SYMPOSIUM M
Flexible and Printed Electronics, Photonics, and Biomaterials

November 27 - December 1, 2005

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* Invited paper
TUTORIAL

FTM: Nanoimprint Technology and Printed Organic Thin-Film Transistors
Sunday, November 27, 2005
1:30 PM - 5:00 PM
Room 201 (Hynes)

Nanoimprint is an emerging lithographic technique that promises high-throughput patterning of nanostructures with simple equipment setups, and can achieve pattern resolutions beyond the limitations set by the light diffractions or beam scatterings in other conventional techniques. It can also directly imprint functional device structures using a variety of polymers. This tutorial will describe the basic principles and experimental details of the nanoimprint technology. It will also discuss some of the recent progress in this field, including several novel applications.

The second part of this tutorial will discuss the fabrication of organic thin-film transistors (OTFTs). The rapid development in this area has been fueled by the promise of low-cost fabrication, lightweight construction, mechanical flexibility and durability, as well as large-area coverage. The tutorial will cover (1) a brief introduction of the effect of the molecular structure and morphology of the organic semiconductors; and (2) recent progress in printing and patterning of OTFTs, such as inkjet, screen, and microcontact printing, as well as focus on new patterning strategies by using the "tailored" adhesives as the patterning-driven force.

Instructors:
L. Jay Guo
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SESSION M1: Nanopatterning and Nanoimprint
Chairs: Y. Chen and L. J. Guo
Monday Morning, November 28, 2005
Room 306 (Hynes)

8:00 AM *M1.1
6 nm Half-Pitch Nanoimprint Lithography and Applications in SRAMS, OTFTs, and Biochips. Stephen Chou1, Michael D. Austin2, Nihua Li3, Xiaogang Li1, Haixiong Get3, Zhen Li1, Keith Morton1, Hua Tan2, Wei Zhang4 and Linsun Kong2
1Department of Electrical Engineering, Princeton University, Princeton, New Jersey; 2Nanoxon Corporation, Monmouth Junction, New Jersey.

We report some recent developments in nanoimprint lithography (NIL) tools, masks, resists, and processes for fabrication of 6 nm half-pitch, 0.04 μm mNIR ≥ 20, a 20 nm half-pitch SRAM metal layers, OTFTs with 20 nm channel length and biochip for DNA analysis. First, to explore the ultimate resolution of NIL, we explored and developed novel molds of 6 nm half-pitch and various NIL resists, and then transferred the 6 nm half-pitch gratings on the mold into in NX-2000 uv-NIL resist using NX-2000 NIL tool (Fig. 1). The mold for the 6 nm half-pitch lines was fabricated by cleaving a GaAs/AlAs/sub>0.7%</sub>GaAs/sub>0.3%</sub>As superlattice grown on GaAs with molecular beam epitaxy (MBE), and selectively etching the AlAs/sub>0.7%</sub>GaAs/sub>0.3%</sub>As layers in hydrofluoric acid. Second, to test NIL capability of making complex patterns, we fabricated SRAM cell metal layer of the 0.04 μm mNIR ≥ 20, and 20 nm half-pitch using NIL (NX-2000 tool and NX-2010 resist) (Fig. 2). The mold was fabricated in silicon dioxide using 35 kV electron beam lithography with polystyrene as a negative resist and reactive ion etching. The imprint showed an excellent critical dimension (CD) control of 1.3 nm, with residuals of 0.2% (4a for thermal CNTs). Third, to investigate NIL in fabrication of organic thin-film transistors (OTFTs), we fabricated OTFT with channel length as small as 20 nm (Fig. 3) and achieved significant current gain as the channel length became smaller. The molds for OTFTs were fabricated using EBL at Princeton NIL. Fourthly, we fabricated a broad range of biochips for DNA analysis. The NIL molds of these chips were fabricated using single or multiple NIL steps and mixed with other lithographies. Finally, we will present the results of ultra-thin resist layer thickness with a thickness control to 4 nm using NX-2000 NIL tool (single wafer imprintor) and NX-3000 (step-and-repeat imprintor).

8:30 AM *M1.2
The Use of Nanoimprint Lithography for Creation of Biomaterial Surfaces and Structures. Lars Montelius1, Patrick Carlberg2, Richard Buck3, Mark Sundberg4, Jenny Rosengren5, Ian Nichols6, Sven Tagerud2, Alf Mansson7, Waldemar Hallstroem1,3, Christelle Prinz1, Fredrik Johansson1,3 and Martin Kanje1
1Physics Department, University of Lund, Lund, Sweden; 2Chemistry and Biomedical Sciences, University of Kalmar, Kalmar, Sweden; 3Cell and Organism Biology, University of Lund, Lund, Sweden.

Recent years have seen a large interest in the development of nanoimprint lithography (NIL). [1,2] opening new avenues for nanoscale research. Simultaneously, there is a growing trend in Nanoscience in general to apply nanotechnology in the life science area. Here, in this new area of science the challenge is the need to make many samples due to the necessity to investigate processes governed by the variabilities that are inherent to biological systems. Hence, the use of wafer scale nanoimprint lithography is very promis[2]. In this report, we will therefore address the use of advanced nanotechnology for the study of protein interactions. In particular we will report on two projects that we are presently working with in this area. The first one concerns the successful creation of a nano-scale system employing proteins and the second one deals with fabrication of nanotextured surfaces for effective nerve cell guidance. In the first project we are studying the muscle proteins myosin and actin being responsible not only for the controlled muscle behavior in all living systems but also for the function of e.g. the internal cellular machinery. By forming nanochannels using the combination of nanostructured bi-layers of PMMA and LOR-surfaces in combination with selective surface functionalization of the exposed SiO2 surface [3], we have achieved efficient immobilization of the myosin molecules, and hence we have managed to fabricate efficient tracks for guiding the movements of motor actin filaments [4]. In this report we will discuss various forms of transport systems such as monomers, injectors, roundabous, crossings and components directing the flow of motor proteins with a control at the nanometer scale. Further, we will discuss about the potential for using such a system for high-throughput drug screening. In the second project we have studied the interplay between nerve cells and nanotextured surfaces. The surfaces being investigated have had both grooves of various shapes and widths/pitches as well as nanopillars of varying dimensions. In this talk I will describe the effective guiding that we have obtained. Acknowledgement: This work is partly performed within the Nanometer Consortium at Lund University supported by the Swedish projects NaPa and Nano2Life and by the Swedish Science Council, the Swedish Strategic Research Council and by the Swedish Agency for Innovation Systems. REFERENCES 1. S.Y. Chou, P.R. Krauss, P.J. Renstrom, Appl. Phys. Lett. 70 (1995) 2114. 2. Heidari B., Maximov I., and Montelius L. 2006. Nanoimprint lithography at the 6 in. wafer scale. J. Vac. Sci. Technol. B 18:5575. 3. M. Sundberg et al. Analytical Biochemistry, 323 (2003) 127-138. 4. R. Bunk, J. Kluth, J. Rosengren, I.A. Nichols, S. Tagerud, P. Omiling, A. Mansson, L. Montelius, Towards a nano-traffic system powered by molecular motors, Microelectronic Engineering 67-68 (2003) 899-904

