrode pattern for wiring, and the pads for connection are formed on two strings of one group, and the electrode pattern for wiring and the pad for connection only are formed on the strings of the other group. The circuit composition and a concrete structure of the string will be discussed. It will be shown that all logic circuits and flip-flop circuits can be constituted using a few kind of string.

16.8 Titanium-coated Polystyrene Spheres for Electronic Ink, Jun Hee Sung; In Bae Jang, Hyoong Jin Choi and In-Joo Chin; Polymer science and engineering, Inha university, Incheon, South Korea.

Electrophoretic nanoparticles have been widely used in the electronic paper technology, in which the electric field induces electrostatic migration of the charged nanoparticles through a fluid suspension containing a contrasting dye. Optical characteristics are determined by the refractive index mismatch between the particles and the dispersing medium, and the scattering coefficient of the electrophoretic nanoparticles depends strongly upon the particle size. In our study the titanium dioxide nanoparticles were modified to have an organic-inorganic hybrid structure in order to suppress the density mismatch between the titanium dioxide particles and the suspending medium that tends to cause severe sedimentation. Polystyrene spheres (500 nm) were synthesized by a surfactant-free emulsion polymerization using a cationic initiator. Hydrolyzed titania species were then combined with the cationic polystyrene spheres to yield core-shell structure of the titania-coated polystyrene spheres with various shell thicknesses (20-90 nm) depending on the titania concentration. Surface potential of the hybrid particles in a low dielectric medium was studied. The mobility of the titania-coated polystyrene spheres strongly depends on the shell thickness. Polybutene succinimide with a basic anchoring group and polyisobutylene chain was used as charge control agent. Not only it provided a good electrohydrodynamic mobility including selective ion adsorption, proton transfer, and contact electrification but also it increased the electrostatic and steric stabilization.

16.9 Device Quality Mercurous Chloride (Hg2Cl2) Crystals For Use in ALWIR AOTF Imaging System, Abdul R. Qureshi1, Abdalla M Elsamadicy1, R. J Naumann1, Gerald Karr1, Don Gregory1, Lloyd W Hillman1, Sudhir B Trivedi2 and Donald Gullion1; 1The University of Alabama in Huntsville, Huntsville, Alabama; 2Brimros Corporation, Baltimore, Maryland; 3NASA-MSFC, Huntsville, Alabama.

In recent years, acousto-optic tunable filters (AOTF’s) have become an attractive choice for stand-off chemical detection. However, chemical agent infrared absorption/emission is primarily limited to the 8-10 micron wavelength region, and there is no technologically matured material for AOTF imaging in this wavelength range. Therefore, in this research work we have employed the Physical Vapor Transport (PVT) technique to grow a mercurous chloride (Hg2Cl2) crystals for use in a LWIR AOTF imaging system. We purified the material and characterized the density, properties and structure to produce device quality crystals. Lane x-ray diffraction technique was used to determine the crystallographic orientation of the crystal. Optical transmission measurements as well as Fourier Transform Infrared Spectrometry (FTIR) were used to determine the spectral transmittance of the samples. Further we used a laser beam analyzer to obtain the scattering profile.

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10.10 Metal and Oxide Stack Layer Formation Using a Novel Selective Deposition for Flexible Display Applications. Daekyun Jeong, Nohheon Park, Hyunjung Shin, Jaegab Lee, Myungwoon Sung and Jiyoung Kim; 1 Advanced materials engineering, Kookmin University, Seoul, South Korea; 2Chemistry, Kookmin University, Seoul, South Korea.

Most of flexible substrates are easily degraded by high temperature and plasma treatments. Unfortunately, deposition and patterning processes frequently need higher than 200°C temperature process as well as plasma exposures. We successfully developed a novel process to form selectively stacked metal/oxide stack layers at lower than 200°C without any plasma exposures. In this study, we use micro-contact printing (μCP) to define OTS (octadecyl-tetrachlorosilane, (CH3(CH2)nSiCl3)) mono-layers providing non-polar surfaces and subsequently inhibiting nucleation of ZrO2 and Cu using CVD. We adopt atomic layer deposition (ALD) like CVD of tungsten hexamethyldisilazane is more strongly affected by surface reaction than those of conventional ZrO2 and Cu CVD. In this presentation, we will introduce novel approach to fabrication of Cu/ZrO2/Si stack capacitors and the electrical characteristics of the capacitors. SiO2/Si was patterned by photolithography and etching. Polydimethylsiloxane (PDMS) was poured on the pattern SiO2/Si mold. After curing, the PDMS was peeling off OTS was placed using spin coating. In this study, Si (100) wafers with resistivity of 5 10 ohm cm were selectively used as a substrate and cleaned by RCA cleaning methods. SiO2 thin films (7 8 A) were grown by SC-1 cleaning. Then, we define OTS pattern using μCP. Zirconium oxide thin film was grown by atomic layer deposition with water vapor (H2O) as a source and Zr precursor (Zr(OCH3)4) as a reactant. The substrate temperature was 170°C and working pressure was 500 mtorr. Sequence of gas supply was Zr precursor (2 sec) / Ar purging (8/sec) / H2O (2sec) / Ar (24/sec). N2 gas was used as a carrier gas. The very thin OTS was selectively deposited using metal-organic digital chemical deposition at 150°C substrate temperature with (hfac)Cu(DMB) and H2 as a Cu precursor and a reductant, respectively. Selective deposition and patterning of devices were confirmed with SEM images. The measured dielectric constant of Cu / ZrO2 / SiO2 / n-type(100) capacitors without any further annealing were made by a use of HP4284a at 100kHz. The measured absolute electric values of 25. The leakage behaviors were measured using Keithley 5517A. We will also report the formation and characteristics of Cu/ZrO2 stack layers on the flexible substrates This research was performed by the financial support of ‘Centre for Nanomaterials Technology’ under ‘21st Century Frontier R&D Program’ of the Ministry of Science and Technology, Korea.

10.11 Interconnecting Indium Tin Oxide Islands on a Spherical PET Surface. Habin Bhattacharyya, Sigurd Wagner, Yeh-Joon Tung and Mike Hack; 1Princeton University, Princeton, New Jersey; 2Universal Display Corporation, Ewing, New Jersey.

One approach to fabricating a transparent display backplane on spherical surfaces is to pixelate indium tin oxide (ITO) on a clear plastic substrate, e.g., polyethylene terephthalate (PET). The plastic substrate protects the ITO islands from cracking by taking up most of the spherical deformation strain. We show that ITO islands can be interconnected with aluminum metallization that conforms with the PET substrate during plastic deformation. Our process is to (1) fabricate square indium tin oxide islands on PET, (2) fabricate aluminum interconnects for the ITO islands, and (3) deform the PET along with the aluminum lines to a spherical shape. In step (3), the entire structure is shaped into a spherical dome with a 10-cm radius of curvature. This corresponds to a maximum radial strain of 1.5% at the top of the dome. By controlling the deformation rate and the substrate temperature, we have made aluminum conductors that are 30 nm wide and 300 nm thick and cross over 150-nm tall ITO islands. We study ITO islands caused by spherical deformation both as a function of their size and area fill factor. We present island yields as well as the electrical characteristics of the deformed aluminum interconnects. This work is supported by the Army Research Office.

10.12 Top Gate TFT for Large Area Electronics. Mark Metline and Andrei Sazonov; Electrical and Computer Engineering Dept, University of Waterloo, Waterloo, Ontario, Canada.

The TFT fabrication by PECVD at low processing temperature (≤100°C) is of great importance because of compatibility with low-cost plastic foils substrates. The first bottom gate amorphous silicon TFTs fabricated at 75°C in our lab demonstrated the leakage current of 10⁻¹² A, the threshold voltage of 15V and the field effect mobility of 10⁻² cm²/Vs [1]. To increase field-effect mobility, reduce the threshold voltage and reduce the mask count, microcrystalline silicon based top gate TFT was designed. We fabricated TFT at maximum processing temperature of 75°C. Recently developed high quality PE-CVD silicon nitride was used as gate dielectric. Microcrystalline silicon was used as a channel. TFTs demonstrated the leakage current about 10⁻¹³ A. The TFT parameters were extracted using the model developed in UW [2]. Devices showed the threshold voltage of 5.10 V, the field effect mobility of 10⁻⁴ cm²/Vs, the subthreshold slope of 5.7 V/decade and the Ion/Ioff ratio of about 10⁸. High source and drain contact resistance of 2 MOhm were attributed to low efficiency of phosphorous doping in amorphous silicon at 75°C, which also limited the Ion value. The measurement shows that using a top gate TFT circuit, radiation resistance and field effect mobility can be improved by an order of magnitude. The characterizations of top gate TFTs with improved source/drain contacts will be presented. [1] C. Metzger, M. Metline, A. Sazonov. Mat. Res. Soc. Symp. Proc. 769, 303 (2003) [2] P. Servat, A. Nathan, J. V.Aci.Sci. Technol. A 20, 1038 (2002)

10.13 Mechanically strained a-Si:H AMOLED driver circuits. Peyman Servat, Sheng Tso, Dena Strikhibeh and Aroki Nathan; Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, Canada.

This paper investigates the variations in the performance of amorphous silicon (a-Si:H) thin-film transistor (TFT) pixel driver circuits for active-matrix organic light-emitting diode (AMOLED) displays, that are subject to compressive or tensile mechanical strain. The strain is induced by bending of the flexible and rigid TFT substrates, and is measured by the observed changes in the resistance of in situ strain gauges. Mechanical strain impacts the performance of the circuit in terms of its drive current, which may be attributed to the mobility [1] and Fermi energy [2] shifts in the individual TFTs. Here, strain-induced changes are observed in both transient and steady-state behaviour of the TFTs. The effect of strain-induced mismatches on transistor pairs, by virtue of (longitudinal or transverse) strain orientation with respect to direction of current flow is also examined. Our measurements show that the variation in drive current of the TFT can be as much as -2% for hard strains (10⁻⁴). These findings are critical from the standpoint of the long term stability of the drive current, even in matched current mirror circuits, and need to be taken into consideration when designing TFT driver circuits for mechanically flexible AMOLED displays. [1] H. Gleskova, S. Wagner, W. Soboyejo, and Z. Suo, Mat. Res. Soc. Proc. 715, A3.4.1 (2002). [2] W. E. Spear and M Heintze, Phil. Mag. B 54, 343 (1986).


Metal migration and surface modification have been observed in metal-doped amorphous arsenic and antimony based chalcogenide systems such as As2Se3 and Sb2S3 under the irradiation of an electron beam. Surface expansion of order of 5%-35% of the film thickness was observed by applying a 5 to 30 kV electron accelerating voltages. This electron beam induced surface modification (EBIM) was utilized to produce submonolayer and nanometre dimensional patterns which will have applications in single stage processing of X-ray masks fabricated on an X-ray transparent silicon nitride (Si3N4) membrane. Masks with a silver deficient trough-like structure have been obtained at lower accelerating voltages (5-10 kV). Silver rich protruding-like structures were obtained at higher accelerating voltages (15-30 kV). These two types of masks exhibit a different X-ray absorption behavior by comparison with the regions unexposed to the electron beam.

10.15 Low resistivity ITO films on polymer foils in roll-to-roll deposition. Joachim Delachew and Gerd Lippold; Solaricon GmbH, Leipzig, Germany.

We report on the production of Indium-Tin Oxide (ITO) thin films on polyimide plastic foils with excellent optical properties and with a sheet resistance of below 10 Ohms/square. The production of such low resistivity ITO-coated polymer films is of increasing interest for flexible electronic devices such as displays or solar cells. Using a recently developed DC magnetron sputtering in a modular roll coater, resistivities of 1-2·10⁻⁴ Ω cm, free electron concentrations of 1-2·10¹⁷ cm⁻³ and free electron mobilities of up to 30 cm²/Vs can be reproducibly obtained for 100-300 nm thick ITO films on 25 μm polyimide foil. Optical emission spectroscopy (OES) of the plasma was used for process parameter optimization. In this communication, we report on the dependence of optical properties (spectral transmission/reflection) and electrical parameters on the process conditions. The ITO films are laterally and vertically homogenous as...
Low cost and flexible integrated circuits will enable many new applications for our daily life. Amorphous silicon (a-Si) is in the current material of choice for low-cost thin film transistors (TFTs) that are widely used as switching devices in active-matrix liquid-crystal displays. Organic (molecular crystals or polymeric) semiconductors with advantages of flexibility and compatibility with low-cost plastic substrates are another major candidates. Another promising but less explored approach is to use flexible (polymeric) substrates and high performance inorganic materials for the active devices. Inorganic compound semiconductors have advantages of high carrier mobility and excellent long-term stability. The key issue is the requirement of low temperature processing compatible with the low melting temperatures of polymers. The recent advances in thin film processing of inorganic materials offer an exciting opportunity to develop large area manufacturing technologies for inorganic TFTs. In this work, we will report our recent development of Metal-Insulator-Semiconductor Field Effect Transistors (MISFET) fabricated on polymeric substrates (Polyimide and PET-Poly(ethylene terephthalate) using a CdS compound semiconductor layer and an oxide-based insulator deposited by low temperature soft solution deposition techniques.

