SYMPOSIUM H
Giant-Area Electronics on Nonconventional Substrates
March 31 - April 1, 2005

Chairs

Michael S. Shur
Rensselaer Polytechnic Institute
110 8th St.
Troy, NY 12180-3590
518-276-2201

Patricia Wilson
Foster-Miller, Inc.
195 Bear Hill Rd.
Waltham, MA 2451
781-684-4171

Martin Stutzmann
Walter Schottky Institut
Am Coulombwall 3
Garching, 85748 Germany
49-89-2891-2760

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* Invited paper
SESSION H1: Film Growth and Processing for Giant Area Electronics
Chair: Martin Stutzmann
Thursday Morning, March 31, 2005
Room 208 (Moscone West)

9:00 AM *H1.1

Many modern electronic devices need to be lightweight and flexible to meet diversified customer demands. At United Solar, we have been manufacturing amorphous silicon alloy solar cells on flexible stainless steel substrates. Rolls of stainless steel, one and a half-mile long, 14 inches wide and 511 mill thick, go through the following processes to complete the solar cell structure: 1. wash machine that washes the roll, 2. back-reflector machine that sputters a bi-layer of Al and ZnO, 3. A-Si alloy processor that deports nine layers of amorphous silicon and amorphous silicon germanium alloys by plasma-assisted chemical vapor deposition, and 4. an anti-reflection coating machine that sputters a layer of Indium Tin Oxide. The 1.5-mile long solar cell is next cut and processed to make a variety of photovoltaic products.

We have also used 1 mil thick pyrolytic to deposit solar cells using the roll-to-roll processor. The cell performance is similar to that on stainless steel; specific power exceeding 1000 W/kg has been achieved.

9:30 AM H1.2
Gas Permeation Barrier Films Grown by Atomic Layer Deposition on Polyester and Polyimide Substrates. Robert Scott McLean1, Peter F. Cancila, Markus Groner2, Steven George2, Yoshihito Park3, CRC&R, DuPont Co., Wilmington, Delaware; 2Dept. of Chemistry and Biochemistry, University of Colorado, Boulder, Colorado; 3Aviza Technology, Scotts Valley, California.

Increasingly, prospective electronic and display devices on inexpensive flexible substrates are comprised of organic materials. While their low processing temperature is compatible with these substrates and the electronic performance satisfactory, the environmental stability is often not, because of reactivity with air and moisture. The problem is further exacerbated by facile permeation of atmospheric gases through flexible plastic substrates. To be usable in electronic and display devices, plastic substrates will require coatings that exclude atmospheric gases. Estimates are that these barrier coatings need to reduce the permeability of a bare plastic substrate by a factor of 1000 to 10000. In this presentation we show that thin inorganic coatings produced by atomic layer deposition (ALD) offer the prospect of a simple ultra-barrier technology for plastic substrates for use in flexible electronics. Specifically, we describe the barrier properties of very thin (<25 nm) Al2O3 and HfO2 films grown by ALD on polyethylene terephthalate (PET), polyethylene naphthalate (PEN) and Kapton® polyimide films. The substrate growth temperature was between 100 °C and 300 °C. These films were amorphous with featureless microstructure. Reduction in O2/H2O permeation through ALD Al2O3-coated plastic substrates, was excellent, at least 10,000 X better than the bare substrate. However, equivalent performance with ALD HfO2 required the plastic substrates to be pre-coated with a thin seed layer of either e-beam evaporated Al2O3 or SiO2. With the limited thickness range (100-25 nm), we investigated, barrier properties improved with ALD film thickness and gate temperature.

9:45 AM H1.3
High-K Polymerized Dichlorotetramethyldisiloxane Films Deposited by Radio Frequency Pulsed Plasma for Gate Dielectrics in Flexible Polymer FETs. Yi Fan Xu1, Paul R. Berger2, Jai Cho3, 1Electrical and Computer Engineering, The Ohio State University, Columbus, Ohio; 2Physics, The Ohio State University, Columbus, Ohio; 3Chemistry and Biochemistry, University of Texas at Arlington, Arlington, Texas.

Polymerized dichlorotetramethyldisiloxane (DCTMDS) films deposited by radio frequency pulsed plasma polymerization (PPP) demonstrated very high dielectric constants for an organic-based system, in the range of 7 to 10, and enable all-polymer flexible electronics. High-k gate dielectrics are highly desirable for metal-insulator-semiconductor field effect transistors (MISFET) as the capacitance of the gate insulator scales with permittivity, which is in turn proportional to the FET output current. The PPP process readily lends itself to deposition of thin gate dielectric films above or below electroactive polymer channels with little to no observable layer intermixing. The PPP DCTMDS dielectric constants were determined from C-V measurements of fabricated MIS structures at 1 MHz. The magnitude of the dielectric constant depends on polarizability of the polymer and its molecular volume given by the Clausius-Mosotti equation. The high dielectric constants of PPP DCTMDS films is due to the high polarizability of the -Cl group. The few reports of flexible polymer dielectric films used as gate insulators in polymer FETs (PFET) utilize polyvinylphenol or polyvinyl alcohol, which generally have dielectric constants ranging from 3 to 3.5, compared to the more common choice for PFETs of rigid SiO2 which has a dielectric constant of 3.9. The design of experiments for this PPP DCTMDS dielectric film study explored two variables. Part one examined how gate voltage affects the permittivity of polymerized DCTMDS dielectric films. Part two identified the optimal temperature window for post-deposition annealing to reduce the leakage current. The pulsed plasma gate dielectric (GGO) resulted in higher constant dielectric DCTMDS films for higher duty cycles. The variation of dielectric constants does not show any trend with varying film thicknesses, indicating that the thickness of the deposited film is not significant for controlling permittivity. Post-deposition annealing improves the electrical integrity of PPP DCTMDS films. The leakage current of the PPP DCTMDS reduces with higher annealing temperature up to 200 °C, but heating above 200 °C elevates the leakage current, due probably to the volatilizing low molecular weight oligomers or breakage of relatively weak chemical bonds. Therefore, the optimal annealing temperature was in the range of 150 °C to 200 °C. Film shrinkage in this temperature window was minimal and within the measurement uncertainty. Annealed samples have low leakage current densities below 0.1 pA/μm² at 10 V for film thicknesses above 100 nm. The PPP DCTMDS films are resistant to typical chemical solvents, and have withstood conventional photolithographic processing with no observable film shrinkage, warping or peeling. Film adhesion was excellent and withstood the scotch tape test. The high performance of polymerized DCTMDS films (high dielectric constant and low leakage current density) makes it a promising insulator for flexible polymer circuits.

10:30 AM H1.4
High Performance, Low Voltage Organic Thin-Film Transistors and Circuits. Stijn De Vusser1.2, Soeren Steudel1.2, Kris Mynss1, Jan Genoes1 and Paul Hereams1.2, 1MCPC, IMEC, Heverlee, Belgium; 2ESAT, KULeuven, Heverlee, Belgium.

