SYMPOSIUM H
Flexible Electronics—Materials and Device Technology
April 22 – 25, 2003

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*Invited paper
SESSION H1: FLEXIBLE ELECTRONICS

Chair: Babu R. Chandraker
Tuesday Morning, September 14, 2010
Salon 14/15 (Marriott)

8:30 AM *H1.1
THE ALLURE OF ‘FLEXIBLE’* Daken E. Keys, D-Port Displays, Research Triangle Park, NC.

Our desires as consumers are driving technologies to enable the integration of more features with lower cost with increased performance. There are tremendous revolutions in technologies occurring. It appears that flexible is going to become an increasingly significant factor in our lives. Why now? Flexible electronics and devices are already having an impact on the design of smaller devices. We might be surprised at the impact these devices are having on our lives today. Consider the FilmOLED displays and the potential impact to meet the demands that we are placing on the marketplace for state-of-the-art devices that are flexible? There are significant efforts underway to create transistor arrays on flexible substrates. Existing concepts for roll-up or conformal displays are being pursued. And, if printing of flexible electronic and displays can be implemented, new vistas can be achieved in manufacturing and hence the cost of the component and device. In the OLED displays world, we have pursued a model to support our exploration of technologies and their shortcomings in a roll-to-roll manufacturing process. There are many technology challenges remaining in the flexible electronics and display world. The most significant of these will be discussed. Why is flexible so important? Why do we want it so much? Let’s explore the need and then speculate on what is to come for “flexible.”

9:00 AM *H1.2

In the last few years, industrial research into materials fulfilling the needs of the maturing OLED display industry has intensified considerably. A first generation of polymers (polymer-OPVs) is now being commercially exploited in first monochromic polymer LED display applications. Based on these materials, non-planar displays have already been demonstrated. However, proof of concept devices have been monochromic. Especially the RGB materials need considerable improvement to be suitable for flexible full color displays. We will therefore report on the progress in the development of polymers for red, green, and blue emission. Our main focus here is on improving the properties of various polymers derived from the spirotetrahydrocyclic core. Depending on the color, the main issues are strongly: for BLUE polymers, efficiency, color coordinates, and processibility are already at a commercial level while operational lifetime still needs strong improvement. RED materials are in an almost contrary situation: here, the operational lifetime is excellent, whereas the efficiency and the driving current are requiring further improvement. For GREEN, achieving saturated emission, while maintaining the other properties (high efficiency, long operational lifetime), is still challenging. We will demonstrate the current status of material development within Covion. In addition, we will report on advances in film deposition, printing, and inkjet printing techniques based on InkJet printing. This technology potentially allows the efficient manufacturing of high resolution OLED devices on a variety of substrates, including flexible layers.

9:30 AM *H1.3

Based on the success of amorphous silicon TFTs in both solar cells and AMOLEDs, and with the imminent penetration of OLEDs into display applications, macroelectronics has now become a standalone field of electronics research. The emphasis in this paper will be on materials and material-related issues in the development of large area and/or flexible electronics. Emphasis will be placed on areas that are important for successful implementation of electronics whose utility stems not from small dimensions, but from other physical attributes such as form factor and cost. Materials of interest include both Si-based and organic FET technologies. While displays are perhaps the best example of application of flexible electronics for such materials, the focus will be on other potential applications such as smart cards, RF tags, and sensor array networks. Successful implementation of such systems will require innovations in flexible, lightweight, wearable, device, circuit, and system design. The potential of flexible electronics changes from lightweight, rugged, and bendable electronics to the ultimate in low-cost manufacturing through roll-to-roll fabrication. This paper will assess the state of the art with regard to achievement of the goals of flexible electronics for specific systems that offer novel operational capabilities. At the extreme, one can envision a future where microelectronics 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. TFT device performance can improve significantly at the same time the promise of low cost manufacturing can be realized, then perhaps ‘microelectronics’ can find a role beyond displays.

10:00 AM *H1.4

Flexible, free shape displays are the enabling technology for new rollable, lightweight, extremely thin portable electronic devices (e.g. portable digital audio players). Polymer Light Emitting Diodes (PLEDs) 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 as diffusion barriers and transparent electrodes. The structural integrity, dimensional stability and thermal properties of the substrate stack are crucial to ensure processability, device functionality and reliability. The mechanical properties of the thin functional layers, such as the transparent electrodes, limit the bending radii achievable for a given substrate and, ultimately, of the display. The fracture mechanics of diffusion barriers and conducting layers is therefore of particular importance and is studied by a combination of mechanical, optical and electrical measurements. Effective permeation rates of the diffusion barriers are measured using an optical method based on the oxidation of thin calcium layers used in the calcium test also allows a direct visualization of barrier defects such as cracks and pinholes. These tools are applied to characterize and improve the performance of high performance substrate materials based on transparent polymers when exposed to higher temperatures above 300°C which are suitable for flexible PLED displays.

11:00 AM *H1.5

Amorphous and microcrystalline silicon thin-film transistors, which dominate active matrices and thin-film solar panels, are now being made on flexible and deformable substrates. While flexible solar panels on steel and plastic have been made for some time, flexible TFT arrays are more recent, and deformable circuits are altogether new. Flexible and deformable electronics could enable conformal displays and detector arrays, such as electroluminescent actuator and tactile arrays, e-textiles, and shaped solar panels. Amorphous silicon transistors and solar cells respond to increasing mechanical strain in three steps: (1) Elastic deformation causes small, reversible changes in electrical performance; (2) The most brittle device material fractures close to its failure strain; the device becomes unstable but may remain functional. (3) Even larger strain causes definitive fracture and thus electrical failure. The devices fail more easily in tensile than compressive strain because of different mechanisms for crack formation. Thin-film transistors, which rely on in-plane carrier transport, appear to be more sensitive to deformation than solar cells, which function by top-to-bottom transport. We discuss research issues in high-performance transistors on flexible substrates; 3D shaped electronic surfaces; electronic fibers; and elastic circuits.

11:30 AM *H1.6
CRITICAL PROCESS ISSUES IN ROLL-TO-ROLL MANUFACTURING OF MACROELECTRONICS* James E. Shear, Rolltronics Corp., Menlo Park, CA.

There is a great deal of interest currently in a variety of technologies related to the production of flexible electronic devices, which have advantages for the user of lightweight, compactness, and convenience; in principle, devices that are currently powerful but rather cumbersome to use could be made much more like familiar “information appliances” such as paper. Fabricating electronics on plastic, however, is not so simple. Further, the roll-to-roll substrate handling systems are used, and these in turn pose challenges for microelectronic processing: dimensional control,
defects, thermal and mechanical characteristics are all new territory compared to familiar silicon and glass substrates. I will explore some of these issues from the perspective of what is currently practiced in commercial web processing and how this knowledge can be brought to bear on microelectronics.

SESSION H2: FLEXIBLE SI TFTs
Chair: Jin Jiang
Tuesday April 22, 2003
Salon 14/15 (Marriott)

1:30 PM *H2.1
LOW TEMPERATURE POLY-SI (LTPS) ON FLEXIBLE POLYMER SUBSTRATES FOR ACTIVE-MATRIX DISPLAYS AND OTHER APPLICATIONS. Nigel Young, Michael Trainor, Sos-Young Yoon, David McCallum, Richard Wilks, Andy Pearson, Peter Green, Philips Research, Redhill, UNITED KINGDOM. Sander Rosendael, Philips Research, Eindhoven, THE NETHERLANDS; and Elizabeth Hallworth, Philips Research, Redhill, UNITED KINGDOM.

For a number of years we have been developing LTPS technology on a range of polymer substrates for active-matrix LCD and LED displays and other applications. Our current vehicle for this technology is a 2.1720 in (1673x830) drawing mobile phone display with integrated CMOS drivers, and this will be discussed in detail. Important issues include the choice of materials, the deposition method, the resulting processing temperature, and device hydrogenation. Our substrate studies have included PES (Sumitomo Bakelite), PI (UBE and Dupont), PPE (Ferranti) and PNA (Promerus) and particular consideration has been given to shrinkage, alignment, adhesion and crystallization issues. The relative merits of TFTs formed on these substrates using either a simple gate-overlapped structure, or a self-aligned structure will be demonstrated. In this work, particular attention has been given to the choice of gate insulator (silicon dioxide or silicon nitride) and the method of deposition. Over and above the basic TFT properties, the dielectric defect density and its dependence on the deposition temperature has to be considered.

Several other layers are required above the TFT in order to make a complete AMOLED. We will show that polymer dielectrics are suitable for the formation of cross-over dielectrics, in-cell scatterers, and the cell spacers required to make a transflective display.

2:00 PM H2.2
LOW TEMPERATURE n-SiH PIXEL CIRCUITS FOR MECHANICALLY FLEXIBLE A MOLED DISPLAYS. Arashin Nathan, Kogil Salarina, Anil Kumar, Peyman Servati, Karim S Karam, and Denis Strickland, Univ of Waterloo, Dept of Electrical and Computer Engineering, Waterloo, ON, CANADA.

In this paper, we present amorphous silicon (a-Si:H) thin film transistor circuits fabricated at low (~100oC) temperatures that compensate for material shortcomings such as metastable threshold voltage (Vt) shift and low mobility, and supply stable and predictable drive currents to drive mechanically flexible active matrix organic light emitting diode (AMOLED) displays. We use a vertically staked pixel architecture that enables high aperture ratio and high on-pixel integration with low parasitic capacitance and leakage current. The simplest pixel driver circuit possible in the two TFT, voltage-programmed circuit. Since the current through the OLED depends on the gate voltage of the drive TFT, this circuit is very sensitive to any Vt increase in the TFT. Due to this, the OLED brightness with the 2-TFT pixel circuit will gradually decrease and the pixel will eventually turn off. To overcome this problem, we have developed current-programmed pixel circuits based on the current mirror circuit family. The OLED current in these circuits is virtually independent of any threshold voltage or mobility variation in the drive TFT. We examine the effects of Vt mismatch in the current mirror TFTs on the stability of the output drive current. Results show that the Vt mismatch is enhanced with temperature, but that all circuits can be made stable with the proper compensating Vt. All circuits meet the speed requirements of a QVGA 60 Hz refresh rate display, and occupy less than 300x1000 mm.

2:15 PM H2.3
ULTRA-LOW TEMPERATURE POLY-SI THIN FILM BY EXCIMER LASER RECRYSTALLIZATION FOR FLEXIBLE SUBSTRATES. Sang-Myeon Han, Min-Chool Lee, Kook-Chul Moon and Min-Koo Han.

TFTs on flexible substrate has attracted for flat panel display application. However, process temperature of TFT fabrication on flexible substrate should be less 200oC. The purpose of our work is to report a ultralow temperature (150oC) poly-Si (ULTPS) active layer for TFTs on flexible substrate. It has been reported that a-Si film deposited by plasma-enhanced chemical vapor deposition (PECVD) at 200oC has a large hydrogen content (~15%) which requires a troublesome dehydrogenation process. We developed a low hydrogenated (less than 3%) n-type-Si film utilizing inductively coupled plasma chemical vapor deposition (ICP-CVD) without net hydrogen addition. It is well known that n-type-crystal silicon is obtained in the condition of high plasma power density and high H2/SiH4 flow ratio. ICP-CVD has rather high plasma density so that a density of n-type-Si film increases and hydrogen content decreases. The n-type-Si film was crystallized by XeCl (318nm) excimer laser annealing (ELA) and no ablation of crystallized film was obtained. FTIR measurement exhibited that the hydrogen content was decreased after the laser was irradiated. Our experimental result shows that n-type-Si film deposited by ICP-CVD is probably suitable for active layer of TFTs on flexible substrate.

2:30 PM H2.4
THIN FILM TRANSISTORS ON PLASTIC SUBSTRATES USING SILICON DEPOSITED BY MICROWAVE ECR Plasma CVD. Leung Teng and Wayne A. Anderson, University at Buffalo, The State University of New York, Dept of Electrical Engineering, Buffalo, NY.

Thin film silicon transistors fabricated on plastic substrates at low temperatures are promising candidates for low-cost, large-area, unbreakable, lightweight and flexible flat panel displays. High-quality channel materials with fewer defects are important to realize TFTs with good performance, such as high mobility and low leakage current. We fabricated bottom-gated TFTs on polyimide film at below 300oC with active channel layers deposited by microwave plasma electron cyclotron resonance chemical vapor deposition (MCR-CVD). The ECR condition enables the transistors to effectively absorb the microwave energy and, thus, a high-density plasma (5 x 1016 cm-3) at a low gas pressure is possible which enhances the generation efficiency of SiH3 radicals and is favorable to the formation of a better quality Si film. Hydrogen was introduced during the Si film deposition. The deposited Si film showed a high photoconductivity of 5 x 105 S/cm. The TFT fabrication processes that are compatible with the plastic substrates were optimized. The gate oxide quality was examined by the high frequency C-V characteristics of the MOS capacitors. The high frequency C-V curves showed a small flat-band voltage (VFB) and stress-out, which implied high-quality oxide with little fixed charge and small Si/SiO2 interface trap density. The MOS capacitor C-V curve showed a high oxide breakdown field of 9 MV/cm. The TFT on polyimide film with an active Si layer deposited at 190oC and 8 mTorr hydrogen had a field effect mobility of 3.9 cm2/Vs, a threshold voltage of 4.1 V, a subthreshold swing of 0.73 V/decade and an ON/OFF current ratio of 5 x 106.