9:00 AM M1.3
Hot Embossing as a Dry Transfer Printing Process for Flexible Electronic Devices. Ashante’ C. Allen, Erik Sunden, Andrew Cannon, William King and Samuel Graham
Mechanical Engineering, Georgia Institute of Technology, Atlanta, Georgia.

The development of new manufacturing technologies is necessary for the creation of nanomaterial-based flexible electronic devices. The interest in 1-D nanomaterials such as electronic inorganic solar cells, high flexibility, high transport mobilities and unique optoelectronic and piezoelectric properties. However, the direct synthesis of these materials on polymer substrates is challenging due potential processing incompatibilities. To circumvent this issue, a number of techniques have been developed to organize nanomaterials onto substrates such as solution based processing and dry transfer techniques. In general, dry transfer printing methods offer advantages as the need to address substrate-to-substrate incompatibility is mitigated. In this work, a dry transfer printing method based on hot embossing is presented. The method was demonstrated through the patterning of carbon nanotubes (CNTs) and ZnO nanowires on silicon and sapphire master stamps which were used to print on polymer substrates. The masters were utilized both as flat stamps or etched to create microtextured surfaces. Iron or gold catalyst was patterned on the stamps to direct the self-assembly of the nanomaterials. The nanomaterials were transferred to the polymers under the glass transition temperature, resulting in the simultaneous transfer of the microtextured features and nanomaterial patterns with resistances between 1-5000 kΩ. Thus, the method shows the ability to directly transfer the electrical components from the master stamps onto the polymer substrates. Since carbon nanotubes possess a band gap which can lie between 0.1-1eV, experiments were performed to analyze the optical detection characteristics of the printed devices. Data revealed that the resistances of the carbon nanotube traces were very sensitive to ambient lighting as well as laser excitation at frequencies of 488 nm and 807 nm. Laser powers as low as 100 μW were detectable.
Additional demonstrations of the capability of these devices were performed through field emission testing. By coating the backside of the polymer film gold and then depositing a catalyst on the front and back, an atmospheric plasma was created upon the application of a DC bias. Such field emission devices will have applications in a number of areas including flexible polymer field emission displays and ionized mass analysis for MEMS sensors, as well as in the creation of electronic devices. Without loss of generality, this method is amenable to other semiconductor nanomaterials synthesized by this vapor liquid solid growth method. Techniques by which catalysts can be used to control the synthesis of disimilar materials on the same masters will be discussed.

9:15 AM *M1.4 Chemical Nanopatterning via Nanoimprint Lithography for Liquid Crystal Displays. Sungguok Park1, Helmut Schiff2, Celestino Pedeste3, Jens Gobrecht4, Toralf Scharf4, Joachim Grupp4 and Naci Basturk4. 1Mechanical Engineering, Louisiana State University, Baton Rouge, Louisiana; 2Laboratory for Micro- and Nanotechnology, Paul Scherrer Institut, Villigen PSI, Switzerland; 3Institute for Microtechnology, Neuchâtel, Switzerland; 4ASULAB, Marin, Switzerland.

Nanoimprint lithography (NIL) is the next generation lithography for the fabrication of nanostructured surfaces with the potential of low-cost, mass production. As an easily accessible and flexible method, NIL opened new possibilities for interdisciplinary nanoscale research, particularly in the areas where two-dimensional nanomaterials are required, such as optoelectronics, photonics, and bioengineering. One potential application belonging to the abovementioned categories is liquid crystal displays. All the applications of LCs utilize the simple principle that LCs can easily be aligned by a proper treatment of the contact surfaces. While rubbing process is usually employed to produce linear gratings in the contact surfaces in the production of LC displays, a deliberate introduction of nanostructures allows creating more sophisticated surface alignment conditions and, thus, new functions of LCs interacting with the structures, which are keys for the next generation LC displays. The concept of using nanopatterning methods for achieving high functionality and high flexibility on LCs has been suggested in a few studies. However, the systematic investigation has not been performed yet, mostly due to the lack of simple and reproducible methods to fabricate large area chemical nanopatterns. This can now be overcome thanks to the development of the NIL technology. In this presentation, we will report on the use of chemical patterns to align a nematic LC in LC cells. The chemical patterns at the micro- and nanometer scale down to 30 nm in feature size were fabricated by combining NIL, with subsequent reactive ion etching, chemical modification with a fluorinated silane in the gas phase, and lift-off. Simultaneous control over both polar and azimuthal orientation of LC is possible by using the chemical nanopatterns as LC alignment layers. The polar orientation is determined by the ratio of the homeotropic/planar surface potential areas while the LC azimuthally orients along the direction of the silane patterns. The thermal transition behavior of LC on chemical patterns of appropriate chemical compositions such as chemical potential and film thickness, a possible candidate to achieve bistability for the future LC display.