Organic Thin-Film Transistors (OTFT’s) have gained increasing interest since the last decade, as they are a promising technology for low-cost electronic circuits. Potential applications include driving devices for active matrix organic displays, large area electronic circuits and RF-ID tags. Evaporated pentacene is one of the most frequently used organic semiconductors, with a performance comparable to amorphous Si. Here, we report on high performance, low voltage pentacene OTFT’s and circuits. Devices and circuits were fabricated on a glass wafer. Ti was used as the gate layer, SiO2 as the gate dielectric, and Au as source and drain electrodes, respectively. The pentacene was deposited on top of the Au electrodes. Inverters and ring oscillators have been designed and fabricated. At 15V supply voltage, we have observed inverters showing a voltage gain of 8 and an output swing of 13V. The ring oscillators consist of a chain of 5 inverters, followed by two buffer stages. The output of the last inverter in the chain was fed back to serve as the input of the first inverter. Oscillations started at supply voltages as low as 15V, while a supply voltage of only 15V, a stage delay time of 1ps is calculated. This value is considered to be very fast, as compared to literature values. The output buffer speed limits the output swing in the current density. We still observe beyond 8V is obtained at 15V supply voltages. In contrast to previously published results, our oscillators operate at high speed, even at low supply voltages. Comparably fast ring oscillators have been reported before; however, these required typical supply voltages of more than 70V for a comparable delay time. The low-voltage aspect of our work is crucial, as this power output can be obtained from rectification using an organic (pentacene) diode. These results have an important impact on the realization of RF-ID tags: by integrating our circuits with an organic diode, the fabrication of organic RF-ID tags comes closer. In conclusion, we have fabricated ring oscillators based on OTFT’s. Compared to previously published results, our circuits perform considerably well or better; however, the supply voltage and the output limits require for this performance is substantially lower than what has been published before. This is an important step towards the realization of organic RF-ID tags.

10:45 AM H1.5

We are investigating the growth of polycrystalline GaAs with controlled grain size for use as a polycrystalline thin film photovoltaic

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material. GaAs and its alloys have produced extremely efficient single-crystal photovoltaic cells, but their performance in polycrystalline film form has been limited by minority carrier recombination in the grains and at grain boundaries. Typical thin-film deposition techniques for polycrystalline GaAs tend to proceed with an uncontrolled nucleation step followed by growth. This leads to small, randomly oriented grains and high-density grain boundaries. This talk presents a method for controlled nucleation followed by selective gallium deposition on the nucleation sites which has the potential to produce large grain films on a broad range of thin film PV substrates. While the above processes have been developed for thin film photovoltaics, they also have application to precisely positioning semiconductor dots on interesting substrates. Initial work focused on process development using Si substrates. Submicron diameter gallium deposits are fabricated on Si using a combination of near-field scanning optical microscopy (NSOM) based lithography and gallium electrodeposition. A silicon substrate is coated with a thin layer of photoresist, and the NSOM is used to expose an array of holes in it. After development, gallium is electrodeposited into the holes from an aqueous GaCl₃ solution. In the next step, an anneal in a chemical vapor deposition reactor converts the gallium to GaAs. Subsequent metalorganic chemical vapor deposition (MOCVD) growth occurs selectively on these dots, enlarging them and forming regular arrays of GaAs disks up to 20 microns in diameter. Transmission electron microscopy, AFM, NSOM, and photoluminescence have also been used in the process and indicate reasonable material quality. This work validates the fundamental concept of controlling polycrystalline GaAs grain size by controlling the nucleation step, but is not practical for low cost devices. Alternative techniques for controlled nucleation in large area films will be presented including microcontact printing of Ga containing solutions directly on the substrate and direct decomposition of triethyl gallium in the MOCVD reactor. We will also discuss extensions of this approach to alternate substrates, and possible methods for defining the orientation of the GaAs seed crystallites.

11:00 AM H1.6
Incorporating Optical Fiber Based Sensors into Fabrics. Anuj Dhawan1, Tushar Ghosh1 and John Muth1; 1ECE Dept Box 7911, NC State University, Raleigh, North Carolina; 2College of Textiles, NC State University, Raleigh, North Carolina.

Optical fiber sensors can be sensitive, environmentally robust, immune to electromagnetic interference and remotely interrogated. By incorporating optical fibers into woven and non-woven fabrics these sensors can be distributed across large areas. Recent work addressing the challenges of incorporating optical fibers into woven and non-woven fabrics will be addressed. In the weaving processes, macroscopic, and microscopic bending is an issue due to the fibers going over and under the yarns. Bending losses are quantified by placing the optical fiber on frames of different radii of curvature and measuring the resulting loss of transmitted light. As an example, non-woven process, electrospinning was used to overlay a net of sub-micron diameter fibrous material over the fibers. This was done to allow the optical fiber in place while still permitting flexibility. To form sensors, standard telecommunications grade optical fiber was modified by tapering the fibers such that the evanescent wave extended into the environment. These fibers were then combined with environmentally sensitive thin films deposited by pulsed laser deposition and incorporated into the fabrics. The use of a pulsed deposition method permitted a variety of coating to be tested including metallic nanoparticles with strong plasmon resonances that were sensitive to variations in the surrounding index of refraction.

11:15 AM H1.9
Low-Damage Patterning Technique of Pentacene using a S/N-/PVA-Photoresist Multi-Layer Mask. Nobukazu Hirai, Nobuhide Yoneya, Noriyuki Kawashina, Makoto Noda, Kazuma Nomoto, Masaru Wada and Jiro Kasahara; Fusion Domain Laboratory, Materials laboratory, Sony Corporation, Tokyo, Japan.

We discuss a degradation mechanism for patterning process of pentacene using PVA photoresist and present a low-damage patterning technique. The low-damage patterning technique of an active layer OTFT is indispensable for device integration. The patterning process for organic semiconductors is problematic because of their poor resistance to organic solvents. Therefore, shadow mask techniques are often used, but these cannot be applied to fine patterning. T. N. Jackson et al. performed fine patterning of a pentacene layer using an O₂-plasma with a mask of water-soluble poly(vinyl alcohol) (PVA) with a high concentration (Cr(VI)) is not a preferable material because of its hazardous nature. We performed structural and electrical investigations on the degradation mode of pentacene TFT in patterning process using PVA photoresist, and it was revealed that PVA photoresist and its solvent of water didn’t affect the crystallinity of pentacene, although a typical photoresist solvent, such as PGMEA, induced a structural-phase transition from thin-film phase to bulk phase. Repeating a process of pentacene TFT was affected by the PVA photoresist as opposed to the PGMEA. However, a considerable increase in off-current was observed even in the case of the PVA photoresist. The off-current increase was investigated for two types of PVA; one with a photosensitive functional group and the other without it. We observed an off-current increase only in the case of PVA photoresist with the photosensitive functional group. Therefore, off-current must be caused by an interaction between the photosensitive functional group of PVA photoresist and pentacene. In fact, off-current could be suppressed by the insertion of a Si₃N₄ layer between the pentacene and the PVA photoresist layers. An O₂-plasma etching of a pentacene layer also increased off-current. We found that the off-current could be decreased by annealing the TFT in a vacuum. This phenomenon indicated that oxygen doping caused by the O₂-plasma etching of a pentacene layer could be de-dep by thermal annealing in a vacuum. Based on these results, we developed a low-damage patterning technique using O₂-plasma etching of a mask of a Si₃N₄/PVA-photoresist multi-layer mask followed by annealing in a vacuum. This technique was used to demonstrate a 2.5-inch 180x120 pixel pentacene-TFT addressing AM-TN-LCD. [1] T. N. Jackson et al., 42nd Electronic Materials Conference Digest, p.2, 2000.