2:45 PM H2.5
HIGH PERFORMANCE POLYSILICON THIN FILM TRANSISTOR CIRCUITS ON FLEXIBLE STAINLESS STEEL FOILS. Themis Aslanakis and Melinda K. Hartlin, Display Research Laboratory, Department of Electrical & Computer Engineering, Lehigh University, Bethlehem, PA; Apostolos T. Voutson and John W. Harttall, Sharp Labs of America, Inc., NJ.

In recent years, there has been an increased interest in the use of flexible substrates in microelectronic fabrication. Flexible substrates, such as polymers and metals, have the potential to be utilized in roll-to-roll processing, resulting in low cost, rugged systems. Thin flexible stainless steel foils offer a number of advantages over polymers for circuits and circuit fabrication, such as superior flexibility, higher linearity and dynamic range than currently available pixel circuits while minimizing the pixel area. Charge injection effects at the gate of the drive TFT have been reduced by using smaller switching TFTs with circuit topologies that provide increased output current. All circuits meet the specifications of a QVGA 60 Hz refresh rate display, and occupy less than 300x1000 mm.

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implementation of high performance circuitry having a high degree of scalability and complexity on thin metal foils, thus making the fabrication of efficient, inexpensive and versatile systems on flexible foils for a large variety of applications a realistic prospect.

4:00 PM **H2.7**

FLEXIBLE MONOCRYSTALLINE Si FILMS FOR THIN FILM DEVICES FROM TRANSFER PROCESSES.

Christopher Berger, Thomas A. Wagner, Markus B. Schubert, Jürgen H. Werner.
Institute of Physical Electronics, University of Stuttgart, GERMANY.

Transfer of monocrystalline silicon films to nearly arbitrary foreign substrates has proven to be a promising alternative to the direct deposition of thin silicon films on foreign substrates. Transfer technologies combine the high electronic quality of monocrystalline silicon material with the advantages of thin films. Our transfer approach is based on epitaxial growth of a monocrystalline Si film on a wafer. The epitaxial growth is followed by a process of selective etching of the silicon film, leaving a thin film on the substrate. This process allows for the fabrication of photonic devices.

With market opportunities continuing to drive electronic products to smaller size, significant research efforts continue to shrink semiconductor devices in accordance with Moore's Law. However, a new market opportunity is emerging for which the significant driver is not semiconductor complexity, but rather lower product cost arising from the novel integration of technologies making use of organic and flexible substrates. These new technologies present opportunities for research into new materials and fabrication processes. These new research opportunities extend from organic MEMS, microfluidics, and embedded passive devices to printed organic transistors and polymer optical waveguides. This talk will discuss these new technologies and present some of the market drivers for these efforts.

SESSION H3: ORGANIC ELECTRONICS - OFFSh
Chair: Norbert Fruehstorf
Wednesday, April 23, 2008
Salon 14/15 (Marriott)

8:30 AM **H3.1**

ORGANIC ELECTRONICS FOR LARGE AREA ELECTRONIC DEVICES. Marc Chacon-Mazariegos, Motorola, Inc., Motorola Labs, Schaumburg, IL.

In this session, we will discuss the impact of organic electronics on large area electronic devices. We will cover topics such as organic field-effect transistors, organic light-emitting diodes, and organic photovoltaics. We will also discuss the potential applications of these technologies in areas such as flat panel displays, sensors, and energy harvesting.

9:00 AM **H3.2**


In this session, we will discuss the latest advancements in all-organic field-effect transistors. We will cover topics such as organic semiconductors, device engineering, and applications. We will also discuss the potential for these technologies in areas such as flexible electronics and printable circuits.

9:15 AM **H3.3**

ALL ORGANIC ELECTROCHEMICALLY TUNABLE RECTIFIERS AND AMBIPOLE TRANSISTORS ON FLEXIBLE SUBSTRATES.

Miaoqing Chen, Magnus Berggren, Tommi Remonen, Thomas Kugler, Mats Robertsson, Dept of Science and Technology, Linköping University, SWEDEN.

In this session, we will discuss the latest developments in all-organic electrochemical rectifiers and ambipolar transistors. We will cover topics such as device fabrication, performance, and potential applications. We will also discuss the potential for these technologies in areas such as flexible electronics and energy harvesting.
Solution-based conducting polymer poly(3,4-ethylenedioxythiophene) (PEDOT:PSS) used as active material, were spin-coated onto patterned polyimide substrate, baked for 30 minutes at 150°C, and transferred to a solid thin film layer, and then patterned by means of a plotter. Gelled electrolyte structures were realized across the top of PEDOT:PSS channel and gate regions by screen-printing technique. The electrolyte layers were thoroughly washed with ethanol to form an electrochemical cell. Upon external bias beyond the oxidation and reduction potentials, electrochemistry, that is reduction (dedoped) and oxidation (doped) process, takes place in the electrochemical cells. Thus a reversible switching function can be realized at the channel regions. In one single tunnel rectifier the threshold voltage can be tuned from 0 V to 0.8 V. Both tunnel rectifiers and multichannel transistors exhibit on/off current ratio of 1000 at low voltage biasing. In an electrochemical transistors, multichannel transistors, and multichannel passive arrays, both threshold voltage and on/off ratio has been realized. The both n- and p-channel transistors have threshold voltage near to 0 V at gate voltage and drain-source voltage below 4.5 V. Furthermore, the multichannel transistors have open circuit memory function. The tunnel rectifiers can be further constituted multi-channel switch that is suitable for large area display application.

9:30 AM *H3.4
DISPLAY, MEMORY, AND SENSOR APPLICATIONS OF ORGANIC TRANSISTORS. HE KANG, M. Mashrui, M. Leifens, T. Somyen, A. Gelgers, Bell Laboratories-Lucent Technologies; A. Fachetti, T.J. Marks, Northwestern University, Evanston, IL.

Organic-based transistors are now routinely prepared with semiconductor mobilities of 0.1 cm2/νs and on/off ratios above ten thousand. With these values approach the requirements for certain amorphous silicon-type devices, such as the transistors used to control electrophoretic display pixels, they are well beyond the performance levels exhibited by crystalline silicon. Rather than competing directly with silicon, newer applications of organic-based electronics focus instead on capabilities unique to organic materials, such as low temperature and large area fabrication, chemically tunable energy levels, charge storage, and chemical sensitivity. This talk will focus on the molecular design of organic semiconductors aimed specifically at plastic displays, nonvolatile memory elements, and vapor sensor arrays. Proof of concept and future research opportunities for each application will be discussed. Methods for all-printed fabrication processes and highly flexible substrates will be emphasized.

10:30 AM *H3.5
ORGANIC THIN FILM TRANSISTORS FABRICATED ON FLEXIBLE SUBSTRATE FOR ALL-ORGANIC ELECTRONIC DEVICE. Seong Hyun Kim, Taehyong Zung, Basic Research Lab., ETRI, Daejon, KOREA.

In the organic thin-film transistors (OTFTs) study, the formation of good gate dielectrics is one of the most important processes when being fabricated on plastic substrates. We investigated the electrical properties of the OTFTs fabricated on plastic substrates such as polyethylene naphthalene diimide (PEN) film. We varied the dielectric materials such as organic and inorganic materials including polyvinyl alcohol (PVA), acrylate, Al2O3, and ferroelectric PZT. In the electrical measurements, the flexible field effect transistor (FET) devices showed the typical L-V characteristics. The field effect mobilities of our flexible OTFT to be greater than 1.4 x 10-1 cm2V-1s-1. Several properties of OTFT on the plastic substrates will also be discussed.

11:00 AM H3.6

Organic semiconductors are an attractive transistor technology for inexpensive displays because of their low processing cost and their potentially superior mechanical properties for applications in flexible electronics. A key issue in the development of organic electronics is to devise simple, reliable and low cost patterning techniques. We are developing a variety of non-lithographic methods to fabricate polymeric thin film transistors (TFTs). We will describe a novel method to integrate a network of microfluidic channels with an array of electrochemical cells. Several chemical substances are used to pattern solution-processable organic semiconductors over the electrode array to create TFTs suitable for active matrix addressing of display media. We have fabricated prototype arrays containing 64 x 64 pixels with an edge-dimension of 100 microns. The technique has been demonstrated with regio-restricted polythiophenes and co-polymers of thiophene and fluorene. The performance of the TFTs will be presented and compared to other deposition approaches.

11:15 AM H3.7
AMOLED TFT PIXEL CIRCUITRY FOR FLEXIBLE DISPLAYS ON METAL FOILS. Martin Trocellier, Thomas Aftanas, Mikhail K. Han, Display Research Laboratory, Department of Electronic Computer Engineering, Lehigh University, Bethlehem, PA; Apostolos T. Voutsas, Moshiko Adachi, John W. Hartnell, Sharp Laboratories of America, Camas, WA.

Active matrix organic light emitting diode displays based on thin, flexible metal foil substrates offer a novel approach to fabricate light, flexible and rugged displays. In our process, the use of metal foils allows devices to be fabricated at higher process temperatures yielding better device characteristics than glass or plastic substrates for superior display performance. Furthermore, the conductive nature of metal foil substrates compared to insulating substrates like glass or plastic makes them more efficient and light weight when used as the conductive substrate through the use of the conductive substrate as a global power electrode. We are implementing Active Matrix Organic Light Emitting Diode (AMOLED) displays on flexible stainless steel substrate using two different pixel circuit topologies and two different layout realizations. We will report on AMOLED array characteristics having either 2T2F or 4T4F pixel circuitry architectures. In the most simple scheme, a 2T2F pixel circuitry utilizes two p-type transistors to establish the OLED driving current. This circuit is realized with two different pixel layouts. The more traditional layout uses separate data lines, address lines and power supply lines. When using metal foil substrates such as stainless steel, we can exploit the high conductivity of the substrate to eliminate the need for power supply lines. Power is brought in to each pixel through contact holes to the metal substrate. Due to the potential variation in TFT performance across a large area array, it is necessary to account for changes in the TFT threshold voltage or mobility. The 4T4F circuit compensates for such changes in order to achieve higher uniformity of the display. This circuit topology utilizes two n-type and two p-type devices. It behaves like a current copy circuit that replicates the reference current in the data line through the OLED. As with the previous circuit, we are implementing two different pixel layouts. One with a power supply line, and another with contacts to the conductive substrate.

11:30 AM H3.8
LARGE AREA PLASTIC CIRCUITS FORMED BY THERMAL TRANSFER PRINTING. Michael Lefensfeld, John A. Rogers, Bell Laboratories-Lucent Technologies-Nanotechnology Division, Murray Hill, NJ; Graciela Blanchet, DuPont, Central Research & Development, Wilmington, DE.

Organic materials and polymers have shown the ability to play vital roles in robust, bendable transistors that can be printed over large areas at very low cost. These features are difficult to achieve with conventional electronic systems, which use brittle inorganic materials and high cost processing tools. In this talk, we describe a printing method that is capable of patterning, with micron resolution, all conducting layers of polymer circuits. The approach uses a laser transfer method to pattern, in a sequential fashion, the gate and then the source/drain electrodes directly on the substrate. The electrical characteristics of such organic devices depend on many variables, such as the intrinsic characteristics of the semiconductor, the dimensions of the electrodes, the dielectric thickness, and the various chemical and physical conditions that can occur between these elements. With printed polycarbonate (PAN) source/drain electrodes doped with single wall carbon nanotubes, ohmic contacts with small resistances can be formed with a wide range of organic semiconductors, including pentacene, FCuPc, n-OT, n-TT. This property is important because it shows that these printed, bottom contact devices can avoid the strong contact effects that often limit the performance of organic transistors when contacted in the linear regime. High mobilities of up to 0.3-0.5 square centimeters per volt second were achieved in these printed devices.

11:45 AM H3.9
FLEXIBLE ORGANIC FIELD-EFFECT TRANSISTORS FABRICATED BY THE ELECTRODE-PeELING TRANSFER. Tetsuhi Yasuda, Kazuhiko Fujita and Tetsuo Tsutsumi, Department of Advanced Materials Science, College of Engineering, Kyushu University, Fukuoka, JAPAN.

Much progress has been shown in the research and development in organic and polymeric field-effect transistors. In recent years, the potential for low-cost, lightweight and mechanically flexible devices, compared with the conventional silicon-based transistors. Especially, polymeric dielectric layer and plastic substrates have significant advantages over conventional glass or silicon substrate for a flexible device. However, when such flexible materials are used for organic electronic devices, one problem arises, e.g. it is difficult to
pattern the detailed metal electrodes by employing a conventional photoelectrochemical technique and etching process to the flexible substrate including organic semiconductor/polymers or polymeric dielectric layers. In the present study, we propose a novel way to fabricate a flexible organic field-effect transistor using electro-deposition instead of chemical reaction for the metal contact. The fine patterns of source-drain metal electrodes were formed on a solid substrate, where microleasing pattern process such as photolithography is not suitable. An organic dielectric layer (poly- n-methoxyaniline) was deposited by a chemical vapor deposition. Then patterned gate electrode was deposited using a shadow mask. On the top surface of the gate electrode, a flexible substrate was fixed and the stack of the flexible substrate/gate electrode/dielectric layer/source-drain electrode was peeled away from the solid substrate. The peeling process involved with the help of a self-assembled monolayer (silane coupling agent) to form a connecting buffer layer between the gold electrodes and the dielectric layer. Then an organic semiconductor material was deposited on the fresh peeled-off surface on the flexible substrate. The presence of polyvinyl alcohol used as the active semiconductor material. A good field-effect transistor characterization was shown even after the substrate was bent.