Novel Nanocasting Method of Creating High Aspect Ratio Structure on Thin Flexible Substrate with Nanoparticles. Zhiyu Hu1, Anat Burger2, Christin Smith3 and Thomas G. Thundat1. 1Life Sciences Div., Oak Ridge National Laboratory, Oak Ridge, Tennessee; 2MIT, Boston, Massachusetts; 3Clemson University, Clemson, South Carolina.

A novel approach of nanocasting is described to create high aspect ratio solid metal electrodes, electrode arrays, wires, interconnects, and circuitry on thin poly- (dimethylsiloxane) (PDMS). Using gold nanoparticles-3-D conductive circuit structures can be patterned and formed on a thin PDMS flexible substrate. Comparing with thin film deposition method the created circuit demonstrates superior mechanical characteristics and excellent electrical properties. The structure can be as tall as 1 mm in letter L shape-like and as thin as a few micrometers. The described process is simple and highly repeatable. This method can also be used to fabricate high aspect ratio structure using other metals, alloys, semimetals, semiconductors, and ceramics.

A Concept for Flexible Thermoelectric Device. Masatoshi Takeda, Keisuke Yokoyama and Masaki Itaya; Department of Chemical Engineering, Oregon State University, Corvallis, Oregon; School of Electrical Engineering and Computer Science, Oregon State University, Corvallis, Oregon; 3Department of Chemistry, Oregon State University, Corvallis, Oregon; 4Howlett-Packard Co., Corvallis, Oregon.

We propose a new structure of thermoelectric (TE) device that has a potential to overcome the problems of current TE device. Conventional TE device (Peltier device) consists of p-type and n-type bulk materials connected with solder and mounted on a ceramic substrate. This structure adheres to the basic concept of thermoelectric conversion but has some problems in practice: 1) the device is brittle due to the difference in thermal expansion and high stiffness of the materials and the substrate, 2) the structure is ill-suited to mass production, 3) it is difficult to fabricate large-size device, 4) the device can not be attached to curved surface, etc. The TE device we propose is based on thin film technology. We use a resin film as a substrate on which patterned p- and n-type TE material films are deposited to fabricate p-n couples. On the opposite side of the resin film, patterned metal sheets are attached. The combination of resin film and metal sheet enables us to generate in-plane temperature gradient, which can be converted into electrical potential by the p-n couple, from a heat flux passing through the resin film.

Self-supporting flexible polymer foils of 10 μm thickness have been structured using irradiation by fast heavy ions and subsequent etching. Very deep, well defined nano-structures can be prepared in this way. These can then be used as templates for application of electric and optical devices. Electron microscopy shows that compact, void-filling, polycrystalline growth in the polymer films is possible and indicates that a robust hybrid structure on the nano-scale can be fabricated. Metals and Semiconductors can be grown. Electrical experiments on simple devices indicate a low sensitivity to mechanical forces exerted on the foil, suggesting that the embedded nano-devices can be used as reliable sensors in applications with considerable strain on the foils. A variety of addressing schemes for simple elements and arrays will be discussed.

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during deposition process, mainly due to their intrinsic low thermal and mechanical properties compared with other inorganic or metal substrates. In this work, therefore, it is in a common sputtering method at high temperature. Consequently, reduced electrical resistivity and long-term stability of the ITO surface cannot be achieved and maintained, which is directly related to the performance of flexible devices. In this work, colorless polyimide substrates with ITO thin films have been prepared with a novel fluorene-containing colorless aromatic PI derived from 2,3-bis(3,4-dicarboxyphenyl)hexafluoropropane diisocyanate (6FDA) and 2,2′-bis(4-(3,4-dicarboxyphenyl)phenyl) hexafluoropropane diisocyanate (TFDB). On the other hand, some inorganic materials, such as SiO2, have been investigated. The SiO2 buffer layer was inserted between the polyimide substrate and ITO layers. The reduced melting point and high solubility of inorganic silica cause a considerable damage at the interface between the gate insulator and the poly-Si film. However, inductively coupled plasma chemical vapor deposition (ICP-CVD) may not cause any ion-bombardment due to the remote plasma process. The purpose of our paper is to report a high quality SiO2 gate insulator for poly-Si TFTs on plastics employing ICP and N2O plasma process. We have proposed N2O plasma pre-treatment in order to reduce the trap densities of the channel and the breakdown voltage of silicon dioxide film. Plasma treatment may also improve the hysteresis of the capacitance-voltage (C-V) characteristics due to the suppression of contamination. We have deposed a 100nm thick silicon dioxide films at 1500°C by ICP-CVD process without N2O pre-treatment. We have annealed the SiO2 film by using XeCl excimer laser annealing(ELA) rather than thermal annealing in order to improve C-V characteristics. The oxide quality such as trap densities was evaluated by C-V measurement. Experimental results show that the proposed treatment decreased the trap density by the magnitude of 1 order. The flat-band voltage was improved from -3 V to -1.8 V. The proposed treatment also improved the breakdown voltage of gate oxide to 15MV/cm. The hysteresis in C-V characteristics was significantly improved, which is attributed to the reduced mobile charges by N2O plasma treatment. Experimental results show that ICP oxide employing N2O plasma treatment and ELA annealing method may be suitable for a gate insulator of very low temperature (<200°C) poly-Si TFTs.


The reduced melting point and high solubility of inorganic nanoparticles have been shown to be useful in the low-temperature solution-based fabrication of semiconductor devices. These inks have been patterned using various techniques to form inorganic logic elements, multi-layer structures, and MEMS. Here we report a new technique known as offset liquid embossing that is used to print the nanoparticle inks. Structures created include multiple layers of gold and spin-on-glass printed without the need for etching or planarization, and 100 nm resolution.

17.11 Large area p-i-n flexible image sensors, Manuel Vieira, P. Louros, A. Fantoni, M. Fernandez, C. Mendes, R. Schwarz and M. Schubert; DEETC, ISEL, Lisbon, Portugal; 2IPE, Univ. Stuttgart, Stuttgart, Germany.

Large area a-Si:C:H imagers fabricated on plastic substrates at low temperatures are strong candidates for flexible electronic. They can be manufactured, at low cost, taking profit from the amorphous silicon technology. Large area p-i-n image sensors on plastic substrates (PET) were produced at low temperatures (110°C) by PE-CVD and compared with similar sensors deposited on glass substrates. The same sensing element structure ITO/p-Si:H:C/H(i/i)/Si:H/Al or ITO was used for both devices. The imager is an optically addressed read-write device based on large area (4x4 cm²) sensing element and a scanning reader. Imaging is performed in a simultaneous write-read two step process: the write exposure, which converts the optical image into packets of charge that remain confined at the illuminated regions and the optical read, which performs the charge to current conversion by detecting the photocurrent generated by a moving point scanner. The output signal at the XY coordinates is amplified and recorded as an electronic signal.
image whose magnitude depends on the light pattern localization and intensity. No charge transfer to move the packets of charge within the sensor is needed during the image acquisition process. In this work the efforts are focused mainly on the optimization output characteristics of the sensor when fabricated on plastic substrates. The role of the sensor configuration and readout parameters on the image acquisition process is significant. Acceptance of lateral transfer characteristics show a high quantum efficiency, broad spectral response, and reciprocity between light and image signal. A numerical simulation supports the imaging process. First results show that when high image intensities are analyzed the sensor located on plastic substrates present a high image-blue effect due to an increased lateral transport near the ITO/p interface. At the illuminated regions the photogenerated hole drift to the ITO and lateral leakage occurs by conduction through the ITO at the different potential between the ITO and the ITO. To avoid this effect a higher resistive p-layer has to be used and also the scanner and the optical image should be kept on opposite sides.


An a-Si:H TFT on plastic is of increasing interest for mobile applications. One of the key issues for an a-Si:H TFT on plastic is to lower the substrate temperature. However, if the process temperature is less than 200°C for use of PES (Polyethersulfone), the TFT exhibits low field effect mobility, high threshold voltage and a large threshold voltage shift due to mechanical stress at the interface between active layer and plastic substrate. That is the stress would be generated by the difference in the coefficient of thermal expansion between active layer and plastic substrate. This stress makes active layer cracks and degrades the polymer substrate. Since this kind of stress depends on the layer thickness, we studied the characteristics of a-Si:H TFT on plastic substrate as a function of the SiNx layer thickness. To reduce the stress, we adopted the double layered gate insulator, the organic material as a far from gate insulator was coated, and the 2nd gate insulator of SiNx was deposited by PECVD at 150°C. The a-Si:H and a-Si:H for ohmic contact layers were consecutively deposited on top of the SiNx. The a-Si:H was used to for S/D. As SiNx thickness is decreased from 400 nm to 50 nm, the stress between active layer and plastic substrate is reduced. And the field effect mobility is increased from 0.1 to 0.42 cm²/Vs. Threshold voltage is decreased from 5 V to 1.5 V. We will present our result in detail with a mechanism at the symposium.


The effects of near-substrate plasma density on the properties of reactive sputtered d.c. magnetron doped zinc oxide (ZnO:Al) for use as a transparent conductive oxide. Plasma density variation is achieved using an unbalanced magnetron and external Helmholtz coils. Since this method the substrate ion-to-neutral flux ratio was varied from 0.2 to about 3.5. The ZnO:Al films were characterized by resistivity, transmission, Hall effect, and theta-two theta x-ray diffraction. At low substrate temperatures (< 88°C) increased near-substrate plasma density improved the film quality dramatically, while for higher substrate temperatures (> 135°C) no improvement was observed. It was verified that the improvement of properties at lower substrate temperature was not due to substrate heating by the plasma. In addition, it is argued that the observed improvement is not due to an increase in overall crystalline quality, but rather is likely due to chemical effects. The implications for low temperature growth of ZnO:Al on temperature sensitive substrates such as plastics will be discussed.

17.14 Flexible Substrate Based Gas Sensors for Air Pollution Monitoring. Serghei Dmitriev1, Gheorghe Duca1, Igor Dementiev2 and Alexander Craciun1; 1Industrial and Environmental Chemistry, Moldova State University, Chisinau, Moldova; 2Department of Physics, Moldova State University, Chisinau, Moldova.

Last years the considerable attention of researchers is directed on the creation of different type flexible based electronic devices for different application. In the given report we present results of investigation of possibility to produce gas sensors on flexible substrates (polymer roll base). As gas sensitive materials were chosen glass chalcogenide semiconductors on the base of solid solutions of (As2S3)-(As2Se3)1-x (where x=0.3, 0.5, 0.6 and 1.0) and also solid solutions of As-Ti-Se system. Thin films of the mentioned above materials were deposited on laser roll film by means of thermoevaporation under vacuum. At the thickness of 1-2 μm the deposited layers are possessed the specific resistance in the range of 1010-1014 Ohm. cm on dependence on chemical composition. The change of conductivity of these films in the presence of gas impurity in air was used as sensitive parameter. Gas sensitive characteristics of obtained structures were tested with such toxic and inflammable environmental pollutant gases as carbon monoxide, methane, nitrogen dioxide, hydrogen and other. All measurements of gas sensitivity were performed at room temperature. For further increase of the gas sensitivity and selectivity the very thin layer of Pd was deposited onto the surface of semiconductor layer. The last one has allowed to increasing the gas sensitive characteristics by order. Then the sensor remains were deposited on the surface of the gas sensitive layer. The dimensions of the developed gas sensitive elements were 100x100x350 mm.

17.15 Polymeric Electrochromics are Ready to Use. Gürsel Sonmez, Clifton K. Shen and Fred Wudl; Chem. & Biochem., UCLA, Los Angeles, California.