11:30 AM H1.8
Direct Patterning of Organic Materials and Metals Using a Micromanipulated Printhead. J. Chen1, V. Leblanc1, S. H. Kang1, M. A. Baldo1, P. J. Benning2, V. Bulović1 and M. A. Schmidt2; 1Microelectronics Technology Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts; 2Hewlett-Packard Company, Corvallis, Oregon.

We report on an electrostatically actuated micromanipulated printhead (MEMS) shown integrated with an x-y-z micromechanical manipulator that can be used to selectively modulate the flux of evaporated organic semiconductors and metals, and generate patterns of the deposited materials. This printing scheme could enable patterned large area organic optoelectronic devices on diverse substrates. The micromanipulated printhead reported here consists of a free-standing silicon microshutter actuated over a 25 micros square aperture by a comb-drive actuator. The device is fabricated starting with a SOI wafer and using Deep Reactive Ion Etching to pattern both the through-wafer aperture and the free-standing structure and actuation mechanism. An operating voltage of 30 V is used to open the aperture with the microshutter. The simulated first mechanical resonant frequency of the device is 6 kHz. We tested the printing method in a vacuum chamber by depositing organic semiconductor, Alq₃, and silver on glass substrates. An effusion cell was used to sublime the active materials, with its height adjustable to facilitate study of the effects of distance between the source and the microshutter. The microshutter was mounted on a ceramic package with electrical feedthrough at a fixed position in the chamber. The substrate on which material is deposited was attached to a microshutter manipulator with stepping motors to allow relative motion of the substrate with respect to the microshutter for arbitrary pattern printing. 30x30 micron pixel size Alq₃ (tris-(8-hydroxyquinolino) (ALUMINUM) matrix was directly printed on ITO coated glass substrate. The influence of deposition conditions on the pixel profile was studied with atomic force microscopy and light interference microscopy (WYKO). The results show that the molecular jet print technique is capable of patterning small molecule organic light emitting devices at high resolution. 30 micron wide metal patterns directly written at 1100 °C using the same technique was also demonstrated.

11:45 AM H1.9
Highly Efficient Flexible Devices using a Statistical Copolymer of Oxadiazole containing PPV. Hermosa Christian1, Subramanian Vaidyanathan2, Changhee Ko1, Rick Beyer3 and Mary E. Galvin1; 1Materials Science and Engineering, University of Delaware, Newark, Delaware; 2Materials Research Technologies, Murray Hill, New Jersey; 3Multifunctional Materials Branch, WMRD, Army Research Laboratory, Aberdeen Proving Grounds, Maryland.

With polymers as the active layer in a plastic substrate, construction of flexible devices is possible, although the use of calcium cathodes places stringent requirement on the morphology of the device. Our work focuses on the development of polymers that will function with higher work function cathodes, making encapsulation less problematic. Additionally, we seek to fabricate stable, flexible PLEDs with a simple device configuration for military display applications. To this aim we have made efficient multi-layered flexible PLEDs using a statistical copolymer of hole transporting dialkoxy-substituted PPV with an electron transporting oxadiazole containing PPV derivative as the emissive layer. Even in single layering device we shows good performance. When PEDOT:PSS was coated on the ITO and
LiF was evaporated between the emissive layer and Al, external quantum efficiency is significant improved to 1%. Several other cathode materials were also screened, and those results will be reported as well.

SESSION H2: Giant Area Electronics and Circuits
Chair: Virginia Chu
Thursday Afternoon, March 31, 2005
Room 2008 (Moscone West)

1:30 PM *H2.1*
Flexible, Conformal, and Electronic Surfaces
Sigurd Wagner, Electrical Engineering and PRISM, Princeton University, Princeton, New Jersey.

The display industry is beginning to manufacture on four-square-meter glass substrates, to supply the rapidly growing market for flat panel television sets. Within ten years, large area electronic surfaces will sell in the store for $1,000 or less per square meter. The arrival of manufacturing technology for low-cost giant integrated circuits is encouraging research into revolutionary concepts for electronic surfaces. Mechanical flexibility will be part of the next generation of display technology and eventually will enable surround displays. In the cards are conformally shaped sensors and displays, electronic textile circuits integrated by weaving, and elastic sensor and actuator skin. All of these already have been demonstrated in the lab. Giant electronics is shaping up as a rich area of research as the integration of electrical, optical, mechanical, and bio-chemical functions over large surfaces. These will need new electronic materials and fabrication processes, circuits, communication and system architectures. I will discuss specific issues in materials, devices and circuits for flexible, conformal, and electronic surfaces.

2:00 PM H2.2
Lateral Nonuniformity And Mesoscale Effect in Giant Area Electronics. Victor G. Karpov, Diana Shvydka and Yann Roussillion; Physics and Astronomy, University of Toledo, Toledo, Ohio.

The recently developed physics of conventional giant area thin-film devices, such as terrestrial photovoltaics, is extended to the general field of giant area electronics. In particular, it has been established that large area, thin-film semiconductor structures often exhibit strong fluctuations in electronic properties on a mesoscale level that originate from relatively weak microscopic fluctuations in material structure such as grain size, chemical composition, and film thickness. Amplification comes from the fact that electronic transport through potential barriers is exponentially sensitive to the local parameter fluctuations. These effects create new phenomena and establish the physics of giant-area, thin-film devices as a distinctive field of its own. We show that (i) giant-area semiconductor thin-film devices are intrinsically nonuniform laterally, (ii) the nonuniformity can span length scales from millimeters to meters depending on external drivers such as light intensity and bias, and (iii) this nonuniformity can significantly improve and stabilize of, e.g., flexible substrate photovoltaics, light-emitting arrays, and liquid-crystal displays. In addition to the experimental data on lateral nonuniformity effects, we present a theoretical analysis based on the concept of random diode array proven relevant in describing a system of large number nonlinear interconnected elements. In our work we derive a fundamental length scale that discriminates between the cases of small and large-area devices, and beyond which a new physics emerges. A new approach is developed to block the effects of lateral nonuniformities in thin-film semiconductor structures. Because the nonuniformity modulates the surface photo-voltage distribution, it generates laterally nonuniform electrochemical reactions when exposed to light and immersed in a proper electrolyte (red wine effect recently highlighted in the media). Such treatments result in a nonuniform interfacial layer that balances the original nonuniformity. This approach has been successfully implemented for photovoltaic devices where it improved the device efficiency from 2% to 12%. We feel that enhanced understanding of the effects of nonuniformities will help to improve the performance and stability in many giant area device applications. REFERENCES 1. V. G. Karpov, A. D. Compaan, Diana Shvydka, Random diode arrays and mesoscale physics of large-area semiconductor devices, Phys. Rev B 89, 045325, (2004). 2. V. G. Karpov, Electrochemical reactions when exposed to light and immersed in a proper electrolyte. 3. V. G. Karpov, Critical disorder and phase transition in random diode arrays. Phys. Rev. Lett., 91, 228006 (2003). 4. V. G. Karpov, Blocking thin film nonuniformities: photoinduced self-healing. Appl. Phys. Lett. 84, 416 (2004).