SESSION H4: ORGANIC ELECTRONICS - OLEDs
Chair: Bruce E. Grade
Wednesday Afternoon, April 23, 2003
Salon 14/15 (Marriott)

1:30 PM *H4.1
FLEXIBLE OLED DISPLAYS. Anna Chawang, Mark Rothman, Sokhnan Moe, Jeff Silverman, Mike Weaver, Richard Hewitt, Kamran Rajan, Mike Huq, and Julie Brown, Universal Display Corporation, Ewing, NJ.

Light-emitting display (OLED) technology is rapidly gaining momentum as the technology of choice for future flat panel display applications where low power consumption, low cost, and superior viewing ability are desired. The flexibility of both polymeric and small molecule OLEDs further enables the use of these materials in flexible displays. OLED displays on flexible plastic substrates have been demonstrated; the principal limitation of OLED displays on plastic, however, is their lifetime. The materials currently used in OLEDs are very sensitive to moisture and oxygen, and plastic substrates are generally too permeable to handle. We will describe recent advances in the packaging of our flexible OLED (FOLED™) displays, which are based on our highly efficient electroluminescent OLED (PHOLED™) technology. Various packaging approaches will be discussed along with their performance with respect to lifetime, flexibility, and manufacturability.

2:00 PM *H4.2

The field of organic light emitting diodes (OLEDs) has matured considerably within recent years and first products are commercially available. After a brief review on the improvement of individual OLEDs, we will introduce research towards the preparation of active matrix (P-MOLED), active matrix (A-MOLED) and full color displays. Different P-MOLEDs based on vacuum deposited organic compounds have been prepared by various fabrication techniques. We discuss n 2 inch organic display with 50x10 single pixels and 0.5x0.5 mm 2 pitch whereby cathode separation was achieved using photoresist barriers featuring a distinct undercut. In contrast to the widespread quasistatic evaporation in cluster-like deposition technologies, MOLED Displays originating from dynamic film-process will be shown. The superior aspects of in-line fabrication process concerning device characteristics such as cross-talk or contrast and fabrication parameters like material yield or throughput will be discussed. Due to the inherent limitations of multiplexing and in order to satisfy the need for large area, high resolution displays the basic concepts for an active matrix addressing scheme are dealt with. In this regard transparent and electrically inverted top-side emitting diodes will be demonstrated. The latter are advantageous for the incorporation of powerful n-channel thin film transistors in the A-MOLED driver backplanes. An all-organic smart pixel device comprising a single Pentacene based organic field effect transistor (OFET) and a conventional OLED has successfully been demonstrated. Furthermore, we present a new flash-sublimation technique for the spatial selective deposition of small organic molecules will be presented. We prepared OLEDs comprising thin-deposited Tris[8-hydroxyquinoline]aluminiun (Alq3) and Alq3 doped with DCm2 which demonstrate the suitability of this technique for the preparation of full-color displays based on small organic molecules.

2:30 PM *H4.3

Whereas most of the focus on organic light emitting diodes (OLEDs) is focused on carbon based organic materials, we are exploring Si-Si chain polysilane polymers for light emission. The emission in carbon based oligomers is controlled by n-π ** excitation, whereas transition, which is used to achieve white light mainly in the higher wavelength region of the visible spectrum. In polysilanes, however, the emission is controlled by a larger π-π ** transition, which could potentially provide UV to blue light emission. But, in spite of potential availability of emission in higher energy region, the issue of emission degradations is much more serious in polysilanes because of π-π bonds. In order to understand this degradation, a new co-polymer based on methylphenyl silane and phenyl-phenyl silane was prepared by Wurtz condensation reaction of dichloromethyl phenylsilane and dichlorodimethylsilane in appropriate ratio using a binary solvent system and phase transfer catalyst. Then the PL investigation was performed on spin cast films of thicknesses (measured by spectroscopic ellipsometry) varying between 30-100 nm. The degradation of luminescence from these films on various substrates, hydrophilic and hydrophobic surfaces (e.g. quartz and Si), is examined after excitation with light sources of several energies. The room temperature PL spectrum on these films shows a sharp emission at 365 nm when excited with a source of 325 nm. However, the PL intensity at 365 nm deteriorates exponentially with time. In addition, the peak of the PL spectrum shows a shift upward extended exposure to light. We have further examined the cause for this degradation by characterizing the material for its transmission behavior and changes occurring in it by GPC and NMR.

2:45 PM *H4.4
ORGANIC LIGHT EMITTING DIODES AND PHOTO_DETECTORS FABRICATED ON A POLYMERIC SUBSTRATE FOR FLEXIBLE OPTICAL INTEGRATED DEVICES. Yutaka Ohmori, Osaka Univ, Collaborative Research Center for Adv Sci Tech (CRTs), Osaka, JAPAN.

Organic light emitting diodes (OLED) and organic photo detectors (OPD) have been investigated for optical integrated circuits. High-speed operation of the devices has been investigated and realized. OLEDs have been fabricated on an indium-oxide (ITO) coated polymeric substrate with silicon dioxide and silicon nitride buffer layers. The OLED consists of dimine derivative (α-NPD) layer as a hole-transporting layer, rubrene doped in 8-hydroxyquinoline aluminum [Alq3] layer as an emissive layer, and Alq3 layer as an electron-transporting layer terminated with indium tin oxide (ITO) buffer layer. The device emits yellow light centered at 560 nm, and the maximum emission intensity reaches as high as 50mW/cm2. The optical pulse of more than 100 MHz has been generated from the OLEDs, which are compatible with the glass substrates fabricated on a glass substrate. Using several emissive materials, such as α-NPD or porphin derivative, optical pulses as high as 100 MHz have been generated. The OPD, which consists of superlattice structure of trityl phthalocyanine and fluorinated metal phthalocyanine as photo-absorbing layers, have been fabricated and investigated. As decreasing the individual layer thickness of the phthalocyanines, the response frequency increased to several MHz under reverse bias conditions. Optical transmission experiments of moving picture signals have been performed utilizing the OLEDs. The details of the device characteristic have been discussed for both devices fabricated on a polymeric and a glass substrate, for comparison.

SESSION H5: LARGE AREA PRINTING AND DEPOSITION
Chair: Bruce E. Grade
Wednesday Afternoon, April 23, 2003
Salon 14/15 (Marriott)

3:00 PM *H5.1

The evolution of consumer electronics toward low-cost, low-power and even disposable devices creates new challenges for manufacturing on flexible, plastic substrates. Processing temperatures are often limited...
to 300°C and below. Circuit patterning by plasma etch is constrained by cost objectives and compatibility with the substrate materials. The present work describes an emerging method for depositing directly photopatterned metal oxide thin films from a metal-organic precursor. The method described, Photochemical Metal-Organic Deposition or PMOD, can be used in lieu of plasma etch to pattern device elements. Alternatively, PMOD can be used to deposit a patterned hard mask for high plasma etch selectivity to the substrate below. Our initial studies have focused on the patterning of TiO₂ in a model system for both hard mask applications, and as a high-k dielectric. Precursors are known to include a variety of hexametacarbonyl and acetylene coordinate complexes. In these studies, the precursors are deposited on silicon wafers by spin coating from a casting solvent. Patterns are formed using a contact printing mask with a broadband deep UV light source. Patterns can also be created using electron beam direct write. Results are shown for TiO₂ films patterned optically to generate features down to 0.5μm. Edge definition and pattern stability are optimum following a partial exposure, which is then removed by the precursors to the extent that differential solubility of the converted pattern allows the image to be developed. Full conversion of the pattern is completed in a subsequent step. The deposited metal oxide films can be patterned or etched using a process similar to that of photolithography, and is different for a hard mask than for a high-k dielectric, respectively. The work presented here is intended to serve as a model system for the development of other deposition materials and processes used for the fabrication of flexible electronics, including metal conductors, transparent conductors, and dielectric films.

3:45 PM H5.2 ELECTROCHEMICAL PATTERNING OF CONDUCTING POLYMER LAYERS: A NOVEL TECHNOLOGY FOR “PRINTING” POLYMER ELECTRONIC DEVICES. Payman Taheri1, Tommi Remonen2, Lars-Olof Hemmerdal2, Anna Malmström2, Jessica Hill3, David Niskanen1, Luca Leonders3, Thomas Küeger3,4, and Magnus Berggren2. 1Dept of Science and Technology, Linköping University, Campus Norrköping, Norrköping, SWEDEN; 2Acero AB, Norrköping, SWEDEN; 3Agra Genvert N.V., Mortsel, BELGIEN.

Within the context of polymer electronics, a number of additive and subtractive schemes have been proposed for realizing conducting polymer patterns. In the additive methods, conducting polymers are deposited on the substrate with some printing technology. In contrary to this, in subtractive methods, the selective removal or de-activation of certain areas of a uniform polymer layer, which results in the formation of the desired polymer pattern. Whereas, subtractive patterning is usually based on lithography, resulting in a high production rate processes based on printing technologies allow for inexpensive and high volume production processes for the patterning and assembling of polymer electronic devices. Here we present a novel, subtractive approach, which is based on the local destruction of the electrical conductivity in layers of conducting polymers by an irreversible, electrochemical overoxidation process. Experiments have been conducted with PEDOT:PSS, but the method is applicable on other conducting polymers as well. The additive and subtractive layers are defined by a photolithographic mask allowing for high pattern resolution (we have demonstrated in the line widths below 10 micrometers). Alternatively, the contact area between the conducting polymer layer and a pen plotter (containing the electrolyte and metal electrode) can define the deposition area. In combination with a PC-controlled large area plotter, this “digital printing technology” is a highly versatile and flexible laboratory tool for the rapid prototyping of polymer electronic devices. PEDOT:PSS conductivity ratios between pristine and over-oxidized PEDOT:PSS approach 10⁹ and we will discuss the influence of the process parameters, such as chemical composition and concentration of the electrolyte, applied voltage, patterning speed, etc… on the patterning process.

4:00 PM H5.3 CAPILLARY DRIVEN SPREADING OF DIRECTLY PRINTED POLYMER LAYERS USED FOR FLEXIBLE AND PRINTED ELECTRONICS FABRICATION. Scott M. Miller and Sandra M. Troian, Department of Chemical Engineering, Princeton University, Princeton, NJ; Sigurd Wagner, Department of Electrical Engineering, Princeton University, Princeton, NJ.

A variety of printing techniques can be used to directly pattern thin films of elect, resist polymers, or solutions or suspensions of functional device materials. Most of these techniques rely on fluidity of the ‘ink’ to achieve good pattern transfer. The ink commonly remains liquid-like for some period of time before it is solidified. In this time, capillary driven spreading of the printed structures can occur, leading to a loss of pattern fidelity and spatial resolution, and possibly to off-design electrical performance. In general, circuit patterns are non-equilibrium structures, and so such distortion must always be anticipated. We compare experiments of spreading of liquid polymer mask material driven by capillary pressure and in the presence of underlying features to theoretical modeling and computer simulations. These comparisons lead to a general framework for analysis of printed structures that can be applied to a number of printing technologies that utilize fluid inks.

4:15 PM H5.4 EFFECTIVE JET PRINTING OF ORGANIC SEMICONDUCTING POLYMERS. Kiser E. Paul, William S. Wong, Steve Reedy, Palo Alto Research Center (PARC), Palo Alto, CA.

Organic semiconductors are an attractive alternative to conventional inorganic materials because of the ability to process the organic materials from solution, apply them to flexible substrates using lower temperatures and at a lower cost. Direct writing of these materials is the potential to reduce processing steps and material waste. While printing of semiconductors for organic light emitting diodes (OLEDs) is well known, little has been reported on printing semiconductors for organic thin film transistors (OTFTs). We have developed a process to fabricate OTFTs and arrays, using jet-printing to eliminate all photolithographic patterning steps. Active layers of the polymeric semiconductor poly-9,9-diocylfluorene-co-bithiophene (F8T2) are jet-printed to form the TFTs. Many factors are found to affect the characteristics of TFT devices having a jet-printed semiconductor layer, including the substrate temperature, surface energy, printing direction, device geometry, and drop size and overlap. We will discuss the printing conditions that lead to performance similar to that of devices fabricated by spin coating.

4:30 PM H5.5 INKJET PRINTING OF CONDUCTORS AND DIELECTRICS FOR SOFT ELECTRONICS. Yuka Yoshioka, Paul Culver and Ghassan E. Jabbour, University of Arizona, Tucson, AZ.

Inkjet printing has been used for depositing materials in order to build devices or structures. For multiple layer printing we need to be able to deposit inks such that the new liquid ink does not mix with previous layers. If a single solvent, or dispersing medium, such as water is to be used, we must be able to chemically solubilize the early layers in order to print onto them. This might be done by thermal or photo-crosslinking or by co-depositing two reactive inks. A necessary part of the building block will be removal of unwanted reaction products by a washing step. This requires that the printed layers must also adhere to the substrate and each other. Printing has been carried out using both thermal and piezoelectric printheads attached to a computer-controlled 3-axis (xyz) stage. This paper will describe efforts to print and immobilize dielectrics, metal conductors and electronics on polymer gels.

4:45 PM H5.6 NANOIMPRINT LITHOGRAPHY AND NANOWIRE ELECTRONICS ON FLEXIBLE PLASTIC SUBSTRATES. Michael C. McAlpine and Charles M. Lieber, Harvard Univ, Dept of Chemistry, Cambridge, MA.