Nanoimprint lithography (NIL) promises high-throughput patterning of nanostructures at a cost that promises to be economically viable in the development of new materials. This technique in recent years has also stimulated the research for new materials that are better suited as nanoimprint resists. Because imprint lithography makes a conformal replica of surface relief patterns (SRRP) by mechanical embossing, the resist materials used in imprinting should be deformed easily under an applied pressure. The most commonly used materials in the original NIL schemes are thermal plastic polymers, which become viscous fluids when heated above their glass transition temperature. However typical NIL processes to apply a viscosity of the heated polymers remains high and thus the imprinting process requires significant pressure. In addition, these thermal plastic resists normally have a high tendency to stick to the mold, which seriously affects the fidelity and quality of the pattern definition. Furthermore they do not offer the necessary etch resistance. Therefore a nanoimprint resist system with a combined mold release and etch resistance properties that allows a fast and precise nanoimprinting is highly desired. We have developed a new UV-curable nanoimprint resist based on cationic polymerization of silicone epoxy. Uniform film with thickness ranging from sub-50 nm to over 1 micron can be easily spin-coated by using a low viscosity material on a substrate. Due to its very low viscosity, varies patterns of sizes from tens of microns to below 100 nm can be imprinted at room temperature using a pressure of less than 0.1 MPA. Compared to the free radical polymerization of acrylates, the silicone epoxy crosslinkers are insensitive to oxygen inhibition and have very low shrinkage, which relaxes the processing condition and increases the fidelity of the imprinted pattern. Lift-off is also possible by using an under-coating layer of photoresist or a sacrificial layer. Plus good dry etching resistance, low viscosity and low volatility, make such material an excellent resist for UV-assisted nanoimprint. We will also report the development of a fast thermal curable liquid resist that can be spin-coated under a low pressure with high precision and throughput. In nanoimprinting, the liquid resist is first spin-coated on a silicon wafer, followed by imprinting with pressures in the range of 100–300 psi (or lower) at room temperature, and crosslinking after being heated above 80°C within a minute. Due to the tension of the patterned film (g = 19.8 dynes/cm at 20°C), the mold separation is quite easy. Importantly, the mold separation does not require cooling to room temperature. The Young’s modulus of the nanoimprinted film can be adjusted easily by changing the ratio of polymer to crosslinker. The high efficiency and throughput of this new nanoimprint resist system would warrant a potentially viable process for industrial nanofabrication.

10:30 AM *M1.6 Nanoimprint Lithography for 3D nanopatterning. Chun-Chi Chou, Vangelis Fotakis, Tony G. Petropoulos, Darrell D.4, Andrew S. Kim, Bin Li5, Soo Young Sohn2, Cheol Ryoo2 and Yangdoo Ko2. 1Chemical Engineering, University of Texas at Austin, Austin, Texas; 2Materials Reliability Division, NIST, Boulder, Colorado; 3Molecular Imprints, Inc., Austin, Texas.

Nanoimprint lithography (NIL), with its apparent simplicity and resolution down to a few nanometers, has become a preferred technique for one-level nanopatterning of thin organic films, which themselves act as a mask for further nanofabrication steps, or which can be used as-printed thanks to the functionality of the thin film itself. We will review the potential of NIL for optical passive device fabrication and will present our results on reversal NIL to realize 3D relief patterns using suitable polymers. Progress in the use of these patterns for molecular self-assembly will be discussed.

11:00 AM *M1.7 High aspect ratio pattern fabrication by nanoimprint and nano casting lithography. Yasuyuki Hiramatsu, Physics and Electronics Eng., Osaka Pref. Univ., Sakai, Japan.

Nanoimprint lithography (NIL) is expected to fabricate nano optical devices because polymer pattern works itself as an optical element without any additional process. For advanced nano optical element such as quarter wave plate, high aspect ratio patterns are indispensable for optical pickup or ultra high speed optical/photonic switch in optical information processing systems. To fabricate such high aspect ratio patterns, we demonstrate advanced thermal NIL, where the process sequence and condition are optimized to avoid stress concentration. By the process optimization, a defect at the mold removing process is successfully released and we obtain fine pattern in width and size in 2.1 micron in height. On the other hand, we propose nano casting method to fabricate fine patterns. A polymer is spin-coated on the mold and cast in the grooves of the mold. Then, the polymer is bowed to substrate and removes the mold. Using the casting method, 200nm half pitch pattern with 1.9 micron height is successfully transferred. This high aspect ratio pattern shows 1/5 wave shift against Laser light in 633nm wave length.

11:30 AM M1.8 Directly Patternable Dielectric Materials for Step and Flash Imprint Lithography. Frank L. Palmeri6, Jianjun Hao6, Yukio Nishimura6, Colin Flannery5, Michael J. Dowling5, Andrew S. Chan1, Bin Li5, Soo Young Sohn2, Cheol Ryoo2 and Indranil C. Grant Wilson5. 1Chemical Engineering, University of Texas at Austin, Austin, Texas; 2Materials Reliability Division, NIST, Boulder, Colorado; 3Molecular Imprints, Inc., Austin, Texas.

The Back End of Line (BEOL) electrical connectivity in a modern integrated circuit (IC) may contain as many as ten levels of wiring and associated vias (connections between wiring layers). The damascene process used to generate these copper interconnects requires many difficult processing steps. BEOL processing using Step and Flash Imprint Lithography (SFIL) with a directly patternable dielectric material can dramatically reduce the number of processing steps. SFIL with a multi-level template can simultaneously generate both the via and the trench with a single alignment and lithography step. By directly patterning a dielectric material instead of a sacrificial resist material, many hardmask materials and pattern transfer processes are eliminated. This report concentrates on the
characterization of new, Directly Patternable Dielectrics (DPD’s). Dielectric material requirements are both numerous and demanding. SFIR also varies not only for the optimization of the dielectric materials. SFIR requires low viscosity monomers which undergo rapid photo-induced polymerization with minimal shrinkage. A set of materials that are compatible with SFIR processing has been extensively characterized for the optimization of the dielectric properties. Of these materials derived from polyhedral oligomeric silsesquioxane (POSS) structures with various polymerizable organic pendant moieties show promise for this application. A two-stage processing technique is used to control the transition of the POSS materials. This enables the realization of the standard SFIR process to generate a patterned thin film. After pattern generation, the polymeric DPD film is heated to generate crosslinks and improve mechanical and thermal properties. The structure to function relationship of various POSS materials will be examined. Material properties of the precursor liquid such as viscosity, contact angle, and rate of polymerization are discussed. Properties of the UV cured films such as pattern resolution and elastic modulus, and properties of the fully cured resin such as elastic constant, thermal shrinkage, elastic modulus, Poisson’s ratio, CTE, and water sorption are discussed as well.