2:15 PM H2.3
Fine-feature Patternning of Giant-area Flexible Electronics by Microcontact Printing and Digital Lithography.

The development of inexpensive high-performance electronics requiring low-temperature device processing would enable low-cost, giant-area flexible electronics for applications such as high-resolution graphics displays, sensors, and integrated high-performance circuits such as visual paper. The spatial resolution, small drop volume and large-area coverage of jet-printing methods, combined with fine feature stamping and low-temperature semiconductor processing, is one approach for integrating high-performance thin-film transistors (TFTs) onto giant-area flexible substrates. A novel digital-lithographic method, in which an electronically generated and digitally aligned etch mask is jet-printed onto a process surface, was used to fabricate hydrogenated amorphous silicon thin-film transistors (a-Si:H TFTs) on large area substrates. The resulting TFTs possessed on/off ratios of $10^8$ and threshold voltages of 2-3 V. To further demonstrate the efficacy of the digital lithographic process, the technique has been applied to fabricate a-Si based TFTs backplanes on flexible substrates. Given the ability for high-resolution spatial alignment, the digital lithographic process is ideal for registering multipatterning over a large-area flexible substrate in which localized alignment run out is a problem. In combination with digital lithography, a low temperature a-Si:H based $128 \times 128$ pixel matrix display was fabricated on melinex substrates. The display media will also be discussed.

SESSION H3: Giant Area Electronics and Circuits
Chair: Gregory Fain, University of California, Santa Barbara
Thursday Afternoon, March 31, 2005
Room 2008 (Moscone West)
substrates showed a slightly higher response than those on planar substrates. Both planar and cylindrical samples showed a low hysteresis. However, the repeatability error was increased for devices on cylindrical substrates. XRD, SEM, and optical microscopy are used to examine the crystalline phase and microstructure of the PVDF films on various substrates. These techniques are also used to examine changes in the onset of ductile or brittle behavior due to mechanical deformations induced through the application of pressure and repeated cycling. 1. Newman, M.R., et al., IEEE Engineering in Medicine and Biology Magazine, 1994. 13(3): p. 409-419. 2. Fimi-Boiew et al., Proceedings of IEEE Sensors, 2002. 2: 1648-1653 3. Arshak, K., et al., Sensors and Actuators A, 2000. 79: p. 102-114

3:00 PM H2.5
Fully Integrated High Frequency Nanowire Ring Oscillators. Robin Sean Friedman 1, Michael C. McAlpine 1, David S. Ricketts 2, Donhee Ham 2 and Charles M. Lieber 1,2; 1Chemistry and Chemical Biology, Harvard University, Cambridge, Massachusetts; 2Division of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts.

Macroelectronic circuitry implemented on non-crystalline substrates such as glass and plastic holds the promise of making computing devices ubiquitous due to their light weight, flexibility, and low cost. However, the temperature restrictions imposed by these substrates restrict the use of high carrier mobility materials, such as polycrystalline silicon, generally limiting these devices to the modest computational capabilities of amorphous silicon and organic semiconductor thin film transistors (TFTs). Densely assembled films of single-crystal, semiconductor nanowires, which have been shown to function as semiconducting nanowires in high mobility TFTs, can be fabricated via an ambient temperature process on virtually any substrate. Key to determining the viability of such structures in applied circuitry is the demonstration of fully interconnected devices which can operate at high-speed conditions and generate self-sustained, high frequency waveforms; previous work has only demonstrated unidirected devices under direct current (DC), time invariant conditions. While recent work suggests that single carbon nanotubes can function at high frequency, Alternating current (AC) conditions, previously demonstrated unidirected ring oscillators composed of these transistors displayed frequencies of only several hundred hertz. Here we report the fabrication of integrated systems of high performance silicon nanowire transistors. Poly(3-Hexylthiophene) (P3HT) devices with top and bottom gate electrodes were electroplated into the patterned Cu/Cr/polyimide substrate and patterned by ultra-violet shadow mask. For the bottom gate structure, after the formation of Cu(seed)/Cr(adhesion) layers were separated by exposed polymer. By using these techniques, we have demonstrated unidirected ring oscillators which can operate at high frequencies and have been measured to have a frequency of 55 MHz. The systems can function as logic inverters with gain under both DC and AC conditions up to megahertz frequencies. One-chip integration of multiple inverters allow for the generation of ring oscillators with frequencies up to 11.7 MHz, the highest observed frequency for circuits based on nanoscale materials.

3:15 PM H2.6

Organic thin film transistors (OTFT) on flexible substrate utilizing electroplated Au electrodes have potential advantages for the fabrication of flexible devices requiring large area coverage, structural flexibility, low-temperature processing, and especially low cost. In particular, the addition of electroplated electrode with the adhesion layers enables one to obtain reliable devices on the flexible substrate in terms of mechanical flexibility and thermal stability, as proved in the flexible printed circuit board (FPCB) technology. In this work, poly(3-hexylthiophene) (P3HT) OTFT devices with top and bottom gate structures were fabricated with electroplated Au source/drain (top gate structure) or gate electrodes (bottom gate structure). First, since the adhesion of the electrodes on the flexible substrate is of great importance for the application in flexible devices, the adhesion of electroplated Cr/Cu/adhesion was investigated by plasma treatment of polyimide substrate in Au/Cr/Cr/polyimide structures. Cu(seed)/Cr(adhesion) layers were sputter-deposited in sequence on the plasma-treated polyimide substrate. Then, Cu was photoetched on the Cr/Cr/polyimide substrate and patterned by ultra-violet photolithography for electrodes. After photolithography, Au source/drain or gate electrodes were electroplated into the patterned SU-8 mask. For the top gate structure, after SU-8 ashing and Cr/Cu layer removal, spin-coating of P3HT layers, SiO2 gate dielectric deposition, and Al electrode deposition were carried out with a shadow mask. For the bottom gate structure, after the formation of electroplated Cr and Cu(adhesion) layers, SiO2 gate dielectric deposition, gold source/drain evaporation, and P3HT spin-coating were carried out in sequence. The channel length ranged between 5 and 110 μm, and the channel width was 800 μm. Electrical properties of fabricated OTFTs were characterized at various conditions and the IR spectra for the performance of fabricated devices will be discussed.

