SYMPOSIUM I

Flexible Electronics–Materials and Device Technology

April 12 - 16, 2004

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* Invited paper

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)

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 (AM-LCDs), optical scanners, and radiation imaging arrays. The tutorial describes materials growth and preparation, basic material 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:
Siguard Wagner, Princeton University
Jaoa Pedro Conde, Instituto Superior Technic, Lisbon, Portugal

SESSION I1: Flexible Electronics
Chairs: Babu Chalamala and Norbert Fruehauf
Tuesday Morning, April 13, 2004
Room 2018 (Moscone West)

8:30 AM *I1.1
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. It includes an examination of LCD, OLED, electrophoretic, and other technologies; e-paper, consumer electronics, and other novel products; and potential manufacturing approaches like inkjet printing and standard lithography using batch and roll-to-roll techniques.

9:00 AM *I1.2
Progress in Flexible Small Molecule Organic Light Emitting Devices. P. E. Burrows, G. L. Graff, M. Hall and M. E. Gross; Pacific Northwest National Laboratory, Richland, Washington.

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 bulb" at acceptable weight and cost. Two primary roadblocks are encapsulation of a flexible device and extremely high speed deposition of both the encapsulant and the active organic thin film layers to achieve a price point for the completed device competitive with conventional lighting solutions. We will describe recent advances in flexible barrier coatings and their mode of operation and a new technique of continuous feed, high rate deposition of organic thin film layers which may enable high speed rollcoating of low cost OLEDs on large area substrates.

9:30 AM *I1.3
Full Color OLED Displays by Ink Jet Printing. Franky So, Rahul Gupta, Andrew Ingle and Sriram Natarajan; OSRAM Opto Semiconductors, Inc., San Jose, California.

Spin coating is the current process of choice for monochrome polymer OLED displays, but it can not be used for manufacturing area color or full color displays. Ink jet printing is a promising technique for high resolution area/full color polymer OLED display manufacturing. It offers several advantages over other technologies including high printing resolution, good control over film thickness, suitability to print on large area substrates, especially flexible substrates, and reduction in costly material usage. In order to use ink jet printing for OLED manufacturing, several key technical challenges need to be resolved and these include the reliability of inkjet printing and uniformity of the printed films. For full color OLED display manufacturing, polymer films are printed on to pixilated arrays defined by a bank made with dielectric materials. The surface energies of ITO and the bank materials and their interactions with the optimized polymer inks are the key parameters to control the spreading of the liquid on the substrate. On the other hand, ink formulations and their interaction with the print-head control the ink jettability. The formulations and surface properties of the substrate also play a pivotal role in the uniformity of dried films. In this paper, we will first discuss the key parameters to obtain uniform films and show some of our most recent printing results where we have optimized these parameters and obtained uniform polymer films via ink jet printing. The device performance of the printed devices in terms of efficiency and lifetime will be compared with the standard spin coated devices. Finally, we will show our latest results in full color display printing.

10:30 AM *I1.4
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 600C down to 400C. 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 300C or below and by modifying the device structure design, O-LED (Organic LED) FPD addressed by unifrom poly-Si TFTs mounted on flexible plastic substrate with high robustness and very light-weight such as PES (Poly-Ether-Sulfone) or PET (Poly-Ethylen-Telephthalate) etc. is expected. By establishing a reliable low-temperature fabrication process on arbitral 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 *I1.5
Nanostructured Materials for TFT Macroelectronics.
Robert Reuss, Defense Advanced Research Projects Agency (DARPA), Arlington, Virginia.

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 for 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 flash heating techniques. 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 TFT 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.

11:30 AM *I1.6
Poly-Si TFTs From Glass to Plastic Substrates: Process and Manufacturing Challenges. F. Lemmi, Wonsuk Chung, B.C. Drews, A. Hua, S. Lin, P.M. Smith, J.R. Stern and J.Y. Chen; FlexICs, Milpitas, California.

Poly-Si Thin-Film Transistors (TFTs) are currently used in commercial active-matrix displays. They provide superior performance with respect to their amorphous silicon counterparts and allow

integration of driving electronics directly on the display glass plates. For several applications, it can be desirable to have active-matrix displays made on flexible substrates. However, a direct application of a standard TFT process to plastic substrates is not in general possible, mostly because of temperature limits and related dimensional stability issues. In addition, standard flat-panel manufacturing tools are not capable of automatically handling floppy substrates. Therefore, a new process has to be developed, compatible with a suitable way of handling plastic substrates. Plastic sheets are laminated on glass carrier wafers and run through all the automated tools. A low-temperature process using excimer laser annealing is developed and optimized. High-quality TFT backplanes are manufactured with a pixel layout designed for active-matrix OLED (AMOLED) displays. Field-effect mobility in excess of 70 cm^2/Vs on p-channel TFTs are achieved, together with leakage currents lower than 2 pA per micron gate width. Challenges include low-temperature gate dielectric development, reduction of intrinsic film stress, protection of plastic from laser damage, and contact formation. Solutions to these challenges are discussed and TFT transfer characteristics on glass and plastic substrates are presented. Finally, images from prototype monochrome AMOLED displays are presented, with 64×64 pixels and 80 dpi resolution.

SESSION I2/A3: Joint Session: Silicon TFT Processing and Characteristics
Chairs: Jin Jang and Arokia Nathan
Tuesday Afternoon, April 13, 2004
Room 2001 (Moscone West)

1:30 PM I2.1/A3.1

Novel approach to position control of Si grains for a high-performance TFT using an excimer laser. K Nakano[1], Y Hitsuda[1], M Shiomi[1], I Hatada[1], N Saotome[1], Y Negoro[2] and J Sato[1]; [1]Materials Laboratories, Sony Corporation, Atsugi-shi, Kanagawa, Japan; [2]Fusion Domain Laboratory, Sony Corporation, Ohta-ku, Tokyo, Japan.

For applications to a system on panel (SOP), a high-performance poly-Si thin film transistor (TFT) is desirable. Excimer laser annealing (ELA) of a-Si film is a promising crystallization method. However, the performance of poly-Si TFTs formed using conventional ELA is limited due to small grain size and randomly located grain boundaries (GBs) which act as potential barriers for carriers. Therefore, a technique has to be developed to control the location of GBs and avoid GBs in the TFT channel. We propose a novel approach to form position-controlled Si grains by using a-Si precursor film having convex regions of several μm. In this way, high-performance TFTs are achieved. A 47-nm-thick a-Si layer was deposited on a glass substrate. A part of the layer was etched by plasma etching to form a square convex region with sides ranging from 2μm to 12μm. The etching depth was about 7nm. The film was irradiated with a XeCl excimer laser in the energy range from 420 to 460 mJ/cm^2 in N_2. The laser shot number was 100. Electron Backscatter Diffraction Pattern (EBSP) analysis indicated that <111>-oriented grains are formed not only in the convex region but also around it. The size of the essentially round-shaped grains was several μm. Practically only —*summ*—3 GBs were observed in the {111} grains. —*summ*—3 GBs are thought to be electrically inactive, unlike random GBs[1] and might not degrade TFT characteristics significantly. 2-D numerical analysis revealed that there is a concave temperature profile across the convex region and the temperature drop is estimated to be about 100K with a thickness difference of 7nm. This is because the thicker convex region has a larger heat capacity than the adjacent thinner region. Preferential nucleation, that is control of the location of grains, can be realized at this low temperature site. The essentially <111> texture can be explained by the surface energy of the {111} surface, which is the lowest of all surfaces. Not only the controlled grain position but also the preferential <111> orientation leads to good device performance, particularly as regards uniformity, as the interface quality of SiO_2/Si depends on surface orientation. We fabricated n-channel TFTs whose channel was in a convex region (L/W=1μm/1μm). Field-effect electron mobility of 461cm^2/Vs, subthreshold swing of 0.6V/dec and on/off current ratio of $3x10^7$ were obtained. We simultaneously achieved position and orientation control of grains using structured a-Si films. <111>-oriented Si grains of a size of several μm can be obtained at the desired positions. TFTs fabricated in position-controlled Si grains show good device performance. This position-control method can be applied to SOPs and 3-D LSIs. [1] A. Fedotov et al., J. Cryst. Growth 104, 186 (1990).

1:45 PM I2.2/A3.2

A Novel Femto-second Laser Annealing for TFT Device. Zun-Hao Chen, Jia-Min Shieh, Yi-Chao Wang, Yi-Fan Lai and Bau-Tong Daia; National Nano Device Laboratories, Hsinchu, Taiwan.

In recent years, polycrystalline silicon thin-film transistors (poly-Si 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).1,2 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 adapted 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 infrared femto-second Ti: sapphire lasers. Non-thermal melting on transparent a-Si to poly-Si 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 assisted by sequential lateral solidification constitutes super lateral epitaxy that can crystallize amorphous silicon into polycrystalline silicon with large grains of 1micrometer, even when a-Si films are irradiated at an ultralow laser flounce of 45 mJ/cm2, and low laser-shots. The sheet resistance of post-implant annealing of a-Si decreased from 10,000 omega/square to 300omega/square. The traditional TFT process typically uses a top gate self-align TFT architecture with FLA. FLA activation reduces not only the postannealing temperature but also the resistance of source and drain regions, which helps improve device turn-on characteristics compared to traditional furnace activation. FLA 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.

2:00 PM I2.3/A3.3

A simple explanation on the crystallization kinetics of a CW laser crystallization of a-Si. Seong Jin Park, Sang Hoon Kang, Yu Mi Ku and Jin Jang; Advanced Display Research Center, Kyung Hee University, Seoul, South Korea.

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 wafer, 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 of papers regarding electrical and structural characteristics of CLC 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 *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.

2:15 PM I2.4 /A3.4

100-nm Channel Length a-Si:H Vertical Thin Film Transistors. Isaac Chan and Arokia Nathan; Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, Canada.

This paper will report on the fabrication of hydrogenated amorphous silicon (a-Si:H) vertical thin film transistors (VTFTs) with nanometer-scale channel length, L = 100nm, using conventional planar TFT processing technology. The device is a fully self-aligned vertical channel structure realized through optimization of photo-etch processes. The VTFT 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 VTFT are defined only by the intersectional area of the electrodes. This yields the smallest possible TFT size for any given photo-etching resolution. Presently, we can demonstrate VTFTs with critical dimensions of 5-μm square area using standard 5-μm lithography to yield high ON-OFF current ratio (10^7) and low leakage current (1fA at V_d = 1.5V). 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.

2:30 PM *I2.5/A3.5

Issues in processing a-Si/nc-Si TFTs on flexible substrates.
Sigurd Wagner, Electrical Engineering, Princeton University, Princeton, New Jersey.

Long ago silicon migrated long ago to unconventional substrates. Amorphous silicon solar cells are made on foils of steel or organic 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 macroelectronic 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 silicon TFT materials and device processes. Techniques for substrate passivation, planarization, and film adhesion also directly flow from the choice of substrate. Often these three functions are coupled. Their 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. Shrinking and warping calls for pre-process bake. Layers must be made to adhere strongly, to withstand shear caused by 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 material 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 pose a much bigger process challenge. At some point in fabrication the deformable or elastic 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 on new process chemicals, patterning techniques and metallization procedures must be employed. I will illustrate these processing issues with specific examples.

3:30 PM *I2.6/A3.6

Flexible Electronics Devices using SUFTLA and Micro Liquid Process. Tatsuya Shimoda, Technology Platform Research Center, Seiko Epson Corporation, Suwa-gun, Nagano-ken, Japan.

For fabrication of flexible electronics 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 realize flexible devices but also give us a versatile means for a flexible production system. SUFTLA, which stands for "Surface Fee Technology by Laser Annealing/ablation, is a technology that enable TFTs and TFT devices to be transferred from the original substrate to any secondary substrate by irradiating the laser to an exfoliation layer sandwiched between the TFT and the original substrate. The adbantage of this technology over a direct fabrication of TFT on a plastic substrate is that the well-matured conventional TFT fabrication process can be utilized. Therefore, properties and reliability of TFT can be guaranteed. It has been demonstrated that the TFT properties don't change before and after the transfer process. We have successfully developed an flexible AM-LCD(active matrix liquid crystal display) and AM-OLED (AM-organic EL dispaly) by using active matrix poly Si-TFT 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. Candidates for liquid materials include liquid metals, liquid semiconductors, liquid ceramics and organic materials in a liquid form. Devices using organic materials were first explored, and then followed by inorganic materials. In the MLP including an inkjet, the process is divided into three major steps; (1) inkjet process, which enables to make a small droplet from a solution and mechanically positions it accurately on the substrate, (2) self-assembling of the droplet by surface enaergy, which enable a further accurate patterning than the mecanical one and (3) solid thin film formation by controlling a movement of solute which is caused by evaporation of a solvent. As applications of MLP, we have developed a colour filter for LCD, organic EL display, organic TFTs and a micro lens for VCSEL (vertical cavity surface emitting laser) by using organic materials. As for inorganic materilas, metal bus lines for a plasma dispaly were directly inkjet printed using a silver liquid metal and an PZT pizo elemnt was also directly patterned by inket so as to form epitaxial growth. Direct patterning of inorganic films is very encouraging for flexible electronoics 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 I2.7/A3.7

Temperature Dependent Carrier Transport in Single Crystalline Si TFTs inside a Location-Controlled Grain.
Vikas Rana, Ryoichi Ishihara, Jan Wim Metselaar 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 TFTs (c-Si TFTs). TFT fabricated inside a location-controlled grain by μ-Czochralski process [1] showed a high field effect mobility of 450 cm^2/Vs and low-leakage current of 10^{-13} A. [2] The high performance of c-Si TFTs will allow us to integrate 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 TFTs in detail, the temperature dependence of I-V characteristics of c-Si TFTs fabricated inside a location-controlled grain by μ-Czochralski (grain-filter) process were studied. The n-channel TFTs 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 SiO_2 by photolithography. Subsquently, a 250 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 3.21/2.88 μm, were fabricated inside a grain with top gate, self-align structure having LPCVD SiO_2 (120 nm) as a gate insulator. No hydrogenation was done later. Temperature dependence of transfer 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 37°, 52°, 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 TFT behaves like single-crystalline MOSFETs. This was varied for a wide range of laser energy densities. With a low laser energy density, the Ea value at OFF-state (Vgs = -10V) is calculated to be 0.52 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 (-10V< Vgs <-3V) 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 crystalline islands using substrate embedded seeds in excimer-laser crystallization silicon film, Appl. Phys. Lett. 79, 1819 (2001). [2] R.Ishihara, P.C.Van der Wilt, B.D.van Dijk, J.W.Metselaar and C.I.M.Beenakker, Property of single crystalline Si TFT fabricated by μ-Czochralski (grain-filter) process, Proc. of SPIE, Vol. 5004 (2003) Pg.10-19

4:15 PM I2.8/A3.8

Elastic integrated circuits on elastomeric skin.
Stephanie Perichon Lacour 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 begin by fabricating stretchable gold interconnects on the rubber-like membranes. They meet TFT input/output impedance requirements in the megaohm range, can be deformed repeatedly, and thus ensure both the electrical functionality and the stretchability of the circuits. Then we integrate amorphous silicon 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 application of reliable 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 *I2.9/A3.9

Reel-to- Reel Cassette Cluster Tool System with PECVD and Pulsed PECVD Deposition Techniques. Arun Madan, MVSystems Inc., 80401, Colorado.