Critical to transition of embossing-based nanomanufacturing from laboratory to commercial use is the ability to predict polymer flow during embossing. In practice, nanoimprint (NIL) embossing can result in incomplete filling or nonuniform residual layers due to lack of tools for predicting polymer flow. Predicting atomic force microscope (AFM) thermomechanical nanoindentation also requires understanding of polymer relaxation processes in thin films. This paper presents continuum models capturing polymer deformation at length scales less than polymer radius of gyration during AFM nanoindentation and simulations identifying critical geometries, materials properties, and process conditions that govern polymer flow during NIL embossing, thus allowing NIL design rules to be formulated. Film polymer flow during NIL examine rectangular cavities embossing a Newtonian fluid under visco-elastic conditions. Simulations vary mold geometry parameters of indenter width $W$, cavity width $W$, and cavity height $h$, as well as initial polymer film thickness $h_0$ for single cavities and non-uniform asymmetric cavities. Polymer deformation mode and cavity filling time can be predicted based on ratios of cavity height and width, indenter width, and polymer film thickness. Single peak deformation depends solely on $W/h$, and always occurs when $W/h < 1$. Single peak, dual peak shear, and dual peak squeeze flow follow different fill time dependencies predicted by viscous flow theory of laminar flow between plates, Stokes flow, and squeeze flow. Squeeze flow occurs when $W/h > 1$, where $h$ is the initial film thickness. By determining the proper flow mode based on mold geometry and polymer film thickness ratios, a characteristic NIL velocity $v_{cell}$ can be identified, allowing establishment of NIL embossing design rules based on NIL cell number $C_{cell}$, fill flow rate $W/h$, and polymer supply ratio $S/h$. Finite-element simulations of polymer flow during AFM nanoindentation examine a heated probe tip of radius 20 nm indenting a thin film of high molecular weight polymer. A Williams-Landsau-Ferry-Carreau polymer viscosity model with bounds based on reptation and Rouse dynamics matches experimental measurements. High shear rates during nanoindentation thin the polymer and increase indent speed. Simulations vary polymer-tip and polymer-substrate slip, polymer-tip interface temperature, and thin film glass transition temperature to determine non-bulk material properties affecting tip velocity and polymer deformation profile. This paper simulates polymer deformation during nanoimprint embossing and AFM thermomechanical nanoindentation to develop design rules for embossing-based nanomanufacturing. This work reports the importance of shear-thinning effects in AFM nanoindentation and establishes design rules resolving phenomena reported in all previously published investigations of NIL embossing polymer flow.

SESSION M2: Patterning of Biomolecules

Sunday, November 28, 2005
Room 306 (Hynes)
1:30 PM M2.1 Building with Macromolecules on Surfaces with Nanometer Precision. Ashutosh Chilkoti, Duke University, Durham, North Carolina.

I will present recent examples of work from my laboratory on the site fabrication of nanoscale devices. These include paddle-stabilized nanostructured vertical dielectric polymer brushes, stimulus responsive polypeptides and polynucleotides, with the goal of developing and assembling to use tools for biofabrication. In the first example, I will describe the fabrication of stimulus nanoarray capable of controlling passivation of stimulated synthetic polymer brushes, stimulus responsive polypeptides and polynucleotides, with the goal of developing and assembling to use tools for biofabrication. In the second example, I will describe the fabrication of stimulus nanoarray capable of controlling passivation of stimulated synthetic polymer brushes, stimulus responsive polypeptides and polynucleotides, with the goal of developing and assembling to use tools for biofabrication.

2:00 PM M2.2 Pattern Formation of Single DNA Molecules on Polymer Surface for Medical and Electronic Applications. Jingjiao Guan and L. James Lee, Center for Affordable Nanoengineering of Polymer Biomedical Devices, The Ohio State University, Columbus, Ohio; 2Center for Nano and Biomolecular Engineering, The Ohio State University, Columbus, Ohio.

Patterning single DNA molecules is of great interest for genetic analysis and nanoelectronics. A number of methods have been developed to pattern single DNA molecules, but none of them is able to create well-defined array of stretched, oriented, and precisely positioned DNA molecules. We have developed methods to create such an array of single or multiple DNA molecules using topologically micropatterned polymer surface, from which the patterned DNA can be transferred onto other substrates to generate more complicated patterns. This technique has promise for producing DNA chips based on single DNA molecules, DNA-templated nanowire array, and multifunctional nanoparticles for gene delivery.

2:30 PM M2.3 Light-Directed Synthesis of DNA Molecules. Franco Cerrina, Electrical & Computer Engineering, University of Wisconsin, Madison, Wisconsin.

The direct synthesis of DNA constructs in the length of 2000-20,000 base pairs (bp) is at the root of a revolution in genetic engineering. As more and more genomes are decoded, and the function of the genes understood, there is the possibility of actually reprogramming some of the genetic material to achieve specific functions, from medicine to synthetic biology. The well-known base-by-base synthesis of DNA can be greatly enhanced by combinatorial techniques, whereby a large number of single-stranded sub-units (oligomers) are synthesized in parallel and later assembled in longer constructs. Using light-directed synthesis of the oligomers, hundreds of thousands of different short sequences (40-70bp) can be created in a few hours. After amplification, these sequences can be assembled in longer units in a hierarchical, multistage process. The final product – a synthetic DNA strand – can then be used in a multiplicity of biological applications. We will review the state of the art of the base-by-base DNA synthesis, with particular emphasis on chip-based methods, and discuss the problem of the errors found in the sequence of synthetic DNA. Many applications require error-free DNA, and this can be guaranteed only by a sequencing operation of the final product. Typically, samples extracted from the final product are amplified and sequenced, to find the correct one – an expensive and time-consuming process. The number of clones to be sequenced is a strong function of the error rate in the DNA synthesis, so that a rate of less than 1 error per 10,000 bp is necessary to produce a viable process for the synthesis of 2,000 bp genes. We have recently proposed several error-removal methods that can improve the purity of synthesized materials, and produce error-free output material. To achieve this goal it is necessary to combine optimized micro-fabrication techniques in the design and purification of the oligomers, with biological and statistical methods for error removal. In the presentation we will focus on light-directed
formation, and error-removal solutions.

4:00 PM M3.4
Fabrication of Patterned Apatite by Electroplating
Deposition. Seiji Yamaguchi, Takeshi Yabutsuka, Mitsuko Hibino
and Takeshi Yao; Graduate School of Energy Science, Kyoto
University, Kyoto City, Japan.