3:30 PM H2.7
Nanocrystalline Silicon Thin Film Transistors on Optically Clear Polymer Substrates. Alex Katinian 1,2, I-Chun Cheng 1,2, Ke Long 1,2, James C. Sturm 1,2 and Sigurd Wagner 1,2; 1Department of Electrical Engineering, Princeton University, Princeton, New Jersey; 2Princeton Institute for the Science and Technology of Materials, Princeton University, Princeton, New Jersey.

Flexible displays are the next technology generation for flat-panel displays. Growing interest in using flexible materials to build the backplane of displays is due to its light weight, flexibility, and low cost. This enables the possibility of a new class of high-performance, low-cost, flexible backplane technology. Ideally, a flexible backplane should be constructed using fabrication processes already developed for glass with only minor changes. Nanocrystalline silicon (nc-Si: H) TFTs have at least two advantages over the ON current of amorphous silicon TFTs and can be plasma deposited at temperatures in upwards of 150°C. We have fabricated nc-Si:H TFTs on temperature resistant polymer full substrates, first on orange colored Kapton © 200E, and now on a clear polymer. Organic polymer substrates may be processed either mounted on a rigid holder, to ensure dimensional stability, or free-standing. We are working with both methods, but here the focus is on free-standing substrates. Both these substrates have high glass transition temperatures and are therefore candidates for direct substrate of display glass. This introduces the next challenge, overcoming the effects due to the mismatch in coefficients of thermal expansion (CTE) between silicon TFT materials and the polymer substrates. The effects of mismatch become more pronounced as process temperatures increase, this mismatch, and built-in stresses in the device films, can combine to fracture TFT structures during processing. We demonstrate techniques that are available for avoiding device and substrate fractures. We fabricated nc-Si:H TFTs on Kapton © 200E (CTE = 45 to 55 ppm/K), Kapton © 200E (CTE = 17 ppm/K), and on 1737 glass (CTE = 4 ppm/K) for comparison. Stress developed in device layers was compensated by designing stresses, via PE-CVD growth conditions and PE-CVD growth conditions into the silicon nitride films that serve to passivate the front and back of the polymer substrate. The stress in the substrate was decreased by reducing device layer thicknesses and by cutting the device layers into islands separated by exposed polymer. By using the three techniques we have made directly deposited nc-Si:H TFTs on clear polymer foils with electron mobilities of up to 15 cm²/Vs.

3:45 PM H2.8
ZnO Thin Film Transistors on Gate Dielectrics Grown By Atomic Layer Deposition. Peter F. Carcia 1, Robert Scott McLean 1, Michael H. Reilly 1, Yoshii Senzaki 2 and S. G. Park 2; 1Research and Development, DuPont, Wilmington, Delaware; 2Aviza Technology, Scotts Valley, California.

Investigation of large area electronics on low-temperature, flexible substrates frequently focuses on limitations of the semiconductor, especially its too low mobility, fact many applications in the IC industry, where there is a need to replace the thermally grown SiO2 gate dielectric in the highest performance transistors, atomic layer deposition (ALD) is emerging as the preferred method for growing dense, pinhole-free, high performance gate dielectric films. When ALD films are commonly grown at moderate substrate temperature (~ 300 C), introduction of new precursor chemistry and plasma-assist have reduced, and for some materials, eliminated the need for substrate heating, making ALD attractive for low-temperature plastic substrates. In this paper we compare ZnO thin film transistor (TFT) properties on gate dielectrics of Al2O3, HfO2, and HfSiO2 grown by ALD with corresponding properties on thermally grown SiO2. Room temperature mobility >10cm²/V-s, Vth = 2.5 V, and a subthreshold slope ~ 0.5 V/decade. This represents a 4X increase in mobility and a 10X reduction in Vth compared to ZnO TFTs simultaneously grown on SiO2 gate dielectric. Further, we will discuss the effect of ALD growth temperature of gate dielectrics on ZnO TFT properties and the implications for large area electronics on plastic substrates.

4:00 PM H2.9
Temperature Dependence of I-V Characteristics of Organic PN Diodes and Their Application to Sheet Thiet Sensors. Yousuke Kato 1,2, Tatsuyo Sekitani 1,2, Shingo Iba 1, Takayasu Sakurai 2, and Takao Soneya 1; 1Quantum-Phase Electronics Center, The University of Tokyo, Tokyo, Japan; 2Center for Collaborative Research, The University of Tokyo, Tokyo, Japan.

We have fabricated organic pn diodes on plastic films and measured temperature dependence of I-V characteristics in the wide range from
30 to 240°C under N2 environment. The current (Iv) was increased by a factor of 20 with changing the measurement temperatures from 30 to 180°C where I - was monitored at forward voltage bias of 2 V. Furthermore, temperature dependence of I-V curves was reversible and reproducible when the measurement temperature was below 180°C. This result shows the feasibility of organic pn diodes for thermal sensors. Organic polymer diodes have been manufactured on an ITO-coated poly(ethylene naphthalate) (PEN) film (98 μm, Teijin Dupont Films) with thickness of 200 nm. First, the surface of the ITO-coated base films were cleaned by organic solvent in the ultrasonic bath and exposed to ozone (3 min, room temperature). Then, 30-nm-thick copper phthalocyanine (CuPc-p-type) and 50-nm-thick 3,4,5,10-pentylaryle-tetracarboxylic-diimide (PTCDI, n-type) were deposited by vacuum evaporation ($5 \times 10^{-5}$ Pa, 3 min/min). Subsequent processes have been performed without exposure to air. After depositing organic layers, the film was transferred to glove box (<1 ppm O2 and H2O), where a metal mask for cathode was attached to the film, and then loaded into a vacuum chamber. Initially, 150-nm-thick gold was deposited as cathode by vacuum evaporation. The size of cathode was 450 x 450 μm². Prior to measurements of the temperature dependence, the I-V characteristics of the pn diodes at room temperature were measured with a semiconductor parameter analyzer (Agilent, 4156C). All the measurements were performed in the glove box without exposure to light. The current density was 200 mA/cm² at 2 V bias and 0.03 mA/cm² at 2 V. The breakdown and the threshold voltage were -17 V and 4 V, respectively. Then temperature dependence of I-V characteristics was measured. The current density at 2 V bias was enhanced from 200 mA/cm² to 4 A/cm² when the measurement temperature changed from 30 to 180 °C, namely twentyfold enhancement has been observed. This tendency can be fitted by Arrhenius’s formula, indicating a carrier transport of thermal excitation. The evaluated activation energy was 0.6 eV. Furthermore, temperature dependence of I-V curves was reversible and reproducible after many heat cycles from 30 up to 160 °C. We have recently reported a flexible, large-area pressure sensor with an OPET active matrix for electronic artificial skin (E-skin) applications. The present study shows feasibility of organic pn diodes as thermal sensors, which are flexible, lightweight, potentially ultra low in cost even for large area and furthermore compatible with manufacturing process of OFETs. Therefore, we believe that the organic diode should be the strong candidate for large-area thermal sensors for E-skin implementations thanks NEXT IT program and COE program for financial supports. ¹T. Someya, et al, PNAS, 101, 9966 (2004).