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 p-i-n type 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 flexible substrate material is contained within a cassette which includes a reel 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 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 >15 $\AA$/s; in the 'OFF' cycle the ions responsible for dust formation in the plasma are neutarlized. 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 $\AA$, 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 111 to 220 in a controllable way; this has implications for fabricating nc-Si TFT's with high field effect mobility, especially on low cost flexible substrates. (1) US patent #6,258,408B1: Semiconductor Vacuum Deposition System and Method having a Reel to Reel Substrate Cassette.

SESSION I3: Flexible Si TFT Circuits
Chair: Jin Jang
Wednesday Morning, April 14, 2004
Room 2018 (Moscone West)

8:30 AM *I3.1
Amorphous Silicon AMOLED Display Backplanes on Flexible Substrates. Arokia Nathan, Denis Striakhilev, Peyman Servati, Kapil Sakariya, Czang-Ho 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 thin-film transistors (TFTs) 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 TFTs. 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 4V, subthreshold slope of 0.5 V/decade and pA leakage current that 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 Eurodisplay, Nice, p.609, 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 I3.2
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 conventions 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.

9:15 AM I3.3
SLS TFT Uniformity Improvement for an Active Matrix Organic EL and System on Panel(SOP) applications. Myung-Koo Kang, Hyun Jae Kim, Eui-Jin Chung, Chi Woo Kim and Kyuha Chung; Flat Panel Display R&D Team, Samsung Electronics Co., Seoul, South Korea.

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 similar grain boundary location, which can be verified by optical and FIB observation. The model for TFT degradation was developed based on dopant segregation and solutions were suggested for an uniformity improvement. Among solutions were new SLS method and doping condition adjustment. With new conditions, Vth variation can be improved from 0.4V to less than 0.2V, which can be successfully applied to AMOLED or SOP(System on Panel) application.

9:30 AM *I3.4
Organic Light-Emitting Devices for Large-Area Displays Driven by Amorphous Silicon. Walter Riess, Siegfried Karg, Heike Riel, Tilman A Beierlein, Santos Alvarado, Constance Rost, 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 outcoupling efficiency but also provides a tailorable viewing angle and a high contrast ratio. Moreover, the operating voltage required for a current density of 10 mA/cm^2 is not higher than 5 V. Crucial for the excellent performance data achieved were a careful design of the device 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] [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 I4: Organic TFTs I
Chair: Norbert Fruehauf
Wednesday Morning, April 14, 2004
Room 2018 (Moscone West)

10:30 AM I4.1
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 cm^2/Vs. Therefore, OTFT have 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 photolithographic processing, 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 contacts of pentacene TFTs can be made in one 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 display. Therefore, we studied a bottom contact structure. We have studied bottom-gate organic thin-film transistors with a selectively grown pentacene on plastic structure. The pentacene can be self-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 cm^2/Vs, a threshold voltage of -1 V, an I_{ON}/I_{OFF} ratio of 10^7 and off-current of less than 10pA/um have been demonstrated.

10:45 AM I4.2
Approaches to Fabrication and Evaluation of Organic FETs with Macroscopic Grain Sizes and Single Crystal-like Mobilities. Howard E. Katz[1], Christian Kloc[1], Theo Siegrist[1], Michael Lefenfeld[1], Padma Gopalan[1] and Benjamin Ocko[2]; [1]Lucent Technologies, Bell Laboratories, Murray Hill, New Jersey; [2]Brookhaven National Laboratories, Upton, New York.

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 nonidealities 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 *I4.3
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, Korae Electronics Technology Institute, Pyungtaek, Kyunggi, South Korea.

Recently, the stability of organic thin-film transistors has become one of the most important issues in this are of research. In this report, we investigated the stability of polythiophene-based thin film transistors (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 condition. In order to analyze the degradation of the device, transistors were measured in vacuum, dry N_2 and air environment as a function of time. In vacuum and dry N_2 atmosphere, saturation field effect mobility and threshold voltage variations are relatively small compared to those measured in air ambient condition. Devices exposed to air exhibited significant mobility degradation and eventually lose their transistor properties. To realize an air stable device, we applied a passivation layer which protects the active layer from oxygen or water vapor which is believed to be the source of the degradation. With a passivation layer, on/off current ratio, threshold voltage shift were reduced which suggests that a proper passivation layer is a prerequisite in organic-based electronics. We applied various materials as passivation layers and analyzed their effects on the performance.

11:30 AM I4.4
Two origins of source/drain series resistance in bottom-contact pentacene thin-film transistors. Makoto Noda, Nobuhide Yoneya, Nobukazu Hirai, Kazumasa Nomoto, Masaru Wada and Jiro Kasahara; Sony Corporation, Ota-ku, Tokyo, Japan.

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 electrodes; 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 [Necludov et al. Solid-State Electronics 47, 259 (2003), Kymissis et al. IEEE Trans. Electron Device 48, 1060 (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 S/D electrodes patterned by shadow mask, and determined Rs from the dependence of total S/D resistance on the gate length. Rs of the BC TFT was 2.2 kΩ/μm which was 700 times as large as that of the TC TFT. In the TC TFT, only two-dimensionally (2D) grown phase of pentacene was observed on top of SiO_2 gate insulator. On the other hand, the SEM images clearly show two distinct phases in the BC TFT. On top of the gate insulator, the 2D grown phase was observed, whereas on the Au electrodes pentacene film of randomly oriented petaloid structure grew. In the blurred edge region of the electrodes, both phases coexist. This result implies that this mixed phase region is responsible for the Rs for the BC TFTs. In order to eliminate the blurred edges of the electrode, Au-based electrode was fabricated on SiO_2 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 still dominates the TFT characteristics. When the Ti layer became thinner than 3 nm, Rs decreased rapidly. Contact resistance between Ti and pentacene was significantly larger than the observed Rs; thus, essentially all current flows in from Au. From the temperature dependence of Rs, the activation energy of 63 meV was obtained. This value was close to the activation energy of 75 meV, obtained from the temperature dependence of intrinsic mobility. These results indicate that for the Ti layer thicker than 3 nm Rs is dominated by the resistance of semi-insulating pentacene between Au and the hole accumulating layer in the channel. By eliminating Ti layer, we demonstrated BC TFTs with no dependence of mobility on the gate length, and a high performance BC TFT with carrier mobility improved to be as large as 1.1 cm^2/Vs.

11:45 AM I4.5
Temperature-Dependent Contact Resistances in High Quality Polymer Field-Effect Transistors. Douglas Natelson[1,2] and Behrang H. Hamadani[1]; [1]Physics and Astronomy, Rice University, Houston, Texas; [2]Electrical 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 to channel resistance decreases with decreasing temperature. We find that the contact resistivity is approximately inversely proportional to the field-effect mobility over 4 decades of mobility. We compare these result with a recent model for metal-organic semiconductor contacts. Mobilities corrected for this contact resistance approach a record 1 cm^2/Vs at room temperature and high gate voltages.

SESSION I5: Organic TFTs II
Chair: Bruce Gnade
Wednesday Afternoon, April 14, 2004
Room 2018 (Moscone West)

1:30 PM I5.1
Short-channel polymer field-effect transistors with self-assembled thin polymer dielectrics. Lay-Lay Chua, Peter K. Ho, Richard H. Friend and Henning Sirringhaus; Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom.

Polymer field-effect transistors (FETs) manufactured by solution processing and direct printing are one of the most promising approaches for integrating electronic functionalities onto flexible plastic substrates. Downscaling of channel length is one of the paths for improvement of their device performance. We have demonstrated that with the help of surface energy patterning of the substrate inkjet printing is capable of defining submicrometer critical feature sizes enabling fabrication of polymer FETs. However, in order to realize high performance, submicron devices all dimensions, in particular the gate dielectric thickness need to be scaled down to thicknesses much less than 100 nm. This is difficult to achieve with conventional polymer dielectrics posing problems with pinhole formation and increased leakage current when the thickness is dropped below typically 150 nm. In the present work we present several novel approaches to fabrication of high performance polymer dielectrics with thicknesses down to 10 nm. In one approach a self-assembled bilayer is formed from a ternary blend solution containing both the dielectric and the semiconducting polymer, or precursors thereof. This method enables formation of ultrathin, thermodynamically stable dielectric layers. Through kinetic control of the structural properties of the polymer-polymer interface the method allows for the first time a systematic study of the dependence of the field-effect mobility on the surface roughness at a polymer-polymer interface. We will also discuss the effects of dielectric purity on device performance and stability.

1:45 PM *I5.2
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, numerous challenges remain such as optimizing the gate dielectric as well as fabrication processes that are suitable for low-cost manufacturing. The performance characteristics of organic FETs places constraints on circuit speeds, but this is compensated for by ease of processing. This trade-off, as well as some unique properties such as chemical sensitivity, will influence the use of such transistors in commercial applications.

2:15 PM I5.3
Four-probe electrical measurement on a dry-etched pentacene OTFT. Iwao Yagi[1], Kazuhito Tsukagoshi[1,2] and Yoshinobu Aoyagi[1]; [1]RIKEN, Saitama, Japan; [2]PRESTO, JST, Saitama, Japan.

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 532 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.

2:30 PM I5.4
Short Channel Effects in Regioregular Poly(thiophene) Thin Film Transistors. Michael L Chabinyc, Jeng-Ping Lu, Alberto Salleo and Robert Street; 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 essential for the design of pixels in display backplanes. We have investigated the performance of TFTs with channel lengths from 5 to 50 μm fabricated with a regioregular poly(thiophene), (XPT). We observed a pronounced dependence of the output current, bias stress and sub-threshold slope on channel length. The apparent saturation mobility of XPT-based TFTs can be as high as 0.7 cm ^{2}/V s with high drain voltages when extracted from transfer characteristics in short channel devices. This mobility would represent record performance for a polymer semiconductor, however examination of the full characteristics of the TFTs shows that the high currents are, in fact, due to short channel effects. Measurements of space-charge limited diodes support this interpretation. The implications of these results for materials characterization and for the design of polymeric TFTs for display backplanes will be discussed.

2:45 PM I5.5
All-organic printable logic circuits on paper-substrates.
David Nilsson[1], Robert Forchheimer[2] and Magnus Berggren[1]; [1]Dept. of Science and Technology, Linkopings Universitet, Norrkoping, Sweden; [2]Dept. of Electrical Engineering, Linkopings Universitet, Linkoping, Sweden.

We report logic circuits based on electrochemical transistors printed on paper-like substrates. Simple electronic elements such as inverters and oscillators have been extended and combined into larger logical systems. The transistor is based on the popular conducting polymer, poly(3,4-ethylenedioxythiophene) (PEDOT) doped with poly(styrene sulfonic acid) (PSS). By changing the oxidation state of the PEDOT:PSS within the transistor it is possible to modulate the current level, resulting in devices with operating voltage below 3V that require no critical dimension (typical channel width is around 500 microns). Only organic materials are used to manufacture the devices; the electrolyte can either be liquid or gelled, both cellulose based paper and polyester foil can been used as the substrate. Together with common printing-techniques this results in environmental friendly and inexpensive circuits.

3:30 PM *I5.6
Organic Light Emitting Diode (OLED) - Technology Convergence. Stewart Edward Hough, ATA, Madera, California.

Organic Light Emitting Diode (OLED) technology has been the focus of intense development by literally hundreds of companies, universities and other organizations over the last decade. Application of OLED technology has most notably been applied to electronic displays, but the technology also has potential in the lighting and photovoltaic industries. The potential performance and cost advantages that OLED displays offer have caused many to consider them a disruptive technology that could eventually displace CRTs and even LCDs. A number of diverse and even disparate technologies are converging in the OLED platform and have either been adapted for OLEDs from existing technology bases or are nascent and in various stages of development. Overuse of the term potential is deliberate and appropriate in discussing OLEDs as no flat panel (FPD) display technology invented or developed to date has the overall feature set - visual appeal, mechanical form factor, or lower cost manufacturing options - that OLEDs ostensibly offer. This advantage is currently unrealised: over a decade of development has now yielded the emergence of first generation manufactured displays - mostly single color alphanumeric, with a single full-color OLED. This is actually an accomplishment of note as newly invented display technologies often take a decade or more of research and development to get to first commercial implementation. The early pace of development progress and considerable over-promotion produced unrealistic expectations for the technology's early commercial success, but with the positive result that the industry is now focused on the remaining challenges to secure first level market opportunities. Understanding and modeling the risk factors associated with the technology elements that have converged and constitute an OLED display can provide helpful insight and perspective to the development challenges the industry will face with future technology discoveries.

4:00 PM I5.7
Electronic transport of pentacene Thin Film Transistors using organic gate dielectrics. Dietmar Knipp[1,2], Robert A. Street[2], Armin R. Volkel[2] and Pravesh Kumar[1]; [1]Science and Engineering, International University Bremen, Bremen, Germany; [2]Electronic Materials Laboratory, Palo Alto Research Center, Palo Alto, California.

The electronic transport of pentacene thin film transistors (TFTs) on organic dielectrics were investigated. Organic dielectrics facilitate the fabrication of low cost electronics on flexible substrates. The influence of the gate dielectric on the morphology of the pentacene films and the device performance of the TFTs were studied. The poly crystalline films were prepared by thermal evaporation on top of benzocyclobutene (BCB) and poly-vinyl phenol (PVP) dielectrics. Careful control of the preparation conditions of the dielectric and the pentacene films lead to TFTs with mobilities of 0.4 cm^2/Vs on different organic dielectrics. Therefore, the mobility is comparable with the mobilities observed for inorganic dielectrics like thermal oxide and plasma enhanced chemical vapor deposited silicon nitride. The subthreshold slope of TFTs on PVP is improved by a factor of 2-3 comparing the slope with the best results observed for inorganic dielectrics (considering the thickness and the dielectric constant of the dielectric). Subthreshold slopes of 0.4V/decade were measured for 200nm thick PVP films. Furthermore, the TFTs on PVP exhibit threshold voltages very close to 0V. The results reveal that the pentacene molecules tend to align better on smooth PVP surfaces than on the inorganic surfaces, which might lead to better structural order within the first monolayers. The influence of the organic dielectric on the device performance and the electronic transport will be discussed.