The merger of nanoscale devices with the flexibility and low cost of plastics could enable a broad spectrum of electronic and photonic applications, although difficulties in lithographic processing of plastics at the nanoscale has limited exploration of this potential. Here we describe the use of nanoimprint lithography for the production of a wide range of nanoscale designs on flexible organic substrates using a simple, room-temperature approach. This involved the production by electron-beam lithography of an inorganic stamp with nanoscale oxide features which was then fastened to a handheld press and physically molded into a piece of plastic coated with our chosen imprint resist. We utilize this development to create pre-patterned features for use in bottom-up assembly of semiconductor nanowires, which are chosen to provide specific electronic and/or photonic function. The solution-based assembly of such wires allows for an additive hierarchy of devices on these inexpensive, lightweight materials. Specifically, we aligned doped silicon nanowires onto our nanoimprint-patterned metal gate to create fast, flexible thin film transistors. We have also employed direct-handbagging semiconductor nanowires to form cross-arrays of light-emitting diodes. These key functioning elements constitute a robust new catalog of high-performance, low-power ‘plastic’ devices. Potential applications and implications for the future will be discussed.

SESSION H6: POSTER SESSION

FLEXIBLE ELECTRONICS

Chair: Babu R. Chalamah
Wednesday Evening, April 29, 2008
8:00 PM
Salon 1-7 (Merricot)

H6.1 A STUDY OF THIN METAL FOILS FOR FLEXIBLE...
ELECTRONIC APPLICATIONS, Sambit K. Saha, Themis Afentakis, and Milind K. Hatals, Display Research Laboratory, Department of Electrical and Computer Engineering, Lehigh University, Bethlehem, PA; Apostolos T. Voutsa, Sharp Laboratories of America, Camas, WA.

Thin metal foils are lightweight and non-brittle materials. They can also withstand high temperature processing under controlled atmospheres. Hence they are potentially attractive alternatives to quartz and polymers as flexible substrate materials in microelectronic device applications that demand a high degree of ruggedness. High temperature processing enables fabrication of thin film transistors with superior device characteristics. This paper discusses the viability of a variety of approaches towards improving the performance of such transistors. Examples of fabrication where high process temperatures were used. Working transistors were fabricated on thin SiO2 and Si3N4 devices, respectively, have been achieved. Surface roughness of the substrate is an important characteristic that has a significant effect on device performance considerably, hence they have to be controlled prior to device fabrication. The feasibility of using a variety of polishing procedures on available substrate materials such as stainless steel, Kovar, Inconel alloy, Titanium and Molybdenum have been examined in the light of x-ray photoelectron spectroscopy, scanning electron and atomic force microscopy data.

H6.2 Abstract Withdrawn.

H6.3 TETRAHEDRAL AMORPHOUS CARBON FILMS FOR ENCAPSULATION OF FLEXIBLE NEURAL STIMULANT MICROELECTRODE IMPLANTS, Benoko P. Canham, Modhuk Buxit, University of Alabama at Birmingham, Dept of Physics, Birmingham, AL; Robyn Swititz, Carmen Scholz, University of Alabama at Huntsville, Dept of Chemistry, Huntsville, AL; Douglas B. Shire, Cornell University, School of Electrical Engineering, Ithaca, NY.

Implantable microelectronic devices capable of neural stimulation present a promising pathway to restore basic neural functions in humans where non-regenerative specialized tissue responsible for signal transmission has been permanently damaged. Device flexibility is essential because gap-free alignment within the host tissue is necessary and bending often occurs during implantation. Although molecular electronic devices are desirable for this application, their realization awaits significant advances in this field. Alternatively, generation of neurostimuli are within reach of current integrated circuit technology. Challenges of performance and reliability issues arise, however, when these flexible prosthetic devices are implanted into soft tissue and exposed to bodily fluids. Polyimide, the well-established polymeric standard for encapsulation of microelectronic circuits, is hydrophilic enough to allow significant rates of water vapor penetration, which leads to corrosion and device failure. Tetrahedral amorphous carbon (ta-C) is an attractive candidate for protective encapsulating layers on polyimide devices because it possesses excellent mechanical properties, low stress, inertness, and biocompatibility. We have explored this encapsulation approach by creating 100%-intrinsic-thick ta-C films by pulsed laser deposition on polyimide substrates at room temperature. Pyrolytic graphite targets were ablated using a 135-ps excimer laser (308 nm) in high vacuum at 10-5-10-6 mHg. Excellent adhesion to the polyimide substrate and Raman measurements confirmed the tetrahedral carbon nature of films. Atomic Force Microscopy indicates high-quality, dense, pinhole-free ta-C films at optimized 83 °C temperature and 3.6 cm/s deposition rate. Nanodentation measurements have yielded hardness of 29 GPa and Young's modulus of 250 GPa. We will show how we have used this approach to one flexible tridimensional implant simulator and will report on their in vivo biocompatibility. We will also discuss other serious materials issues such as the possible negative effect of intrinsic stress present in ta-C on device performance and the stability of ta-C/polyimide interface.

H6.4 Abstract Withdrawn.

H6.5 ELECTRONIC CIRCUIT COMPOSITION AND STRUCTURE OF WARP AND WOOF FOR A NOVEL HYBRID OPTOELECTRONIC INTEGRATED SYSTEMS WITH TEXTILE STRUCTURES. Shigekazu Kuniiyoshi and Kuniko Tanaka, Chiba Univ, Dept of Electronics & Mechanical Engineering, Chiba, JAPAN.

A new integrated circuit concept that forms electronic equipment by the textile structure using the flexible fiber equipped with the field effect transistor, the light emitting diode, the wiring pattern, etc. is proposed. In this report, the structure of the filamentous body as a basic structure of the cloth with various electronic functions was examined. A plastic optoelectronic fiber, the glass fiber, and the insulation coating thin metal line which is enough flexible to weave the cloth are used as a base substance of the string for cloth. The warp and the woof are located up and down alternately in textile structure. The pick at which the warp crosses with the woof is used as electric connection in the new integrated circuit. The connection pad adjacent each other on the warp or the woof becomes the relation of the front reverse side. The field effect transistor and the electrode pattern for wiring 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 the warp, and the electrode pattern for wiring and the pads for connection are formed on the woof. The circuit composition and a concrete structure of the warp and the woof will be discussed, and it is shown that all logic circuits and flip-flop circuits can be constituted using only five kinds of thread.

H6.6 LOW TEMPERATURE PECVD SILICON OXIDE FOR DEVICES AND CIRCUITS ON FLEXIBLE SUBSTRATES, Mark Maitland and Andrei Sazonov, Univ of Waterloo, Electrical and Computer Engineering Dept, Waterloo, Ontario, CANADA.

The aim of this research is to develop low temperature gate dielectric/patterning layer for μc-Si and poly-Si based devices and circuits compatible with plastic substrates. The PECVD silicon oxide films were fabricated from mixed silicon precursor mixture. The optimum conditions for silicon nitride formation were 250°C, 120°C and 75°C. Helium, argon, and nitrogen were used as diluent gases to optimize density, mechanical stress, uniformity, and electronic properties. Chemical composition and bonding in the films were studied by FTIR spectroscopy. The absorption peak at 1075-1080 cm-1 observed in the spectra of all films corresponds to SiO2 stretching mode. No presence of SiH stretching or NH-stretching vibrations was found in the FTIR spectra. Film uniformity was varied from 2% to 6% for 6" x 6" area. The deposited films have compressive stress varied from 0.063 GPa to 0.117 GPa. Respective film density is in the range from 1.35 g/cm3 to 1.69 g/cm3. The electronic properties were studied on MOS capacitors with 200 nm thick SiO2. The dielectric permittivity was in the range between 2.03 and 3.57. The dielectric breakdown at 9 V/cm was observed for the films deposited at 120°C. The films deposited at higher temperatures are characterized by lower leakage current density, which was 3.7 x 10-10 A/cm2 for the sample deposited at 250°C, 9.1 x 10-9 A/cm2 for 120°C, and 2 x 10-8 A/cm2 for 75°C at 5 V/cm. The μc-Si and μc-Si based TFTs were fabricated using low temperature oxide gate dielectric. TFT performance will be presented and discussed.

H6.7 Abstract Withdrawn.

H6.8 DEVICE GEOMETRIES FOR THIN FILM TRANSISTORS OF NANOCRYSTALLINE SILICON, J-Chian Cheng and Sigurd Wagner, Department of Electrical Engineering, Princeton University, Princeton, NJ.

Nano-crystalline SiC can be deposited over large areas at low substrate temperature and is capable of p and n channel operation. Therefore it is a semiconductor for fully-integrated active matrices. To reach technology readiness the thin film transistors (TFTs) made of nanocrystalline silicon (nc-Si:H) need optimized materials and processes for the channel, the gate dielectric, and the source/drain contacts. They also need experiments with unconventional device geometries. We describe our recent research of the effects of the peculiar properties of nc-Si:H on transistor geometries and on certain process steps. TFTs of nc-Si:H are made as top gate devices to take advantage of the crystalline portion of the nc-Si:H film on the channel film is grown to a thickness at which the crystalline columns just coalesce at the surface. The continuous crystalline surface layer so formed hosts the >10µm thick TFT channel with high hole and electron mobilities and high ON currents. The OFF current is set by conduction through the entire cross section of the channel layer. High ON combined with low OFF currents are obtained from growing the thin amorphous nc-Si:H in the crystalline in their surface. Either ohmic (top) or staggered (bottom) source/drain contacts are usable. The most critical step in making nc-Si:H TFTs is etching through the doped contact layer to the surface of the channel film. The surface of the channel film in the present no-Si:H film on the channel film in the gate region defines differently from the contact regions, growing a new layer in the gate region improves TFT performance. The important mask alignment step also varies with each of the TFT geometries. Prospects are good for further enhancement of TFT performance coming from experiments with TFT geometry.
H6.9
Transferred to H10.10

H6.10
THERMAL VIBRATION IN \( n_{\text{AgI-3AgO-2V_2O_5}} \). A. Tomin, Y. Higuchu, M. Arum, T. Sakanuma, Department of Physics, Ibaraki University, Mito, JAPAN; H. Takashiki, Faculty of Engineering, Ibaraki University, Hitachi, JAPAN.

In recent decades, much attention has been paid to superionic conducting glasses because of their high ionic conduction and application to batteries and other electrochemical devices. Among these, AgI glasses are easy to prepare and they possess high ionic conductivity near room temperature. In order to inspect the thermal vibration of atoms in superionic conducting glasses, X-ray diffraction measurement of superionic conducting glasses \( n_{\text{AgI-3AgO-2V_2O_5}} \) has been performed at 12, 100, 200 and 250 K.

Appropriate amounts of AgI, AgO and V_2O_5 were mixed and melted at 600°C to 1000°C. The sample was poured on a stainless-steel block and pressed by another block. By the method, rapid quench and glass formation of a thin sample can be realized. X-ray intensity data were collected using \( \mu \)-Ko radiation for 80 s per step at 0.1° intervals over the 2θ range of 5° to 115° by a step-scan mode.

The profiles of the X-ray scattering intensity for superionic conducting glasses are discussed with the theory including the thermal displacements of atoms. The temperature dependence of characteristic features of observed structure factor \( S(Q) \) of glasses has been obtained. It was observed that the effective Debye-Waller temperature parameter \( B \) increases with the increase of temperature and also increases with AgI concentration.

H6.11
LOW TEMPERATURE COPPER-INDUCED CRYSTALLIZATION TECHNIQUE FOR GERMANIUM ON FLEXIBLE PET. BY MEANS OF MECHANICAL COMPRESSIVE STRESS. Bahman Holmoukhoon, Dariush Shaberi; Shahs Mahrjandeh, Ali Khakifarzoo, Arash Akhavan, Tehran Univ, Dept of Electrical and Computer Engineering, Tehran, IRAN; Michael Robertson, University of Arkansas, Wolfeville, NS, CANADA.

Mechanical compressive stress has been exploited to devise a low temperature metal-induced crystallization technique. Stress-assisted copper-induced crystallization of amorphous germanium has been performed on flexible PET substrates at temperatures as low as 130°C. Sample preparation was performed by \( \mu \)-beam deposition of Ge and thermal evaporation of Cu at a base pressure of \( 1x10^{-5} \) torr and a substrate temperature of 100°C, forming a Ge-on-CuGe structure with thickness of 500 nm on 500 nm on 120μm thick PET. Compressive or tensile stress was applied by inward bending or stretching the flexible substrate, at temperatures ranging from 130 to 180°C. During thermal treatment at a temperature of 150°C and an equivalent film thickness, the stress thermodynamically needed for Ge layer fracture was monitored, evidencing a three orders of magnitude drop after 90 minutes. A stress resistance of 25 KPa and a hole mobility of 111 μm/Vs was obtained for this sample, measured with Hall effect. XRD, TEM and SEM analyses were also used to verify the crystallinity of the samples. XRD reveals that \( < 220 > \) and \( < 400 > \) exceed the Ge in the partially crystalline PET background. TEM diffraction pattern corroborates the polycrystalline structure of the Ge layer. SEM shows granular surface morphology with an average size of 0.2μm, indicating an enhanced nucleation at buckling sites, where compressive stress is more densely accumulated. These buckling sites are located in parallel lines with 50μm separations. Minimizing crack density was obtained by patterning the amorphous Ge layer before thermo-mechanical treatment. These polycrystalline Ge films were used to fabricate flexible depletion-mode Ge-TFTs on PET with polystyrene gate dielectric and chromium gate metal, showing an ON/OFF ratio of 10^6. Polystyrene was used to minimize gate leakage current caused by crack formation, induced from Ge into the dielectric layer. The resulting leakage current is still high and its minimization is under study.