SESSION H3: Organic Photonics and Electronics for Large Area Substrates and Flexible Displays

Chair: Martin Stutzmann
Friday Morning, April 1, 2005
Room 2000 (Moscone West)

9:30 AM *H3.2 High-Mobility Pentacene-Based Transistors on Plastic Substrates. Siddharth Molapata, Michelle Grigas, Robert Wegs, Robert Rotzoll, Viorel Olariu, Oleg Shchekin, Klaus Dimmler, and Ananth Dodababapu; Organic ID, Austin, Texas; 2Organic ID, Colorado Springs, Colorado; 3The University of Texas at Austin, Austin, Texas.

Organic field-effect transistors (OFETs) are being developed for several electronic applications including displays, biological and chemical sensors, and RFID (radio frequency identification device) tags. To explore the full range of advantages offered by organic electronic materials it is important to be able to manufacture high-performance electronics on flexible substrates at very low cost. Apart from being used in such relatively high-value applications as RFID tags, the polymer-based OFETs will have to have mobility ~ 0.3 cm²/V-s and channel lengths on the order of a few microns. To achieve such performance it is necessary to optimize the dielectric substrate in which pentacene is deposited as well as the injection of carriers into the conduction channel. The paper presents a method for achieving high mobilities in pentacene-based organic field-effect transistors (OFETs) on plastic substrates. These transistors are part of a two-level metal-based organic electronic circuit technology. The fabrication process also includes a critical step which consists of dielectric surface cleaning using gas plasma or ozone, followed by application of various self-assembled monolayer (SAM) materials such as octyltrimethoxysilane (OTS) or hexamethyldisilazane (HMDS). Pentacene is purified and evaporated in vacuum with the substrate maintained at room temperature. The devices with HMDS repeatedly exhibited highest mobility of 0.1 cm²/V-s and on-off ratio up to 10^4. The devices have a channel length in the range 2-4 mm. Devices with HMDS and OTS have mobilities higher than those without any dielectric cleaning or surface treatment, but exhibit more pronounced hysteresis in the I-V characteristics. Very high channel mobilities and relative poor performance of the untreated devices may be attributed to the surface contamination with chemicals used during circuit preparation. The performance of simple electronic circuits such as inverters and rectifiers fabricated using the aforementioned mobility-enhancing method is also discussed. 9:45 AM H3.3 Polymer Light Emitting Diodes with Layer-by-Layer Structure Prepared by ESDUS Method. Katsuhiko Fujita, Takanasu Ishikawa and Tetsuo Tsutsui; Graduate School of Engineering Science, Kyushu University, Kasuga, Fukuoka, Japan.

We have reported a new type of polymer ultra-thin film preparation method, the spray deposition, and the application for organic optoelectronic devices such as an organic light emitting diode (OLED). In this method, a highly diluted solution of an organic material is nebulized into air and concentrated under a controlled evaporation condition. The resulting aerosol is transported by a carrier gas and deposited onto a solid substrate. This method has several advantages that a most insoluble and non-evaporative material can be fabricated into a thin film, and that a separate-coating and layer-by-layer structure of polymers can be performed. An OLED was prepared from highly diluted THF solutions, below 1 ppm, of two poly-phenylenevinylene derivatives. One shows red emission and the other green. The red polymer was deposited on an ITO electrode through a shadow mask with round holes and 0.1 mm line width to result a fine separate-coating and the green one was deposited onto the patterned film. An Al anode was deposited on the polymer film in a vacuum evaporator. The fabricated OLED showed a patterned emission at around 10 V. 10:30 AM H3.4 A Novel Patterning Technique for High-Resolution RGB-OLED-Displays: Laser Induced Local Transfer (LILT). Michael Kroger, Thomas Dobbertin, Henning Krautwald, Thomas Riedl, Hans-Hermann Johannes, and Wolfgang Kowalsky; 1Institut fuer Hochfrequenztechnik, Technische Univ. Braunschweig, Braunschweig, Germany; 2Labor fuer Elektrooptik, Technische Univ. Braunschweig, Braunschweig, Germany.

A novel technique for high-resolution patterning of organic semiconductors is presented. There are mainly three different approaches of realizing full-colour OLED-displays (OLED: organic light emitting diode). One of these is colour from white by applying a colour-converting phosphor matrix (colour from blue). Micro-patterning of red, green and blue OLEDs is to be favoured for reasons of lower costs and higher efficiency. One approach is to convert blue light into green and red light by a colour-converting phosphor matrix (colour from blue). Micro-patterning of red, green and blue OLEDs is to be favoured for reasons of lower costs and higher efficiency. One approach is to convert blue light into green and red light by a colour-converting phosphor matrix (colour from blue).
If bigger substrate sizes of future mass production tools are considered, shadow masking may not fit the requirements, as the mechanical stability of the mask itself will be a problem. Taking this into account alternative patterning techniques have to be developed. In the past we demonstrated a local sublimation method [1], where a Mo-film was deposited onto a thin polyimide-film (PI) and patterned by photolithography and etching thin stripes. Onto the opposite side the desired organic material was deposited by organic molecular beam deposition (OMB). By heating the Mo-stripes with short high current pulses the organic material could be sublimed locally, which then deposits onto an OLED substrate placed in a short distance from the PI-fil. In this work we demonstrate a local sublimation method for which the resistive heating was replaced by a resistive heating performed by a focussed infrared laser beam. An infrared absorbing substrate is thermally treated with either a red, green or blue light-emitting organic material and placed in a short distance (below 50 μm) of the OLED-substrate onto which the organic material is to be patterned. The laser beam is deflected by a scanner onto the target in such a way that the heating speed and laser power are adjusted properly, the target locally heats up to a temperature at which the organic material sublimes and condenses on the opposing OLED-substrate. By repeating this process for each colour red, green and blue stripes can be deposited in widths below 300 μm. As next step a RGB-patterning-tool designed for inline-processing of OLED-displays has been built. First results of RGB-OLEDs patterned by this tool are to be discussed. References [1] E. Becker, T. Hielsl, T. Dehberdt, D. Schneider, D. Hethecker, D. Metzdorf, H.-H. Johannes, W. Kowalsky, Appl. Phys. Lett. 2003, 82, p. 2712.