The ability to have three complementary colors, red, green and blue constitutes an important step forward for the use of conducting polymers (CP) in polymeric electronic devices. As these three legs of color space are completed, all other colors can be obtained according to color mixing theory. Although many red and blue colored polymers in their neutral form have been reported, green colored CP’s have been less common. This is likely due to the difficulty in obtaining the necessary absorptions in the visible to reflect green. Since absorption at only one dominant wavelength is required to obtain blue or red colors, these can be obtained easily by tuning the CP’s band gap. For a green color two absorption bands (red and blue) are required. While these chromophores absorb red and blue in the neutral form of the polymer, they should also deplete together when the polymer is oxidized. However, the difficulty of controlling both chromophores at the same time with the same applied potential to create and deplete two absorption bands in the visible from the same polymer, make a green neutral polymer almost impossible to realize. Recently, we have initiated a study to obtain a CP which reflects green light in the neutral state and is transparent in the oxidized state. We believed that the goal could be achieved with the synthesis of a polymer backbone containing two well-defined, conjugated systems which absorb blue (<600 nm) and red (<500 nm) colors. With this in mind, a 2,3-di(thien-3-yl)-5,7-di(thien-2-yl)thieno[3,4-b]pyrazine (1) monomer that would afford two conjugated chains was designed and synthesized. Electrochemically prepared poly(1) showed high green color saturation, fast switching property and extreme stability that makes this material promising for completion of the deficient third leg of the color space and also opens the way to fabricate polymeric RGB electrochromic devices.

17.16 Direct Synthesis of Carbon Nanotubes on Organic Polymer Substrates. Eun Hwa Hong1, Kun-Hong Lee2, Hyung Suk Kim2 and Chan-Gyung Park3; 1chemical engineering, POSTECH, Pohang, South Korea; 2materials science and engineering, POSTECH, Pohang, South Korea.

Since the discovery of carbon nanotubes (CNTs), various methods of the synthesis of CNTs have been reported: arc-discharge, laser ablation, chemical vapor deposition, flame synthesis and Smalley’s recent invention of high pressure CO(HIPCO) process. None of them is able to synthesize CNTs at low temperature (say, less than 200°C), so that the incorporation of CNTs with low melting point materials such as organic polymers has been severely limited. Therefore, it is very difficult to fabricate a flexible display with carbon nanotubes (CNTs) due to their high synthesis as well as processing temperature. Here, CNTs were directly synthesized on organic polymer substrates by using the heating of catalysts in the reaction mixture. They were applied to flexible field emitter arrays. Since the microwave energy is selectively absorbed by the catalysts, not by the substrates, local heating of the CNTs results in the CNT synthesis even on the organic polymer substrates, and degradation of the substrate material is minimum. In our work, microwaves were directly irradiated on the catalyst particles on organic polymer substrate. Acetylene was used as a carbon source. The nanotubes were observed by using FE-SEM (field emission scanning electron microscope) and HR-TEM (high resolution transmission electron microscope). Various shapes of carbon nanotubes and carbon filaments were observed as well as amorphous carbon as subproducts produced in this way were multi-walled even though the wall structure was not perfectly aligned. Flexible field emitters were fabricated based on these findings. The fabrication process includes (1) sputter deposition of Cr layer on organic polymer substrate, (2) electrodeposition of catalysts, and (3) in situ synthesis of carbon
nanotubes by microwave irradiation. This novel method is an important advancement to the fabrication of flexible field emission displays (FEDs).

SESSION 18: Flexible Displays: OLEDs
Chair: Babu Chalamala
Thursday Morning, April 15, 2004
Room 2018 (Moscone West)

8:30 AM *18.1
Flexible PLED displays and related technologies.

Flexible, free shape displays are the enabling technology for new lightweight, extremely thin, portable electronic devices. Polymer Light Emitting Diodes (PLED) are especially suited for these applications, due to their fast response time, low voltage, high luminous efficiency and viewing angle performance. On the other hand, PLED displays are extremely sensitive to moisture and oxygen. Substrate materials provided with high performance hermetic and conducting properties are therefore an essential component for manufacturing these flexible devices. Polymer based substrates provide the necessary mechanical flexibility; they also require several thin, high stability, functional inorganic layers such as diffusion barriers and transparent electrodes. The structural integrity, dimensional stability and thermal properties of the substrate stack are crucial to insure device functionality and reliability. For polymer-based substrate, several effects lead to dimensional variation of the substrates, such as solvent uptake, physical aging of the polymer base, thermal expansion and stress induced deformations. These effects must be taken into account to successfully perform classic photolithographic steps. Inkjet printing is a critical enabling technology for flexible PLED displays, providing a customised means to dispense solution-based polymers onto a flexible substrate, allowing for multiple-color devices. On the other hand, LIP must meet several challenges, especially to comply with industrial applications. For example, accurate landing position of the droplets to form homogeneous hole-transport and electroluminescent layers as well as good wetting characteristic of the substrates must be obtained with reliable high throughput techniques.

9:00 AM 18.2
Integration of Organic LEDs and Pentacene OTFTs on Plastic Substrate.
Chung Kun Song1, Yong Xian Xu1, Hyun Sook Byun1, Gi Seong Ryu1, Wonyong Won Lee2, Kwang Hyun Kim3 and Chang Hee Lee1; 1Dept. of Electronics Eng., Dong-A University, Busan, South Korea; 2Dept. of Physics, Inha University, Incheon, South Korea.

Recently, organic thin film transistor (OTFT) are attracting much attention because of their noble application such as flexible display, smart card, RF tag, and electronic book. Especially, OTFTs using pentacene as an active layer produce a remarkable performance with the mobility of 5cm2/V.s so that all the use of dielectric is the most critical. The gate insulator should provide a smooth surface for the high quality organic film deposited above it and additionally it should be insulating enough to reduce the leakage current through the gate. For the process compatibility with plastic substrate the organic dielectric layers are widely applied. Most of the present organic dielectric layers exhibit a serious problem of the high leakage current, resulting in the typical on/off current ratio of 103. In this paper we designed and fabricated a prototype of OLED display panel driven by pentacene OTFTs on a plastic substrate. PET was employed for the substrate on which ITO gate contact layer was deposited. For the gate dielectric of OTFTs the organic and inorganic hybrid structure such as PVP/SiO2/PVP was applied in order to enhance the mobility as well as to reduce the leakage current. PVP layer usually provides a high mobility due to the smooth surface but it exhibits a large leakage current. The large leakage current has been compensated by the high insulating SiO2 layer, which was deposited by ion beam sputter. Pentacene film was grown by OMBD system. We analyzed the growth mechanism in detail and obtained an optimum growth condition for high quality organic film. Especially, we developed a novel photochromic method to pattern the organic thin film, which is characterized by using a water-soluble photoresist and thus avoiding the damages to organic film originated from organic solvents employed in the conventional photolithography process. In this method we deposited polyaniline and UV-curing agent solution as such as NMP and BuOH. We could define more fine structure than the conventional process using shadow masks, and we successfully applied it to integrate OLEDs with pentacene OTFTs. Finally, for the pentacene OTFTs we could obtain a typical mobility of 0.2cm2/V.s and on/off current ratio of 105. For the blue OLED DPVBi was used, and Alq3:C540(0.5%) for green OLED, and Alq3:Rubrene(1:1):DCJTB(0.5%) for red OLED. The voltage at 200cd/m2 were 6.5V and 5.8V, respectively. In addition, the maximum luminence was 30,300 cd/m2 and 93,300 cd/m2 and 46,100 cd/m2, respectively. In conclusion, we successfully fabricated a prototype of OLED display panel driven by pentacene OTFTs on PET substrate for the pentacene OTFT which used PVP/SiO2/PVP hybrid gate dielectric produced good performance enough to drive OLEDs.

9:15 AM 18.3
Water Vapour Transport Properties of Different OLED Package Designs.

A highly sensitive water vapour permeation measurement technique for organic light emitting display application is demonstrated. Calcium is used as a sensor to detect the water vapours. Electrical properties of the calcium sensor are measured to monitor the calcium degradation. The amount of the calcium hydroxide is detected by measuring the change in electrical properties of calcium. The sensitivity of this method for the measurement of water vapor transmission rates is less than 10^-8 g/m2/day and can be carried out in a wide temperature range from 30°C to 95°C and up to 95% relative humidity. In this study, the water vapour permeation mechanism in various encapsulated organic light emitting devices and degradation phenomenon were investigated. Water vapour transport rates and diffusion coefficients of flexible plastic and glass based packaged OLED structures are quantified and related to the OLED lifetimes. A novel OLED pre-packaging technique is demonstrated with an improved OLED lifetime.

9:45 AM 18.4
Reflectivity-based metrology to quantify moisture transport through barrier layers for OLED applications.
Bryan D Vogt1, Hae-Young Lee1, N M Rutherford1, L Moro2, Sushil K Satija2 and Wen-li Wu2; 1Polymers Division, NIST, Gaithersburg, Maryland; 2Center for Neutrons Research, NIST, Gaithersburg, Maryland; 3Vitex Systems, Inc., San Jose, California.

Moisture is known to have a detrimental effect on the lifetime of display devices based on organic light emitting molecules. It is essential for industry to be able to integrate effective moisture barrier layers in future OLED devices and there are major ongoing efforts in this area with a target permeation rate lower than 10^-6g/m2/day. Current technology, e.g. ASTM F417 or MOCON 3/31, only has a sensitivity of 10^-5g/m2/day with a typical measurement time of 10 days. It is based on monitoring the moisture accumulation in a detection chamber. There exists an urgent need for new techniques with improved sensitivity. X-ray and neutron reflectivity techniques are known for their high sensitivity in measuring film thickness changes. Using reflectivity to measure moisture permeation allows for a substantial improvement in sensitivity. This is accomplished by first depositing a water absorbent polymer film with a thickness of 10 nm or less on a silicon wafer and then candidate moisture barrier layers are deposited directly onto the polymer thin film. The changes in both the thickness and the scattering density of the thin film due to moisture uptake are measured via neutron or x-ray reflectivity and the results are then converted to the amount of water uptake. The sensitivity of this approach arises from the fact that all the moisture permeated through the barrier will reside within an ultrathin film. A 1 Å layer of water permeated through a barrier film per ten days amounts to a moisture uptake rate of 10^-6 g/m2/day - a two orders of magnitude improvement over the current technology, which can be resolved using reflectivity. However, problems in resolving the thickness change of the polymer film arise if the barrier is a multi-layered stack with spacing commensurate to the polymer thickness. Alternative approaches to exploit the thickness resolution of reflectivity will be discussed.

10:30 AM 18.5
Thin Film Permeation Barriers for Flexible OLED Displays: Technology and Challenges.
Jay Lewis and Dorota Temple; MCNC Research and Development Institute, Research Triangle Park, North Carolina.

It is widely accepted that the development of flexible organic light emitting display (OLED) based displays will require thin film permeation barriers to prevent degradation due to moisture and oxygen. The challenges in thin film permeation barrier technology will be reviewed, including the various display architectures, permeation measurement techniques, barrier materials and deposition technologies. It will be shown that significant progress has been made.
in the development of thin film permeation barriers with sufficiently low permeation rates. But additional challenges exist if the permeation barrier is to be used with a truly flexible display. Because permeation barriers typically include brittle inorganic thin films, a critical aspect of flexible permeation barriers is that they be robust enough to survive under the flexing conditions that present for the application. The large number of brittle components in a thin film OLED, a single microcrack will result in catastrophic failure of the barrier film. We will present data showing the limitation of selected materials and barrier architectures under flexing, and discuss the challenges in realizing a truly flexible OLED display. Various approaches to realizing flexible permeation barriers will be discussed. This work was supported by the Army Research Laboratory (Contract No. DAAD17-01-C-0085).

11:00 AM 18.6
The role of a thin polymer interlayer in improvements of device efficiency and lifetime of polymer light-emitting diodes, Ji-Sung Kim1,2, Ilaria Grizzi2, Mark Leadbeater2, Jeremy Burroughs2 and Richard Friend1,2. 1Physics, Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom; 2Cambridge Display Technology Ltd., Cambridge, United Kingdom.