4:15 PM I5.8
High Performance Integrated Circuits Fabricated on Large-Area, Flexible Substrates. Paul F Baude, David Ender, Chris Gerlach, Michael Haase, Tommie W Kelley, Dawn V Muyres, Steven Dale Theiss and Dennis Vogel; Corporate Research Materials Laboratory, 3M Company, St. Paul, Minnesota.

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 polymeric substrates. Devices over the entire patterned area were functional, and

performance statistics will be included. Devices consisted of shadow-mask patterned layers of gold, alumina and pentacene. TFT mobilities greater than 2 cm^2/Vs were measured and propagation delays from 7-stage ring oscillators of less than 5 microseconds were observed. This all-additive, dry patterning method has been extended to the production of all-sputtered devices using aluminum for the electrodes, silicon dioxide for the dielectric, and ZnO as the semiconductor. Larger aperture masks are under investigation and continuing efforts include application to display backplanes, automation of the alignment process, and lifetime and bias stress profiles of devices fabricated on large substrates

4:30 PM I5.9
Organic field-effect transistors with bending radius down to 1 mm. Tsuyoshi Sekitani[1], Hiroshi Kawaguchi[2], Takayasu Sakurai[2] and Takao Someya[1]; [1]Quantum-Phase Electronics Center, The University of Tokyo, Bunkyo-ku, Tokyo, Japan; [2]Center 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 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 cm$\hat{2}$/Vs and an on/off current ratio of above 10$\hat{5}$ have been fabricated by a vacuum evaporation process. First, the gate electrode was formed by thermal evaporation of 5 nm Cr and 50 nm Au through a shadow mask on a 75 mu_m flexible polyimide-sheet plastic substrate. Then, a polyimide gate dielectric layer was prepared by spin coating and a 30 nm thick pentacene film was deposited through thermal evaporation. Finally the 50 nm Au drain-source electrodes were formed using a shadow mask. The channel length and width of OFETs are normally 50 mu_m and 16 mm, 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.

4:45 PM I5.10
Comparison between organic transistors: effects of material properties and device geometry. Ornella Sanna[1], Annalisa Bonfiglio[1,2], Piero Cosseddu[1], Fulvia Mameli[1], Ileana Manunza[1], Marco Bergliocchi[3], Aldo di Carlo[3] and Paolo Lugli[3]; [1]Dept. of Electrical and Electronic Engineering and INFM, University of Cagliari, Cagliari, Italy; [2]Centre S3 - INFM, National Institute of Physics of Matter, Modena, Italy; [3]Dept. of Electronic Engineering and INFM, 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 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 was made with an identical geometry, on a fully 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 behaviour 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

SESSION I6: Poster Session: Flexible Materials and Device Technology I
Chair: Bruce Gnade

Wednesday Evening, April 14, 2004
8:00 PM
Salons 8-9 (Marriott)

I6.1
High-Performance Nanowire Electronics and Photonics on Glass and Plastic Substrates. Robin Sean Friedman[1], Mike C. McAlpine[1] and Charles M. Lieber[1,2]; [1]Chemistry and Chemical Biology, Harvard, Cambridge, Massachusetts; [2]Engineering and Applied Sciences, Harvard, Cambridge, Massachusetts.

The merger of nanoscale building blocks with flexible and/or low cost substrates could enable the development of high-performance electronic and photonic devices with the potential to impact a broad spectrum of applications. We demonstrate that high-quality, single-crystal nanowires can be assembled onto inexpensive glass and flexible plastic substrates to create basic transistor and light-emitting diode devices. In our approach, the high-temperature synthesis of single-crystal nanowires is separated from ambient-temperature solution-based assembly to enable the fabrication of single-crystal-like devices on virtually any substrate. Silicon nanowire field-effect transistors were assembled on glass and plastic substrates and display device parameters rivaling those of single-crystal silicon and exceeding those of state-of-the-art amorphous silicon and organic transistors currently used for flexible electronics on plastic substrates. Nanowire transistor devices have been configured as low-threshold logic elements with gain; moreover, the high-performance characteristics are relatively unaffected by operation in a bent configuration or by repeated bending. The generality of this approach is further illustrated with the assembly of gallium nitride nanowire UV-light-emitting diodes on flexible plastic substrates. These results suggest that nanowires could serve as high-performance building blocks for the next of generation lightweight display, mobile computing, and information storage applications.

I6.2
Poly germanium and germanium-silicon alloys on plastic for realization of thin film transistors. Bahman Hekmatshoar[1], Davood Shahrjerdi[1], Shams Mohajerzadeh[1], Ali Khakifirooz[2] and Michael Robertson[3]; [1]Electrical and Computer Engineering, University of Tehran, Tehran, Iran; [2]Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Boston, Massachusetts; [3]Physics, Acadia University, Wolfville, Nova Scotia, Canada.

Stress-assisted crystallization of amorphous germanium and germanium-silicon alloys on plastic substrates is reported. PET and Kapton plastic bases have been used to deposit Ge and Si-Ge thin films and to fabricate depletion mode transistors. The GeSi sample consists of consecutive layers of GeSi, Cu-Ge and the top GeSi films. The Cu-Ge layer is the seed of crystallization of the top and bottom SiGe layers. For the Ge sample, the SiGe layer is replaced with pure germanium. After cleaning the plastic substrate in strong solvents, they are given a step of RCA#1 solution followed by blow-drying. All depositions are carried out in vacuum with a base pressure of 1×10^{-6}torr and by e-beam evaporation of silicon and thermal co-evaporation of Ge. Various constituents of the Ge-Si sample have thicknesses of 300, 10 and 100Å, respectively. Crystallization of Ge or Ge-Si layer is achieved using an external compressive stress during annealing at temperatures ranging from 150°C to 180°C. The amount of external mechanical strain is set at 0.05%. This external mechanical stress is essential to enhance the crystallization of amorphous Ge or SiGe films at reduced temperatures. Annealing of these samples takes more than 12 hours. The crystalline quality of the films has been verified using SEM, TEM, Raman spectroscopy and XRD. The percentage of Si in Ge-Si alloy has been examined using RBS and was found to be 30-50% for different samples. Based on cross-sectional TEM, the Cu-Ge layer acts as the seed of crystallization for the rest of Ge-Si alloy and the growth progresses, epitaxially, from the seed layer onto the Ge-Si film. TEM study of the films suggests that some grains become dominant and epitaxial growth from top to bottom as well as lateral growth is observed. Based on our investigation, PET seems to be more suitable due to its inherent stress. It is also a transparent and inexpensive substrate. The crystalline Ge films have been used to fabricate thin film transistors on PET substrates. The sheet resistance of such layers has been monitored during thermo-mechanical post-treatment showing a dramatic drop from 20MΩ/ to a low value of 25KΩ/ after a treatment of 12hours. This measurement on Ge-Si is not quite possible due to high values of sheet-resistance. A hole mobility of 110cm^2/Vs has been obtained for poly-Ge films. Fabrication of TFTs involves deposition of gate oxide where SiO_2 and TiO_2 were used. The Ge-based TFTs are normally-on devices and the current-voltage characteristics of such transistors indicate an On/Off ratio of 10^4 and a threshold voltage of 15V. For the Ge-Si samples the film resistance is very high and fabrication of TFTs in such a case requires appropriate doping to create an inversion layer. Aluminum is considered as a source of doping for such

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.

I6.3
Transparent Conductors for Flexible Displays: a Performance Study. Sonia Grego 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 great relevance for flexible displays. Indium 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 conductive 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 DMD 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).

I6.4
Optical and electrical properties of ionic semiconductor CoO_x 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 (CoO_x) by using electrodeposition from cobalt nitrate ($Co(NO_3)_2$) and sodium nitrate ($NaNO_3$). 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 carrier mobility. It was found that all the films were n-type with electron concentration on the order of 10^{16} cm^{-3} and electron mobility ranging from 30 160 $cm^2V^{-1}s^{-1}$. The mobility of these films compares favorably with amorphous and organic semiconductors. Supported by Petroleum Research Fund.

I6.5
Abstract Withdrawn

I6.6
Electrical characteristics of edge contact type cell for Phase change RAM. Min Soo Youm[1,2], Sun Il Shim[1,2], Man Young Sung[2], Seong Il Kim[1] and Yong Tae Kim[1]; [1]Korea Institute of Science and Technology, Seoul, South Korea; [2]Korea 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 10e4. 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 level should 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.

I6.7
The Electronic Circuit Composition and Structure of String for A Novel Braid Electronics-Systems by Kumihimo-Structure. Shigekazu Kuniyoshi and Kuniaki Tanaka; Electronics & Mechanical Engineering, Chiba University, Chiba, Japan.

A new integrated circuit concept that forms electronic equipment by the braid stucture 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 stucture of the braid with various electronic functions was examined. A plastic optical fiber, the glass fiber, and the insulation coating thin metal line which is enough flexible to construct the kumihimo-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 simplify 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.

I6.8
Titania-coated Polystyrene Spheres for Electronic Ink. Jun Hee Sung, In Bae Jang, Hyoung 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 electrophoretic 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 60 nm) depending on the titania concentration. Surface potential of the hybrid particles in a low dielectric medium was strongly dependent 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 electrophoretic mobility including selective ion adsorption, proton transfer, and contact electrification but also it increased the electrostatic and steric stabilization.

I6.9
Device Quality Mercurous Chloride (Hg2Cl2) Crystals For Use in ALWIR AOTF Imaging System. Abdul R Qureshi[1], Abdalla M Elsamadicy[1], R. J Naumann[1], Gerald Karr[1], Don Gregory[1], Lloyd W Hillman[1], Sudhir B Trivedi[2] and Donald Gullies[3]; [1]The University of Alabama in Huntsville, Huntsville, Alabama; [2]Brimros Corporation, Baltimore, Maryland; [3]NASA-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 immaging in this wavelength range. Therefore, in this reserarch 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 standardized the furnace and growth conditions to produce device quality crystals. Laue x-ray diffraction technique was used to determine the crystallographic orientation of the crysal. Optical transmission measurements as well as Fourier Transform Infrared Spectrometer (FTIR) characterizations were used to determine the spectral transmittance of the samples. Further we used a laser beam analyzer to obtain the scattering profile.

I6.10
Metal and Oxide Stack Layer Formation Using a Novel Selective Deposition for Flexible Display Applications.
Daekyun Jeong[1], Nohheon Park[1], Hyunjung Shin[1], Jaegab Lee[1], Myungmo Sung[2] and Jiyoung Kim[1]; [1]Advanced materials engineering, Kookmin University, Seoul, South Korea; [2]Chemistry, 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 (octadesyl-tetrachlorosilane, (CH3(CH2)n-ISiCl3)) mono-layers providing nonpolar surfaces and subsequently inhibiting nucleation of ZrO2 and Cu using CVD. We adapt atomic layer deposition (ALD) like CVD of which mechanism 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 to the patterned SiO2/Si mold. After curing, the PDMS was peeled off. OTS was placed using spin coating. In this study, Si (100) wafers with resistivity of 5 10 Ωcm were respectively used as a substrate and cleaned by RCA cleaning methods. SiO2 thin films (7 8 A) were grown by SC-1 cleaning. And, then we defined OTS pattern using μCP. Zirconium oxide thin film was grown by atomic layer deposition with zirconium t-butoxide as a source and water (H2O) vapor 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 (80sec) / H2O (2sec) / Ar (240sec). N2 gas was used as a carrier gas. Top electrode (Cu) 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 by AFM and SEM as well as optical microscope. C-V characteristics of Cu / ZrO2 / SiO2 / n-type(100) capacitors without any further annealing were made by a use of HP4284a at 100kHz. The measured dielectric constant is 8.9, which is much lower than bulk crystalline values of 20 25. The leakage behaviors were measured using Keithley 6517A. 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 'Center for Nanostructured Materials Technology' under ' 21st Century Frontier R&D Program' of the Ministry of Science and Technology, Korea

I6.11
Interconnecting Indium Tin Oxide Islands on a Spherical PET Surface. Rabin Bhattacharya[1], Sigurd Wagner[1], Yeh-Jiun Tung[2] and Mike Hack[2]; [1]Princeton University, Princeton, New Jersey; [2]Universal Display Corporation, Ewing, New Jersey.

One approach to fabricating a transparent display backplane on spherical surfaces is to pixellate 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 the 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 mm wide and 300 nm thick and cross over 150-nm tall ITO islands. We study ITO island fracture 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.

I6.12
Top Gate TFT for Large Area Electronics. Mark Meitine 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} cm^2/(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 PECVD silicon nitride was used as gate/passivation 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} cm^2/(Vs), the subthreshold slope of 5..7 V/decade and the I_{on}/I_{off} ratio of about 10^2. 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 I_{on} value. The modeling shows that using μc-Si based n^+ layer, I_{on}/I_{off} ratio and field effect mobility can be improved by an order of magnitude. The characteristics of top gate TFTs with improved source/drain contacts will be presented. [1] C. McArthur, M. Meitine, A. Sazonov. Mat.Res.Soc.Symp.Proc, 769, 303 (2003) [2] P.Servati, A.Nathan, J.Vac.Sci.Technol. A 20, 1038 (2002)

I6.13
Mechanically strained a-Si:H AMOLED driver circuits.
Peyman Servati, Sheng Tao, Denis Striakhilev and Arokia 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 high strains (10-3). 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).

I6.14
Electron Beam induced Chemical Modification of amorphous chalcogenides/metal bi-layers and its application.
R K Debnath, N Nusbar and A G Fitzgerald; Electronic Engineering and Physics Division, University of Dundee, Dundee DD1 4HN, United Kingdom.

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 (ECM) has been employed to produce submicron 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.

I6.15
Low resistivity ITO films on polymer foils in roll-to-roll production. Rumen Deltschew and Gerd Lippold; Solarion 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 reactive DC magnetron sputtering process in a modified industrial roll coater, resistivities of 1-2·10^{-4} Ωcm, free electron concentrations of 1-2·10^{21} cm^{-3} and free electron mobilities of up to 30 cm^2 /(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

proved by high resolution analysis methods.