10:45 AM H3.5

Ionic transition metal complexes are receiving increased attention due to the high efficiencies obtained in organic light emitting devices with air-stable cathodes. We report on devices based on ruthenium(II)-tris-bipyridine complexes that can be sourced directly from a standard U.S. wall outlet. With the aid of the ionic liquid 1-butyl-3-methylimidazolium, these devices show sufficiently fast response time to switch at frequencies up to 120 Hz. Fabricated from a single spin cast organic layer, these devices are prepared in a sandwich-structure cascaded architecture. This architecture sustains high input voltages, provides fault tolerance, and facilitates the fabrication of large area solid-state lighting panels.

11:00 AM H3.8

In the future information will be displayed not only on rigid monitors, but displays will be found embedded in walls, furniture, clothes, or they may appear as roll-up displays similar to the way sheets of paper can be rolled up. The display will have to require large-area or giant-area electronic backplanes. Flexibility, low cost and low power consumption are amongst some of the requirements for such displays, often referred to as electric paper. Electrophoretic ink technology is promising for reflective displays with paper-like appearance. For giant-area display backplane electronics conventional semiconductor processes such as lithography and vacuum deposition may become too costly. Direct-writing techniques such as jet printing can be used as a viable alternative. Here we report on flexible electrophoretic media and the integration with various backplanes technologies. The electrophoretic medium is based on micro-cell structures which are fabricated using photolithography or potentially cheaper molding techniques. The pixels are Mylar foil coated with transmissive conductive indium-tin-oxide (ITO). Typically, the cell structures are about 200 microns square and about 50 microns tall. After filling the cells we deposit the backplane ink through a topcoated polyimide film. The electrophoretic medium is then laminated to the backplane. We have demonstrated ultra-flexible directly addressed electrophoretic displays. However, active matrix addressed displays offer a much larger application space, particularly when the backplane is made by jet printing techniques are promising for potentially inexpensive flexible displays. In one approach a novel digital-lithographic method, in which an electronically generated etch mask is jet-printed onto a process wafer, is used to fabricate a-Si:H thin-film transistor (TFT) backplanes with a pixel resolution of 75dpi. In another approach the a-Si:H semiconductor material was replaced with a jet printed organic semiconductor. Due to the larger feature sizes of the printing technique compared to conventional lithography a reduced fill-factor can occur and its effect on the image quality was investigated. The integration of the electrophoretic medium with the backplane also poses challenges such as the uniformity, the flexibility and the thickness of the medium between the pixels and the backplane. Using a laminating technique we were able to achieve thin glue layers with good thickness uniformity. Furthermore, impurities in the sealing layer or in the glue layer can cause a loss of resolution in the displayed image. We have studied this effect and first results will be presented.

11:15 AM H3.7
The Polymer/Anodized Al2O3 Hybrid Gate Dielectrics of OFET for Flexible Display. Kwonwoo Shin, Sang Yoon Yang and Chan Eon Park; Chemical Engineering, Pohang University of Science and Technology, Pohang, Gyeongbuk, South Korea.

In the study of organic field effect transistors, the formation of good gate dielectric layer is one of the most important processes when being fabricated on the flexible substrate. Until now, the study on the formation of gate dielectrics has been focused on the use of low toxic inorganic materials. But, in our research, we used both inorganic materials and polymer materials to enhance the performance of the gate dielectric layer. Also, we used neither any high temperature processes nor vacuum equipments for making our gate dielectric layer. Our gate dielectric layer consists of anodized Al2O3 layer and spin-coated Poly(methyl methacrylate)(PMMA) layer. By anodizing the surface of aluminum electrode used as gate electrode, we could make Al2O3 passive thin film on the aluminum gate electrode. This passive film had very good insulating and dielectric properties. So it could reduce the leakage current and increase the capacitance of dielectrics. And the additional thin PMMA coating on the anodized Al2O3 could reduce the surface roughness and surface energy of dielectrics. The OFETs having layered PMMA/Al2O3 gate dielectrics showed high performances. The OFETs on the flexible polyimide substrate showed 0.3 cm2/Vs of mobility, 107 of on/off ratio, 0.8 V/decade of subthreshold slope and the OFETs on the SiO2 substrate showed 1 cm2/Vs of mobility, 106 of on/off ratio, 0.9 V/decade of subthreshold slope. The ordering of pentacene was dependent on the surface roughness and surface energy of our dielectrics. The vertical and horizontal orderings of pentacene were investigated with X-ray diffraction and the orientation of the pentacene molecules on the dielectric surface was investigated with Near Edge X-ray Absorption Fine Structure (NEXAFS) in Pohang Accelerator laboratory in Korea.

11:30 AM H3.8
Encapsulation of Flexible Organic Light-Emitting Diodes using Photocurable Coating and Polyvinylidene chloride (PVDC). C. S. B. Ruiz1, Rodrigo F. Bianchi1, Ely Antonio Tadeu Dirani1,2, Fernando Joseppetti Fonseca1 and Adnel Meges de Andrade1; 1PSI, Escola Politecnica/USP, Sao Paulo, Sao Paulo, Brazil; 2FTMT, Pontificia Universidade Catolica de Sao Paulo, Sao Paulo, Sao Paulo, Brazil.

One of the most promising display technologies to come along in the last decade is the organic light-emitting diode (OLED). The potential for such a device is low cost, lightweight, and flexible. This last characteristic is of interest because it would enable processing in a roll-to-roll manner. However, as the organic material is very susceptible to water vapor and oxygen, thorough encapsulation is indispensable, which is crucial to the device lifetime, as well as the excellent adherence of the coatings on the flexible substrate. In this work we have investigated the use of polyvinylidenedi chloride (PVDC) films as protective layers of flexible light-emitting diodes based on (2-methoxy-5-(2-ethylhexoxy)-p-phenylene vinylene) - MEH-PPV. The material coatings were applied onto the bottom and top of a typical device structure (PET/ITO/MEH-PPV/Al), and the electrical and optical characteristics of the OLEDs examined as function of light exposure time and illumination intensity. The improvement in lifetime, as well as the excellent adherence of the coatings on the flexible substrate, on the cathode and on polymer emissive layer shows the potential for such class of barrier materials to be used in OLEDs. This work was sponsored by Fapesp, CNPq and IMP/MCT.

11:45 AM H3.9
Pentacene Field-effect Transistors with 230-nm-thick Polyimide Gate Dielectric Layers. Shingo Iba1, Tatsushi Sekitani1, Yussaku Kato1, Takayasu Sakurai2 and Takao Someya1; 1Quantum-Phase Electronics Center, School of Engineering, The University of Tokyo, Tokyo, Japan; 2Center of Collaborative Research, The University of Tokyo, Tokyo, Japan.