H6.12
A NOVEL METHOD FOR CONSTRUCTING STRETCHABLE METALLIZATION. Jocelle Jones, Stephen Pericich, Lucero, Sigurd Wagner, Princeton University, Department of Electrical Engineering and POEM, Princeton NJ; Zhigang Suo, Princeton University, Department of Mechanical and Aerospace Engineering, Princeton, NJ.

Stretchable metallization is a key to the fabrication of 3D conformal circuits and electrotextiles. The basic concept for reversibly stretchable metallization is a corrugated strip of thin-film metal that is expanded by relief wedge and relieves back upon relacing. The maximum elongation is reached when the stripe is stretched flat. Very recently, three approaches have been demonstrated to fabricate such metallization by deposition of thin films on elastomeric substrates. (1) A film deposited with built-in stress on a flat substrate can be made to relieve by stretching a wave, which can be stretched further. (2) When a film is deposited on a wavy substrate surface it becomes a wave. (3) The substrate is stretched prior to deposition of the film, which upon release relaxes to a wave. We have introduced techniques (1) and (3), and presented them in this paper on the universal film-applicator technique [3]. We carried out experiments with substrate width and elongation, gold metal line width and thickness, and measured the film structure, amplitude and wavelength, as well as electrical conduction loss in relaxed and various stretched states. So far we have strained the substrate by 8 percent while maintaining the initial conductance of the film, which is approximately 3 times that of an ideal gold conductor. We have found a rich variety of microscopic and macroscopic film morphology. We will present the theory of wave interconnects, their fabrication and electromechanical performance, and data on film structure.

H6.13
Abstract Withdrawn.

H6.14
LIGHT TRAPPING IN AMORPHOUS SILICON SOLAR CELLS. Vanessa Terrazon-Daujard, Joelle Guilet, Marion Ferrerol, Arvind Shah, Institute of Microelectronics, University of Neuchâtel, SWITZERLAND; R. Morf, PSI (Paul Scherrer Institute), Villigen, SWITZERLAND; O. Perrioux, TSI (Traitement du Signal et Instrumentation), Jean Monnet University, Saint-Etienne, FRANCE; F. Diego, VHF Technologies S.A., ELIN, Le Lock, SWITZERLAND.

In order to simultaneously decrease the production costs of thin film silicon solar cells and obtain higher performances, the authors have studied the possibility to increase the light trapping effect within thin film silicon solar cells deposited on flexible plastic substrates. In this context, different nano-structure shapes usable for the back contacts of amorphous silicon solar cells on plastic substrates have been investigated: random textures and gratings. Photon trapping has been used to produce randomly textured plastic surfaces. Varying the etching parameters changes the texture size of the surface. The optimization of such back reflectors is so far empirical. Gratings constitute a well-known optical technique and their light trapping effect can be optimized by simulation. They are well adapted to mass production because they can be obtained by directly embossing the plastic substrate. Spectrometry, AFM and SEM measurements have been performed on many different types of back contacts and the most interesting ones have been tested in cells.

A first conclusion is that neither the traditional “Haze factor” determined in air for a wavelength of 650nm nor the “rms roughness” of the surfaces are sufficient as criteria to optimize the back contact roughness for light trapping in cells. The shape of grains is a further essential criterion.

Experimentally, randomly textured back reflectors have a substantial effect on light trapping in amorphous thin film solar cells. The study has led to so far obtained current densities of 14% for solar cells deposited on randomly textured polyethylene terephthalate (PET), and 16% for solar cells deposited on periodic grating structures (glass substrate), compared to a corresponding conventional solar cell co-deposited in a flat mirror reflector. For cells on PET with 6% stabilized efficiency have until now been obtained.

H6.15
GE NANOPARTICLE SIMULATIONS FOR EFFICIENT, FLEXIBLE, THIN-FILM PHOTOVOLTAICS. Song H. Yang and Raju J. Berry, Air Force Research Laboratory, Materials and Manufacturing Directorate, AFFL/MEL WPAB, OH.

Nanoparticles are known to melt at temperatures well below the bulk melting point. This behavior is exploited for the low temperature recrystallization of Germanium to form large-grain thin films. Bulk properties of Germanium structures (diamond, BCS and ST12) were computed by a density functional pseudo-potential method using a local orbital basis set. The computed lattice constants, bulk moduli, and internal atomic positional parameters were found to agree well with experimental results and with other plane wave basis calculations. MD simulations using both empirical potentials and density functional pseudopotentials were conducted to study melting temperatures, coalescence, and energetics of Ge microcrystals as a function of size and chemical termination. Results of these nanoparticle simulations will be utilized to guide experimental efforts aimed at the production of near-single crystal semiconductor thin films on flexible, low temperature substrates.

H6.16
Abstract Withdrawn.
Flexible magnetic lithography is a process qualitatively analogous to contact optical lithography which transfers information from a patterned magnetic mask (log of optical photomask) to magnetic media (analog of photosensitive materials), and for applications in instantaneous parallel magnetic recording. The magnetic mask consists of patterned soft magnetic material (FeNiCo, FeCo) on a flexible plastic substrate, typically Polyethylene Naphthalate (PET). 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 soft magnetic material, thus utilizing the magnetic mask offers superior compliance to magnetic media which is likely to have imperfections and surface particular contamination. Although magnetic in physical nature, flexible magnetic media draws interesting parallels to flexible electronics, especially in the challenges of fabrication of sub-micron patterns on thin flexible plastic substrates. We fabricated samples of sub-micron patterned FeCo and FeNiCo magnetic masks on PET substrates by using combined illumination/relief process of PET films. Results indicate, especially in silicon or quartz were initially illuminated with PET films and processes used standard fabrication procedures. After completing magnetic mask device fabrication, PET films were released from the rigid substrate. We successfully transferred patterns from magnetic masks to hard disk CrPtCo-based magnetic medium. The details of the method, including the physics of the magnetic lithography pattern transfer, fabrication of the magnetic mask on flexible PET substrates, illumination and release of PET films, and magnetic force microscopy (MFM) images of the magnetic transition patterns are reported.

8:45 AM H7.2
ZnO THIN FILM TRANSISTORS FOR FLEXIBLE ELECTRONICS.

One of the challenges for flexible electronics is finding a semiconductor compatible with low temperature processing required by plastic substrates. A common plastic, such as polyethylene terephthalate (e.g., Mylar-T), typically limits device processing to much less than 150°C. One consequence is that electronics based on Si, even amorphous Si, may be incompatible with plastic substrates. That, in part, has flexed a broad interest in organic semiconductors as new low-cost, low-temperature, flexible substrates for electronic devices, especially for thin film transistors (TFTs). However, the electronic properties of most organic semiconductors are inferior to those of amorphous Si, and organic materials frequently degrade in normal atmospheric conditions, requiring protection strategies. In contrast, a stable inorganic semiconductor compatible with temperature sensitive substrates, and with electronic properties equivalent to amorphous Si would enable electronics on a variety of flexible substrates. We show that ZnO thin film transistors by rf magnetron sputtering on substrates held near room temperature. The resistivity of films depends on the oxygen partial pressure during sputtering and underwent abrupt transitions from semiconducting (~10^{-6} cm) to semiconductor (~10^{-5} cm) at 10^{-1} mTorr. We investigated the properties of TFTs devices made in the vicinity of this transition. The best devices had finite effect mobility of ~2 cm^2/Vs and a threshold voltage of -0.1 V. These ZnO films had resistivity -10^{-5} cm, with high optical transparency (~0.8 % for wavelength > 400 nm) and compressive stress < 0.5 GPa. The combination of transparency in the visible, excellent transistor characteristics with low processing temperature, and the prospect of p-type ZnO TFTs for complementary logic applications, make ZnO thin film transistors attractive for flexible electronics on temperature-sensitive substrates.

9:00 AM H7.3
PULSED LASER DEPOSITION OF ZnO THIN FILMS AND NANOSTRUCTURES ON FLEXIBLE SUBSTRATES FOR UV APPLICATIONS.
Masashi Misawa and Renato P. Pucci, University of Alabama at Birmingham, Dept. of Physics, Birmingham, AL.

Zinc Oxide (ZnO) is a promising wide bandgap semiconductor for applications in UV light emitting devices and sensors. Although significant advances in bulk and epitaxial growth, p-type doping, and production of high quality contacts are still needed to enable ZnO as a competitor for large scale UV applications, some of its characteristics suggest it may be a suitable material for integration into flexible electronics platforms. Its compatibility with low temperature deposition, the success of ZnO nanoscale synthesis, its anticipated biocompatibility, and the possibility of using a pulsed laser deposition (PLD) film formation indicate that ZnO may become an important route to deliver high functionality in flexible electronic devices. In order to assess the potential of ZnO in flexible electronics applications we created conformal and nanostructured ZnO films on polyimide substrates for evaluation of structural and optical properties. Specifically, we have used pulsed laser deposition (PLD) to deposit ZnO films with...
thickness between 100 nm and several microns on polycrystalline substrates at room temperature. A KrF excimer laser (398 nm) operated at 50 Hz with fluences of ~1 J/cm² was used to sinter film deposition under O₂ atmosphere at a pressure of 10⁻⁴ Bar. Good flexibility characterized the obtained layers and x-ray diffraction measurements show that films present all reflections of hexagonal ZnO. Atomic force microscopy analysis on the films revealed highly textured surfaces with RMS roughness in the 200 nm range. Improvements in adhesion strength are sought, however, as most of the films adhered poorly to the polycrystalline substrates. We will discuss luminescence measurements on the films in addition to the complex interfacial phenomena exhibited in our samples. In addition, we will report on how we have used a novel PLE-inspired approach known as Nanoparticle Beam Pulsed Laser Deposition (NPBLD) to deposit ZnO nanoparticle on polycrystalline substrates to further enhance the photoresponse of the devices.

[Research funded by NSF-DMR-0106698]


During the last years, much attention has been attracted by organic polymer electronics. Particularly organic field effect transistors are a topic of intensive investigation. Due to the relatively high sensitivity of active polymer functional layers with respect to diffusion of, e.g., water, organic integrated circuits have to be protected using suitable barrier coatings. The diversity of possible applications and designs such as passive or active FET architectures, results in a need for different forms of photo-processing, of which photopolymerization is one example. This study introduces a new process for the fabrication of inorganic-organic hybrid polymers (ORMOCER™), of which various applications have been synthesized via a hydrolysis/polycondensation reaction. The reaction is driven by an organic cross-linking of the organic functional groups such as methacryl, styryl, or epoxy. Thus, the materials can be patterned by UV lithography. The synthesis can be controlled such that the resulting materials show excellent water vapor permeation values which is a key property for the applications. Examples on the dependence of the resulting properties on various factors such as the type of monomer, the concentration, the photo-curing conditions, and the UV dose were investigated. In addition, the influence of the photopolymerization process on the physical properties of the resulting films was studied.

SESSION H8: NOVEL DEVICES AND CONCEPTS
Chair: Jin Jang
Thursday Morning, April 24, 2012
Salon 14/15 (Marriott)

10:15 AM H8.1 NANOCONDUCTION DIRECT FABRICATION OF ALL-INORGANIC LOGIC ELEMENTS AND MICRO-ELECTRO-MECHANICAL SYSTEMS FROM NANOPISTOLS

PRECURSORS: Eric J. Wilhelm, Joseph Jacobson Massachusetts Institute of Technology, Meddelin, Cambridge, MA.

The refined 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 advances in the printing of such nanoparticle inks.

10:30 AM H8.2 Abstract Withdrawn

10:45 AM H8.3 HIGH-Quality INKJET-PRINTED MULTILEVEL INTERCONNECTS AND INDUCTIVE COMPONENTS ON PLASTIC FOR ULTRA-Low-COST RFID APPLICATIONS

Sven Moler, Daniel R. Breding, Daniel, C. Haberey, and Vivien Sohnenrann, University of California, Berkeley, Department of Electrical Engineering and Computer Science, Berkeley, CA.

Printed electronics is widely considered to be a crucial step to achieving ultra-low-cost RFID circuits for use as barcode replacements in consumer products, since it eliminates the need for lithography, vacuum processing, and the use of low-cost electrophotographic manufacturing. While there have been some demonstrations of printed organic transistors to date, there has been little work on the associated passive component and interconnection technologies required to enable the development of RFID circuits. In particular, low-loss inductors are critical to achieve the low-Q inductors necessary for RFID. Last year, we reported on the development of a plastic-compatible printed inductive element technology using ammoxetol gold nanoclusters. Here, we report on robust interconnect and inductive component technologies that have been developed making use of the above materials library. We demonstrate inkjetted conductors on plastic with sheet resistances as low as 0.03 Ω/sq, with conductivity greater than 70% of bulk gold. This conductor technology therefore provides the low-cost solution for printed RFID circuits, as well as being reported to date. This was achieved by study and optimization of the solvent and jetting parameters to control the resulting droplet size, droplet kinetics on the air and on the surface of the plastic, and final film morphology. We will report on the mechanisms for optimization and control of the same. We also demonstrate a bridging technology based on an inkjetted polymide interlayer dielectric. Using this process, we demonstrate various complex multilevel interconnect structures including bridges, tapped planar spiral inductors and multilevel planar balun crossovers. We will demonstrate the use of this technology to demonstrate single-bit passive RFID tags, high-Q inductors, and various other passive components.