SESSION I7: Poster Session: Flexible Materials and Device Technology II
Chair: Norbert Fruehauf
Wednesday Evening, April 14, 2004
8:00 PM
Salons 8-9 (Marriott)

I7.1
Flexible CdS MISFET Fabricated by Low Temperature Solution-based Deposition Technique. Yu-Jen Chang[1], Craig Munsee[2], Jeremy Anderson[3], John F. Wager[2], Doug A. Keszler[3], Greg S. Herman[4] and Chih-Hung Chang[1]; [1]Department of Chemical Engineering, Oregon State University, Corvallis, Oregon; [2]School of Electrical Engineering and Computer Science, Oregon State University, Corvallis, Oregon; [3]Department of Chemistry, Oregon State University, Corvallis, Oregon; [4]Hewlett-Packard Co., Corvallis, Oregon.

Low cost and flexible integrated circuits will enable many new applications for our daily life. Amorphous silicon (a-Si) is 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 advance in soft solution processing of inorganic materials offers 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.

I7.2
Novel Nanocast Method of Creating High Aspect Ratio Structure on Thin Flexible Substrate with Nanoparticles. Zhiyu Hu[1], Anat Burger[2], Christen Smith[3] and Thomas G. Thundat[1]; [1]Life Sciences Div., Oak Ridge National Laboratory, Oak Ridge, Tennessee; [2]MIT, Boston, Massachusetts; [3]Clemson University, Clemson, South Carolina.

A novel approach of nanocast is described to create high aspect ratio sold metal electrodes, electrode arrays, wires, interconnects, and circuitry on soft thin poly-(dimethylsiloxane) (PDMS). Using gold nanoparticles 3-D conductive circuit structure 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.

I7.3
A Concept for Flexible Thermoelectric Device. Masatoshi Takeda, Keisuke Yokoyama and Masaki Itaya; Department of Mechanical Engineering, Nagaoka University of Technology, Nagaoka, Japan.

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 rate 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-sized 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 so as 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. We have confirmed the above concept by computer simulation using the finite element method (FEM) and also by experiments. On the basis of the FEM analysis and TE properties of currently used materials, we estimated output electrical power of about 20 W/m^3 on the assumption that 80K temperature difference is applied between top and bottom of the resin film. Details will be presented at the meeting.

I7.4
Nano-Scale Devices Embedded in Self-Supporting Polymer Foils. Jie Chen[2], Siegfried Klaumuenzer[2] and Rolf Koenenkamp[1,2]; [1]Physics Department, Portland State University, Portland, Oregon; [2]Hahn-Meitner Institut, Berlin, Germany.

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 the deposition of electric and optical devices. Electron microscopy shows that compact, void-filling, poly-crystalline 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 single elements and arrays will be discussed.

I7.5
Excimer Laser Crystallization of Sputter Deposited a-Si Films on Flexible Substrates. Yong Hoon Kim, Sung-Kyu Park, Dae-Gyu Moon, Won-Keun Kim and Jeong-In Han; Korea Electronics Technology Institute, Pyungtaek, Kyunggi, South Korea.

In this work, the characteristics of excimer laser crystallized polycrystalline silicon (poly-Si) films flexible substrates are discussed. The amorphous silicon films (a-Si) were deposited through rf magnetron sputtering and followed by excimer laser crystallization using in-situ pulsed XeCl excimer laser (λ = 308 nm). We examined the effects of various a-Si film deposition conditions on the property of annealed poly-Si film. Initially, 50 nm thick a-Si film was deposited by rf-magnetron sputtering with temperature at 120°C. The applied power was varied from 50 W to 200 W and the working pressure was varied from 3 to 16 mTorr. As the working gas, pure Ar, pure He and Ar/He mixture gases were used to determine the effects of working gases on the properties of resulting films. During a-Si deposition process by sputtering, impurities such as Ar or He atoms are incorporated in the Si film and may manipulate the structure of as-deposited a-Si and poly-Si during laser annealing process. To control the amount incorporated atoms, working conditions such as applied power, working pressure and Ar/He mixture ratio should be optimized. The Ar content of a-Si film was evaluated from Rutherford Backscattering Spectroscopy (RBS). In the case pure Ar, the Ar content decreased as the working pressure was increased. When the working pressure was 5 mTorr the Ar content was about 2 at%. Using Ar/He mixture gas, the Ar contents in the film changed as a function of Ar/He ratio. The deposition rate was highest when the pure Ar was used and decreased as the percentage of He was increased. After deposition of a-Si film, excimer laser was irradiated for crystallization. From TEM observation, annealed films are determined as polycrystalline with average grain size of 200 300 nm and few grains showed maximum size over 500 nm. Additionally, the characteristics of poly-Si were observed by atomic force microscopy (AFM), Raman spectroscopy (RS), and ultra-violet (UV) reflectivity measurements.

I7.6
Polyimide as a plastic substrate for the flexible organic electroluminescent device. Hyuntaek Lim[1], Il Kim[1], Youngkyoo Kim[1,2], Chang-Sik Ha[1] and Jin Woo Park[1]; [1]Polymer Science & Engineering, Pusan National University, Busan, South Korea; [2]Physics, Imperial College, Blackett Laboratory, London, United Kingdom.

In recent years, interests of transparent flexible plastic substrates with a transparent conducting oxide (TCO) layer such as ITO have been increased in the fields of display and aerospace industry. The plastic substrates may be comparatively used to build lightweight, conveniently portable devices, roll-up displays, or conformable displays, which can be readily attached to windows, instrument panels, or other curved surfaces. Organic electroluminescent devices (OELDs) can also be fabricated on flexible plastic substrates creating the potential to reduce the weight of flat panel displays (FPDs). So far, the use of the flexible substrates for OELDs has been restricted mainly to the polyester films due to their excellent transparent property. However, the plastic substrates till now can be severely damaged at high temperature (200 3000°C for sputtering method)

during deposition process, mainly due to their intrinsic low thermal and mechanical properties compared with other inorganic or metal substrates. In this case, therefore, it is impossible to use 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 applied devices. In this work, colorless polyimide substrates with ITO thin films have been prepared with a novel fluorine-containing colorless aromatic PI derived from 2,2′-bis-(3,4-dicarboxyphenyl)hexafluoropropane dianhydride (6FDA) and 2,2′-bis(trifluoromethyl)-4,4′-diaminobiphenyl (TFDB). On the other hand, some inorganic materials, such as SiO2 were recently introduced to OELDs to balance the number of holes and electrons injected to the emitter layer to achieve high recombination efficiencies. In this work, therefore, the effect of the SiO2 buffer layer on the morphology of the colorless polyimide substrate was also investigated. The SiO2 buffer layer was inserted between the polyimide substrate and ITO layers.

I7.7

Micro-scale metallization of Cu and Au on flexible polyimide substrate by electroplating using SU-8 photoresist mask. suhyeon cho[1,2], SooHong Kim[1,2] and Nae-Eung Lee[1,2]; [1]Materials Engineering, SungKyunKwan University, Suwon, KyungGi-Do, South Korea; [2]Center for Advanced Plasma Surface Technology, Suwon, KyungGi-Do, South Korea.

Technologies for flexible electronics have been developed to make electronic or micro-electro-mechanical (MEMS) devices on inexpensive and flexible organic substrates. In order to fabricate the interconnect lines between device elements or layers and metal electrodes in flexible electronic and MEMS devices, formation of metallization lines and metal electrodes on the flexible substrate is essential. Cu lines are often used as interconnect lines in electronic devices and Au as microelectrodes in organic transistors and bioelectronic devices due to its good electrochemical stability and biocompatibility. In this case, the width and conductivity of metal lines are very important for minimizing the size of device. Therefore, the realization of metallization lines and microelectrodes with the scale of a few micrometers on the flexible substrate is very interesting. In this work, micro-scale metallization lines of Cu and Au were fabricated on the flexible substrate by electroplating using the patterned mask of a negative-tone SU-8 photo-resist. Surface of polyimide substrate was treated by O2/Ar atmospheric plasma for the improvement in adhesion between Cr layer and polyimide and in-situ sputter-deposition of 100-nm-thick Cu seed layers on the sputter-deposited 50-nm-thick Cr adhesion layer was followed. SU-8 photoresist was spin-coated and patterned by photolithography. Electroplating of Cu and Au lines, removal of SU-8, and selective wet etch of Cr adhesion and Cu seed layers were carried out. Metallization lines of Cu were fabricated using a sulfuric acid electroplating solution at room temperature on the Cu seed layer. Microelectrodes of Au were electroplated using a noncyanide electroplating solution on the electroplated surface of Cu or on the Cu seed layer. Gap between the Cu and Au lines was successfully filled by spin-coating of polyimide. Micro-scale Cu and Au metal lines with gap filling on the polyimide substrate with the thickness of 6 12 μm and the aspect ratio of 1 3 were successfully fabricated.

I7.8

Ink-jetted Silver/Copper conductors for printed RFID applications. Steven Volkman, Shong Yin and Vivek Subramanian; Electrical Engineering and Computer Science, University of California, Berkeley, Berkeley, California.

Low-resistance printed conductors are crucial for the development of ultra-low cost electronic systems such as radio frequency identification tags. Low resistance conductors are required to enable the fabrication of high-Q inductors, capacitors, tuned circuits, and interconnects. Furthermore, conductors of appropriate workfunction are also required to enable fabrication of printed Schottky diodes, necessary for rectification in RFID circuits. Last year, we demonstrated the formation of low-resistance conductive printed structures using gold nanoparticles. Here we demonstrate, for the first time, technologies for formation of printed conductors using silver and copper nanoparticles. These are particularly advantageous for several reasons. First, both silver and copper offer a 2X reduction in sheet resistance over gold, resulting in improved interconnect performance and inductor Q. Second, the material costs associated with both silver and copper are expected to be significantly cheaper than gold. Third, the workfunction of silver enables the fabrication of all-printed Schottky diodes with a silver rectifying contact to many common printable organic semiconductors. Solutions of organic-encapsulated silver and copper nanoparticles may be printed and subsequently annealed to form low-resistance conductor patterns. We describe novel processes for forming silver and copper nanoparticles, and discuss the optimization of the printing/annealing processes to demonstrate plastic-compatible low-resistance conductors. By optimizing both the size of the nanoparticle and the encapsulant sublimation kinetics, it is possible to produce particles that anneal at low-temperatures (<150C) to form continuous films having low resistivity and appropriate workfunction for formation of rectifying contacts. This represents a major component required for all-printed RFID.

I7.9

High Quality Gate Insulator for Very-Low Temperature Poly-Si TFT Employing Nitrous Oxygen Plasma Pre-Treatment. Moon-Young Shin, Su-Hyuk Kang, Min-Cheol Lee, Sang-Myeon Han and Min-Koo Han; School of Electrical Eng.(#50), Seoul National University, Seoul, South Korea.

A high quality gate insulator, which results in a high breakdown field and low flat-band voltage is very important for a thin film transistor (TFT) application. However, the silicon dioxide as a gate insulator deposited at the temperature less than 200oC exhibits rather poor electrical characteristics such as a large flat-band voltage and interface trap densities. Plasma enhanced chemical vapor deposition (PECVD) are widely used to deposit the gate insulator for very low temperature (<200oC) poly-Si TFT. It should be noted that the large amount of ion-bombardment of the conventional PECVD which may 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 as well as to increase the breakdown voltage of silicon dioxide film. Plasma treatment may also improve the hysterisis of the capacitance-voltage (C-V) characteristics due to the suppression of contamination. We have deposited a 100nm thick silicon dioxide films at 150oC by ICP-CVD with and without N2O pre-treatment. We have annealed the SiO2 film by employing 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 -1.8V. The proposed treatment also improved the breakdown voltage of gate oxide from 6MV/cm to 9MV/cm. The hysterisis 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 (<200oC) poly-Si TFTs.

I7.10

Nanotectonics : Direct Fabrication of All-Inorganic Logic Elements and Micro-Electro- Mechanical Systems from Nanoparticle Precursors. Eric Wilhelm and Joseph Jacobson; MIT, Cambridge, Massachusetts.

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.

I7.11

Large area p-i-n flexible image sensors. Manuela Vieira[1], P. Louro[1], A. Fantoni[1], M. Fernandes[1], C. Mendes[1], R. Schwarz[1] and M. Schubert[2]; [1]DEETC, ISEL, Lisbon, Portugal; [2]IPE, Univ. Stuttgart, Stuttgart, Germany.

Large area a-SiC: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 deposited on flexible 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(SiC:H)/i(Si:H)/n(SiC:H)/Al or ITO was used for both devices. The imager is an optically addressed read-write device based on a 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

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 analyzed. The optical-to-electrical 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 sensors deposited on flexible substrates present a high image-blur effect due to an increased lateral transport near the ITO/p interface. At the illuminated regions the photogenerated holes drift to the ITO and lateral leakage occurs by conduction from the ITO along the interface between the p-layer 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.

I7.12
a-Si:H TFT array using double gate insulator on plastic substrates. Sung Hwan Won, Chang Gyun Jung, Jeong Hyun Ahn and Jin Jang; Advanced Display Research Center, Kyunghee Univ., Seoul, South Korea.

An a-Si:H TFT on plastic is of increasing interest for mobile applications. One of the key issue 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 cracked and peeled from the plastic substrate.. Since this kind of stress depends on the layer thickness, we has 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 insulators, the organic material as a 1st gate insulator was coated, and the 2nd gate insulator of SiNx was deposited by PECVD at 150 °C. The a-Si:H and a n^+ a-Si:H for ohmic contact layer were consecutively deposited on top of the SiNx. Al 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 cm^2/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.

I7.13
Near-substrate plasma effects on the properties of dc magnetron sputtered aluminum doped zinc oxide. James R Doyle, Nathan Schmidt, Thomas Totushek, William Kimes and David Callender; Physics and Astronomy, Macalester College, St. Paul, Minnesota.

The effects of near-substrate plasma density are studied for reactively sputtered dc magnetron aluminum 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. Using 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 tempatures (> 135 C) no improvement was observed. It was verified that the improvement of properties at lower substrate tempeature 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 discussed.

I7.14
Flexible Substrate Based Gas Sensors for Air Pollution Monitoring. Serghei Dmitriev[1], Gheorghe Duca[1], Igor Dementiev[2] and Alexander Craciun[1]; [1]Industrial and Environmental Chemistry, Moldova State University, Chisinau, Moldova; [2]Department 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 very 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)x-(As2Se3)1-x (where x=0; 0.3; 0.5; 0.7 and 1.0) and also solid solutions of As-Tl-Se system. Thin films of the mentioned above materials were deposited on lavsan roll film by means of thermal evaporation under vacuum conditions 10-5 Torr. At the thickness of 1-2 ?m 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 atmosphere 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. Through routine technology mode ready gas sensors were created. Dimensions of the developed gas sensitive elements were 1000x1000x350 mm.