Formation of apatite pattern is considered to lead to development of
various smart biomaterials. Advanced multifunctional biomaterials
will be produced by a combination of bioaffinity of apatite with
mechanical, electric, magnetic or optical properties of other materials.
For example, a cellular biosensing system will be developed by a
culture of cells on the apatite pattern. Also, biosensing devices can be
developed by using adsorbability of apatite to biomolecules such as
proteins. Usually, electroplating deposition (EPD) is applied only to
electric conductive materials such as metals. Recently, we have found
that when a porous insulating material is arranged between
electrodes, particles can be migrated by electric field passing
through the pores. Then we have considered that when a patterned
mask that blocks electric field to pass through is set between
electrodes, particles will be deposited regularly following the mask
pattern. In this study, as the mask, a polytetrafluoroethylene (PTFE)
board with holes of 100 μm in diameter or a layer of resist pattern
with various minute patterns such as lines, dots and corners was used.
A porous PTFE plate, 0.1 μm for average pore size, 68 % porosity, 20
mm in diameter and 0.07 mm in thickness was used as a substrate.
Wollastonite is known for its high bioactivity and is often used as
bioactive material for the purpose of forming apatite. Wollastonite
particles about 3 μm in average diameter were deposited on the
substrate following the mask pattern by EPD. It was observed that
wollastonite particles were deposited transcribing the mask pattern
just after the EPD operation. In the EPD operation, the electric field
passed thorough the area that was not blocked by the mask, and
consequently the wollastonite particles were deposited on the
substrate so as to transcribe the mask pattern. Next, the substrate
was soaked in a simulated body fluid (SBF) with inorganic ion
concentrations (Na+=142.0, K+=7.5, Ca2+=2.5, Mg2+=1.5, HCO3-=
4.2, Cl-=180.0, HPO4−=7.0, SO4−=0.5 mmol dm−3 pH=7.4) nearly equal to
to those of human blood plasma at 36.5 °C for 24 h. After soaking in
SBF, apatite was induced on the wollastonite particles and replaced
them, then apatite pattern was obtained. Generation of apatite was
confirmed by XRD analysis. The distinct boundary between
apatite-existing area and apatite-nonexistent area was verified by
SEM/EDX observations. Apatite dot pattern over about 250 μm in
diameter was obtained when we used the PTFE board as the mask in
the EPD operation, and, apatite line pattern about 100 μm was
achieved for the minimum width when we employed the layer of resist
pattern as the mask. This method is promising for production of
multifunctional materials having bioaffinity.

4:15 PM M3.5
Biphasic Ceramic Lattices for Bone Repair: Hongyi Yang1,
Julian R. G. Evans1, Shoufeng Yang1, Xiaoping Chi1, Ian
Thompson2, Richard James Cook2 and Paul Robinson1; 1Materials
Department, Queen Mary University of London, London, United
Kingdom; 2GKT Dental Institute, Kings College, London, United
Kingdom.

Porous biphasic HA/TCF scaffolds providing osteoconduction and
osteoinduction for bone repair were prepared by extrusion freeforming,
a rapid prototyping method that allows both shape and a hierarchy of
structure levels to be tailored by computer. Biphasic ceramic pastes
with a volatile solvent and binder were extruded through fine nozzles
and solidified by evaporation such that filaments welded to the last layer
of the lattice. In this way, multilayer 3D quasi-crystals were made and
characterised such that the lattice spacing can be varied to provide large
and small channels for vasculization and hard tissue development
respectively, and the overall shape controlled. The organic content was
removed before sintering. Characteristics of the sintered biphasic ceramic
ceramic scaffolds were studied.

SESSION M3: Poster Session: Nanopatterning and
Nanomaterials
Monday Evening, November 28, 2005
8:00 PM
Exhibition Hall D (Hynes)

M3.8.1
A Novel Approach of Developing Hybrid Biomaterials: Two
Photon Induced Polymerization of ORMOCERs for Drug
Delivery, Tissue Engineering and Beyond. Anand Doraiswamy1,
R. J. Narayan1, B. Chichkov2, A. Ovsianskiv2, R. Houbertz2, R.
Modr3 and D. B. Chrisey4; 1Bioengineering Program, School of
Materials Science and Engineering, Georgia Institute of Technology,
Atlanta, Georgia; 2Laser Zentrum Hannover, Hannover, Germany;
3Fraunhofer Institute for Silicate Research, Wurzburg, Germany; 4US
Naval Research Laboratory, Washington, District of Columbia.

We introduce a novel approach of two-photon-induced polymerization
or TPP of hybrid materials for a wide range of biomedical
applications. Organically modified ceramics or ORMOCERs are
hybrid materials that have proportions of organic and inorganic units
that can be modified to tailor the mechanical, optical, chemical and
biological properties. Using this approach we have developed arrays of
micronlevel (a hybrid of hypodermic needles and transdermal
patches) for painless and controlled drug-delivery. We have developed
a variety of geometry of the microneedles for fracture and toughness
studies. In this paper, we have studied the biocompatibility of these
materials using various cell lines such as rat neuroblasts, mouse
myoblasts, human osteoblasts. In a further step, we have developed
Legolike free-standing structures to mimic 3-dimensional multilayered
structures. Each layer with a different composition and one line to
develop a multicomponent bioactive system. We have demonstrated the
potential of the 2PP process in developing high resolution,
periodic, self-standing, biocompatible structures for a wide range of
biomedical applications.

M3.9
DNA Directed Assembly of Colloidal Particles on Patterned
Substrates for Sensors and Photonics. Paul V. Braun1, Margaret
H. S. Shyr1, Daryl P. Wernetto2, Pierre Wiltzius3 and Yi Lu2; 1Materials
Science and Engineering, University of Illinois at Urbana-Champaign,
Urbana, Illinois; 2Chemistry, University of Illinois at Urbana-Champaign,
Illinois; 3Physics, University of Illinois at Urbana-Champaign, Urbana,
Illinois.

We have demonstrated the direct assembly of DNA functionalized
colloidal particles onto patterned substrates with periodic structures
through microcontact printing with complementary single-stranded
DNA. The tethering of the colloidal particles to the surface is followed
using laser diffraction, laser scanning confocal microscopy, and
fluorescence optical microscopy. Through the use of a combinatorial
in vitro selection we have obtained DNAzyme (DNA molecules that
catalyze specific metal ions and catalyze the cleavage of RNA strands
containing an RNA base). This DNA-based sensor motif is attached to either the colloidal particles on the
substrate. In the presence of specific metal ions, the colloidal particles
hybridize to or release from the substrate, and this process is followed
through laser diffraction. The binding of the colloidal particles to the
substrate can also be reversed by heating, melting the hybridized
DNA strands.