11:00 AM H8.4 FLEXIBLE MECHATRONIC SYSTEM OF ELASTOMER ELECTROACTIVE ACTUATOR ADDRESSED BY THIN FILM PHOTOCOCONDUCTOR SWITCH


In microelectronics, thin film integrated circuits drive displays, sensors and actuators on flexible and deformable substrates. We demonstrate the first mechatronic system made of an electro-active polymer (EAP) based actuator, driven by thin film photovoltaic high voltage switches and fabricated on a plastic foil substrate. The actuator are made of a dielectric elastomer that deforms and expands under high voltage. Its geometry is designed so that a small rigid shaft can be linearly translated during the electrostrictive deformation of the elastomer to make a linear actuator. Such linear actuators can be used for a variety of applications such as relay maps and other novel displays. The EAP is connected to the power supply through a phototransistor switch of hydrocarbon-based phototransistors (P-TH). The phototransistor is activated by exposing it to light. We implemented the thin-film switches on flexible and transparent polymer ( Kapton®) substrates. The amorphous silicon is made by Plasma Enhanced Chemical Vapor Deposition (PECVD) at 150°C substrate temperature. Aluminum and copper leads are deposited on top of the n+Si<sub>H</sub> layer by thermal evaporation. Finally the n+Si<sub>H</sub> photon switches are integrated onto the elastomer membrane. We make a linear of five switch/actuator cells. We drove the array with switching speeds up to 100 Hz and voltages up to 20 V across the actuator. We use the fabrication of the thin film photocatalysts, their integration into the EAP module as well as measured and modeled electrical parameters and responses of the EAP/photocatalyst system.

11:15 AM H8.5 NONVOLATILE MEMORY EFFECT ON ORGANIC CIRCUITS

Qiqi Gu, Liping Bu, and Yang Fang, Dept. Materials Science and Engineering, UCLA, Los Angeles, CA.
Electrical bistability is a phenomenon in which a device exhibits two states of different conductivities at the same applied voltage. In this presentation, we report an organic electrical bistable device (OBD) comprising of a thin organic thin film between two metal electrodes. The performance of this device makes it attractive for memory-cell and low-cost displays applications. The two states of the OBD differ in their conductivity by several orders in magnitude and show remarkable stability, i.e., once the device reaches either state, it tends to remain in that state for a prolonged period of time. Moreover, the bistable and low-conductivity properties of an OBD can be precisely controlled by the application of biases to write and erase. These discoveries pave the way for new applications, such as low-cost, large-area, flexible, high-density, electrically addressable data storage devices.

1130 AM H8.6
FABRICATION OF ACTIVE DEVICES AND LOGIC GATES ON FIBERS. YongWoo Choi, Ioannis Rymias and Akintunde Ibiyode Akinwande, Massachusetts Institute of Technology (MIT), Microsystems Technology Laboratories, Cambridge, MA.

Textile fabric is flexible, mechanically durable and inexpensive. Hence, textile is a suitable substrate for large area, flexible and wearable electronics. The ability to fabricate active devices on fiber is a key step for achieving large area and flexible electronic structures. We present a fabrication approach for making devices and logic gates on fibers. Hydrogenated amorphous silicon (a-Si:H) thin-film transistors (TFTs) are fabricated on 127 μm thick polyimide film. The TFT has bottom-gate and back-channel etch structure. The gate and source-drain electrodes are made of the SiNx gate dielectric, a-Si:H channel layer and SiNx passivation layer are deposited with ECR-PECVD at 80°C to avoid the thermal shrinking of the polyimide film. A-Si antifuse layer and indium solder contact layer are deposited with flame evaporation. After patterning the channel layer, the contact patterning is performed to contact the gate and source-drain electrodes. In this paper, we shall present logic gates such as inverter, NAND and NOR gates and ring oscillators that will be fabricated with this process. The logic gates use enhancement load NMOS logic and only require four to five masking layers for fabrication. We shall also present electrical properties of the devices and contact reliability.

1145 AM H8.7
A BASIC CONCEPT OF NOVEL HYBRID OPTO-ELECTRONIC INTEGRATED SYSTEMS WITH TEXTILE STRUCTURES. Kinukji Tanaka, Chiba Univ. Dept of Electronics & Mechanical Engineering, Chiba, JAPAN.

Exponential expansion of electronics during past half a century was achieved on the base of sophisticated “surface and planar” technology of semiconductor crystal. It is now forecasted that we are faced with basic physical limits of Moore’s Law within the several years and those are going to up to the ‘huge wall’. In a general situation view, we are now in groping for a new strategy. It is necessary to take our eyes off from all elemental planar technologies and concepts related with present semiconductor electronics, such as design, processing technology, system configuration, development object, applied area, etc. We should produce an innovative situation in which uniting with different field is inevitably involved, and a lot of reformative models and methods must be proposed in the situation. According to the situation, the system configuration of the above-mentioned, one proposal based on a new technical principle is done here. An opto-electronic hybrid integrated system with “textile structure” is proposed as a novel electronic system and compared with “plane structure” system in present semiconductor technology. The system of textile structure is composed of warp-fiber and woof-fiber on which electronic devices, photoelectric conversion devices and various components are mounted. These elements are designed and arranged so that they are connected directly to the circuits, functional blocks and the final system. Several concrete compositions and characteristics of the proposed system are compared with those of present technology to construct a new electronics system. This proposal is also discussed in flexible electronics concept.

SESSION H9: FLEXIBLE SUBSTRATE TECHNOLOGIES
Chair: Norbert Frechslaf
Thursday, Afternoon, April 24, 2003
Salon 14/5 (Maito)
rf magnetron sputtering on glass substrates. However, when flexible optoelectronic devices are required, a polymeric substrate must be used. Neverthe less, polymeric substrates such as PEN provide a considerably lower working temperature and rougher surfaces as compared to glass substrates. In order to overcome these limitations, we have optimised the rf magnetron sputtering process in order to be able to produce transparent high-conductive low film stress and with a smooth surface GZO films. The films were grown by rf magnetron sputtering at room temperature on two kinds of polymeric substrates (Mylar and PEN from DuPont) in order to investigate the influence of the polymeric substrate and the surface morphology presented by the films. The GZO films deposited on Mylar substrates, at room temperature, showed a very high sheet resistance of 8 kΩ/cm² and a smooth transmittance in the visible region of 80% (including the substrate). In this paper a detailed description on the preparation as well as on the electrical (Hall effect and resistivity as a function of temperature), optical (transmittance and reflectance), and structural (X-ray diffraction) and morphological (FE-SEM and AFM) characterization will be presented.

2:45 PM H0.5
CHARACTERIZING THE MECHANICAL PROPERTIES OF NEW PHOTOPATTERNABLE LOW MODULUS SILICONES BY DEPTH SENSING NANOINDENTATION, Brian Harkness and Sreyen Sornbor, Dow Corning Corporation, Midland, MI; Richard Schleik and Lawrence Drzal, Department of Chemical Engineering and Materials Science, Michigan State University, East Lansing, MI.

The continued advancement of smaller, more complex electronics devices has spawned the development of new materials capable of achieving a high level of performance yet easily processable into complex micro- and nanoscale architectures. For example, in electronics packaging there is an increasing need for low modulus materials capable of functioning as stress buffer layers to absorb the stresses generated by mismatches in the thermal coefficients of expansion of the materials of construction. In response, new silicone based low modulus materials are being developed by Dow Corning for these applications. These materials have also been designed to be spin-coatable and photopatternable to facilitate their application into device architectures. It is the goal of this integration process involved in building complex device structures wherein physical and chemical treatments can change the surface properties of silicone materials. Therefore a need was apparent for a method to directly measure the mechanical properties of silicon thin films deposited on a device surface. Depth sensing nanoindentation is a method for measuring the mechanical properties of materials on a substrate. Recent advances in this technology such as the development of a continuous stiffness module (CSM), and variable frequency testing have extended the technique to allow for modulus and hardness determinations of low modulus materials as a function of indenter displacement. The effectiveness of depth sensing nanoindentation has been evaluated for two photopatternable silicone materials of different modules. Measurements have been conducted on supported 20 µm cured films and cured freestanding bulk samples. The results have been compared to the modulus measured on bulk samples by dynamic mechanical analysis. The close agreement of the two methods provide confidence in using this method for thin film sample analysis.

3:30 PM H0.6
INVESTIGATION OF BARRIER COATINGS ON STAINLESS STEEL FOIL SUBSTRATES FOR HIGH TEMPERATURE POLY-SILICON TFT PROCESSING, Samkit K. Shah, Themis Afferentis, Mitindra K. Hoti, Displays Research Laboratory, Department of Electrical and Computer Engineering Lehigh University, Bethlehem, PA; Apostolos Voutsas, Sharp Laboratories of America, Camarillo, CA.

Thin stainless steel foils present an excellent alternative to polymers substrates for the fabrication of devices and circuits for flexible electronics. A major advantage they offer results from the increased thermal budget tolerance that they provide which enables the utilization of high temperature processes in fabrication and the production of high performance devices and circuits. Commercially available stainless steel foils can be obtained in a variety of thicknesses, but owing to constraints arising from surface roughness and composition in available foils, some modification of the surface is necessary before devices can be fabricated on them. The method of substrate preparation assumes more importance when devices are fabricated at high temperature, especially in the region of C. High temperature fabrication processes can adversely affect the integrity of stainless steel-silicon dioxide interfaces and flatness of the substrate surface as well as promote increased diffusion of constituent species into the substrate. This study examines the properties of stainless steel foils as substrates for device fabrication and their performance. Barrier metal layers that prevented constituent species from the surface from diffusing into the fabricated devices were systematically investigated and will be presented in this paper. The efficacy of using various single and multi-level barrier layer structures using metals such as Titanium, Molybdenum, Tantalum, Titanium and Nickel in preventing diffusion of constituent species into fabricated thin film transistors was analyzed using scanning electron microscopy, energy dispersive spectroscopy and X-ray photoelectron spectroscopy and determined that the diffusion barrier characteristics of the stainless steel played a pivotal role in controlling the quality of the substrate-silicon oxide interface. Both non-channel and p-channel devices have been fabricated on flexibly-stainless-steel foils with the highest quality TFT characteristics will be presented. The approach presented in this paper constitutes an indispensable first step for the utilization of flexible stainless steel foils for microelectronic fabrication, and is suitable for both low and high temperature processing.

3:45 PM H0.7
FABRICATION OF SILICON OXY-NITIDE FILM AS A FLEXIBLE DIFFUSION BARRIER LAYER FOR ORGANIC LIGHT-EMITTING DIODE BY RADIO-FREQUENCY MAGNETRON SPUTTER Deposition, Po-Liang Wang, Wing-Kiung Wong, S-Wan Tong, Chun-Sing Lee, Shu-Yong Lee, Center of Super Diamond and Advanced Thin Films (COSDAT) and Department of Physics and Materials Science, City University of Hong Kong, Hong Kong SAR, CHINA.

Silicon-nitride (SiOxNy) films were deposited on polyethylene terephthalate (PET) substrate by magnetron sputtering deposition. Silicon nitride (Si3Na) was used as the target material. By varying the oxygen and argon flow ratio during deposition, SiOxNy films with different properties were obtained. The optical, electrical, chemical and water barrier properties were evaluated and characterized. The optical transmission of the optimized films can be as high as 90% and the root mean square (r.m.s.) surface roughness was 27 A. The SiOxNy film showed great potential as a water diffusion barrier for plastic substrates.

4:00 PM H0.8
OPTIMIZATION OF 75°C AMORPHOUS SILICON NITRIDE FOR TFT’S ON PLASTICS, Christina McCarthy, Mark Meytin, Andre Szakos, Univ of Waterloo, Electrical and Computer Engineering Dept, Waterloo, CANADA.

Amorphous silicon nitride (α-SiNₓH) is widely used as the gate dielectric and passivation layer in α-Si:H based devices. For devices on plastic substrates deposited at low temperature, the α-SiNₓH quality seems to determine the device performance. This paper investigates the effects of hydrogen dilution, helium dilution, amonia-silane gas flow ratio, and RF power on the properties of PE/CDV silicon nitrides deposited in large-area parallel-plane reactors at substrate temperatures of 75°C. The chemical composition and bonding of the SiNₓH films was studied using FTIR spectroscopy. The physical properties were investigated, and the density, growth rate, and compressive stress of α-SiNₓH films were determined. The electrical properties such as leakage current, breakdown, stability, trap density, and dielectric constant of the films were characterized by I-V and C-V measurements of metal-insulator-semiconductor (MIS) structures. Analysis of Variance (ANOVA) was performed on the results, and the deposition conditions for the optimal film properties were determined. The optimum film had SiNₓH stoichiometry of x ≈ 0.62 with hydrogen concentrations of 24 at%, and exhibited compressive stress of σᵥ = 1.2 ± 0.2 GPa. The film displayed good stability under electrical stress with chemic leakage of Rₜₐₕ = 6.5 ± 0.3 10¹²Ω.cm. Strong relationships between the film properties and deposition conditions were observed, and are discussed within the paper. α-Si:H bottom gate TFTs were fabricated using the optimized nitrides for gate dielectric and passivation layers, and the influence of α-SiNₓH on TFT performance is discussed.