I7.15
Polymeric Electrochromics are Ready to Use. Gursel Sonmez, Clifton K.F. 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 electrochromic 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 were absent to date. 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 but, for a green color two absorption bands (red and blue) are required. While these chromophores absorb red and blue colors 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.

I7.16
Direct Synthesis of Carbon Nanotubes on Organic Polymer Substrates. Eun Hwa Hong[1], Kun-Hong Lee[1], Hyung Suk Kim[2] and Chan-Gyung Park[2]; [1]chemical engineering, POSTECH, Pohang, South Korea; [2]materials 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 selective heating of catalysts using microwave radiation, and they were applied to flexible field emitter arrays. Since the microwave energy is selectively absorbed by the catalysts, not by the substrates, local heating occurs, resulting 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 hydrocarbon source. The morphology and structure of carbon 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 films were observed as well as with amorphous carbons, and CNTs 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 I8: Flexible Displays: OLEDs
Chair: Babu Chalamala
Thursday Morning, April 15, 2004
Room 2018 (Moscone West)

8:30 AM *I8.1
Flexible PLED displays and related technologies.
Giovanni Nisato, C.A.H. Mutsaers, O.J.A. Buijk, P.C. Duineveld, E.A.W. Janssen, J.M. de Goede, P.C.P. Bouten and H. Zuidema; Philips Research, Eindhoven, Netherlands.

Flexible, free shape displays are the enabling technology for new robust, 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 layers are therefore an essential component for manufacturing these flexible devices. Polymer based substrates provide the necessary mechanical flexibility; they also require several thin, brittle, functional inorganic layers such 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 ageing of the polymer base, thermal expansion and stress induced deformations. These effects must be taken into account to successfully perform classic photolithographic steps. Ink-jet printing is a critical enabling technology for flexible PLED displays, providing a customisable means to dispense solution-based polymers onto a flexible substrate, allowing for multi-color devices. On the other hand, IJP 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 I8.2
Study of Water Vapour Transport Properties of Diffrent OLED Package Designs. Senthil Kumar Ramadas, Soo Jin Chua, Ke Lin Karen, Mark Auch Dai Joong, Xin Bo He and Adrian Paul Burden; Opto-and Electonic Systems Cluster, Institute of Materials Research and Engineering, Singapore, Singapore.

A highly sensitive water vapour permeation measurement technique for organic light emitting display applications 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 system for the measurement of water vapour transmission rates is less than 10^{-8} g/m^2/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 packaging technique is demonstrated with an improved OLED lifetime.

9:15 AM I8.3
A reflectivity-based metrology to quantify moisture transport through barrier layers for OLED applications. Bryan D Vogt[1], Hae-Jeong Lee[1], N M Rutherford[3], L Moro[3], Sushil K Satija[2] and Wen-li Wu[1]; [1]Polymers Division, NIST, Gaithersburg, Maryland; [2]Center for Neutron Research, NIST, Gaithersburg, Maryland; [3]Vitex 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 integrate effective moisture barrier layer in future OLED devices and there are major ongoing efforts in this area with a target permeation rate lower than 10⁻⁵ g/m²/day. Current technology, e.g. ASTM F372 or MOCON 3/31, only has a sensitivity of 10⁻³ g/m²/day with a typical measurement time of 10 days. It is based on monitoring the moisture accumulation in a detection chamber via IR. 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 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 be converted to the amount of water uptake. The sensitivity of this approach arises from the fact that all the moisture permeated through the barrier layer will reside within an ultra thin film. A 1 Å layer of water permeated through a barrier film per ten days amounts to a moisture uptake rate of 10⁻⁵ 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 can arise if the barrier is a multilayered stack with spacing commensurate to the polymer thickness. Alternative approaches still exploiting the thickness resolution of reflectivity will be discussed.

9:30 AM *I8.4
Integration of Organic LEDs and Pentacene OTFTs on Plastic Substrate. Chung Kun Song[1], Yong Xian Xu[1], Hyun Sook Byun[1], Gi Seong Ryu[1], Myung Won Lee[1], Kwang Hyun Kim[1] and Chang Hee Lee[2]; [1]Dept. of Electronics Eng., Dong-A University, Busan, South Korea; [2]Dept. of Physics, Inha University, Inchon, 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.sec so that the realization of such applications has been more convincing. However, there still exist several issues which should be addressed for the application on plastic substrate. above all the issue 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 crystal film. Especially, we developed a new photolithography process to pattern the organic thin film, which is characterized by using a water-solube photoresist and thus avoiding the damages to organic film originated from organic solvents employed in the conventional photolithography process. The water-solube photoresist consists of polyaniline and UV-curing agent and solution 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.sec 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 luminescence were 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. the pentacene OTFT which used PVP/SiO2/PVP hybrid gate dielectric produced good performance enough to drive OLEDs

10:30 AM *I8.5
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 device (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 barriers are 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 present for the application. Unlike the case of brittle transparent electrodes, 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 I8.6
The role of a thin polymer interlayer in improvements of device efficiency and lifetime of polymer light-emitting diodes. Ji-Seon Kim[1,2], Ilaria Grizzi[2], Mark Leadbeater[2], Jeremy Burroughes[2] and Richard Friend[1,2]; [1]Physics, Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom; [2]Cambridge 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-secbutylphenyl)imino)-1,4-phenylene)), (The Dow Chemical Company) solution. With the interlayer, the external quantum efficiency (EQE) increases 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 3.0V) at 1000 cd/m2 for green-emitting LEDs. About 4.0 % EQE was also observed in blue 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 *I8.7
Using materials research as the catalyst for industrial manufacturing of OLEDs in Singapore. Adrian Paul Burden, Opto- & Electronic Systems, Institute of Materials Research and Engineering, Singapore, Singapore.

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 at the opposite end of the spectrum. 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 device structures comprising both fixed logo and passive 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 just how widely and deeply 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 will 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 I8.8
Dye Source Concentration Optimization for Three-Color OLED Integration by Dry Dye Stamping. Ke Long, Florian Pschenitzka and J. C. Sturm; Electrical Engineering, Princeton University, Princeton, New Jersey.

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 103, 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 dyes from the dye source onto 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 lamination at an elevated temperature to a pre-patterned foil. Excess 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 about 0.3%. Device efficiency up to 3 cd/A was observed. Using this dye patterning method, a three-color passive-matrix test array with 300 mm x 1mm RGB subpixels was demonstrated. 1. F. Pschenitzka and J. C. Sturm, Appl. Phys. Lett. 78 (17), 2584 (2001). 2. F. Pschenitzka and J. C. Sturm, Appl. Phys. Lett. 79 (17), 4354 (2001).

SESSION I9: Materials and Processes for Flexible Electronics I
Chairs: David Brennen and Giovanni Nisato
Thursday Afternoon, April 15, 2004
Room 2018 (Moscone West)

1:30 PM *I9.1
Patterning and Layering of Electronic Materials Using Graphic Printing Processes. Dan Lawrence, Flint Ink Corp., Ann Arbor, Michigan.

Printing methods familiar to the graphic arts industry allow the placement of specially designed electronic materials at high speed and low cost. Processes such as offset lithography, gravure, and flexography have advantages in aspects of process capability when compared with ink jet printing. For both historical and pragmatic reasons, the patterning and layering capability of printing has been limited to suit the resolving power of the human eye. Experiments have been conducted to benchmark existing capability of these processes and materials on flexible substrates. Such experiments will provide a foundation for exploring the viability of existing printing infrastructure for the mass production of commercial products. In addition, improvements in these electronic materials and the mechanics of printing processes may provide significant advancement of future application capability.

2:00 PM I9.2
Oxide Semiconductors for Flexible Electronics. Peter F. Carcia, Robert McLean, I Malajovich and Michael Reilly; Research and Development, DuPont, Wilmington, Delaware.

Inorganic semiconductors provide an enabling technology for high performance, low cost, robust electronics on flexible plastic substrates. In this paper we discuss progress in developing inorganic oxide semiconductors as thin film transistors (TFTs) for flexible electronics. Besides improvements in ZnO TFTs, we present new results for In2O3-based TFTs. We prepared oxide semiconductors by rf magnetron sputtering from oxide targets on substrates maintained near room temperature. ZnO and In2O3 sputtered films were determined to be polycrystalline (XRD) with grain size (AFM) smaller than 40 nm. Both films were optically transparent in the visible, which may be a particular advantage in active matrix addressing of displays. TFT devices were fabricated on a gate dielectric of Al2O3 made by e-beam evaporation and on the thermal oxide of Si. For In2O3 TFTs, we found that sputtering at 4 mTorr (Ar

O2) total pressure and a partial pressure of O2 in the range 0.1-1.0 mTorr produced excellent device properties: field-effect mobility of 7 cm2/V-s with on/off > 104 on an Al2O3 gate dielectric. On SiO2 gate dielectric, In2O3 devices had higher threshold voltage with lower mobility than on Al2O3. These devices on SiO2 also exhibited a long (several weeks) relaxation time, in which TFT properties improved in a manner we interpreted to be due to self-passivation of traps. Fabricating ZnO TFTs on Al2O3 gate dielectric also increased field-effect mobility with a much reduced threshold voltage, compared to devices on SiO2. ZnO devices on Al2O3 gate could be operated with several microampere current at less than 3 volts, attractive for driving either liquid crystal and OLED displays.

2:15 PM *I9.3
Flexible magnetics on plastic substrates: magnetic lithography, magnetic nanostructures and other applications.
Zvonimir Z Bandic[1], Christian Bonhote[1], Jordan Katine[1] and Michael Rooks[2]; [1]Hitachi San Jose Research Center, San Jose, California; [2]IBM Watson Research Center, Yorktown Heights, New York.

FlexibleMagnetics 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 magnetics draws interesting parallels to flexible electronics, especially in fabrication challenges on plastic substrates. Some of those 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 magnetics, relevant for information storage industry is 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 parallel magnetic recording. The magnetic mask consists of nanopatterned magnetically soft material (FeNiCo, FeCo) on a thin flexible plastic substrate, typically Polyethylene Teraphtalate (PET) or polyimide. When uniformly magnetized media 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 fabricated magnetic masks, and magnetic force microscopy images of the the magnetic transition patterns. Besides fabrication of magnetic nanostructures and devices on plastic substrates, we also present our results on nanoscale patterning of plastic thin film. We will present our results on fabrication of sub-100 nm scale nanochannels in polyimide films, as well as self-assembly of ordered arrays of polyimide nanodots. Nanoscale patterned plastic films are interesting for its potential application in patterned media, as well as for its application in micro- and nanofluidics, due to the machanical flexibility and biological inertness of plastic materials.We will discuss interesting biosensing systems that may result from synergy of magnetic nanostructure functionality, electronic control and patterned nanofludic channells on plastic substrates.

2:45 PM I9.4
Performance of barrier layer for flexible substrate using PVD deposition process. Mux Narasimhan, Symmorphix Inc., Sunnyvale, California.

In this presentation, we discuss the PVD process and its use for deposition of barrier layers on flexible substrates. Specifically, promising results on the WVTR through PEN substrate coated with a proprietary thin film layer are presented and compared with results of the same coating on other flexible substrates such as PES and others.

3:30 PM *I9.5
Development of the Electrophoretic Display Module with High-Performance Organic TFT Array on PES Plastic Substrate. MunPyo Hong[1], Bo Sung Kim[1], Yong Uk Lee[1], Min Seong Ryu[1], Tae-Young Choi[1], Kyuha Chung[1], In Nam Kang[2], Bon Won Koo[2] and Lyong Sun Pu[2]; [1]Flat Panel Display R&D Group, Samsung Electronics, Yongin-City, Gyenggi-Do, South Korea; [2]Electronic Materials Lab, Samsung Advanced Institute of Technology, Yongin-City, Gyenggi-Do, South Korea.

Organic thin-film transistors (OTFTs) have been rapidly developed in the past few years. Especially, it is important to develop new gate dielectrics and passivation materials as well as organic semiconductors for increasing the mobility and improving the stability of organic transistors. Recently, a variety of organic gate dielectrics have been introduced besides conventional inorganic insulators such as SiO2 and SiNx. The use of organic gate dielectrics susceptible to solution coating leads to not only improve the performance of TFT but also promise low-cost and large electronic device application. We have developed the novel organic gate insulators based on blend of polystyrene and polyacrylic that are very clear and photo-definable. These organic gate dielectrics were evaluated to give a strong chemical resistance in several etchants and strippers. OTFT devices were fabricated as the top contact structure. The gate electrodes were created by deposition and patterning Cr layer on a PES plastic film. Next, our gate dielectric materials were applied, and then pentacene and Au electrodes were evaporated on these layers. They operated with mobilities about 3-5 cm2/Vs and on-off current ratio over 10E5. On the other hand, organic passivation material has also been developed to maintain the TFT performance and stability. The OTFT array protected by the passivation layer didn't show any noticeable TFT performance degradations before and after passivation process. 4-inch sized TFT array on the PES plastic film could be successfully fabricated by using a couple of organic gate dielectrics and passivation materials based on the result of unit cells. This plastic OTFT backplane was laminated with electrophoretic film and drove the electrophoretic display; the OTFT based electrophoretic display module has the number of 120 X 160 pixels in which pixel size is 500 um X 500 um. This technology could be extended to new display applications such as flexible e-papers and e-books as well as conventional slim mobile displays in the near future.

4:00 PM I9.6
Roll-to-roll processes for the manufacturing of Microcup® electronic paper. Yi Shung Chaug, Jeanne Haubrich, Mike Sereda and R.C. Liang; SiPix Imaging Inc., Fremont, California.

Simple, cost-effective roll-to-roll processes for the manufacturing of patterned conductor films have been developed. The technique involves printing proprietary masking patterns, depositing conductive material, and stripping away undesired areas. In one approach, a pattern is printed on the plastic substrate with a masking coating. Then, conductive material is deposited on the patterned substrate and the undesired areas are stripped away, leaving behind the patterned electrode structures. In other approach, a first masking pattern is printed, followed by a 2nd masking coating which is repelled by the first masking layer, stripping off the first masking pattern, depositing the conducting layer, stripping off the unwanted conducting material on the 2nd masking coating, and leaving a high resolution conductor pattern on the web. No photolithographic exposure, development or chemical etching is needed. These processes are useful for producing rolls of electrodes with features as small as 25 microns for the roll-to-roll manufacturing of Microcup® electronic paper as well as other flexible circuit board applications. High performance Microcup® passive matrix electrophoretic displays (EPDs) based on the patterned ITO films have also been prepared.