We report that adding a thin (less than 10 nm) polymer interlayer between a PEDT:PSS hole-transporting layer and an emissive semiconductor layer improves significantly both the device efficiency and the lifetime of RGB polymer light-emitting diodes (LEDs). The interlayer is spin-coated directly on the top of the PEDT:PSS layer from a TFB, poly(2,7-(9,9-di-n-octylfluorene)-alt-(1,4-phenylene) (4-seco-butylphenyl)(imino)-1,4-phenylene) (ETL). (The Dow Chemical Company) solution. Without the interlayer the exciton quantum efficiency (EQE) decreases from 0.7 % (0.4 cd/A at 3.7 V) to 1.9 % (1.0 cd/A at 3.3 V) at 100 cd/m2 for red-emitting LEDs and from 1.9 % (6.2 cd/A at 3.4 V) to 3.0 % (10.1 cd/A at 3.0 V) at 1000 cd/m2 for green-emitting LEDs, which is about 35 % higher than without the interlayer. These increases in the efficiency were accompanied by a significant increase in both the DC and pulsed lifetime of the devices. In this presentation, we will discuss the main role of this thin polymer interlayer in terms of its efficient exciton blocking properties at the PEDT:PSS/ emissive semiconductor interface. The exciton lifetime of the emissive semiconductor, which is significantly quenched at the direct interface with PEDT PSS, recovers by inserting the interlayer. In particular, the thinner the emissive semiconductor layer the more complete the recovery from exciton quenching was observed. This blocking property of the interlayer from exciton quenching plays an important role in improving the device performance.

11:15 AM 18.7

Bridging the gap between materials research and product development is a challenge in all aspects of materials science and engineering. This is because materials research is by very nature upstream and product development is focused downstream of the material flow. This issue has been plainly illustrated by the length of time and the sheer size of investment required for organic light emitting diode (OLED) display technology to be commercialized. Moreover, flexible display products are unlikely to arrive for another two to three years. In particular, the sensitivity of these electronic materials to the environment and the operating lifetime requirements of devices place high demands on the choice of material systems. This presentation will cover two themes. Firstly it will provide an update on the technical work being performed at IMRE on flexible OLED technology, focusing on the progress with demonstrator devices that aim to bridge the gap between upstream research and product development. In particular, details of devices comprising both fixed logo and pattern matrix will be discussed, showing how they may be used as a vehicle to consolidate research, develop processes and fire the imagination of a nation. Secondly, the presentation will consider the relevance of this research and development to local industry and how such an activity is facilitating and promoting the growth of a new manufacturing sector. This will be described in both the context of the need of local industries and the role of multinational companies, with a value chain analysis illustrating how just how important such a materials-based technology can penetrate. Although this naturally begins with rigid displays on glass, the opportunities that a truly disruptive technology such as flexible displays will offer create an immeasurable impact on a manufacturing community that is prepared to respond. *The presenting author acknowledges his colleagues in IMRE and the Singapore Economic Development Board.

11:45 AM 18.8

One approach towards achieving full-color OLED displays, involves dye-stamping to create a local dye pattern on a host polymer, and subsequent solvent-vapor-enhanced dye diffusion to drive the dye into polymer at room temperature[1]. In this work, we describe a process for achieving RGB OLED pixels beginning with a host film and the hole transport layer (HTL) of poly(9-vinylcarbazole) (PVK) polymer doped with blue dye Coumarin 47 (C47), created by spin coating. Red dye Nile red (NR) and green dye Courmarin 6 (C6) were locally applied using a stamping plate of a pre-patterned dye source layer on a glass substrate. The dye source is a polymer Vylon 163, to which the red dye NR or green dye C6 were added. Vylon was used because of its anti-sticking properties and its low glass transition temperature (Tg), which allows dyes to diffuse out. The stamping plate was aligned to and brought into contact with the device plate at 70°C for one hour, to transfer the dye source from the Vylon to the surface of the device polymer. Then the device sample was put into an acetone vapor ambient for annealing, to diffuse the dyes throughout the bulk polymer film. Whereas photoluminescence (PL) comes from all dyes in the polymer, the electro-luminescence (EL) is dominated by the lowest energy dye, so that only red or green EL results from the region where red or green dyes are printed[2]. A blocking layer (BL), an electron transport layer (ETL) and a cathode layer complete the structure. Unlike most patterned devices, where the HTL is uniform and ETL patterned, in this case HTL is patterned with dyes with uniform ETL on top. The optimum dye concentration in the vylon is affected by loss of dyes during the dye source patterning, which involves the strong local temperature at an elevated temperature to a pre-patterned foil. Even dye concentration leads to quenching of excitons in the final devices. This concentration was optimized using SIMS, PL and EL, and was about 6% (by weight) in the vylon to give a final device concentration of up to 2%. Device efficiency up to 3 cd/A was obtained using the dye patterning method, a three-color passive-matrix test array with 300 mm x 1mm RGB subpixels was demonstrated. J. F. Pchenitschka and J. C. Sturm, Appl. Phys. Lett. 78 (17), 2584 (2001). 2. F. Pchenitschka and J. C. Sturm, Appl. Phys. Lett. 79 (17), 4354 (2001).
Flexible Magnetics stands for design, fabrication and characterization of magnetic devices and systems built on thin flexible substrates. Although device and system functionality is magnetic in nature, flexible magnets draws interesting parallels to flexible electronics, especially in fabrication challenges on plastic substrates. Some of these challenges include substrate surface quality and maximum processing temperature, tooling issues related to mechanical properties of flexible substrates, adhesion of thin films deposited on plastics, as well as thermal stability of fabricated devices. One application of flexible magnets, relevant for information storage industry, is in magnetic lithography. Magnetic lithography is a process qualitatively analogous to contact optical lithography which transfers information from a nanopatterned magnetic mask (analog of optical photomask) to magnetic media (analog of photoresist), and is interesting for applications in instantaneous and parallel magnetic recording. The magnetic mask consists of nanopatterned magnetically soft material (FeNiCo, FeCo) on a thin flexible plastic substrate, typically Polyethylene Terephthalate (PET) or polyimide. When uniformly magnetized mask is brought into intimate contact with the magnetic mask, an externally applied magnetic field selectively changes the magnetic orientation in the areas not covered with the soft magnetic material. Flexible substrate of the magnetic mask offers superior compliance to magnetic media which is likely to have imperfect flatness and surface particulate contamination. We discuss nanofabrication challenges of magnetic masks on plastic substrates, including electron beam lithography, electroplating and lift-off processing on the nanometer scale, adhesion of metal thin films on PET and polyimide substrate, and release of plastic films from rigid substrates used during the processing. We present results on nanoscale patterning of magnetic thin film. We will present our results on nanoscale patterning of plastic thin film. We will present our results on nanoscale patterning of plastic thin film. We will present our results on nanoscale patterning of plastic thin film. We will present our results on nanoscale patterning of plastic thin film. We will present our results on nanoscale patterning of plastic thin film.
as an efficient way to improve the electronic mobility of ITO without losing the optical properties. The preliminary results indicate that it is possible to achieve a charge limited mobility on the order of magnitude. In this paper a correlation between the thickness of the buffer layer and the electrical, morphological and structural properties of the ITO/EnO will be discussed.

SESSION 110: Poster Session: Flexible Materials and Device Technology III
Chair: Jin Jang
Thursday Evening, April 15, 2004
8:00 PM
Salons 8-9 (Marrriott)

110.1 Pentacene Organic TFT with Al2O3 Gate Dielectric Deposited using Atomic Layer Deposition Method
YongWoo Cho1, JinSeong Park4, Joannis Kymissis2, Ming Wang4, Roy G. Gordon3 and Akintunde Akinwande1,2,1 Microsystmes Technology Lab., Massachusetts Institute of Technology, Cambridge, Massachusetts; 2Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; 3Department of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; 4Department of Materials Science & Engineering, Stanford University, Stanford, California.

The field effect mobility of pentacene OTFT has improved to a value comparable to that of a-Si TFT. However, for applications such as flexible electronics and Electrotextile, the operating voltage of pentacene OTFTs required to obtain sufficient current modulation (high on/off ratio) is still high (20 V). The high operating voltage is due to the low transconductance, $g_{m}=Id/dV$. The $g_{m}$ can be increased by increasing the capacitance of the gate dielectric as well as increasing the field effect mobility. The high capacitance also results in the increase in effective mobility due to the trap filling in the gap. Al2O3 has a dielectric constant of 10 (7.5 for thin film), which is about 2.5 times higher than that of parylene-C or SiO2 film that is often used as a gate dielectric for pentacene OTFT. For the flexible electronics and Electrotextile application, the film should be formed at low temperature. Using Atomic Layer Deposition (ALD) method, an Al2O3 film with high quality was deposited at low temperature (150°C). In ALD, the film growth by sequential and self-limiting surface reaction is possible to control the film thickness precisely and allows for excellent conformal growth, which is desirable for flexible electronics and Electrotextile applications. In addition, ALD can tailor the composition and structure of the film, such as nanolaminate, so as to have the desired properties. The ALD Al2O3 films were grown using water, H2O, and trimethylaluminum (TMA), Al(CH3)3. We fabricated pentacene OTFT using the ALD Al2O3 film as a gate dielectric. For electric fields below 2 MV/cm, the leakage current density of 10^2 and 10^4 A/cm2. Above 2 MV/cm, the leakage current density increased to 10^1 A/cm2 and catastrophic breakdown occurred at 8 MV/cm. The field effect mobility of the OTFT with ALD Al2O3 gate dielectric, which is similar to that of the OTFT with parylene gate dielectric fabricated at the same time. On-current at 80 V of gate voltage was 3X10^4 A and 1.5X10^4 A for the 200 nm thick ALD Al2O3 gate dielectric and the 140 nm thick parylene gate dielectric, respectively. The OTFTs have an active area of 1250μm and 50μm, respectively. The on-current for pentacene OTFTs with ALD Al2O3 gate dielectric is about twice the on-current for pentacene OTFTs with parylene gate dielectric even though the ALD Al2O3 gate dielectric of the OTFT is thicker.

110.2 Molecular weight dependent mobilities in polymer diodes and transistors.
Chia Tsung Goh1, R. Joseph Kline1, Michael D. McGehee, Ekaterina N. Kudinovskaya, James Liu1 and Jean M. J. Frechet2, 1Department of Materials Science & Engineering, Stanford University, Stanford, California, 2Department of Chemistry, University of California - Berkeley, Berkeley, California.

Semiconducting polymers are strong candidates to be used as the active material in flexible light-emitting diodes, transistors and solar cells because they can be deposited from solution at low temperature. Regioregular poly(3-hexyl-thiophene) is currently one of the best semiconducting polymers for charge transport. It has been used to make field effect transistors with a mobility of 0.1 cm2/V·s and photovoltaic cells with an energy conversion efficiency of 3.5%. Reported values for the mobility of this polymer vary widely. Our studies show that some of the variation in mobility can be attributed to well known parameters, such as regioregularity, casting solvent and dielectric surface of the substrate, but this is only a small portion of the variation that is also attributable to changes in molecular weight. In field effect transistors, where current travels in the plane of the film, we find that the mobility increases from 6.8 x 10^-5 to 2.8 x 10^-7 cm2/V·s as the molecular weight increases from 3.2 to 31.1 kg/mole. In diodes, where current travels perpendicularly to the plane of the film, we find that from 3.3 to 31.1 kg/mole, the mobility is in the range of 1.3 x 10^-5 to 3.3 x 10^-4 cm2/V·s as the molecular weight in increased from 2.89 to 31.1 kg/mole. Furthermore, we find that the mobility is field dependent for low molecular weight films, but that it is not field dependent for high molecular weight films. Field dependent mobility measurements show that the activation energy for hopping decreases from 143 meV to 125 meV as the molecular weight is increased. X-ray diffraction and atomic force microscopy measurements show that the films consist of nanocrystalline rods. Collectively, these findings suggest that charge transport is hindered in low molecular weight films by charge trapping at the boundaries between crystals. These experiments highlight the importance of controlling the molecular weight of semiconducting polymers and shed light on how charge travels through polymer films.

110.3 Fabrication Techniques for the Processing of Adhesiveless Ultem Polyimide Dielectric Film. Kevin M. Durocher1, Irene De3 and Stacey Goodman1,1 General Electric, Niskayuna, New York; 2General Electric, Niskayuna, New York; 3General Electric, Niskayuna, New York.