4:15 PM H0.9
MICROENCAPSULATION OF POLYMER COATED COLOR PIGMENTS FOR MULTICOLOR ELECTROPHORETIC DISPLAY, Myeong-Ju Jeong, Chul Ann Kim, Seong Deok Ahn, Yong Hoon Lee, Seung Yool Kim, Jeong Young Sung, Electronics and Telecommunications Research Institute, Daejeon, KOREA; Chul Hwan Kim, DP Solution, Inc., Daejeon, KOREA.

In this study, we have investigated microencapsulation of red, green, and blue color polymer balls for multi-color electrohoretic display. The charged color pigments have been prepared by physical coating of red, green or blue color balls with functionalized polymer, then surface charging process. These color balls were microencapsulated in suspending fluid through in-situ polymerization.

4:30 PM H0.10
CONTROLLING THE CURVATURE OF FLAT FIBERS FOR
E-TEXTILE APPLICATIONS. Eitan Rodeheder and Sigurd Wagner, Department of Electrical Engineering, Princeton University, Princeton, NJ; by Xiaogang Suo, Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ.

In the most fundamental approach, e-textile circuits will be made by weaving component fibers into circuits. The weaving pattern will determine the circuit function. A key requirement of such e-textile circuits is reliable electrical contact between the fibers. Contacts which rely only on the pressure between fibers are preferred since they preserve the desirable tactile feel. Since thin-film design fabrication technology is planar, the component fibers, made by the slit-lift technique, are fine. Thus, a slight edge-to-edge curvature (with a radius of curvature as large as 500 km) can either prevent or promote electrical contact. Using fibers with thin-film transistors of amorphous silicon, we study the processes that produce the desired fiber curvature. A layer of stressed silicon nitride is used to create the curvature. The stress in this layer can be controlled by the deposition conditions. We present a study of this stressed layer and its effect on fiber curvature as well as electrical evaluation of transistor function.

SESSION H10 FLEXIBLE INTERCONNECTS AND DIELECTRICS
Chair: Babu R. Chalamala
Friday Morning, April 25, 2003
Salon 14/15 (Marriott)

8:30 AM H10.1 LASER-CRYSTALLIZED HIGH QUALITY ITO ON PLASTIC SUBSTRATES FOR FLEXIBLE DISPLAYS. Wenshan Chang, Paul Wetkold, Dayanand Dixit, Paul White, Michael O. Thompson, Cornell Univ, Dept of Materials Science and Engineering, Ithaca, NY.

In the study presented here, we successfully demonstrated that high quality ITO films could be obtained on polymeric substrates using excimer laser crystallization. ITO films were first deposited at 110°C on PEN substrates by DC magnetron sputtering, and then irradiated by a homogenized pulsed XeCl excimer laser beam (308 nm, 35 ns pulse duration) in a vacuum chamber. It was possible to reliably attain ITO films with sheet resistances down to 150 Ω/sq combined with more than 80% transmittance and good etching behavior. Extremely well conductive ITO films could be obtained using single HCl etchant at room temperature. With continued work, the possibility exists to improve these properties further, and we will report on our latest results.

8:45 AM H10.2 EFFECT OF UV IRRADIATION ON THE PHYSICAL/CHEMICAL PROPERTIES OF THE ITO/PES SYSTEM TOWARD OLED-BASED FLEXIBLE DISPLAYS. Byung-Soo So, Jin-Ha Hwang, Je-Ho Lee, Tae-Sung Oh, and Young-Hwan Kim, Hanguk Univ, Dept of Materials Science and Engineering, Seoul, KOREA.

OLED (Organic Light-Emitting Diodes) have been extensively studied since efficient green emission was demonstrated in a three-layered structure (Indium-Tin-Oxide/organic materials/met al). Since the Indium-Tin-Oxide surface is directly compatible with organic electroluminescent material, the physical/chemical properties of ITO are crucial to optimized OLED performance toward OLED-based flexible electronics. The physical properties of ITO thin films strongly depend on the deposition parameters which control microstructure, stoichiometry, and crystallinity, including additional post treatments. The application of ITO as electrodes in OLED devices requires low resistivity (below 1E-3 ohm-cm), low surface roughness (below 1 nm) and high transparency (above 80%). The current work has aimed at improving the physical/chemical features of the ITO/PES system, employing several post annealing processes. The post annealing processes incorporate conventional baking, excimer laser (308 nm) annealing and UV (365nm) irradiation on the ITO thin film (100nm) deposited on PES films by low temperature DC magnetron sputtering. Furthermore the effect of oxygen radicals was investigated. The electrical/ optical properties were performed using Hall effect, DC 4-point resistance measurement, UV spectrometry, and Ellipsometry. The chemical/microstructural features are characterized by FESM, XRD, Raman spectroscopy, AFM, and AES/UPS, in terms of morphology, crystallinity, roughness, and stoichiometry. Optimized UV treatments and enhanced excimer laser and radiation of the ITO, compared to that of excimer laser annealing. The role of silicon oxide will be considered as barriers against unwanted impurities. The electrical/optical properties are combined with the chemical/microstructural characterization, which elucidate the underlying mechanism occurring in post treatment concerning UV-irradiation. The ramifications will be made discussed in conjunction with OLED-based materials toward flexible displays.

9:00 AM H10.3 STRETCHABLE GOLD CONDUCTORS ON ELASTOMERIC SUBSTRATES. Carolina Chambers, Stephanie Perichon-Lacour, Sigurd Wagner, Department of Electrical Engineering and POEMS, Princeton University, Princeton, NJ; Zhigang Suo, Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ.

3-D displays, sensor skins, mechatronic structures, and e-textiles will rely on flexible and stretchable electronic circuits. It is likely that such circuits will be made of rigid semiconductor islands interconnected with stretchable metallization. However, free-standing metal films fracture or tear at strains in the order of 1%. We report a short of the ten-percent extension needed for deformable circuits. We have discovered that fine metal lines made on an elastomeric substrate can be stretched by ten percent without losing electrical conduction. A free-standing metal film fracture by localized plastic deformation, e.g., the film forming a sharp bend. By suggesting that the elastomer substrate allows de-localized plastic deformation, we fabricated 1-mm-thick polydimethylsiloxane (PDMS) membranes with up to 10% strain, 1-mm wide gold lines deposited by electron beam evaporation. Then we evaluated the structure of the gold films by optical and scanning electron microscopy, and measured the electromechanical characteristics in a strain tester, with contact electrodes applied to the film. We find that 50-nm-thick lines retain their electrical conduction up to 10 percent strain. Also, the tensile strain is cycled between 0 and 5 percent, the electrical resistance in the stressed and relaxed states are reproducible. We will describe substrate and conductor preparation, and their structural, mechanical, and electrical properties. Key words: elastic, stretchable, gold film, PDMS, electrical conduction.

9:15 AM H10.4 A COMPARATIVE STUDY OF ADHESION PROPERTIES OF METAL FILMS ON POLYIMIDE SUBSTRATES TREATED BY VARIOUS PLAStMA TREATMENT TECHNIQUES. Soo Heong Kim, Young Sik Lee, So Hyeom Cho, Nam-Kang Lee, and Hun Me Kim, Dept of Materials Engineering, Center for Advanced Plasma Surface Technology, and Intelligent Micro-Systems, Sungkyunkwan University, Suwon, Kyunggi-Do, KOREA. "Dept. of Mechanical Engineering and Intelligent Micro-Systems, Sungkyunkwan University, Suwon, Kyunggi-do, KOREA.

With an increase in the use of polyimides[1] for applications in the flexible electronics, the techniques of surface treatments to enhance polymer-metal adhesion are becoming more and more important. Especially, plasma surface treatments to improve the adhesion of metal/Pt are very useful in realizing required flexibility of metal/metalization lines formed on the flexible substrates in developing flexible electronic devices. In this study, we investigated adhesion properties of Cu/Cr/polyimide[1] systems by varying surface treatment conditions using various plasma treatment techniques such as: oxygen, atmospheric plasma and reactive ion etching. We determined the contact angle measurement and X-ray photoelectron spectroscopy (XPS). The chemical interaction between Cr and plasma-treated polyimide films was investigated by XPS. The adhesion properties in Cu/Cr/polyimide[1] systems will be discussed.

9:30 AM H10.5 EDGE AND STP COVERAGE BY METAL INTERCONNECTS FOR THREE DIMENSIONAL CIRCUITS. Robin Bastlacharya, Sigurd Wagner, Princeton University, Dept of Electrical Engineering, Princeton, NJ; Mei Huang and Shoko Suna, Dept of Electrical Engineering, Dept of Mechanical and Aerospace Engineering, Princeton, NJ.

Three-dimensional integrated circuits is a new and exciting field that has been spurred on by the need for conformal displays and detector arrays. These circuits are fabricated by interconnecting rigid sub-circuit islands on a flat, deformable substrate. To prepare for interconnects, we apply a patterned deformable sacrificial material over the flat substrate. We then deform the substrate, with the sub-circuit islands and sacrificial pattern on it to a spherical surface. Following deformation, we vaporize interconnect metal and then lift-off the sacrificial material, leaving only the metal lines that interconnect the islands. The remaining size for a circuit island to remain intact increases with the islands thickness. The larger the island has to be, the thicker it must be made to prevent it from cracking. We have found that 40 micronometer square islands must be at least 0.8 micrometers thick. With such thick islands, interconnect metal becomes difficult because of the three-dimensional
The technologies for flexible electronics have been developed to make electronic or electro-mechanical devices on inexpensive and flexible organic substrates. In order to interconnect device elements or layers, metatization on the flexible substrate is required. In this case, the width and conductivity of the interconnect are very important in minimizing the size of device. Realization of metatization process with a few micrometer scale on the flexible substrate is required. Compared to the conducting polymer lines with high electrical resistance, the metal lines with low electrical resistivity are desirable for the realization of micro-scale devices. In this work, micro-scale metatization lines of Cu were fabricated on the flexible substrate by electroplating using the patterned mask of SU-8. The use of negative tone, chemically amplifying UV photo-resist, Cr was used as an adhesion layer between the Cu seed layer and the polyimide for the enhanced adhesion between Cu and polyimide films. Electroplating of copper line was carried out as a function of temperature in the bath and current density on the surface. Cu lines with the width of 2-4 μm and the aspect ratio of 2-3 were fabricated. We used dry plasma processes to remove the SU-8 mask. The flexibility and adhesion property of Cu line (electroplated)/Cu(seed)/Cr/Polyimide are evaluated and discussed.

11:30 AM H10.10 Abstract Withdrawn

11:30 AM H10.10 DEVELOPMENT OF HIGH PERMEABILITY CORE MATERIAL FOR EMBEDDED SOLENOID INDUCTORS IN FLEXIBLE ORGANIC SUBSTRATES. C.K. Liu, P.L. Cheng, S.Y.Y. Leung, T.W. Law, I.T. Chong and D.C.C. Lam, Department of Mechanical Engineering, Hong Kong University of Science and Technology, Hong Kong SAR, CHINA.

Capacitors, resistors and inductors are surface mounted components on circuit boards, which occupy up to 70% of the board area. For molded applications, these components are embedded inside the molded body. Ceramic tape substrates and sintered at temperatures over 700 degC in co-fired process. These high temperature fabrication processes are incompatible with organic substrates, and low temperature processes are used if possible. The use of metallic inorganic inductors are fabricated using the low temperature sol-gel route was developed for insertion into solenoid inductors in organic substrates. Crystalline NiZn ferrite powder was added to the sol-gel precursor of NiZn. The solution was deposited onto the substrates as thin films and heat-treated at varied temperatures. The changes in the microstructure were characterized using XRD, TGA and DTA. Results show that addition of NiZn ferrite induced low temperature transformation of the NiZn thin film. NiZn films high phase transformation temperature of 250°C is approximately 35% lower than the transformation temperature for unseeded NiZn thin films. Electrical measurement of NiZn NiZn core solenoid inductors indicated the inductance increased by 30% - 100% compared to inductors without the NiZn core. The relation between the increase in inductance and connectivity in the microstructure is discussed and compared with composite electrical properties models.

11:45 AM H10.11 HIGHLY CONDUCTIVE AND TRANSPARENT Ti-DOPED ZINC OXIDE THIN FILMS. Yang-Ming Lu, Shu-Tai Liao, Chen-Ming Chen, Kun Shan University of Technology, Department of Electronic Engineering, TAIWAN, ROC.

Highly conductive and transparent indium-doped zinc oxide thin films have recently gained much attention because they are composed of inexpensive, abundant materials. The Ti-doped ZnO thin films were deposited by simultaneous magnetron co-sputtering from both Zn and Ti targets in a mixture of oxygen and argon gases onto heated Corning 7059 glass substrates. By adjusting the Ar/O2 ratio and other process parameters including RF power, and substrate temperature, the electrical property of ZnO thin films was studied from an isolation to a good conduction. The results show that deposition rate is an approximately linear function of DC power, Ti Target power, and 300nm thick targets at 300 watts. At 300 watts, the growth rate decreases due to strong interference between Zn and titanium sputtered atomic fluxes. The incorporation of titanium atoms into zinc oxide films is not effective to increase the Ti target power increased to a value of 250 watts. The atomic percent of titanium in the films are measured to be 1.33% and 2.51% corresponding to 250 watts and 300 watts of Ti target power applied.
respectively. The XRD patterns shown only a single ZnO phase and shifted to lower 2θ values imply Ti atoms incorporated into the ZnO lattice before solution annealing. The reactivity of undoped ZnO films is extremely high and decreases to a value of 3.78 - 10.2 cm<sup>-2</sup> when 2.5% atomic percent of Ti is incorporated. All of the zinc oxide films show good transmittance and in the range of 400 - 700 nm. The average percent transmittance is 70.8% in this study. The optical energy gap increases with increasing the doping amount of Ti in the films. The maximum value of optical energy gap gained in this study is 3.18 eV when the doping amount of Ti is 2.5 atomic%.