4:15 PM *I9.7
Flexible Electronics for Space Applications. Erik Brandon, NASA Jet Propulsion Laboratory, Pasadena, California.

Flexible Electronics for Space Applications

4:45 PM I9.8
Enhancement of the electrical properties of ITO deposited on polymeric substrates by using a ZnO buffer layer.
Elvira Maria Correia Fortunato, Carlos Nunes de Carvalho, Ana Pimentel, Guilherme Lavareda, Alexandra Goncalves, Antonio Marques and Martins Rodrigo; Materials Science, FCT-UNL, Caparica, Portugal.

Transparent Conductive Oxides (TCO) have a wide range of applications, ranging from transparent electrodes in optoelectronic devices, heat reflecting surfaces or even in solar cells. In all these applications a worldwide rule already accepted by the scientific community must be verified: higher transmittance associated to a low resistivity. Nevertheless the already obtained values for optical transmittance around 90% are difficult to increase, because we are close to the theoretical optical limits of these oxides. The other possibility is by reducing the electrical conductivity (sigma). Concerning this point and since sigma = qNm, the only way to achieve such goal is by increasing the carrier concentration (N) or the electron mobility (m). The carrier concentration is limited to the maximum solid solubility of the dopant, while the electron mobility depends more on the structural defects, grain size and also on the dopant concentration. In this paper we present results of ITO deposited at room temperature by Plasma Enhanced Reactive Thermal Evaporation on intrinsic polycrystalline zinc oxide (buffer layer) deposited by rf magnetron sputtering on polymeric substrates,

as an efficient way to improve the electronic mobility of ITO without loosing the optical properties. The preliminary results indicate that it is possible to decrease the resistivity by more than one 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/ZnO will be discussed.

SESSION I10: Poster Session: Flexible Materials and Device Technology III
Chair: Jin Jang
Thursday Evening, April 15, 2004
8:00 PM
Salons 8-9 (Marriott)

I10.1
Pentacene Organic TFT with Al_2O_3 Gate Dielectric Deposited using Atomic Layer Deposition Method.
YongWoo Choi[1], JinSeong Park[3], Ioannis Kymissis[2], Annie Wang[2], Roy G. Gordon[3] and Akintunde I. Akinwande[1,2]; [1]Microsystmes Technology Lab., Massachusetts Institute of Technology, Cambridge, Massachusetts; [2]Department of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; [3]Department of Chemistry and Chemical Biology, Harvard University, Cambridge, Massachusetts.

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 100V). The high operating voltage is due to the low transconductance, $g_m=dI_d/dV_g$. 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. Al_2O_3 has a dielectric constant of 10 (7.5 for thin film), which is about 2 3 times higher than that of parylene-C or SiO_2 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 Al_2O_3 film with high quality was deposited at low temperature (150°C). In ALD, the film growth by sequential and self-limiting surface reaction makes it 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 Al_2O_3 films were grown using water, H_2O, and trimethylaluminum(TMA), $Al(CH_3)_3$. We fabricated pentacene OTFT using the ALD Al_2O_3 film as a gate dielectric. For electric fields below 2 MV/cm, the leakage current density of 100 200 nm thick Al_2O_3 films was in the range of 10^{-8} and 10^{-7} A/cm^2. Above 2 MV/cm, the leakage current density increased to 10^{-4} A/cm^2 and catastrophic breakdown occurred at 8 MV/cm. The field effect mobility of the OTFT with ALD Al_2O_3 gate dielectric is 0.1 cm^2/Vs, 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 Al_2O_3 gate dielectric and the 140 nm thick parylene gate dielectric, respectively. The width and length of the OTFT were 1250μm and 50μm, respectively. The on-current for pentacene OTFTs with ALD Al_2O_3 gate dielectric is about twice the on-current for pentacene OTFTs with parylene gate dielectric even though the ALD Al_2O_3 gate dielectric of the OTFT is thicker.

I10.2
Molecular weight dependent mobilities in polymer diodes and transistors. Chia Tzun Goh[1], R. Joseph Kline[1], Michael D. McGehee[1], Ekaterina N. Kadnikova[2], Jinsong Liu[2] and Jean M. J. Frechet[2]; [1]Department of Materials Science & Engineering, Stanford University, Stanford, California; [2]Department 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 cm^2/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 treatment, but that a lot of the variation 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^{-2} cm^2/V-s as the molecular weight increases from 3.2 to 31.1 kg/mole. In diodes, where current travels perpendicular to the plane of the film, we find from the space charge limited current that the mobility increases from 1.3 x 10^{-5} to 3.3 x 10^{-4} cm^2/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. Temperature dependent mobility measurements show that the activation energy for hopping decreases from 143 meV to 126 meV as the molecular weight is increased. X-ray diffraction and atomic force microscopy measurements show that the low molecular weight 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.

I10.3
Fabrication Techniques for the Processing of Adhesiveless Ultem Polyimide Dielectric Film. Kevin M. Durocher[1], Irene Dris[1] and Stacey Goodwin[1]; [1]General Electric, Niskayuna, New York; [2]General Electric, Niskayuna, New York; [3]General 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 flex circuit configurations from single sided to double sided constructions. As well, the need for high performance steers circuit construction towards the minimization in use of adhesives; adhesiveless flex 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 module singulation. This paper addresses the key steps for flexible substrate fabrication describing the key advantages and disadvantages of the approach.

I10.4
Novel Opto-Electronic Braid System with Kumihimo-Structure as a New Concept of Flexible Electronics. Kuniaki Tanaka and Shigekazu Kuniyoshi; Electronics & Mechanical Engineering, Chiba University, Chiba, Japan.

In last spring meeting we proposed a novel 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 warps and woofs. 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 each other 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 and by controlling the phase of 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 system. 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.

I10.5
Improvement of organic electroluminescent devices by the Tuning of Charge Transport Balance and Drift Mobility.
Byung Doo Chin, Mu-Hyun Kim, Min Chul Suh, Seong Taek Lee and Ho Kyoon Chung; Samsung SDI, Research Center, Yongin-City, Kyunggi-Do, South Korea.

We have prepared organic electroluminescent devices with improved efficiency and lower driving voltages by the optimized of 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 measurement shows that amorphous hole transporting materials mixed 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 so that doping concentration profile provides a control parameter for charge transport and exciton 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.

I10.6
Oriented growth of anthracene and pentacene thin films. Hua Zhou[1], Lan Zhou[1], Brian Wang[1], Ricardo Ruiz[2], Alex C Mayer[2], Alexander Kazimirov[3], George G Malliaras[2] and Randall L Headrick[1]; [1]Department of Physics and Materials Science Program, University of Vermont, Burlington, Vermont; [2]Department of Materials Science and Engineering, Cornell University, Ithaca, New York; [3]Cornell High Energy Synchrotron Source, Cornell University, Ithaca, New York.

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 (00L) 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 materials and devices with improved properties and performance. Electrical transport measurements of films fabricated by these methods are underway.

I10.7
Growth and Electrical Properties of Pentacene Ultra-thin Films. Ricardo Ruiz[1,2], Alex C. Mayer[2], George G. Malliaras[2,1], Randall L. Headrick[5], Alexander Kazimirov[3] and James R. Engstrom[4]; [1]Cornell Center for Materials Research, Cornell University, Ithaca, New York; [2]Materials Science and Engineering, Cornell University, Ithaca, New York; [3]Cornell High Energy Synchrotron Source, Cornell University, Ithaca, New York; [4]Chemical and Biomolecular Engineering, Cornell University, Ithaca, New York; [5]Department of Physics, University of Vermont, Burlington, Vermont.

Understanding charge transport in organic/inorganic 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. In 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.

I10.8
Electrical Hysteresis of PEDOT/PSS-Metal Contact Devices.
Zhengchun Liu, Yi Su and Kody Varahramyan; Institute for Micromanufacturing, Louisiana Tech University, Ruston, Louisiana.

Poly(ethylene dioxythiophene) doped with poly(styrene sulfonate) or PEDOT/PSS is an air-stable, solution processable p-type semiconductor polymer. Recently, it has been intensively studied for electronic applications. Since the semiconductor-metal contacts are very important for device fabrication, we investigated the electrical properties of PEDOT/PSS-metal contacts using Al-PEDOT/PSS-Au as a test device. It is 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 when the device is presumably 'reverse' biased. Secondly, 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 sweep. The device exhibits 'hysteresis' in its multiple current-voltage characteristics and quasistatic capacitance-voltage characteristics. An MIS structure at the Al-PEDOT/PSS interface, caused by reaction between Al and the dopant poly(styrene sulfonate), is believed to be responsible for the rectification behavior of the device. A model in terms of ion motion and 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 pushed to the Al-PEDOT/PSS interface, leaving a depleted 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 accelerate such process but cannot recover the original state because some H+ ions become H atoms. This case is similar for other cations like Na+.

I10.9
White Electroluminescent Devices using Blue and Red Light-Emitting Conjugated Polymer Blends. Do-Hoon Hwang[1], Moo-Jin Park[1], Suk-Kyung Kim[1], Changhee Lee[2], Yong-Bae Kim[3] and Hong-Ku Shim[4]; [1]Applied Chemistry, Kumoh National Institute of Technology, Kumi, South Korea; [2]Department of Physics, Inha University, Incheon, South Korea; [3]Liquid Crystal Research Center, Department of Chemistry, Kon-Kuk University, Seoul, South Korea; [4]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 full color displays using color filters 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 and/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 composites or blends of blue(B), green(G), and red(R) emitting dyes 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. Inefficient 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.

I10.10
Synthesis and transistor performance of tetracene derivatives.
Hyunsik Moon[1,2], Evert-Jan Borkent[1], Andrew J. Lovinger[1] and Zhenan Bao[1]; [1]Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey; [2]Macromolecular 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, polyacenes, such as tetracene and pentacene, and oligothiophene derivatives have been intensively studied, showing high mobilities and on/off ratios. However, only few polyacene derivatives have been reported because of the difficulty in incorporating functional groups into polyacenes. In this work, we prepared halogenated and alkyl-substituted tetracene

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 tetracenes) had platelet-shape single crystals and di-substituted derivatives (5,11-dichloro or 5,11-dibromo tetracenes) 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 chloro group is expected to alter the size and shape 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.
Reference 1. Bredas JL, Calbert JP, da Silva DA, Cornil J, Proc. Nat. Acad. Sci., 99 (9), 5804 (2002).

I10.11
Abstract Withdrawn

I10.12
Orgnaic Thin Film Transistors based on Electron Donor-Acceptor-Donor Type Co-oligomer with π-stacked Structure. Woong Sang Jahng[1], Hyunsik Moon[2] and M David Curtis[1,2]; [1]Chemistry, University of Michigan, Ann Arbor, Michigan; [2]Macromolecular 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 coverage, structural flexibility, and solution processing. In OTFTs, early work has been limited to a few types of conjugated materials, such as thiophene oligomers, polythiophene, and pentacene, etc. However, most of these materials are packed in the so-called herringbone pattern, 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 πstacked oligomers and co-oligomers. These πstacked oligomers may facilitate carrier transport by decreasing the hopping barrier between neighbor 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-dibutyl-2,2-bithiazol-5-yl)-(3,4,3'4'-bis(ethylenedioxy)-2,2-dithienyl (BT2B). BT2B has a pstacked structure in which donor-acceptordonor groups in the molecule are alternately distributed. Stille coupling reactions were used to prepare this compound. The solid-state structure of BT2B features π-stacking with 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.

I10.13
An original flexible structure for Organic Photovoltaic Devices. Ornella Sanna[1], Piero Cosseddu[1], Mario Cossu[1] and Annalisa Bonfiglio[1,2]; [1]Dept. of Electrical and Electronic Engineering and INFM, University of Cagliari, Cagliari, Italy; [2]Centre 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 insulating 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 supporting 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 the non-ideal working conditions (no nitrogen atmosphere, no protection from oxygen), the dark I-V characteristics are in agreement with the results already reported in literature for the employed organic materials. A comparison between dark and light measurement are presented, reporting quite good results 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.

I10.14
Hydrogen in Ultralow Temperature SiO_2 for Nanocrystalline Silicon Thin Film Transistors. Alexis Z Kattamis, I-Chun Cheng and Sigurd Wagner; Princeton University, Princeton, New Jersey.

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 quality of the SiO_2 gate dielectric. This is a generic problem because all ultralow temperature, plastic compatible, TFT technologies battle instabilities and leakage of the gate insulator. SiO_2 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 oxide deposited at 150°C on nc-Si:H is 0.8 at. %. This is much higher than in thermal oxides on crystalline silicon (x-Si), which display concentrations of less than 0.003 at. %. The leakage currents for thermal oxides on x-Si at a bias of 5V are $2x10^{-9}$ A/cm2 whereas for 250°C PECVD oxides on nc-Si:H the currents are $1x10^{-7}$ A/cm2. As the temperature of the SiO_2 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 nc-Si:H substrate and the silane source gas. We analyzed the 300nm gate oxide in capacitor structures of Al / SiO_2 / n+ nc-Si:H / Cr / glass and Al / SiO_2 / x-Si. Vacuum annealing the nc-Si:H prior to PECVD of the oxide allows hydrogen to effuse from the nc-Si:H film and reduces the amount of hydrogen incorporated into the oxide that is deposited on top. SiO_2 film 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 $5x10^{-8}$ A/cm2 using helium dilution, and the vacuum anneal of the nc-Si:H lowered the current by an additional factor of two. Thus we observe that both the nc-Si:H anneal and the SiO_2 deposition at high helium dilution lessen the oxide leakage current.

I10.15
Electrical and optical investigations of ion implanted polycarbonate. Jae Hyung Lee and Dae Jeong Yang; Korea Atomatic Energy Research Institute(KAERI), Teajon, South Korea.

Polycarbonates(PC) were implanted with N^+, Ar^+, Kr^+, Xe^+ ions at the ion energy of 20 50keV, and the dose rates of 5×10^{15} 7×10^{16} ions/cm^2. The relationship between the electrical and optical properties of an ion implanted PC was investigated by means of the UV-Vis and Furier transform infrared spectroscopy(FT-IR) and Surface resistance measurements. The electrical conductivities, which depend not only on the ion dose but also the incident energy, were found to have a relationship to the optical absorbance. Optical absorption provides information regarding the optically induced transitions and the variations in the energy band gap after ion beam irradiation. 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 band gap, which implies an increase of the conductivity of the ion beam irradiated polymers, can be explained by the formations of carbon networks and conjugated double bonds. After ion beam irradiation, the transmittance in the UV-A(320 400nm) range decreases from 88 to 2% and the surface resistance decreases in the order of 10^7ohm/.