Flexible printed circuits are a technology and product enabler for miniature, high density electronic systems, especially mobile communications and automotive applications. Over the past ten years, flexible printed circuit densities have increased, dramatically, while the area they occupy has decreased. The ever shrinking circuit form factor and increasing I/O and interconnect densities drive flexible circuit configurations from single sided to double sided to quad layered. As well, the need for high performance steers circuit construction towards the minimization in use of adhesives; adhesiveless circuit constructions enable direct metal and lamination bonding without the use of added dielectric materials. Removing adhesive layers such as epoxies or acrylics allows for a thinner flexible device and for a homogeneous dielectric stack (e.g., all polyimide construction) and superior electrical performance. High resolution flexible circuit processes have been established using General Electric Ultem [registered trademark] polyetherimide materials (Ultem [registered trademark] has excellent electrical properties, e.g., dielectric constant and dissipation factor). Adhesiveless single and double sided flexible circuits have been fabricated and tested for performance (electrical, mechanical, thermal) and reliability (thermal cycling, tear propagation, flexural endurance, and solderability). Critical flex circuit fabrication processes have been evaluated, e.g., metal adhesion, micro-via formation, lamination, photolithography and singulation. This paper addresses the key steps for flexible substrate fabrication describing the key advantages and disadvantages of the approach.

110.4 Novel Opto-Electronic Braid System with Kumihimo-Structure as a New Concept of Flexible Electronics. Kumiaki Tanaka and Shigekazu Kuniyoshi, Electronics and Mechanical Engineering, Chiba University, Chiba, Japan.

In last spring meeting we proposed a new concept of electronics based on opto-electronic integrated systems with textile structure. Basic logic circuits consisting of field effect transistors, pads for fiber-connection and several patterns of electrode on plastic optical fibers were designed for the integrated systems. It was shown that all logic circuits and flip-flop circuit were constituted using only five kind of warp and woof. In this paper we will show another concept of new electronics based on opto-electronic braid system with Kumihimo-structure. The system of braid structure is composed of more than three strings on which electronic devices, such as cylindrical field effect transistors and diodes, photoelectric conversion devices and various components are mounted. These elements are designed and arranged so that they are connected by weaving to form partial circuits, functional blocks and the final system. Because the structure of braid system has the translation-symmetry and the rotation-symmetry, the Kumihimo system reduces the difficulty in designing circuit that appear with increase in the scale of the integration. Considering the side of manufacturing technology, some complex systems of component-arrangement without periodicity can be produced by introducing the twisting process by combining the translation-cycle with the programmed sequence of weaving strings. Multiple construction and bundling of the braid to prepare bulk type equipments with pillar and pole structure are discussed comparing with textile-integrated systems. The characteristics of proposed technology are also discussed from scientific and social situating point of view. The results of concrete design of the Kumihimo logic circuits will be shown in another paper contributed to this meeting.

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We have prepared organic electroluminescent devices with improved efficiency and lower driving voltages by the optimized device structure, which is strongly affected by charge transport balance. With a model small molecule-polymer hybrid system, time-of-flight and transient electroluminescent measurements were performed to study the balanced charge transport and its role for device performance. Analysis of time-of-flight measurements shows that amorphous bulk-transporting material with light-emitting polymer increases the mobility, with transition from nondispersive to dispersive transport induced by the charge trapping effect. In the case of doped electrophosphorescent system, dopant can also act as a trapping site. For polymer, doping concentration profile provides a control parameter for charge transport and excitation diffusion. Graded concentration profile was formed not only by the doping control but also by the laser thermal transfer method. Improved device performance and its analysis with positional exciton formation control were presented. Such a device optimization method must be an essential technique for designing better OLED structure of large-sized and flexible electronics.

Azimuthally oriented anthracene thin films were grown by a new process, with domain sizes in the centimeter range. The morphology consists of parallel, oriented row like structures, which have identical crystallographic orientations. This is in contrast to films grown by conventional techniques that are oriented with (001) planes parallel to the surface, but are composed of grains with random azimuthal orientations. Depending on the exact growth conditions, fine filaments, micron-wide rows, or fully continuous films are formed. Synchrotron x-ray diffraction studies confirm that the films are highly ordered and oriented. Pentacene epitaxial growth by vapor deposition atop oriented anthracene was studied using in-situ synchrotron x-ray scattering. Pentacene layers are found to be highly oriented. This represents true epitaxial growth in an organic thin film system. Epitaxial organic heterostructures have the potential to produce novel materials and devices with improved properties and performance. Electrical transport measurements of films fabricated by these methods are underway.

Understanding charge transport in organic/molecular and organic/organic interfaces is crucial for the development of flexible electronics. Charge transport in pentacene thin film transistors is believed to occur in the first few monolayers adjacent to the gate substrate. However, a complete study that relates film thickness and morphology with the transport mechanisms is still missing. An attempt to address this problem, pentacene films were evaporated onto silicon oxide and onto polymethylmethacrylate (PMMA) substrates. Film morphology and crystal structure were analyzed by atomic force microscopy and synchrotron X-ray radiation. Top-contact thin-film effect transistors fabricated with these films were used to evaluate the electrical properties and the field-effect mobility as a function of film thickness.

**110.5 Improvement of organic electroluminescent devices by the shifting of Charge Transport Balance and Drift Mobility.** Byung Dooshim, Min-Hyun Kim, Min Chul Suh, Seng Tack Lee and Ho Kyoung Chung; Samsung SDF, Research Center, Yongin-City, Kyunggi-Do, South Korea.

**110.6 Oriented growth of anthracene and pentacene thin films.** Hua Zhou1, Lan Zhou1, Brian Wang2, Ricardo Ruiz3, Alex C. Mayer4, Alexander Kazimirov4, George G. Malliaras2 and Randall L. Headrick1
1Department of Physics and Materials Science Program, University of Vermont, Burlington, Vermont; 2Department of Materials Science and Engineering, Cornell University, Ithaca, New York; 3Cornell High Energy Synchrotron Source, Cornell University, Ithaca, New York.

**110.7 Growth and Electrical Properties of Pentacene Ultra-thin Films.** Ricardo Ruiz1,2, Alex C. Mayer3, George G. Malliaras3,4, Randall L. Headrick3, Alexander Kazimirov3 and James R. Ewing3
1Center for Advanced Functional Polymers, Department of Chemistry and School of Molecular Science (BK21), Korea Advanced Institute of Science and Technology, Taejon, South Korea; 2Department of Physics, University of Vermont, Burlington, Vermont; 3Department of Physics, University of Vermont, Burlington, Vermont; 4Department of Physics, University of Vermont, Burlington, Vermont.

**110.8 Electrical Hysteresis of PEDOT/PSS-Metal Contact Devices.** Zhenan Bao1,2, Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey; 2Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey.

**110.9 White Electroluminescent Devices using Blue and Red Light-Emitting Conjugated Polymer Blends.** Do-Hoon Hwang1, Moo-Jin Park2, Suk-Kyoung Kim3, Changhee Lee2, Yong-Bae Kim3 and Hong-Ku Shin3
1Department of Chemistry, Kon-Kuk University, Seoul, South Korea; 2Electrochemical Research Laboratory, Center for Advanced Functional Polymers, Department of Chemistry and School of Molecular Science (BK21), Korea Advanced Institute of Science and Technology, Taejon, South Korea.

White EL devices attract much attention because these applications include color display using external filter, as well as LCD back light applications. Several approaches have been done to obtain white LEDs. The doping method has been widely used to obtain white light. For small molecule device, red emitting material is co-deposited with blue or green emitting materials. The doping method has been widely used to obtain white light. For small molecule device, red emitting material is co-deposited with blue and/or green emitting materials. In solution processed polymer devices, it is reported conjugates or blends of blue/green and red emitting polymers or polymers emitted white light. In this study, white light-emitting devices were fabricated using blends of a blue light-emitting polyfluorene copolymer and a red emitting PPV derivative. Insufficient energy transfers between the blue and the red light-emitting polymer, which was observed in PL spectra of the blend films, provides a good advantage to get a white light emission due to better blend ratio controllability. The EL devices were fabricated and white light-emission was obtained for a certain blend ratio.

**110.10 Synthesis and transistor performance of tetracene derivatives.** Byung Moon1,2, Evert-Jan Borkent3, Andrew J. Lovinger4 and Zhenan Bao1
1Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey; 2Macromolecular Science and Engineering, University of Michigan, Ann Arbor, Michigan.

Over the past decade, remarkable progress has been made on the performances of organic thin film transistors (OTFTs), which are essentially governed by both microscopic, single-molecular structure and macroscopic organization in thin film. To improve device performance, it is desirable to understand various aspects including molecular properties, film-forming characteristics, role of solid-state film morphology and device stability. Up to date, polycarboxylic and petroleum, and oligophenol derivatives have been intensively studied, showing high mobilities and off/on ratios. However, only few polycarboxylic derivatives have been reported because of the difficulty in incorporating functional groups into polycarboxylic. In this work, we prepared halogenated and alkyl-substituted tetracarboxylic derivatives, which show very important for device fabrication, we investigated the electrical performances of PEDOT/PSS contacts using Al-PEDOT/PSS/Au as a test device. It was probably the first time that such a device is found to have an abnormal hysteresis in its electrical characteristics. Al-PEDOT/PSS was reported to be a Schottky contact and the work function of PEDOT/PSS and that of gold are very close. Thus the Al-PEDOT/PSS-Au device is supposed to be a Schottky diode. However, our results reveal that the device exhibits unexpected abnormal electrical properties. First, the 'forward' bias curve occurs with the device is presumably 'reverse' biased. Second, the 'turn-on' voltage of the I-V curve increases during the following repeated measures when the voltage of Al is sweeping from negative to positive (Au is always grounded) and finally becomes stable at 3.4 V. This 'turn-on' voltage can be partially recovered (or reduced) with time or by exerting an opposite swept. The device exhibits hysteresis in its multiple current-voltage characteristics and quasi-static capacitance-voltage characteristics. An MIS structure based on the Al-PEDOT/PSS interface, caused by reaction between Al and the dopant polystyrene sulfonate, is believed to be responsible for the rectification behavior of the device. A model in terms of ion motion and electronic charge storage is proposed to explain the above hysteresis phenomena. The authors believe that both the polarons and ions (e.g. H+) contribute to the electrical conduction of PEDOT/PSS. When a positive voltage is applied to the aluminum electrode, H+ ions are pulled to the Al-PEDOT/PSS/Au diode and negatively charged region behind. An internal electrical field (i.e. additional potential barrier) forms in this manner. Therefore, larger voltage is needed to turn 'on' the device during the following measurement. In the mean time, an electrochemical process may happen at the PEDOT/PSS-Au interface—the H+ ions may get electrons and produce H atoms. With time some H+ ions can slowly diffuse back to the depleted region such that the internal electrical field can be reduced. Opposite external electrical field can promote such process but cannot recover the original state because some H+ ions become H atoms. This case is similar for other cations like Na+.
derivatives, investigated the change in their solid state packing by specific tailoring of functional group substitution, and studied its effect on charge transport properties and device performance. Transmission electron microscopy demonstrated that mono-substituted derivatives (5-bromo- or 5-chloro tetracene) had platelet-shape single crystals and di-substituted derivatives (5,11-dichloro or 5,11-dibromo tetracene) needle-shaped single crystals. Based on preliminary data of crystal structures, dichlorotetracene has a π-π stacking motif, which, in principle, facilitates better carrier transport. 1 Substitution of an electron withdrawing group is expected to decrease the bandwidth of the molecule as well as the electronic properties, which will affect the packing mode and density. In this presentation, we discuss the effect of the bromo, chloro, and methyl functional groups on molecular packing, thin-film morphology, and charge transport, and establish structure-property relationships in the tetracene derivatives.


110.11 Abstract Withdrawn

110.12 Organic Thin Film Transistors based on Electron Donor-Acceptor-Donor Type Co-oligomer with 7T-stacked Structure. Wayne Nguyen1, Hyunsik Moon1 and Mark Curtiss2,1; 1Chemistry, University of Michigan, Ann Arbor, Michigan; 2Macromolecular Science and Engineering Center, University of Michigan, Ann Arbor, Michigan.

Recently, organic conjugated materials have been studied very intensively as active materials for organic thin film transistors (OTFTs). The unique properties of these materials make them more attractive than inorganic semiconductors. Applications requiring larger area and high mobility are expected to become reality. In OTFTs, early work has been limited to a few types of conjugated materials, such as thiophene oligomers, poliythene, and pentacene, etc. However, most of these materials are packed in the so-called planar herringbone packing, in which the molecules are arranged in a face-to-edge structure, and π-π contacts are minimized. Our group has published the synthesis and characterization of several kinds of stacked oligomers and co-oligomers. These stacked oligomers may facilitate carrier transport by decreasing the hopping barrier between neighboring molecules through their face-to-face structure. 1,2 In order to understand their electrical properties, such as carrier mobility, we report the synthesis, characterization, and transistor properties of 5,5'-bis(4,4-difluor-2,2-bithienyl)-2,2-bithienyl-5-yl)-3,4,4'-bis(ethylenedioxy)-5,5'-dithienyl (BT2B). BT2B has a stacked structure in which donor-acceptor-donor groups in the molecule are alternately distributed. Stacking interactions were used to prepare this compound. The solid-state structure of BT2B features a short intermolecular distance of 3.5 Å. In thin films, the π-stacks are parallel to the film substrate as determined by X-ray diffraction. The carrier transport in thin films of co-oligomers, characterized by space-charge-limited current (SCLC) spectroscopy and field effect mobility, will be discussed.