SESSION H11.1/L12: JOIN SESSION DEVICES

Chair: Jerome Cornil
Friday Afternoon, April 25, 2003
Salon 1 (Raymond)

1:30 PM *H11.1/L12.1
PRINTING APPROACHES TO ORGANIC OPTOELECTRONICS ON PLASTIC, TEXTILE AND PAPER SUBSTRATES. Y. Yoshida and G.E. Jabbour, Optical Sciences Center, The University of Arizona, Tucson, AZ.

The latest developments in the use of inkjet printing as a tool to pattern a given electrode promises a maskless non-contact approach to generate specific pattern on given substrate. Many factors including surface tension of the printed solution, substrate surface properties, and moisture have direct effects on the thermal quality and performance of the organic based devices. Issues related to device fabrication on plastic, textile and paper substrates will be discussed and results of tested devices will be presented.

2:00 PM *H11.2/L12.2
FULLY PRINTABLE LIGHT EMITTING DISPLAYS. Sue A. Carter, M. Kreger, J. Leger, Y. Nakazawa, J.J. Breeden, M. Wilkinson, University of California, Dept. of Physics, Santa Cruz, CA and AddVision, Incorporated, Scotts Valley, CA.

One of the main premises of semiconducting polymers is the ability to fabricate inexpensive optoelectronic components that will lead to the wide-scale use of new technologies, such as large area light-emitting displays and photovoltaics. This vision relies on being able to manufacture semiconducting polymers using very inexpensive manufacturing processes where the labor and processing costs can be considerably less than the materials cost. In this talk, I will give an overview of the technical and cost considerations for making polymer displays and detectors where all layers are deposited under atmospheric conditions using a liquid-based manufacturing technique, such as inkjet, screen-printing or web-based processes. I will discuss our work on fully screen-printed light emitting polymer displays with focus on the technical challenges in printing the light emitting polymer layers (n-type, p-type and electrode (cathode), and obviating sufficient lifetimes and power efficiency on plastic substrates under such manufacturing conditions. I will conclude by showing our most recent results and prototypes of fully printed light emitting polymer displays.

2:30 PM *H11.3/L12.3
IN-SITU ELECTRICAL AND SPECTROSCOPICAL STUDY OF DEGRADATION MECHANISMS AND LIFE TIME PREDICTION OF ORGANIC BASED ELECTRONIC MATERIAL SYSTEMS. Jean Vittorio Manca, Ilse Kesters, Lawrence Lautens, Ludwig Gorin, Dirk Vandervorst, Jan D’Hae, Marc Olierisger, Luc De Schepper, Limburg Universitair Centrum, Institute for Materials Research, Dienbenplein, Belgium, IMEC, Division IADMEC, Dienbenplein, BELGIUM. Ornella Scammi, University of Catania, Catania, ITALY.

In order to tailor the synthesis of new robust organic materials for electronic applications it is of key importance to understand the underlying degradation mechanisms. The strategy used by our group to study these mechanisms is to monitor the behavior of the materials submitted to a given stress conditions with so-called in-situ electrical and spectroscopical techniques and to subsequently use analytical techniques to determine the failure mode, degree of degradation and nature of morphological changes. This approach will be illustrated for several new polymer conductors and semiconductors in films and in light emitting devices. The in-situ electrical measurement technique was developed by our institute for a high resolution study of the electrical characteristics and aging behavior of a given material during thermal annealing, in the function of temperature, time, etc. With this technique, a test structure is submitted to a desired temperature profile and atmospheric conditions, and the electrical property of interest is measured continuously during the treatment, i.e. in-situ. For the in-situ spectroscopical studies [in-situ IR and UV/VIS], a thermoregulated oven is used in which polymers can be analyzed at different voltages and under different atmospheres for steady state and fatigue conditions by a variety of the most appropriate measurements. Films are heated following the temperature profile of choice and data are collected and analyzed with a high degree. It will be shown that with these techniques activation energies can be determined for the degradation/manifestation of materials degradation and the degradation mechanisms can be monitored during linear heating experiments and during isothermal treatments. With the presented in-situ techniques, the degradation kinetics can be studied under a matrix of degradation stress parameters, allowing the construction of a kinetic degradation model. Such a model is required in order to make a correct prediction of the degradation under operational conditions, based on the degradation data obtained under accelerated ageing conditions.

2:45 PM *H11.4/L12.4
FABRICATION OF ORGANIC LIGHT EMITTING DEVICES BY LOW PRESSURE COLD WELDING. Changsoo Kim and Stephen R. Forrest, Dept of Electrical Engineering, Princeton, Princeton, NJ.

We demonstrate a method for high resolution patterning of metal cathode contacts for organic electronic devices using low pressure cold welding. The contacts are formed by transferring a metal film from a patterned, soft elastomeric stamp onto unpatterned organic and metal layers predominately on a substrate. Use of an elastomeric stamp allows for a thousand-fold decrease in the pressure needed for a high-quality pattern transfer as compared to that required with rigid stamps[1]. In our demonstration, we fabricate an array of organic light emitting devices (OLEDs) based on the green phosphor f aic rtr<sub>2</sub> (phenylpyridine) iridium [triglypy] doped into a 4,4',8,8'-biphenyl (CBP) host. Here, the cathodes consist of ultrathin (< 1 nm) layers of LiF and Al capped by a 15-nm-thick Au layer. Au deposited across the entire organic layer surface, 100-nm-thick layer of Au is transferred onto the Au layer by pressing a stamp onto the substrate using a conventional semiconductor flip-chip bonder. The cathode patterning is finished by removing the thin layer between the contact patterns by gentle sputter etching. The 200 µm-diameter cathodes were uniformly obtained over the whole substrate area with a yield exceeding 97%, and the pattern edge resolution was approximately 1 µm. The stamping and Au layer removal processes do not adversely affect the performance of OLEDs fabricated by conventional shadow mask patterning. For example, the voltage corresponding to a current density of J = 10 mA/cm<sup>2</sup> was (9.2 ± 0.3) V, and the external quantum efficiency at J = 1 mA/cm<sup>2</sup> was (6.0 ± 0.3)% for both stamped and control devices. This technique is potentially suitable for roll-to-roll fabrication of a wide range of organic electronic devices including OLEDs, organic thin-film transistors, and photovoltaic cells.


3:30 PM *H11.5/L12.5
PROGRESS IN THE GROWTH OF PENTACENE THIN FILMS AND DEVICES. Raid Tromp, IBM Tokyo Research Center, Yorktown Heights, NY.

Recently, the growth of pentacene thin films on a variety of substrates has become of interest to the surface and interface science community. For instance, careful preparation of the substrate allows the pentacene thin film grain size to be increased very significantly. In this talk I review recent results on the growth of pentacene films on semiconductor, insulator, and metal surfaces.

4:00 PM *H11.6/L12.6
SELF-ALIGNED VERTICAL CHANNEL POLYMER FIELD-EFFECT TRANSISTORS. Natalie Strunskus, Richard H. Friend, Henning Sirringhaus, Cavendish Laboratory, University of Cambridge, Cambridge, UNITED KINGDOM.

Manufacturing of high-performance conjugated polymer transistor circuits on flexible, plastic substrates requires patterning techniques capable of defining critical features with submicrometer resolution. We demonstrate here the use of self-aligned embossing to produce polymer field-effect transistors with submicrometer critical features in planar and vertical configurations. Embossing is used for the controlled micromilling of vertical sidewalls into polymer multilayer structures without smearing. High-mobility vertical-channel polymer field-effect transistors on flexible poly(ethylene terephthalate) substrates have been fabricated, in which the critical channel length of 0.7 ± 0.9 mm is defined by the thickness of a spin-coated insulator layer. We demonstrate that gate electrodes can be self-aligned to minimize overlap capacitance by inkjet printing using the embossed grooves to define a surface-energy pattern.
INKJETTED ORGANIC TRANSISTORS USING A NOVEL PENTACENE PRECURSOR, Steven K. Voldman, Steven Molen, Brian Mattis, Paul C. Chang, and Vivek Subramaniam, University of California, Berkeley, Department of Electrical Engineering and Computer Sciences, Berkeley, CA.

Pentacene is one of the most promising organic materials for organic transistor fabrication, since it offers higher mobility, better on-off ratios, improved environmental stability, and better reliability than most other organic semiconductors. However, its severe insolvibility renders it useless for the solution-based fabrication of electronic devices. Solution-based processing of these devices is the key to enabling ultra-low-cost circuit fabrication, since it eliminates the need for lithography, subtractive processing, and vacuum-based film deposition. Because it allows the use of entirely additive printing techniques, it is expected to result in the development of low-cost reel-to-reel fabrication methodologies. Prompted by a recent paper from Aziz et al describing the synthesis of a novel pentacene precursor, we demonstrate the first inkjet-printed pentacene transistor fabricated to date. This is achieved using a substrate-gated transistor structure in conjunction with an inkjet-printed pentacene precursor active layer. A subsequent thermal cycle is used to convert the precursor into a high-quality pentacene film. Unoptimized conditions yield transistors with an on-off ratio of >1,000 and a field-effect mobility of 0.010 cm²/Vs. Further improvement is expected with optimization, to approach the mobility of 0.05 cm²/Vs reported by Aziz. We study the effect of annealing conditions on the pentacene precursor characteristics, and establish qualitative models describing the various effects. The precursor is converted to pentacene via heating, through the decomposition of the Diaz-Alder product. As the anneal temperature increases above 120°C, performance increases dramatically. The process is therefore compatible with numerous low-temperature plastics. As the anneal time is increased to several minutes, performance likewise increases through increased precursor decomposition. However, exposure to excessive temperatures or times tends to degrade performance. This is caused by morphological and chemical changes in the pentacene film.

N- AND P-TYPE BUILDING BLOCKS FOR ORGANIC ELECTRONICS BASED ON OLIGOTHIOPHENE CORES, Antonio Fischetti, Michael Mashbash, Howard E. Katz, and Tobin J. Marks.

Organic semiconductors exhibiting complementary-type carrier mobility are the key components for the development of the field of “plastic electronics”. We present here a novel series of \( \alpha_{1.8} \) and isomeric pure \( \beta_{3.1} \)-diperfluoroalkyl-substituted thiophene oligomers [DnHnT] and isoDnHnT, respectively. \( \text{C}_n\text{H}_{2n+1}\text{(thiophene)}_{n-1}\text{C}_n\text{H}_{2n+1}, n = 2 - 6 \) and study the impact of fluorocyl substitution and conjugation length \( \text{vs.} \text{vs.} \) the corresponding fluorine-free analogues [DnHnT] and isoDnHnT. \( \text{C}_n\text{H}_{2n+1}\text{(thiophene)}_{n-1}\text{C}_n\text{H}_{2n+1}, n = 2 - 6 \). Trends between the fluorinated and fluorine-free families in molecular packing, optical absorption, HOMO-LUMO gap, and p-p interactions are found to be strikingly similar. However, fluorocyl substitution substantially enhances thermal stability, volatility, and electron affinity. Thin film transistor (TFT) devices were fabricated employing both vacuum- and, for shorter and \( \beta_{3.1} \)-substituted oligomers, solution-deposited semiconducting layers. Field-effect transistor measurements indicate that the longer members of both DnHnT and isoDnHnT series are n-type semiconductors with unoptimized mobilities and FET on/off ratios approaching 0.05 cm²/Vs and 10⁵, respectively. These families represent the first example of a homologous series of variable \( \text{n} \) conjugation length n-type OTFT components.


Recent interest in the science and emerging applications of electroactive organic and bio-organic materials motivates research into non-invasive methods for forming high resolution electrical contacts on these classes of "soft" molecular materials. Many of the lithographic techniques that were developed for traditional microelectronic systems require processing protocols that are too severe for these organics. We have developed a soft-contact lamination approach using metal-coated elastomeric stamps that provides a convenient and non-invasive way of probing organic materials. This method exploits the surface relief of elastomeric stamps to define, with nanometer resolution, the geometry and separation of electrodes that are formed by directional deposition of thin metal films onto the stamps. Soft contact of these metal-coated stamps with the organic non-invasively establishes multiple independent electrical connections.

As proof of concept we demonstrate successful fabrication of top-contact thin film transistors with channel lengths between 250 nanometers and 150 microns on pentacene and PC61BM. Advantages of this approach include a reversible contact that can be established at room temperature without the application of pressure or adhesives that are generally used with traditional lamination or wet bonding methods. This procedure provides a powerful tool for studying the physics of charge transport in chemically fragile or ultrathin soft materials. We use this method to investigate fundamental interface and contact properties between metal electrodes and organic semiconductors. By comparing the laminated contacts to conventional ones formed by thermal evaporation, it is possible isolate the electrical effects of depositing hot metal onto organic semiconductors.