I10.16
C(U)-investigations on organic MOS-structures. Georg Jakopic, Helmut Schoen, Bernhard Lamprecht, Barbara Stadlober and Guenther Leising; Joanneum Research, Weiz, Austria.

The analysis of the behaviour of MOS-like structures of organic semiconductor devices can provide usefull information about intrinsic properties of the semiconductor as well as of the insulator material. 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 itself regarding its intrinsic properties (dielectric constant and dielectric strength, mobility of majority and minorty carriers, carrier density,...) and the forming of structurally and chemically pure interfaces is of vital importance. We have investigated C=f(U) on different organic semiconductor systems and we 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 material purity. Spin-Coating processes for the fabrication of the dielectric layer not only determine 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.

I10.17

Photosensitive Carbazolylethylmethacrylate Copolymers on Flexible Substrate for Optical Information Registration.

Stefan Robu[1], Igor Dementiev[3] and Serghei Dmitriev[2]; [1]Department of Chemistry, Moldova State University, Chisinau, Moldova; [2]Industrial and Environmental Chemistry, Moldova State University, Chisinau, Moldova; [3]Department of Physics, Moldova State University, Chisinau, Moldova.

This report present results of study of some organic materials suitable for creation of photothermoplastic media (on flexible base) for optical information recording. In particular, speech is about donor-acceptor systems on the base of carbazolyl containing polymers, in particular, carbzolylethylmethacrylates (CEM) with oktylmethacrylates (OMA) and polyepoxypropylcarbazolyl (PEPC) copolymers sensibilization of which was made by means of 5-20% of trinitrofluorenone (TNF), N-fenylamino-2,4,7-trinitrofluorenone (FNF) and ditianomethylen-2,4,7-trinitrofluorenone (DTF) (containing donor-acceptor groups) and additives of photochromical substances of indolynospirobenspyran series. There were studied the dependencies 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 60oC 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 10-3-10-4 J/cm2. The introduction of PP layers of 6-10% photochromium 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-trimethylindolynospirobenzopyrane possess the greatest effect of sensibilization. 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 photopolymer CEM:OMA, demonstrate photosensitivity of 10-6 J/cm2. at 80-85oC 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

I10.18

Charge trapping and scattering by extrinsic gas dopants in Alq_3. S.K. So and H.H. Fong; Department of Physics, Hong Kong Baptist University, Hong Kong, Hong Kong.

The effects of various ambient gases (N_2, O_2, H_2O) to the electron mobility of *tris*(8-hydroxyquinoline) aluminum, Alq_3, were examined. For clean Alq_3, the electron transport is non-dispersive and essentially trap-free as revealed by optical time-of-flight measurements. At 295K, the electron mobility (μ_e) spans the range $0.2\text{-}1\times10^{-6}$ $cm^2V^{-1}s^{-1}$ when the field varies from 0.4-0.9 MV cm^{-1}. Exposing pristine Alq_3 to moisture of dosages in the range 1-100 Torr·s causes a gradual reduction in μ_e by a factor of 4. In contrast, exposing the sample to same dosages of oxygen does not cause any noticeable changes in μ_e. The effect of oxygen on μ_e can be observed only at much higher oxygen dosages (>105 Torr·s). It is proposed that H_2O diffuses into Alq_3 during exposure and 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 Alq_3-based organic light-emitting diodes.

I10.19

Organic Thin-Film Transistors Developed by Alignment-Free Printing Technique. Masahiko Ando[1,2], Hiroshi Sasaki[3], Masahiro Kawasaki[1,2], Shuji Imazeki[1,2] and Toshihide Kamata[4]; [1]Optelectronic Industry and Technology Development Association(OITDA), Tsukuba-city, Ibaraki, Japan; [2]Advanced Research Laboratory, Hitachi, Ltd., Hitachi-city, Ibaraki, Japan; [3]Hitachi Research Laboratory, Hitachi, Ltd., Hitachi-city, Ibaraki, Japan; [4]National 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 an organic TFT with high performance. Especially, it is very serious problem for the preparation of an organic TFT on a flexible substrate by printing techniques. Because the flexible substrate often shows deformation during the device preparation, which causes the misalignment of each device components, leading to the degradation of the TFT performance. In this study, we have developed a novel alignment-free fabrication process of printable electrodes 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 using a hydrophobic 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. Hydrophobic SAM was dip-coated and the substrate was irradiated from the opposite side of the gate electrodes with UV light. The UV-exposed areas unshadowed 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 stripes just above the gate electrodes using a micro-pipette and baking in vacuum. We confirmed that organic TFTs with channel length of 3μm can be made by employing this patterning technique. The channel length was completely restricted by the hydrophobic stripes 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 0.14 cm2/Vs, -13V and 10$\hat{4}$, 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 means that the coated SAM layer for the alignment-free electrode fabrication also contributes to self-assembling 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 contraction between OITDA and NEDO.

I10.20

Conducting Polypyrrole-based Field Effect Transistors fabricated by Spin Coating and Inkjet Printing. Fengliang Xue, Yi Su and Kody Varahramyan; Institute for Micromanufacturing, Louisiana tech university, Ruston, Louisiana.

Polypyrrole (PPy) is one of the most widely used conducting polymers due to easy processing and good stability. Highly doped polyprrole 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 featuring 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 polymer 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 Åthermal 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, metal 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 electrical 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 switch-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 on for flexible polymer transistors. References 1. K. Potje-Kamloth, Critical Reviews in Analytical Chemistry, 32(2),121-140,2002 2. T. Cui, G. Liang, and K. Varahramyan, IEEE Transactions On Electon Devices, 50(5), 1419-1422, 2003 3. A.J.Epstein,F.-C.Hsu,N.-R.Chiou, and V.N.Prigodin, Synthetic Metals, 137,859-861,2003 4.

A.J.Epstein,F.-C.Hsu,N.-R.Chiou, and V.N.Prigodin, Current Applied Physcics 2, 339-343, 2002

I10.21
Abstract Withdrawn

I10.22
High-quantum-efficiency white organic LEDs based on Ir complexes and wide gap organic materials. Junji Kido[1] and Soichi Watanabe[2]; [1]Polymer Science and Engineering, Yamagata University, Yonezawa, Yamagata, Japan; [2]Grad. School of Sci. and Eng., Yamagata University, Yonezawa, Yamagata, Japan.

Wide gap organic carrier transport materials were synthesized and used in organic LEDs. One of the newly synthesized hexaphenylbenzene derivatives possesses wide energy gap of 3.49 eV and fluorescence peak at 350 nm. A blue-light-emitting OLEDs based on these materials and Ir complex (FIrpic) exhibited high external quantum efficiency of 11percent and luminous efficiency of 12 lm/W at 130 cd/m2. By adding yellow-emitting Ir complex layer to the blue device, white light with high quantum efficiencies was obtained. The maximum external quantum efficiency of 10 percent was achieved.

SESSION I11: Poster Session: Flexible Materials and Device Technology IV
Chair: Babu Chalamala
Thursday Evening, April 15, 2004
8:00 PM
Salons 8-9 (Marriott)

I11.1
Creating New Building Blocks for Organic Transistors: Synthesis, Assembly and Electrical Properties of Pentacene and Tetracene Derivatives. Qian Miao and Colin Nuckolls; Chemistry Department, Columbia University, New York, New York.

In order to create new building blocks for organic transistors, several new derivatives of pentacene and tetracene have been synthesized. Their assembly and electrical response in thin film have been studied. Dihydrodiazapentacene have the same molecular shape as pentacene but are much easier to prepare and have much greater environmental stability. Thin films made from the dihydrodiazapentacene behave as field effect transistors with mobilities and on/off ratios high enough to be useful in certain applications. Some of the derivatives synthesized for this study have unexpectedly high solubility in polar solvents such as DMF and DMSO. The crystal structure from DMF reveals self-assembled channels with each of the aniline functionalities forming a hydrogen bond with solvent. In more non-polar solvents, the solid-state assembly switches to a herringbone motif characteristic of the linear acenes. 6, 13-diazapentacene forms vacuum-evaporated films, which are highly ordered polycrystalline and have unique morphology and conductivity up to $10^{-2}\Omega^{-1}cm^{-1}$. Its crystal structure indicates that 6, 13-diazapentacene molecules stack co-facially with each other rather than in a herringbone motif. Several derivatives of tetracene have also been synthesized to control the packing mode and to enhance the contact between molecules and the substrate.

I11.2
Growth Process Control of Polymorphic Thin Films and Single Crystals for the Adjustment of Structural and Electronic Properties of Pentacene. Barbara Stadlober[1], Hannes Maresch[1], Valentin Satzinger[1], Heinz Pichler[1], Helmut Schoen[1], Anja Haase[1], Werner Rom[1], Georg Jakopic[1], Dieter Somitsch[2], Reinhard Kaindl[3] and Josef Kalcher[4]; [1]Institute of Nanostructured Materials and Photonics, Joanneum Research, Graz, Austria; [2]Institute of Experimental Physics, Karl-Franzens University, Graz, Austria; [3]Institute of Mineralogy and Petrology, Karl-Franzens University, Graz, Austria; [4]Institute of Chemistry, Karl-Franzens University, Graz, Austria.

Due to its outstanding carrier transport capabilities pentacene is a prominent candidate for the active semiconducting layer in organic thin film transistors. This compound crystallizes in a layered structure with herringbone arrangement within each layer. Pentacene appears in several polymorphic structures, which differ basically by their c-axis lengths, meaning that the angle at which the molecules adsorb relative to the substrate changes from phase to phase. Obviously the interaction of the π-electron systems between adjacent molecules 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 polymorphic 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 polymorphic 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.

I11.3
Broadening the Spectral Response of Bulk Heterojunction Organic Devices Using a Conducting Polymer Blend. Adam P Smith[1], Michael F Durstock[1], John B Ferguson[1], Rachel R Smith[2] and Barney E Taylor[2]; [1]Air Force Research Laboratory, Polymer Branch, Wright-Patterson Air Force Base, WPAFB, Ohio; [2]University of Dayton Research Institute, Dayton, Ohio.

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(thienylene 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.

I11.4
Electron-Accepting Materials Containing Thiazolo[5,4-d]thiazole. Mark David McClain[1,2] and Douglas Scott Dudis[2]; [1]Department of Science & Mathematics, Cedarville University, Cedarville, Ohio; [2]Materials & 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-accepting 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 alkylthiophene-capped thiazolo[5,4-d]thiazole which are being pursued to address the stability and charge mobility limitations. Polymers were prepared via dehalogenative polycondensation of dibrominated monomers using zero valent nickel catalysts. The synthesis, characterization, and properties of these materials will be presented.

I11.5
Self - Degradation of MEH-PPV due to Oxygen/Moisture Traps through C-V Analysis and Attenuated Total Reflection IR Spectroscopy. Rajneek Kumar Khillan, 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 [2-methoxy-5-(2-ethylhexoxy)-1,

4-phenylene vinylene] (MEH-PPV), is widely used as an Electroluminescent Polymer for the fabrication of PLEDs. The degradation of MEH-PPV is a major factor for short lifetime and low efficiency of PLED. Deep Level Transient Spectroscopy (DLTS) and Thermally Stimulated Current (TSC) are usually used for studying the polymer degradation. In this paper we present a different way to investigate degradation of MEH-PPV polymer by means of Quasi-static and High-frequency C-V analysis, and Attenuated Total Reflection (ATR) IR spectroscopy. Our experimental results of ATR IR spectroscopy of 800Å film of MEH-PPV on Aluminum show the formation of carbonyl peak at 1651 cm^{-1} with aging which indicates the presence of oxygen. These results are consistent with other researchers. High frequency C-V curve of our MIS (Al/MEH-PPV/p-Si) capacitor shows 63.7% decrease in capacitance (C_{max}) after 24 hrs, which indicates increase in thickness of the polymer layer assuming minimal dielectric constant change. This increase in thickness suggests the absorption of moisture thus forming volatile components which causes the polymer layer to swell. High resolution microscope images show the swelling of the polymer layer which causes the metal layer on top of polymer to swell and ultimately burst within 48 hrs. In our quasi-static C-V measurement we found extension of the weak inversion region in the form of platform before strong inversion. This suggests that the minority carriers from the p-Si start recombining with the holes in the MEH-PPV polymer layer. This platform extends until the minority carriers recombine. After recombination of the minority carriers, the quasi-static C-V curve follows the strong inversion. With aging, further extension of the platform in the weak inversion region is observed. Other researchers have shown that the molecular oxygen serves as a trap in the MEH-PPV layer which attaches with the electron to form negative ion O_2^- , an n-type carrier trap. Extension of this platform in the weak inversion region with aging can be explained due to more hole-electron recombination in MEH-PPV layer. The oxygen combines with electron to form negative ions which recombines with the holes of the MEH-PPV polymer. In this case it takes more time for carrier recombination and thus causing more extension. Thus both the C-V analysis and Attenuated Total Reflection IR Spectroscopy are two powerful tools for investigating degradation of polymer materials for improving reliability of PLEDs.

I11.6
Tetrahedra from Aryleneethenylenes - From Small Molecules to Luminescent Glasses. Heiner Detert, Institut fuer Organische Chemie, Johannes Gutenberg-Universitaet, Mainz, Germany.

Stilbenoid oligomers exhibit efficient photo- and electroluminescence in the blue to yellow region but the application of these low molecular weight molecules is limited by their strong tendency towards crystallisation. OPVs as side chains or in the main chain of a polymer or dispersed in polymeric matrices are suitable ways to overcome this limitation, an alternative is opened by globular molecules. This poster presents the synthesis of silanes and methanes with four alkoxy-substituted stilbenoid chromophores connected to the central atom, thus giving these molecules a tetrahedral shape. These molecules with monodisperse conjugated segments form amorphous films, in the solid state, the absorption spectra are shifted to the red whereas the fluorescence is not affected by aggregation. The film forming capability is depending on the shape, the lengths of the conjugated segments and the flexible side chains.

I11.7
Fabrication and Photoelectrical Characteristics of Polymer-Organic-Blend Photodetector. Difei Qi, Sandra Selmic and Kody Varahramyan; Institute for Micromanufacturing,Electrical Engineering Program, Louisiana Tech University, Ruston, Louisiana.