M3.9
Patterning of Biomolecules/Materials Using PECVD
Generated Surfaces. Joseph M. Slovik, Eric R. Beckel, Timothy J.
Bunning, Hao Jiang and Rajesh R. Naik; Materials and Manufacturing
Directorate, Air Force Research Laboratory, Wright-Patterson AFB.

Currently, surface patterning of biomolecules/biomaterials involves
techniques such as dip pen nanolithography, micromolding, and inkjet
printing. These techniques are directed towards controlled deposition
of particular substances on a number and types of biomolecules
that can be processed. Alternatively, plasma enhanced chemical vapor
deposition (PECVD) provides an excellent generalized platform with
a wealth of different substrate surface chemistries that can be utilized
for the incorporation of a variety of biomolecules and other functional
materials. These can include proteins, viruses, enzymes, peptides, and
water soluble nanopart.icles. Of interest are functionalized quantum
dots, peptide encapsulated gold nanoparticles, and small
biomaterialization peptides. Herein, we utilized common coupling
techniques for the patterning of quantum dots, gold nanoparticles,
and peptides on PECVD generated surfaces; and as a result, create a
biologically active surface for the biomaterialization of inorganic
materials.

M3.9
Stability of Some Non-Precious Dental Alloys in Artificial
Saliva. Julia Claudia Mirza Rosa1, Juan Rodriguez Castro1, Daniel
Mareci2 and Delia Aleelei2; 1Mechanical Engineering, Las Palmas de
Gran Canaria University, Las Palmas de GC, Spain; 2Technical
University Gh. Asachi, Iasi, Romania.

In recent years a number of new highly corrosion resistant alloys
combining Nickel, Cobalt, Chromium and Molybdenum have been
introduced as biomaterials. The aim of this study is to investigate the
corrosion behaviour of two Nickel based alloys (Wiron NT and
Wirolloy) and two Cobalt alloys (Vitallium and VeraPDI) in
Carter-Brugirard AFNOR/NF (French Association of Normalization)
artificial saliva [1]. The microstructures of the alloys were investigated
by optical microscopy before immersion in artificial saliva. The
microhardness of all the alloys was also measured. Using the linear and cyclic polarization curves [2] and electrochemical impedance spectroscopy, the corrosion resistance of the alloys was determined. The corrosion potential, the Tafel slopes, the polarization resistance and the corrosion current density are measured from the linear polarization curves. The transpassivation potential, the breakdown potential and the repassivation potential are obtained from the cyclic polarisation curves. The electrochemical impedance spectroscopy Bode-phase plots show two maxima and the equivalent circuit is consistent with the model of a two-layer structure involving an outer passivating film (high potential) and a complete corrosion product layer (low potential) for each alloy. The results obtained, regardless of the alloy type or the technique (microscopy, electrochemical, mechanical), show that the alloys exhibit a good corrosion resistance. Initial salt spray tests performed after immersion was analysed with SEM. All the results obtained, for the protective oxide layer on the surface of the alloys, were consistent with the micrographs obtained in the scanning electron microscope. Further, research has shown that certain amino acids have a significant effect on the nucleation and growth of the COM. To directly monitor the nucleating effects of amino acids on COM, we patterned thin layers of amino acids onto our crystal templating surfaces. Amino acids were immobilized on the surface through amide linkages to carboxyl terminated micropatterns, while the remaining regions in the pattern were functionalized with hydrophilic methyl terminated SAMs. These patterns are currently being tested for their ability to control COM nucleation and orientation on the polar-regions of the pattern. If the method proves successful one could imagine tailoring the amino acid composition of a surface to mimic protein surfaces determined to play an active role in kidney stone formation. We hypothesize that amino-acid, micropatterned SAM may play a role in elucidating COM crystallization phenomena on protein surfaces and these studies will have ramifications for potential application in the design of synthetic peptides for use in stone therapy.

M9.7 Method for the investigation of the relaxation time and viscosity of embossable films. Maud Forest1, Elin Sondersgard2, Etienne Barthel1, Caroline Heitz1 and Lena Saint Marcus1; 1Laboratoire du Surface du Verre et Interfaces, UMR 125 CNRS/Saint-Gobain, Aubervilliers, France; 2Département, Mesures, Contrôles, Saint-Gobain Recherche, Aubervilliers, France.

Viscosity and relaxation time are crucial physical parameters for development of resists for nanoimprinting. These parameters will control not only the embossing time but also the stability of the obtained profile after embossing. When the resist is a thermoplastic it is possible to characterise the bulk material and to some extent extrapolate the properties to a thin film. Such assumptions are clearly wrong when the resists are thin layers of more complex nature, like embossable sol-gels or reticulating polymers. In these systems the mechanical properties will be highly dependent on factors like the evaporation of the solvents and the amount of condensation or reticulation of the material. The bulk material and the thin film can therefore be of very different chemical nature and any valid mechanical characterisation has to be done directly on the embossable thin film system. Unfortunately there is currently no single characterisation method allowing for quantitative mechanical measurements on fairly thin films. We present an original optical characterisation method, based on diffraction from an embossed structure, which allows us to follow the evolution of the mechanical properties of a thin film. The key idea is that the evolution of the diffraction peaks is related to the relaxation of the profile of the pattern. Real time measurements of the relaxation profile of UV embossable thin films will be presented.

M9.8 Directed Assembly of Nanomaterials on Topographically Patterned Substrates Using Inbuilt Fringing Fields. Chad R. Barry and Heiko O. Jacobs; Department of Electrical and Computer Engineering, University of Minnesota, Minneapolis, Minnesota.

We report on a new printing approach to deposit nanomaterials onto desired areas on nanostructured thin films. The nanostructured thin films act as templates to direct the assembly process. The approach makes use of local electrostatic fringing fields to direct the assembly of charged nanomaterials from the gas phase. The fringing fields occur as a result of the different charging characteristics and work functions of the materials involved. In the first demonstration we use a topographically patterned PMMA thin film on top of a silicon substrate to create localized confined charge accumulation within the topographic confinement. The results show that inbuilt potentials between different materials are sufficiently large to direct the deposition of nanomaterials. A gas phase assembly process has been used to deposit silicon and metallic nanoparticle layers onto our patterned substrates. The strength and lateral dimensions of the inbuilt potential have been characterized using scanning probe based methods. The spinning fields were confined to 50 nm sized areas and exceeded 1 MV/m

M3.5 Effects of Fluorides and Surface Treatment on Titanium and Titanium Alloys in Dentistry. Julia Cladina Mirza Reza1, Domingo Herrerra Santana2 and Heinz Sturm2; 1Mechanical Engineering, Las Palmas de Gran Canaria University, Las Palmas de GC, Spain; 2Federal Institute of Materials Research, BAM VI 2901, Berlin, Germany.