We have fabricated pentacene field-effect-transistors (FETs) with 230-nm-thick polyimide gate dielectric layers cured at 180°C on polyethylene naphthalate (PEN) film. With the source-drain bias of -8 V, the transistors showed field effect mobility of 0.15 cm2/Vs, the
on/off ratio of 10^7 and the subthreshold swing of 1.7 V/decade. Pentacene FETs (top contact geometry) with polyimide gate dielectrics of thicknesses from 220 nm to 920 nm were fabricated. First, a 5-nm-thick chromium adhesion layer and a 50-nm-thick gold layer were deposited through shadow masks to form gate electrodes on PEN film. Then, polyimide precursors were spin-coated and cured at 180°C for 1 h. The polyimide gate dielectric thicknesses, the rotation velocity during spin coating and the viscosity of polyimide precursors were systematically changed. Pentacene was purified by the vacuum sublimation method and deposited in the vacuum system to form a 50-nm-thick layer. Subsequently, the samples were transferred, without exposing to air, to the glove box (O_2 and H_2O < 1 ppm), where the metal masks were placed onto the film. After loading the samples into the vacuum system, a 60-nm-thick gold layer was deposited to form source and drain electrodes on the top of the pentacene layer. The channel width and length are 1.6 mm and 50 μm respectively. The device characteristics were measured with a semiconductor parameter analyzer (Agilent 4156C) in the glove box. When source-drain voltage V_DS was applied to the transistor with a 230-nm-thick dielectric, the field effect mobility in saturation region was 0.13 cm^2/Vs, the on/off ratio was 10^7 when off current was defined as minimum drain current I DS at positive gate bias. The subthreshold swing was 1.7 V/decade. Field-effect mobility in saturation region increases with increasing gate bias V GS and reached 0.5 cm^2/Vs at the gate voltage of -40 V. In case of transistor with a 470-nm-thick dielectric, the mobility was 0.08 cm^2/Vs, the on/off ratio was 10^5 when a drain voltage V_DS of -4 V was applied. These characteristics are comparable to the reported characteristics of the pentacene devices with polyvinylphenol (PVP) gate dielectrics. These results demonstrate feasibility of low voltage operation of flexible organic FETs with polyimide gate dielectric layers, which would be a key technology for large area sensor sheets like electronic skin (E-skin). The authors thank MEXT IT program and C-0S program for their financial support. This work was partly done at the Photonics Lab, Phys. Res. Inst., The University of Tokyo, Phys. 92, 5259 (2004). 2 Yusaku Kato, etal., Appl. Phys. Lett. 84, 3780 (2004). 3 T. Somcya, etal, Proc. Natl. Acad. Sci. U.S.A. 101, 9996 (2004).
3:15 PM **H4.4**

Ink jet printheads are now widely used in manufacturing processes that require precise dispensing of materials. Today, Spectra manufactures a variety of drop-on-demand ink jet printheads for the industrial printing market, but new markets present fresh challenges to our technology. In response to requirements for dispensing novel electronic fluids, we are developing next generation jetting technology based on our silicon MEMS technology with three-dimensional silicon technology and piezo-based pumping chambers integrated into the chip structure. This presentation will discuss the current status of ink jet printing as a manufacturing process in the electronics industry. It will address the functional and physical design features and properties of Spectra’s MEMS process, its characteristics, reliability and usability. To meet the needs for a simple R&D tool, Spectra has designed a Lab Deposition System that couples disposable ink jet modules with a simple x-y-stage. The Lab Deposition System has the capability to visualize drops in flight, key to understanding the dynamic performance of unique fluids. Examples of opportunities and applications in electronics printing for MEMS-based ink jet technology will be presented.

3:30 PM **H4.5**
High-Mobility Ambipolar Field-Effect Transistors Based on Transition Metal Dichalcogenides. Vitaly Podzorov1, R. Zeis*, Christian Kloc*, Ernst Bucher2 and Michael Gershenson1; 1Physics Department, Rutgers University, Piscataway, New Jersey; 2Lucent Technologies, Murray Hill, New Jersey.

We report on fabrication of a novel class of high mobility field-effect transistors based on transition metal dichalcogenides [1]. The unique structure of the single crystals of these layered inorganic semiconductors enables fabrication of FETs with intrinsically low field-effect threshold and high charge carrier mobility, comparable to that in the best single-crystal Si FETs (up to 500 cm2/Vs for the p-type conductivity in the WSe2-based FETs at room temperature). Among other interesting properties of these FETs are the ambipolar operation and mechanical flexibility. These remarkable characteristics make FETs based on transition metal dichalcogenides very attractive for basic research and for applications in "flexible" electronics.


3:45 PM **H4.6**
Polyaniline Films on Flexible Substrates for Strain Gauge Applications. Rodrigo Fernando Bianchi1, Enil Mara1, Silmar A. Travain2, Fernando Josepelli Fonseca3, Ely Antonio Teden Dirani1,2 and Adnei Melges de Andrade1; 1PSI, Escola Politecnica/USP, Sao Paulo, Sao Paulo, Brazil; 2ETMT, Pontificia Universidade Catolica de Sao Paulo, Sao Paulo, Brazil; 3IFSC/USP, Sao Carlos, Sao Paulo, Brazil.

This work describes the design and the operation of thin polyaniline films used to produce a conducting polymer base-strain gauge sensor. Polymer strain gauges are of great interest due to their large recoverable strains, low cost, and potential for integration with other polymer devices, including diodes, transistors and batteries. Thin polyaniline films were prepared by in-situ polymerization method on an interdigitated chromium-gold microelectrodes previously deposited on poly(ethylene teraphthalate) - PET substrates. The electrical characteristics of the polymer device were carried out as function of the polyaniline doping level using a Wheatstone bridge circuit in order to improve the device performance and efficiency. This circuit allows the measurement of small strains characteristics of the polymer system deformation around 0.1 % and gauge factor higher than 3, which is typical of inorganic solids material under tension. The excellent adherence of the PANI films on PET, as well as the recoverable strain of greater than 1 % may be useful in the design of future devices. This work was sponsored by Fapesp, CNPq and IMMP/MCT.

4:00 PM **H4.7**

This paper deals with the electrical characterization of coplanar waveguide (CPW) transmission lines printed onto non-woven textile substrates using conductive inks. After the transmission lines were printed, tests were carried out to determine their suitability for wide-band applications (e.g., digital signaling). The tests for the conductive-ink line characterizations included DC parameters and Time-Domain Reflectometry metrics. The transmission-line test samples were screen printed onto three different, carefully selected types of non-woven textile substrates using conductive inks of different compositions and viscosities. The printed test samples show visual variations in the continuity of the transmission lines, giving rise to geometrical variations in the CPW structure and characterization parameters. A custom test fixture was fabricated to allow the use of traditional microwave probing techniques during the characterization phase, and thus to reduce the errors derived from measurement interconnects. The methods described are scalable to large area flexible and stretchable textile substrates.