110.13 An original flexible structure for Organic Photovoltaic Devices. Ornella Sanna1, Piero Coscudo1, Mario Cosso1 and Annalisa Bonfiglio1,2; 1Dept. of Electrical and Electronic Engineering and INFM, University of Cagliari, Cagliari, Italy; 2Centre S3 - INFM, National Institute of Physics of Matter, Modena, Italy.

A simple idea is proposed for the realization of organic photovoltaic devices on flexible substrates. According to this, a transparent layer, a few micrometers thick and completely flexible, works as mechanical support. It is an insulting material, which has good mechanical and electrical properties and, most important, it is completely transparent to ultraviolet light. For this reason it could be suitable for being used as transparent support layer for large area photovoltaic devices. Starting from this flexible, transparent layer an organic semiconductor is sandwiched between the two electrodes, being one of them transparent. Different organic semiconductors, deposited both by spin-coating and by thermal evaporation, have been used in order to test the device behaviour. The quality of semiconductor layers has been tested by Atomic Force Microscopy which has shown a good coverage of the transparent electrode by the organic semiconductors. In spite of these promising working conditions, the material used respectively with respect to the photocurrent. Due to the extreme mechanical flexibility of their structure, it could be possible to build working devices, able to be transferred on unusual substrates as, for example, textiles or 3D surfaces, paving the way to very innovative applications. Work is in progress in this direction.


Nanocrystalline silicon is a candidate material for fabricating high mobility devices on plastic substrates. A major issue in the processing of nanocrystalline silicon thin film transistors (nc-Si:H TFTs) at ultralow temperatures is the size of the SiO2 gate dielectric. This is a generic problem because all ultralow temperature, plastic-compatible, TFT technologies battle instabilities and leakage of the gate insulator. SiO2 deposited at less than 250°C by radio frequency plasma enhanced chemical vapor deposition (RF-PECVD) typically exhibits high drift and leakage currents. Secondary ion mass spectrometry measurements show that the hydrogen concentration in PECVD SiO2 oxide deposited at 120°C is much higher than in thermal oxides on crystalline silicon (s-Si), which display concentrations of less than 0.003 at. %.

The leakage currents for thermal oxides on s-SiI at a bias of 3 V are 2x10-6 A/cm2 whereas for 250°C PECVD oxides on nc-Si:H the currents are 1x10-7 A/cm2. As the temperature of the SiO2 deposition is reduced to 150°C these current values degrade by up to two orders of magnitude. The hydrogen content which may cause drift currents across the PECVD oxide originates from the Si-n+ substrate and the silane source gas. We analyzed the 800nm gate oxide in capacitor structures of Al / SiO2 / + n nc-Si:H / Cr / glass and Al / SiO2 / s-Si. Vacuum annealing the nc-Si:H prior to PECVD of the oxide allows hydrogen to diffuse from the nc-Si:H film and reduces the amount of hydrogen incorporated into the oxide that is deposited on top. SiO2 deposition from silane and nitrous oxide at high helium dilution has a still greater effect on lowering the hydrogen content. The leakage currents at a 5V bias dropped from 1x10-7 A/cm2 to about 5x10-9 A/cm2 using helium dilution. The vacuum annealing of s-Si:H lowered the current by an additional factor of two. Thus we observe that both the nc-Si:H anneal and the SiO2 deposition at high helium dilution lessen the oxide leakage current.

110.15 Electrical and optical investigations of ion implanted polycarbonate. Jae Hyung Lee and Dae Jeong Yang; Korea Atomic Energy Research Institute(KAERI), Taejon, South Korea.

Polycarbonates(PC) were implanted with N+, Ar+, Kr+, Xe+ ions at the ion energy of 20 50keV, and the dose rates of 5x1015 7x1016 ions/cm2. The relationship between the electrical and optical properties of an ion implanted PC was investigated by means of the absorption edges, which indicates a lowering of the energy band gap. The ion implanted PC leads to a shift in the optical absorption edges, which indicates a lowering of the energy band gap. The decrease of the energy gap, which implies an increase of the conductivity of the ion beam irradiated polymers, can be explained by the formation of carbon networks and conjugated double bonds. After ion beam irradiation, the transmittance in the UV-A(320 400nm) range decreases from 88 to 27% and the surface roughness decreases in the order of 10-3nm.

110.16 C(U)-investigations on organic MOS-structures. Georg Jakopic, Helmut Schoen, Bernhard Lamprecht, Barbara Stadlober and Guenter Leising; Joanneum Research, Weiz, Austria.

The analysis of the behaviour of MOS-like structures of organic semiconductor devices can provide useful information about intrinsic properties as well as about the impact of the surrounding environment. Depending on the sign and the value of the bias voltage, information about the dielectric constant, substrate (semiconductor) doping, charges in the dielectric layer and at the interface between dielectric and semiconductor is available via the measurement of the oxide-capacitance in accumulation and inversion regime, flatband voltage and their difference to the predicted theoretical value, etc. For organic semiconductor devices like field effect transistors, the optimization of each material regarding its intrinsic properties (dielectric constant and dielectric strength, mobility of majority and minority carriers, carrier density, etc.) and the formation of structurally and chemically pure interfaces is of vital importance. We have investigated organic semiconductor-mos structures and present results on the influence of different parameters. If dealing with thin film of small molecules grown by thermal evaporation, growth parameters like average and initial evaporation rate, substrate temperature, substrate precleaning, residual gas composition in the
vacuum chamber play a significant role for the microscopic layer formation and consequently for the semiconductor properties as well as the performance of an organic photovoltaic device. The fabrication of the dielectric layer not only determines the dielectric properties but also the interface between dielectric and semiconductor (an important influence have e.g. solvent residuals and their possible diffusion into the semiconductor layer with subsequent degradation acceleration. Last but not least illumination studies have been performed and related to intrinsic trap filling and carrier release processes.

11.17 Photosensitive Carbazolylethynylmethyleneacylate Copolymers on Flexible Substrate for Optical Information Registration. Stefan Robu1, Igor Dementiev2 and Sergei Dmitriev2, 1Department of Chemistry, University of Chisinau, Moldova; 2Industrial and Environmental Chemistry, Moldova State University, Chisinau, Moldova; 3Department of Physics, Moldova State University, Chisinau, Moldova.

This report presents results of study of some organic materials suitable for creation of photothermal media (on flexible base) for optical information recording. In particular, a speech is about donor-acceptor systems on the base of carbazolylethynylmethyleneacrylate (CEM) with olythynylmethyleneacrylate (OMA) and polyeoxypropyloxyethylcarbazol (PEPC) copolymers photosensibilization of which was made by means of 5-20% of trinitrofluorenone (TNF), N-phenyl-2,4,7-trinitrofluorenone (TNF), and ditianomethylen-2,4,7-trinitrofluorenone (DTF) (containing donor-acceptor groups) and additives of photochromical substances of indolynospirobenspyran series. There were studied the dependences of photosensitivity on sensibilizer concentration and temperature of heating of polymeric material and also the spectral diapason of photosensitivity. It was established that maximum of photosensitivity is observed at the concentration of sensibilizing agent 12.14%. Heating above 60°C leads to sharp decrease of photosensitivity of developed organic materials. It was established that donor-acceptor systems as photoplastic (PP) layers possess photosensitivity on the level 10.8-10.41/cm2. The introduction of PP layers of 6-10% photochromical additives leads to 2-3 times increasing of the photosensitivity of the given donor-acceptor system. At that the essential growth of photosensitivity is observed in the blue-green part of visible spectrum. Also, it was established that 8-nitro-1,3,3-trimethylindolynospirobenspyran possess the greatest effect of sensitization. The fact that adsorption band (500-600 nm) is in the visible part of spectrum confirms the amplification of concentration of donor-acceptor groups in PP layers and, as result, considerable growth of photosensitivity. The received results are discussed. Thus, donor-acceptor systems, developed on the base of polymer CEM-OMA, demonstrate photosensitivity of 10.6 J/cm2 at 80-85°C that 2-3 times higher than in case of usual donor-acceptor systems. Acknowledgments: This work has been supported by CRDF Grant ME2-2317-CH-02.

11.18 Charge trapping and scattering by extrinsic gas dopants in Alq3: S. K. So and H. H. Fong; Department of Physics, Hong Kong Baptist University, Hong Kong, Hong Kong.

The effects of various ambient gases (N2, O2, H2O) to the electron mobility of tris(8-hydroxyquinoline) aluminum, Alq3, were examined. For clean Alq3, the electron transport is non-dispersive and essentially trap-free as revealed by optical time-of-flight measurements. At 295K, the electron mobility (μe) spans the range 0.2-1.0x10^-4 cm2/V.s when the field varies from 0.4-0.9 MV cm^-1. Exposing pristine Alq3 to moisture of dosages in the range 1-100 Torr·s causes a gradual reduction in μe by a factor of 4. In contrast, exposing the sample to same dosages of oxygen does not cause any noticeable changes in μe. The effect of oxygen on μe can be observed only at much higher oxygen dosages (>105 Torr·s). It is proposed that H2O diffuses into Alq3 during storage. H2O subsequently acts as charge scattering centers for externally injected free electrons. On the other hand, oxygen induces charge traps at high dosages. Moisture control appears to be the most critical factor for the long-term operation of Alq3-based organic light-emitting diodes.

11.19 Organic Thin-Film Transistors Developed by Alignment-Free Printing Technique. Masahiro Ando1,2, Hiroshi Sasaki1,2, and Masahisa Kawasaki1. 1Institute of Advanced Industrial Science and Technology (IITDA), Tsukuba-city, Ibaraki, Japan; 2Advanced Research Laboratory, Hitachi, Ltd., Hitachi-city, Ibaraki, Japan; 3Hitachi Research Laboratory, Hitachi, Ltd., Hitachi-city, Ibaraki, Japan; 4National Institute of Advanced Industrial Science and Technology, Tsukuba-city, Japan.

Alignment of the device components in a Thin Film Transistor (TFT) is one of the most important factors for the preparation of organic TFT with high performance. Especially, it is very serious problem for the fabrication of an organic TFT on a flexible substrate. Several alignment-free fabrication techniques for printable electrolodes for organic TFTs. This process provides accurate definition of the device components without increasing process complexity, where solution-processed source/drain electrodes are self-aligned to a gate electrode by a spin-coating self-assembly monolayer (SAM) optically patterned by back substrate exposure technique. After stripe patterns of gate electrodes were formed on glass substrates, transparent SiO2 film was deposited. Hydrophilic SAM was fabricated and the substrate was irradiated from the opposite side of the gate electrodes with UV light. The UV-exposed areas unshielded with the gate electrodes were transformed from hydrophobic to hydrophilic. Source and drain electrodes were fabricated by painting water-based ink of Ag nanoparticle on the hydrophilic areas interposed between the hydrophobic strips just above the gate electrodes using a microapplicator and baking in vacuum. We confirmed that organic TFTs with channel length of 2μm can be made by employing this patterning technique. The channel length was completely restricted by the hydrophobic strips just above the gate regions. In this study, we fabricated pentacene TFTs by using this novel process and examined its TFT performance. Pentacene layer was deposited by thermal evaporation. The field effect mobility, threshold voltage and on/off current ratio for the pentacene TFT fabricated through the above process were estimated to be 0.04 cm2/V.s, -13V and 10.3 respectively. The obtained field effect mobility was about two times larger than that of the case without the SAM treatment. This mobility improvement is mainly due to the large grain size of pentacene in the TFT prepared by our newly developed method. This study shows that the coated SAM layer for the alignment-free electrode fabrication also contributes to self-assembly of the deposited pentacene and improvement of the film quality. This alignment-free process for source/drain electrodes will give a clue to a novel fabrication process for high-definition printable organic TFTs. A part of this work belongs to "Advanced Organic Device Project" under cooperation between OITDA and NEDO.