Since hygiene products like toothpastes and prophylactic gels contain fluoride ions, in the dentinal environment the most aggressive ions for the protective oxide layer of titanium and titanium alloys are the fluoride ions. The aim of this paper was to investigate the effects of fluorides on the passive films of titanium and titanium alloys. In order to exhibit bioactivity, the titanium alloys must be previously subjected to a special surface treatment, involving changes in the passive film properties. In this paper, titanium and two titanium alloys were studied, Ti-5Al-4V and Ti-6Al-4Fe, with the composition presented in the Table 1. The alloys were soaked in 10M aqueous NaOH solution at 60°C for 24 hours and then were immersed for 3 months in Carter-Brugiraud (French Association for Normalisation) artificial saliva with addition of NaF 0.02 M. For comparison, samples with the same composition but without chemical treatment were immersed also in order to differentiate the treatment effects. Data about mechanical and electrochemical behaviour are presented. ESEM observations of the passive layer and EDX measurements were performed. EDX maps of elemental distribution were used to determine the oxide layer composition, the alloy morphology and to identify the contamination particles. The mechanical behaviour was determined using optical metallography, Vickers microhardness and tensile tests. The electrochemical behaviour of these films was determined in artificial saliva with fluorides additions, using the electrochemical impedance spectroscopy technique. It resulted that the tested oxide films presented passivation tendency and a very good stability, and no form of local corrosion was detected. The electrochemical behaviour of these films is described by an equivalent circuit with three time constants. The mechanical and EDX data confirm the presence of an outer porous passive layer with a high oxygen content and an inner compact and protective passive layer where Ti is the dominant element. EIS confirms the mechanical results. The results emphasised that the use of the surface treatment increase the passive layer resistance in the presence of fluoride ions. One of the main drawbacks of this treatment is that the samples were susceptible to contamination by bacteria taking into account that the artificial saliva is an ideal medium for bacterial growth if aseptic conditions are not ensured.

M3.6 Controlling the size, orientation, density and nucleation of calcium oxalate monohydrate crystals using self-assembled monolayers. Tania M. Cabrera, Leigh M. Friguglietti and Richard W. Gurrey; Department of Chemistry, Simmons College, Boston, Massachusetts.

Calcium oxalate monohydrate (COM) is the main inorganic component of kidney stones. To understand how each functional group can promote COM nuclei formation, and how impurities interact with the different faces of the crystals, is to better understand kidney stone formation. Studies of the effect of impurities on the crystal growth of COM would be greatly facilitated if nuclei seed crystals of COM were templated on surfaces, whereby, the size, orientation, and density of the COM seed were controlled by the functionality of the templating surface. The nucleation effect of the organic functionalized SAMs was studied in order to develop different templating agents. We adopted a route to crystal formation using micropatterned, self-assembled monolayers (SAM) of alkanethiols on gold. The gold substrate was patterned with topographically functionalized areas of differing composition. This patterned surface had the potential to control nucleating activity towards COM through microcontact printing. Micron-sized squares of carboxylic acid-terminated and hydroxyl-terminated alkanethiols were surrounded by a hydrophobic medium. These patterns were used to control the ability to control COM nucleation and orientation on the polar-regions of the pattern and the results were documented using, differential interference contrast and scanning electron microscopes. We propose that this method can be used to control crystal growth of COM from aqueous solutions, to further aid in the study of impurity interactions with growing calcium oxalate solutions and can also allow direct visualization of the different surfaces of a crystal positioned appropriately without having to manipulate the microscopic crystal. Further, research has shown that certain amino acids have a significant effect on the nucleation and growth of COM. To directly monitor the nucleating effects of amino acids on COM, we patterned thin layers of amino acids onto our crystal templating surfaces.
M3.9 Dynamic all-optical tuning of transverse resonant cavity modes in photodetectors. Optical Birefringence and tunable dispersion compensation. Gilles Benoit,1,2, Ken Kuriki,1,2 Jean-Francois Viens1,2, John D. Joannopoulos3 and Yoel Fink1,2,3
1DMSE, MIT, Cambridge, Massachusetts; 2Research Laboratory of Electronics, MIT, Cambridge, Massachusetts; 3Physics Department, MIT, Cambridge, Massachusetts.

Fibers with multiple radial alternating submicron layers of high index amorphous silicon and low index fluorine doped germanium have been shown to exhibit optical cavity modes for transverse illumination. We previously demonstrated the precise placement and thickness control of the defect layer leading to optical cavity quality factors of 35. Here we introduce an additional layer of high index germanium in the fiber system namely the ability to independently control the composition of the optical defect layer. Specifically, we report on the fabrication of all optical tunable fibers with an optical cavity layer consisting of a highly photodarkened germanium layer. We demonstrate a 2 nm optically induced reversible shift of a cavity resonant mode at 1.55 μm with quality factor of 225 under transverse illumination at 514 nm. Dynamic all optical tuning is reported at frequencies up to 400 Hz. Experimental results are compared with simulations based on the amplitude and kinetics of the transient photodarkening effect characterized in situ in thin films by combined transmission and ellipsometry measurements. These results present significant opportunities for device fabrication such as tunable dispersion compensators on very long length scales. We present preliminary group delay dispersion measurements and demonstrate pulse compression at telecommunication wavelengths in a transmission fiber containing a cavity layer induced Gires-Tournouer interferometer.

M3.10 Ruthenium(II) Complexes and Polymers: Potential Materials for Applications in Solar Cells. Veronica Marin1,2, Elisabeth Holder1,2, Martijn M. Wienk2,3, Dmitry Kosozov1,2 and Ulrich S. Schubert1,2
1Laboratory of Macromolecular Chemistry and Nanoscience, Eindhoven University of Technology (TU/e), Eindhoven, Netherlands; 2Dutch Polymer Institute (DPI), Eindhoven, Netherlands; 3Laboratory of Molecular Materials and Nanosystems, Eindhoven University of Technology (TU/e), Eindhoven, Netherlands.