Polymer optoelectronics and microelectronics have been recognized as next generation technologies. One of the widely investigated materials for photodiode, LED and solar cell applications is the insoluble conjugated polymer poly(p-phenylene vinylene) or PPV. In this paper we present experimental results of a blended polymer-organic compound photodiode. This diode is based on a soluble derivative of PPV, poly(2-methoxy-5- (2,9-ethyl-hexyloxy)-1,4-phenylene vinylene) or MEH-PPV, and the organic material ethyl viologen dibromide or EVD. Possible applications of this polymer/organic blend photodiodes are imaging systems, large sensor systems and optical networks. The MEH-PPV acts as an electron donor with a relatively low quantum efficiency of 0.07% [1] due to a limited exciton diffusion length, molecular structure distortion, and low hole mobility. The EVD acts as an excellent electron acceptor, therefore we predict that it will significantly increase the photoconductivity of a pristine MEH-PPV film. In making the photodiodes, solutions of MEH-PPV and EVD were spin-coated on indium tin oxide coated glass substrates. The thicknesses of these polymer-organic thin films were approximately 130nm. An aluminum cathode was thermally evaporated. These devices were illuminated under a monochromatic light in UV and visible range wavelengths. These thin polymer-organic blend photodiodes have shown a ten-fold increase in responsivity and quantum efficiency compared to pure MEH-PPV photodiode devices. The increase in photoconductivity of blended MEH-PPV:EVD photodiodes may be due to ultra fast charge transfer by EVD^{2+} cation. The results from this work clearly demonstrate the application of the reported approach for the realization of polymer photodiodes with increased photoconductivity characteristics. Reference [1] K. Petritsch and R. H. Friend, "Ultrathin Organic Photovoltaic Devices," Synthetic Metals, vol.102, p. 976, 1998.

I11.8
Photolithographic Micropatterning of an Electroluminescent Polymer Using Photobase Generator. Lee Sang Kyun[1], Jung Byung-Jun[2], Ahn Taek[2] and Shim Hong-Ku[2]; [1]Electronic Materials Lab, SAMSUNG Advanced Institute of Science and Technology, Yongin, Kyounggi, South Korea; [2]Chemistry, Korea Advanced Institute of Science and Technology, Daejeon, ChungCheong, South Korea.

Recently, much attention has especially been focused on the techniques of photopatterning for conjugated polymer by introducing the chemical amplified photolithographic (CAP) method which is used in conventional manufacturing methods for the intergrated circuit (IC) chip. This technology uses the application of generating acid upon photolysis and solubility change between exposed area and unexposed area. Renak et al.reported the patterning of poly-(p-phenylenevinylene)(PPV) derivatives by using a photoacid generator (PAG) in elimination reaction upon the irradiation through a photomask. In the present work, we report a new photolithographic micropatterning method for conjugated polymer using halo-precursor conjugated polymer and photobase generator (PBG) and its application for polymer LEDs. The methods of PPV synthesis were published abundantly in previous literature. Especially, the Gilch route is a prevalent method using excess strong base because of simplicity without thermal elimination step and relatively rare side reactions. But if base less than one equivalent is used, an organic soluble haloprecursor polymer is obtained, and then it can be converted into the fully conjugated polymer by thermal elimination. o-Nitrobenzyl carbamate derivatives such as PBG are well-known to generate the base upon the photolysis reaction, which is photolytically converted of carbamate derivatives to amine upon irradiation with UV light below 400 nm. Consequently, the generated amine rendered the halo-precursor PPV to conjugated PPV by base-catalyzed dehydrohalogenation reaction (E2 elimination).

SESSION I12: Materials and Processes for Flexible Electronics II
Chair: Arokia Nathan
Friday Morning, April 16, 2004
Room 2018 (Moscone West)

8:30 AM *I12.1
Recent Advances in the Synthesis of Polyfluorenes as Organic Semiconductors. David Joseph Brennan[1], Yu Chen[1], Shaoguang Feng[2], James P. Godschalx[2], Gary E. Spilman[3], Paul H. Townsend[1], Scott R. Kisting[1], Mitchell G. Dibbs[1], Jeff M. Shaw[1], Dean M. Welsh[1], Jessica L. Miklovich[1] and Debra Stutts[2]; [1]Advanced Electronic Materials, The Dow Chemical Company, Midland, Michigan; [2]Chemical Sciences, The Dow Chemical Company, Midland, Michigan; [3]Polymer Chemistry, The Dow Chemical Company, Midland, Michigan.

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 (PFETs). One polyfluorene that has received a great deal of attention in recent years is poly(9,9-dioctyfluorene-*alt*-bithiophene) or "F8T2". F8T2 has charge mobilities as high as 0.02 cm^2/V-s with current on/off ratios of up to 10^6. F8T2 is also more resistant to doping by atmospheric oxygen than other polymeric semiconductors and has good solubility in solvents such as mesitylene. This favorable solubility has allowed the preparation of inks for use in various printing applications. While F8T2 polyfluorene is the "workhorse" polymeric semiconductor at Dow, efforts are underway to prepare new materials which might yield improvements in charge mobility, solubility, and other properties when compared to F8T2. These efforts have resulted in the synthesis of new polyfluorenes and related polymers as second generation polymeric semiconductors with an excellent combination of charge mobility, environmental stability, and processability. The paper will focus on the recent advances in the synthesis, fabrication, and electrical characterization of polyfluorenes for semiconducting applications.

9:00 AM I12.2
Electron-Transporting Thiophene-Based Semiconducturs Exhibiting Very High Field Effect Mobilities. Antonio Facchetti, Myung-Han Yoon and Tobin J Marks; Northwestern University, Evanston, Illinois.

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 electron-transporting conditions. Furthermore, the key structural features of these compounds allows 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 I$\{on}$:I$\{off}$ ratios approaching 1 cm$\{2}$/(Vs) and 10$\{7}$, respectively. This family represents a key milestone in the design, understanding, and development of the next generation of highly efficient n-type OTFT components.

9:15 AM *I12.3
Towards Printed Organic Electronics–Design of Enabling Materials for Low-Cost Transistors. Beng S Ong, Materials Design and Integration, Xerox Research Centre of Canada, Mississauga, Ontario, Canada.

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, fabrication using 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-performing semiconductor polymers and other TFT materials will be presented.

9:45 AM I12.4
Crystalline Organic Semiconducting Thin Films Cast from a Novel Soluble Thermolytic Oligothiophene. Paul C Chang[1], Amanda R Murphy[2], Josephine B Lee[1], Jean M J Frechet[2] and Vivek Subramanian[1]; [1]Department of Electrical Engineering and Computer Science, University of California, Berkeley, California; [2]Department of Chemistry, University of California, Berkeley, California.

One of the main attractions of organic semiconducting materials is the potential for low-cost solution-based processing. However organic thin film transistors (OTFTs) that have exhibited the highest field-effect mobilities 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 releases a bulky end group upon thermolysis to form an insoluble oligothiophene. Devices with channel lengths from 5 to 40 um were fabricated from solution where an initially amorphous film was thermolyzed at temperatures ranging from 150-250° C. All films showed enough surface energy such that the thiophene molecules reorganized into highly crystalline films. Crystallinity was characterized by x-ray diffractometry and atomic force imaging, the latter of which depicted the nucleation of molecular terraces. The formation and overall height of terraces was observed to be dependent upon the thermolyzing temperature, the surface energy of the substrate, and the purity of the material, and was correlated to overall performance. For both dip-cast and spin-cast samples, devices were fabricated at a process temperature of 180° C with mobilities of 0.05 cm^2/Vs and on/off ratios > 10^5. The devices were relatively stable in both air and common solvents, degrading by 25% in mobility even when immersed from the solvents from which they were initially cast. The solubility characteristics and process temperatures for these devices may be particularly suitable for solution processing on flexible substrates.

10:30 AM *I12.5
Polymer Electrodes for Flexible Organic Optoelectronic Devices. Woohong H. Kim, Leonidas C. Palilis, Antti J. Makinen and Zakya H. Kafafi; Naval Research Laboratory, Washington, District of Columbia.

Progress has been recently made in developing and patterning highly conducting polymer electrodes for flexible substrates. Encouraging device performance was demonstrated for molecular organic light emitting diodes (MOLEDs) using these polymers as anodes.[1] Ultraviolet photoemission studies have shown that the hole injection barrier between these polymer anodes and common organic hole transporters is on the order of 0.5 eV, comparable to that measured for ITO electrodes.[2] 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(3,4-ethylenedioxy-thiophene)-polystyrenesulfonate close to the boiling point of glycerol was necessary to optimize its surface sheet resistance for use as polymer anodes in high performance MOLEDs.[3] 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. 1. W. H. Kim, A. J. Mäkinen, N. Nikolov, R. Shashidhar, H. Kim, and Z. H. Kafafi, Appl. Phys. Lett. **80**, 3844 (2002). 2. A. J. Mäkinen, I. G. Hill, R. Shashidhar, N. Nikolov, and Z. H. Kafafi, Appl. Phys. Lett. **79**, 557 (2001). 3. W. H. Kim, G. P. Kushto, H. Kim, and Z. H. Kafafi, J. Polymer Science Part B: Polymer Physics **41**, 2522 (2003).

11:00 AM I12.6
Patterned growth of organic small-molecule layers. Soeren Steudel[1,2], Dimitri Janssen[1,3], Stijn Verlaak[1,2] and Paul Heremans[1,2]; [1]Polymer and Molecular Electronics, IMEC, Leuven, Belgium; [2]Electrical Engineering, Katholieke Universiteit Leuven, Leuven, Belgium; [3]Chemistry, Katholieke Universiteit Leuven, Leuven, Belgium.

With ongoing improvements in the performance of small molecule organic thin film transistors (OTFT) and the first demonstrations of inverters and oscillators the route towards circuits based on organic small molecules like pentacene is open. A major challenge on this way is the patterning of the polycrystalline film to electrically separate neighboring transistors without degrading their electrical properties. We will demonstrate a novel approach to this problem. By locally changing the chemistry of the dielectric surface by means of self-assembled monolayers (SAM) we predefine active and passive areas of the circuit. The subsequent growth of the organic film by sublimation takes place under growth conditions which cause the formation of a high-mobility, well-connected two-dimensional (2D) film in the predefined active area contrasting with ill-connected, low-mobility 3D-film in the passive area. We will explain this patterned growth in terms of a microscopic theory of nucleation of organic semiconductor on inert substrates and present experimental results for various surface treatments and growth conditions.

11:15 AM I12.7
Interaction of surface conditions and characteristics of offset printed functional polymer structures. Arved C. Huebler, Thomas Fischer, Ulrich Hahn, Nicole Brandt, Dirk Zielke, Uta Fuegmann, Wolfgang Beier and Zlatomir Shalabutov; Institute for Print and Media Technology, Chemnitz University of Technology, Chemnitz, Germany.

Polymerelectronics 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 of processing these functional materials and thus to the implementation of many new applications. Printing technologies as continuously working high speed microstructuring technologies suitable for flexible substrates offer excellent fundamentals for economically advantageous production strategies concerning polymerelectronical 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 I12.8
New conjugated 2,7-carbazole-based materials for electronic applications. Nicolas Drolet[1,2], Jean-Francois Morin[1], Ye Tao[2] and Mario Leclerc[1]; [1]Department of Chemistry, Laval University, Quebec, Quebec, Canada; [2]Institute 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 different 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 (OPVCs). In OLEDs, poly (N-ethylhexyl-2,7-carbazole) has demonstrated very good performances as a stable blue emitter. Electroluminescence as high as 600 cd/m^2 at 10V has been obtained with device 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-carbazolenevinylene-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 3,7 x 10^{-2} cm^2/V.s with an excellent I_{on}/I_{off} ratio of 10^6 have been obtained for many of those oligomers 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-carbazolenevinylene unit should be excellent candidates in OPVCs. Preliminary results from such polymeric photovoltaic devices will also be reported.

11:45 AM I12.9
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 many electroactive organic films is the insolubility of the necessary conjugated 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 polyconjugated 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 X-ray photoelectron spectra have been obtained to characterize HW-CVD films produced using aniline as a precursor. The aromatic ring structure, essential for the polyconjugated 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 I13: Organic Electronics and Optoelectronics
Chair: Bruce Gnade
Friday Afternoon, April 16, 2004
Room 2018 (Moscone West)

1:30 PM *I13.1
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. Amorphous silicon (a-Si) technology offers the potential for fabricating the required active matrix backplanes on low temperature (< 150oC) 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 *I13.2
Development of high current efficiency and long life organic LEDs having charge generation layers. Junji Kido[1] and Toshio Matsumoto[2]; [1]Polymer Science and Engineering, Yamagata University, 4-3-16 Jonan, Yamagata, Japan; [2]IMES, Fujisawa, Kanagawa, Japan.

A new type of organic LEDs having charge generation layer (CGL) were developed. By applying voltage, holes and electrons are generated at CGL and injected to adjacent organic layers to recombine 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 from a device, using fluorescent emitter materials, having three CGLs. The lifetime of the device is over 5000 hours at the initial luminance of 11000 cd/m2.

2:30 PM I13.3
Total Field Screening in Organic Light-Emitting Diodes. John C deMello[1], Paul J Brewer[1], Andrew J deMello[1], Donal D C Bradley[1] and Paul A Lane[2]; [1]Chemistry, Imperial College London, London, United Kingdom; [2]C. 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 I13.4
Improved light extraction from polymer LEDs with stamped Bragg gratings. Jonathan M Ziebarth and Michael D McGehee; Geballe 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 guided modes. 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 reduces 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 using holographic and soft lithography techniques. In order to optimize the outcoupling 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 modeled the 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 *I13.5
Polymer Based Photodetectors. K S Narayan, Dinesh Kabra and Soumya Dutta; 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 processibility 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 provide a convenient lateral geometry where light can be coupled and can 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 I13.6
Organic switches for memory applications.
Luisa Dominica Bozano, Kenneth R. Carter, Vaughn R. Deline, Jane

E. Frommer and J. Campbell Scott; IBM Almaden Research Center, San Jose, California.

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

4:15 PM I13.7
Light Sensitive Polymer Thin Film Transistors Based on BAS-PPE. Yifan Xu[1], Paul R. Berger[1,2], James N. Wilson[3] and Uwe H.F. Bunz[3]; [1]Department of Electrical Engineering, The Ohio State University, Columbus, Ohio; [2]Department of Physics, The Ohio State University, Columbus, Ohio; [3]School 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 V_{DS} also shows that BAS-PPE is a p-type polymer and favors hole injection and transport. A sweep of I_{DS} versus V_{GS} demonstrates that under darkness I_{DS} 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.