11.20 Conducting Polyppyrole-based Field Effect Transistors fabricated by Spin Coating and Inkjet Printing. Pingliang Xue, Y. Su and Kody Varahramyan; Institute for Micromanufacturing, Louisiana tech university, Ruston, Louisiana.

Polyppyrole (PPy) is one of the most widely used conducting polymers due to easy processing and good stability. Highly doped polyppyrole has been used for chemical gas sensors, biosensors, and source/drain/gate electrodes [1-2]. Recently, it has been mentioned demonstrating field effect behavior in transistor applications, but no experimental results measuring MISFET characteristics were reported [3-4]. In this paper, we present highly conducting PPy polymer as a semiconductor material for field effect transistors application. Our experimental results show such conducting polymer is promising for flexible polymeric electronics. Both inkjet printing and spin coating were used for deposition of PPy polymer for comparison of transistor's performance. Heavily doped n-type silicon was used as a starting material. Then, 2200 Athermal oxide is grown as gate dielectric. Finally, conducting PPy polymer was spin coated, and metal Al was thermally evaporated using a shadow mask to form source and drain electrodes. The silicon substrate was used as gate electrode after thermal oxide was stripped away on the backside of the wafer. When inkjet printing was used, Al was first deposited to form source and drain electrodes, then conducting PPy polymer was printed in channel region using a drop-on-demand inkjet printer Fabrication and electrical characterization of the devices were performed in ambient environment. Keithley electric probe station was used for device characterization. The experimental results show that source(drain) to channel contact is Schottky contact, which is preferred for low leakage current, because such a highly conducting polymer transistor is normally-on. Positive gate voltage is required to deplete PPy polymer in order to switch the device off. From measured Id-Vd curves, we obtained that the turn-off voltage was around 25 Volt, the saturation mobility was 0.022 cm2/v.s, and the on-off current ratio Ion/Ioff was about 1000 at the drain voltage of 30V. The experimental results show that device performance from inkjet printed PPy polymer transistor is not as good as that of the spin coated transistor. It is possibly due to inkjet printed dot boundary and surface roughness. Further research work is still going forward to improve PPy polymer transistors. References 1. K. Potje-Kamleh, Critical Reviews in Analytical Chemistry, 32(2), 121-140,2002 2. T. Cui, G. Liang, and K. Varahramyan, IEEE Transactions On Electron Devices, 50(5), 1419-1422, 2003 3. A. J. Epstein, F.-C. Hsu, N. R. Claudio, and V. N. Prigodin, Synthetic Metals, 137,806-861,2003 4.
forming a hydrogen bond with solvent.

for this study have unexpectedly high solubility in polar solvents such

 films, which are highly ordered polycrystalline and have unique

structure indicates that 6,13-diazapentacene molecules stack

cofacially with each other rather than in a herringbone motif. Several

derivatives of tetracene have also been synthesized to control the

lengths, meaning that the angle at which the molecules adsorb

depends strongly on the stacking nature of the molecules. It has been

argued, that a smaller angle between the molecular axis and the

surface normal results in a larger orbital overlap which is expected to

give better carrier transport properties. Therefore it is of major

interest to clarify and control the growth conditions for the different

phases. We have synthesized high-quality pentacene single crystals

and epitaxial thin films under different growth conditions and

investigated them by atomic force, scanning electron and polarization

microscopy. The aim was to identify the critical growth parameters

with respect to surface quality, thickness and crystallinity of the

crystals and with respect to homogeneity, size and shape of grains,

ordering, substrate dependence, morphology and phase formation of the

polycrystalline thin films. The polycrystalline phase identification

and the macrostructure of crystals and films were determined by

X-ray diffraction, whereas micro-structural differences, small impurity

concentrations and the temperature dependence of the structure were

investigated by Raman microscopy. It turned out that the growth

process, the film quality and/or the phase formation are highly

sensitive to the deposition rate, the choice of the substrate material,

the substrate temperature, the film thickness and the purity of the

source material. We observed a clear power-law dependence between

deposition rate and grain size. In order to draw a bow between the

structural and the electronic properties of pentacene, thin film

transistors were fabricated based on the different pentacene phases

and different dielectric and electrode materials. Moreover, the carrier

transport properties of pentacene single crystals were investigated by

space charge limited current measurements as well as by time of flight

measurements. It turned out, that the transistor characteristics are

strongly correlated with the morphological as well as the structural

parameters of the active layer, with the integrity and the dielectric

properties of the insulator and with the contact resistance

characteristics of the electrodes. We found a threshold-like

dependence of the mobility on grain size, which can be described by a

field-activated transport mechanism. Careful control of the growth

process results in devices with high hole mobilities, low leakage

currents, high on-off ratios and reproducible trapping dynamics.

SESSION 111: Poster Session: Flexible Materials and

Device Technologies

Chair: Babu Chalamala

Thursday Evening, April 15, 2004

8:00 PM Salons 8-9 (Marriott)

111.1 Creating New Building Blocks for Organic Transistors:

Synthesis, Assembly and Electrical Properties of Pentacene

and Tetracene Derivatives. Qian Miao and Colin Nuckolls;

Experimental Physics, Karl-Franzens University, Graz, Austria;

and Photonics, Joanneum Research, Graz, Austria; 2Institute of

Mineralogy and Petrology, Karl-Franzens University, Graz, Austria.

While organic bulk heterojunction photovoltaic devices containing

a donor conducting polymer such as MDMO-PPV and a suitable

electron acceptor such as PCBM have been shown to convert solar

energy to electrical energy, they cannot compete with the power

conversion efficiency realized by devices comprised of traditional

semiconductors. One approach for improving the power conversion

efficiency of organic devices is to increase the number of incident

photons that are absorbed. This can be done by broadening the

spectral response of the device. Systems with an MDMO-PPV/PCBM

electroactive layer absorb only a small portion of the solar irradiance

spectrum. By incorporating conducting polymers that absorb in other

regions of the spectrum, such as poly(thiophylene vinylene)s and

poly(para-phenylene)s, more of the incident radiation can be

absorbed, and thus converted to electrical energy. Results of our

investigations involving blending donor polymers with different band

gaps into bulk heterojunction devices with PCBM as the acceptor will be

presented.

111.4 Electron-Accepting Materials Containing

Thiazolo[5,4-d]thiazole. Mark David McClain1,2 and Douglas Scott

Dudia1; 1Department of Science & Mathematics, Cedarville

University, Cedarville, Ohio; 2Materials & Manufacturing Directorate,

Polymer Branch, Air Force Research Laboratory, WPAFB, Ohio.

Flexible conductive and semiconductive materials are sought for key

technologies such as photovoltaics, batteries and sensors. Conjugated

molecules and polymers containing electron-acceptor heterocycles

show promise as n-doped materials for these applications. Stability

and charge transport are recognized as critical limiting factors in

existing materials. We report model compounds and polymers based on

thiophene-capped thiazoles which were designed to address the stability

and charge mobility limitations. Polymers were prepared via dehalogenative

polycondensation of dibrominated monomers using zero valent nickel catalysis.

The synthesis, characterization, and properties of these materials will be

presented.

111.5 Self - Degradation of MEH-PPV due to Oxygen/Moisture

Traps through C-V Analysis and Attenuated Total Reflection

IR Spectroscopy. Rajneek Kumar Khillian, Yi Su and Kody

Varahramyan; Institute for Micromanufacturing, Louisiana Tech

Univ., Ruston, Louisiana.

Lifetime and efficiency of the Polymer Light Emitting Diodes (PLED)

has still to be improved to compete with the conventional

semiconductor devices. Poly [5-methoxy-5-(2-thiylexoy)]-1,

Polyfluorenes are a class of polyaromatic macromolecules that are characterized by a conjugated backbone structure that consists of 9,9-dialkylfluorene units in combination with units of another aromatic group. These materials have been designed to perform as the organic semiconducting layer in polymeric field effect transistors (FETs). One polymer of interest is poly(9,9-dioctylfluorene-alt-bithiophene) or "F8T2". F8T2 has charge mobilities as high as 0.02 cm²/V·s with current-on/off ratios of up to 10⁸. F8T2 is also more resistant to doping by ortho- and para-disubstituted phenolic semiconductors than other polyfluorenes. Polyfluorenes have shown excellent combination of charge mobility, environmental stability, and good solubility in solvents such as chloroform. This favorable solubility has allowed the preparation of inks for use in various printing applications. While F8T2 polyfluorene is the "workhorse" polyfluorene, other polyfluorenes are being developed to extend its applications. Polyfluorenes show promise in the areas of optical and electronic devices, artificial vision systems, and printed electronics.
Organic semiconductors exhibiting complementary n-type carrier mobility are the key components for the development of the field of plastic electronics. We present here a novel series of oligothiophenes designed to improve performance and stability under electronic applications. Furthermore, the key structural features of these compounds allow additional modifications of the n-type conducting core to achieve material solubility and processability. Thin film transistor (TFT) devices were fabricated employing both vacuum- and solution-deposited semiconducting layers. Field-effect transistor measurements indicate that all the members of this new series are n-type semiconductors with mobilities and $\mu_{on}/\mu_{off}$ ratios approaching 1 cm$^2$/Vs and 180, respectively. This family represents a key milestone in the design, understanding, and development of the next generation of highly efficient n-type OTFT components.


Organic/polymer thin film transistors (TFTs) are potentially useful for fabricating very low-cost integrated circuits for large-area electronic devices (e.g., active matrix displays) where use of current silicon technology can be prohibitively costly. Their compatibility with flexible plastic substrates has also rendered them ideal for creating compact, lightweight, mechanically flexible, and structurally inspiring electronic device designs (e.g., electronic papers). For low-cost manufacturing, new TFT fabrication methods with simple solution-based techniques such as printing in a non-sterile environment is highly desirable. This presentation will discuss the issues, challenges, and advances in the development of enabling materials for fabricating low-cost TFTs. Our progress in the design of high-performance semiconductor polymers and other TFT materials will be presented.

Crystalline Organic Semiconducting Thin Films Cost from a Novel Soluble Thermolytic Oligothiophene. Paul C Chang, Amanda R Murphy, Josephine B Lee, Jean M J Frechet, and Vivek C. A. Murph y 2, Josephine B Lee', Jean M J Frechet 2 and Vivek Subramanian 1,2; 1Department of Electrical Engineering and Computer Science, University of California, Berkeley, California; 2Department of Chemistry, University of California, Berkeley, California.

One of the main attractions of organic semiconductor materials is the potential for low-cost, solution-based processing. However, organic thin film transistors (TFTs) that have exhibited field-effect mobilities of $0.05$ cm$^2$/Vs and $\mu_{on}/\mu_{off}$ ratios of $10^2$ to $10^3$ have thus far tended to be fabricated with evaporated small molecules with limited solubility. Here we report on OTFTs made from a novel thiophene based oligomer. The functionalized oligomer is soluble in common solvents, but relatively high-mobility, thin films are formed by simple solution-based techniques such as printing in a non-sterile environment is highly desirable. This presentation will discuss the issues, challenges, and advances in the development of enabling materials for fabricating low-cost OTFTs. Our progress in this design of high-performance semiconductor polymers and other TFT materials will be presented.


Progress has been recently made in developing and patterning highly conducting polymer electrodes for flexible substrates. Encouraging device performances were demonstrated for molecular organic light emitting diodes (MOLEDs) using these polymers as anodes. Ultradet photoemission studies have shown that the hole injection barrier between these polymer anodes and common organic hole transporters is in the order of 0.5 eV, comparable for ITO electrodes. The electrical properties and film morphology of these chemically modified polymers were found to be strongly affected by the annealing temperature. For instance, heating glycerol doped poly(ethyleneoxy-thiophene-poly(thiophene) results in the boiling point of glycerol was necessary to optimize its surface sheet resistance for use as polymer anodes in high performance MOLEDs. Here we present flexible MOLEDs based on conducting polymer anodes that show low driving voltage, high luminance and power conversion efficiency. The paper will address the processing and patterning of conducting polymer electrodes and their, use in electronic and optoelectronic devices. The overall performance of the devices is highly dependent on the electronic and physical properties of the conducting polymers. We have investigated the performance of two different polymeric anodes, poly(3-hexylthiophene-2,5-di carboxylic acid diimide) and poly[2,2'-bithiophene-$N$-[4-(3-ethoxy-2-propoxy)phenyl]amine], their physical properties, and their specific charge carrier transport behavior.

11:00 AM 112.9
Patterned growth of organic small-molecule layers. Soeren Steudel, Dimitri Jansen, Stijn Verlack, and Paul Hermans; 1Department of Chemistry, Laval University, Quebec, Canada; 2Department of Microstructural Sciences, Canada National Research Council, Ottawa, Ontario, Canada.

Polymer electronics as an innovative field of research advances the development of new organic materials with improved semiconducting, conducting and light emitting properties and leads to a growth of knowledge on processing this material and its implementation in many new applications. Printing technologies as continuously working high speed microstructuring technologies suitable for flexible substrates offer excellent fundamentals for the implementation of polymer-based mass applications and high-end products. A new printing technology for functional organic materials on the base of conventional offset (waterless) printing has been developed at our institute within the scope of current research projects. The perfect offset printing process as a multiparameter system depends on many chemical and physical specifics of the materials and components involved in the process. We investigated the impact of surface properties and process parameters on the properties of the structured functional layers. In particular, the surface tension determination by contact angle measurements has been taken into consideration. Surface roughness has been characterized by means of atomic force microscopy and alpha step profiles. In addition we had to pay particular attention to process parameters such as web speed, the printing material transfer mechanism or the substrate pretreatment. Electrical properties of printed polymer layers were examined by the four-probe method or by output characteristics of multilayer systems. Spectroscopic methods were used for morphological investigations.

11:30 AM 112.8
New conjugated 2,7-carbazole-based materials for electronic applications. Nicolas Drollet, Jean-Francois Morin, Ye Tao and Mario Leclerc; 1Department of Chemistry, Laval University, Quebec, Canada; 2Institute of Microstructural Sciences, Canada National Research Council, Ottawa, Ontario, Canada.
2,7-carbazole-based polymers and oligomers are a new class of organic conjugated materials that give access to a wide range of molecular structures having both optical and electrical properties. Depending on the targeted application, these properties may be easily tuned via chemical structure modifications to meet all requirements for the development of highly efficient devices, such as organic light-emitting diodes (OLEDs), organic field-effect transistors (OFETs) and organic photovoltaic cells (OPVs). In OLEDs, poly(N-ethylhexyl-2,7-carbazole) has demonstrated very good performances as a stable blue emitter. Electroluminescence as high as 66 cd/A, a quantum efficiency of 68 Cd/A, and a current efficiency of 0.65 cd/A. The synthesis of other large band-gap 2,7-carbazole-based polymers helped us to improve the device performances. It has also been possible by using different co-monomers to get pure green and red light emission. Moreover, 2,7-carbazolevinylene-based materials have led to an easy access of very pure and well-defined oligomers, particularly promising for p-type OFET applications. Indeed, hole mobility as high as 8.7 x 10^-4 cm^2/Vs with an excellent Ion/Ioff ratio of 10^6 have been obtained with these oligomeric devices in optimized device configurations. On the basis of the high hole mobility obtained in OFETs, it was then assumed that low-band-gap polymers derived from 2,7-carbazolevinylene unit should be excellent candidates in OPVs. Preliminary results from such polymeric photoelectric devices will also be reported.

11:45 AM 112.9
Hot Wire Chemical Vapor Deposition as a Novel Synthetic Method for Electroactive Organic Thin Films.
Gillian A. Zaharias, Helen H. Shi and Stacey F. Bent; Chemical Engineering, Stanford University, Stanford, California.

The synthesis and deposition of semiconducting organic thin films has been an active area of research since discoveries that such films can be used to make cheap, flexible electronic devices. A major obstacle in the production of electroactive organic films is the instability of the necessary semiconducting polymers, which makes spin-coating into thin films very difficult. In addition, synthesizing these materials in solution often produces environmentally hazardous byproducts. We are exploring the use of hot-wire chemical vapor deposition (HW-CVD) as an alternative, solvent-free technique to produce compact polycrystalline films from vaporized monomers such as pyrrole, acetonitrile and aniline. Our most promising results to date come from our attempts to deposit polyaniline, a polymer with a wide variety of optoelectronic applications, many of which have been limited by the complexity of processing the polymer. Infrared, UV-visible and near-infrared photoelectron spectra have been obtained to characterize HW-CVD films produced using aniline as a precursor. The aromatic ring structure, essential for the polycrystalline network that leads to semiconducting properties, is largely preserved in our method. Careful tuning of CVD conditions is, however, required to minimize monomer fragmentation while still producing measurable film growth. These results suggest a growth mechanism involving competition between radical-initiated polymer formation and destruction.

SESSION 113: Organic Electronics and Optoelectronics
Chair: Bruce Graff; Friday Afternoon, April 16, 2004
Room 2018 (Moscone West)

1:30 PM 113.1
a-Si TFT OLED Fabricated on Low-Temperature Flexible Plastic Substrate; Kalluri R. Sarma, Honeywell, Phoenix, Arizona.

Active matrix organic light emitting diode (AM OLED) display fabricated on a flexible plastic substrates has a potential for being lower cost, lighter weight, lower power and highly rugged with superior image quality, compared to the current glass substrate based AM LCDs. Anomorphous silicon (a-Si) technology offers the potential for fabricating the required active matrix backplanes on low temperature (<150°C) plastic substrates for producing AM OLED displays. We have developed the low-temperature a-Si TFT processes, and backplane electronics designs to fabricate and successfully demonstrate AM OLEDs using 4"-size flexible plastic substrates. In this paper we will first discuss the development of the low-temperature a-Si TFT, and the backplane designs and processes used in this demonstration. We will then discuss the design and process technology challenges including management of thermal stresses due to CTE mismatch and lack of dimensional stability of the flexible plastic substrate, and the approaches for developing large area AM OLEDs on flexible plastic substrates.

2:00 PM 113.2
Development of high current efficiency and long life organic LEDs having charge generation layers; Janji Kid0, Toshio Matsumoto0, 1 Polymer Science and Engineering, Yamagata University, 4-3-16 Jonan, Yamagata, Japan; 2IME, Fuyusawa, Kanagawa, Japan.

A new type of organic LEDs having charge generation layer (CGL) were developed. By applying voltage, holes and electrons are generated in the CGL and injected into the organic layers. The charge recombinates with the carriers with opposite polarity. Thus, current efficiency can be greatly improved. An extremely high current efficiency of 66 cd/A, which is equivalent to 22 percent external quantum efficiency, was observed at a device using fluorescent emitter materials, having three CGLs. The lifetime of the device is over 6000 hours at the initial luminance of 11000 cd/m2.

2:30 PM 113.3
Total Field Screening in Organic Light-Emitting Diodes.
John C deMello1, Paul J Brewer1, Andrew J deMello1, Donal D C Bradley2 and Paul A Lucey3; Chemistry, Imperial College London, London, United Kingdom; 2C. S. Draper Laboratory, Cambridge, Massachusetts.

We report electroabsorption (EA) measurements on operational organic light-emitting diodes (OLEDs). The measurements show complete elimination of the EA signal above device turn-on, indicating full screening of the internal field by the injected charges. The charge transport mechanism in these devices closely resembles that observed in light-emitting electrochemical cells (LECs), with charges moving primarily under the influence of diffusion. We discuss the origin of the screening phenomenon, and present drift-diffusion based modelling studies to rationalise the observed behaviour. The field-free bulk has far reaching implications for device operation as bulk transport and exciton dissociation and recombination processes are all field dependent.

3:15 PM 113.4
Improved light extraction from polymer LEDs with stumped Bragg gratings; Jonathan M Zibarth and Michael D McGhee; Gable Laboratory for Advanced Materials, Stanford University, Stanford, California.

In normal polymer LEDs, light extraction is reduced by total internal reflection, which typically causes fifty to eighty percent of the emitted photons to be trapped in the device. By increasing the extraction of light from polymer LEDs, equivalent brightness levels can be achieved at reduced currents and drive voltages. This is extremely attractive for flexible polymer LED displays because reducing power consumption and operating temperatures while increasing the operating lifetimes. We have increased the external efficiency in the forward direction by more than 70% by using a Bragg grating to scatter light out of the polymer film. The gratings are made by holographic and soft lithography techniques. In order to optimize the coupling efficiency of the grating, we have empirically varied the thickness, grating depth, grating location, and optical properties of the semiconducting layers and electrodes. We have also fabricated complete structures to determine the waveguide modeshape and absorption loss. We find that it is important to use an LED structure that is slightly different from that of conventional polymer LEDs in order to minimize waveguide losses. One of the key issues is using a low loss metal (e.g. silver) over a very thin layer of calcium, which is needed because of its ability to efficiently inject electrons into the polymer. The angular distribution and polarization of the scattered light is in good agreement with the waveguide model.

3:30 PM 113.5
Polymer Based Photodetectors; K S Narayan, Dinesh Kabra and Soumya Datta; Jawaharlal Nehru Center for Advanced Scientific Research (JNCASR), Bangalore, India.

Recent developments in our laboratory related to polymer-based light sensors are reviewed. The inherent processability of the active polymer medium is utilized in the implementation of different designs for the opto-electronic applications. The utility of these devices as sensitive photodetectors, image sensors and position sensitive detectors is demonstrated. The schottky-type layer formation at interfaces of polymers such as polyalkylthiophenes and aluminum and the enhanced photo-induced charge separation due to high local electric field is tapped for these device applications. The sensitivity of polymer-based field effect transistors to light also provides a convenient lateral geometry where light can be coupled and control the transistor state. The range of these polymer-detectors available in the sandwich and planar type configurations along with the option of operating in the diode and transistor modes should be an attractive feature for many potential applications.

4:00 PM 113.6
Organic switches for memory applications; Luis Dominicos Rozano, Kenneth R. Carter, Vaughn R. Deline, Jane
Motivated by the need for low voltage solid state crosspoint memory elements, we have fabricated metal-organic layered structures and metal-polymer-blend devices designed to have bistable properties. Depending on the history of the device, the current-voltage characteristics of the devices exhibit multiple states at a fixed voltage in the low voltage regime (0-2.5 V). The current density changes by up to 5 orders of magnitudes. The extreme values of the device current at 1V are associate to the ON and OFF states (or 1 and 0) used for memory and can be set by applying voltages corresponding to the maximum and minimum in the current voltage curve, respectively. The ON/OFF ratios, lifetime, switching time and retention time of the devices have been studied as a function of device structure, size and temperature. These properties are presented and discussed in term of charge storage.

Light Sensitive Polymer Thin Film Transistors Based on BAS-PPE. Yifan Xu', Paul R. Berger1,2, James N. Wilson3 and Uwe H.F. Bunz3, 1Department of Electrical Engineering, The Ohio State University, Columbus, Ohio; 2Department of Physics, The Ohio State University, Columbus, Ohio; 3School of Chemistry and Biochemistry, Georgia Institute of Technology, Atlanta, Georgia.

The photoresponse of 2,5-bis(dimethylaminostyryl)-1,4-phenylene-b-alkyne-b-1,4-bis(2-ethylhexyl)benzene terpolymer (BAS-PPE) based polymer field effect transistors (PFET) is investigated. BAS-PPE is a photoluminescent conducting polymer with a bandgap of 2.25 eV. The BAS-PPE PFETs were fabricated using an open coplanar configuration and light is illuminated onto the top side of the PFETs. A sweep of V_DS demonstrates that I_DS saturation is suppressed during illumination, which suggests that pinch-off can not be reached since the injected photo-generated carriers continues unabated. Also, with incident light, the channel can not be turned off, even at high positive gate biases, due to the accumulation of photo-generated carriers. A sweep of VALLED also shows that BAS-PPE is a p-type polymer and favors hole injection and transport. A sweep of IDS versus V_GS demonstrates that under darkness IDS is smallest at around 10 V gate bias, and then increases with more positive V_GS. It is surprising that I_DS under darkness at 40 V gate bias is even higher than at -40 V, even though there is carrier injection in addition to thermal generation at negative gate bias. Negative gate bias attracts holes to the polymer/insulator, and some holes may be trapped at this interface, while a positive gate bias expels holes from the polymer/insulator interface and far fewer holes are trapped there. Therefore, at positive gate biases, more holes are collected at the drain electrode resulting in a measured higher I_DS. A sweep of V_GS also shows an increase in I_DS with different light intensities. Comparing the data at V_GS at -40 V, 0 V and 40 V, we find that at zero gate bias the highest I_light/I_dark ratio is achieved. The I_light/I_dark ratio reaches as high as about 6000 at a light intensity of 71.5 mW.