Silver nanoparticles have been frequently used as a conductor in printed electronics due to their low sintering temperature and high conductivity. We have tried to find the effect of interaction between the silver nanocrystal and capping molecule on electrical behavior. In this study, we chose two types of capping molecules with different interaction force to silver nanocrystal in spite of same chain length. Monodispersed silver nanocrystals with 9 nm were prepared from thermolysis of binary silver-surfactant complexes without size selection procedure. Silver nanocrystals associated with binary capping molecules were characterized by X-ray diffraction, UV-Visible spectra, Fourier transform infrared, transmission electron micrograph and elemental analysis. Furthermore, sintering and electrical behaviors with the ratio of two different capping molecules having different interaction force with silver nanocrystals were investigated.

M3.12 Photoreactive Lithographic Deposition of Amorphous Titanium Oxide Films from a Photosensitive Titanium Complex. Xin Zhang and Ross H. Hill; Chemistry, Simon Fraser University, Burnaby, British Columbia, Canada.

Crack-free amorphous titanium oxide films were photochemically deposited on silicon substrates from titanium (IV) 2-ethylhexanoato n-butoxide. Photosensitive titanium (IV) complexes with photoinduced photosensitivity and thermal stability were prepared from titanium (IV) alkoxides by ligand exchange reaction. Synthesis, composition, and thermal stability of the titanium (IV) complexes were investigated by Fourier transform infrared spectroscopy, nuclear magnetic resonance, microanalysis, and thermal gravimetric analysis. Among the prepared photosensitive titanium (IV) complexes, titanium (IV) 2-ethylhexanoato n-butoxide was determined to be the best precursor photochemically deposit uniform and continuous amorphous titanium oxide films. The photochemistry of the precursor films from titanium (IV) 2-ethylhexanoato n-butoxide was studied by Fourier transform infrared, UV-vis and mass spectroscopy. A mechanism is proposed to explain the photochemical decomposition of titanium (IV) 2-ethylhexanoato n-butoxide. Product films that resulted from photolysis of the precursor films were found to be amorphous, as indicated by X-ray diffraction and transmission electron microscopy. The product films consist of titanium oxide with no detectable carbon contamination, as evidenced by Auger electron spectroscopy. Upon annealing at 500 degree Celsius in air, the amorphous titanium oxide films were converted to anatase. Patterned titanium oxide films, with a feature size of 1 micron or less, were obtained by applying direct photolithography or direct electron-beam writing lithography to the precursor films, without use of a photoreactive.

M3.13 Gold nanotube membranes with tunable tube diameter and their applications. Woo Lee, Hong Jin Fan, Sung Kyun Lee, Steffen Richter, Sven Matthias, Wolfgang Zacharias, Dietrich Hesse, Kornelius Nielsch and Ulrich Goesele; Max Planck Institute of Microstructure Physics, Halle, Germany.

One advantage of shadow mask techniques over conventional photolithos-based nanopatterning is a resist-free process. The process has a low risk of cross-contamination or structural failure in nanopatterning, apart from simplicity and speed in the surface nanostructuring process. In this contribution, we present a simple and widely applicable method for fabricating perfectly ordered arrays of Au nanotubes in the form of membranes, which can be used as shadow masks for the fabrication of nanodot arrays with a perfect array configuration on a cm2 scale. One big advantage of using Au nanotubes as masks is that the electrodeposition of metals to replicate a master pattern structure of nanoporous anodic aluminum oxide (AAO) or macroporous silicon membrane. By taking advantage of the unique capability for controlling the pore diameter of AAO templates, we fabricated structurally well-defined metal nanotube membranes with different aperture sizes (80 nm - 300 nm). On the other hand, control over the shape and 2-D arrangement of metal nanotubes could be achieved by using patterned silicon substrates as replication masters. The fabricated nanotube membranes not only in sputter deposition of metals and ferroelectric materials to generate 2-D arrays of nanodots with tunable dot size, but also in electrochemical deposition of noble metals to transfer the pattern of the masks to various substrates. In addition, large-scale growth of 2-D perfect hexagonal arrays of ZnO nanorods will also be demonstrated by combining the vapor-liquid-solid (VLS) growth process and the electrochemical techniques with the use of catalytic Au nanodots. The fabricated metal nanotube membranes
exhibited interesting optical transmission properties depending on the tube diameters. Optical properties of the metal nanotube membranes having sub-wavelength apertures will be discussed. Financial support from the German Federal Ministry for Education and Research (BMBF, Project No. 03N8701) is greatly acknowledged.

M3.14
Abstract Withdrawn

M3.16

We investigate the potential of commercially available porous templates to be used for the fabrication of functional anisotropic conductive films. Galvanostatic deposition into porous polycarbonate membranes was utilized to fabricate arrays consisting of 200 nm diameter nanowires. A tape-lift off procedure was used to completely remove any residual metal from both sides of the polymer membrane to form an anisotropic conductive film. The ten micron thick film has roughly three hundred million nanowires per square centimeter, and it shows almost zero electrical resistance perpendicular to the surface. While appearing completely open to circuits between any points on the surface, the preparation of the film, and characterization using SEM, AFM and resistance measurements are presented.

M3.17
A Large Scale Synthesis of Silver Nano Particle in Aqueous Phase. Young Ah Song, Tae-Hoon Kim and Sung Il Oh; Manufacturing Engineering Team, Samsung Electro-Mechanics, Suwon, Gunggi-Do, South Korea.

The most widely used methods of silver nano particles in a aqueous phase are chemical reduction of silver salts by reducing agents such as sodium and potassium borohydrides. However this method is usually known as its production of relatively larger size of particles, 20–30 nm above, due to be stabilized by high molecular weight agent (PVP, amphilic polymer etc.) and a few solid loading contents that amount only to 10–5 ~ 10–3M. In this study, we successfully synthesized a 10 nm size of silver nano particle in high solid concentration of 10–2M. By stabilizing with a strong capping thiol ligand of mercaptosuccinic acid (MSA), the growth rate of nucleation of silver atoms could be hindered. However, in an aqueous phase, a H2O molecule could combine with either two carbyol groups in the MSA molecule through a hydrogen bonding interaction and make connections with other silver particle. To prevent agglomeration and precipitation of silver nano particles, we used another agent to hinder hydrogen bonding and could obtain stable silver nano particle colloid solution.

M3.18
Vibrational Coupling in Conjugated π Systems in Relation to Optimization of Fluorescence Yield through Phonon Confinement. Lake Andrew O’Neill1,2, Hugh James Byrne1,3, Patrick Lynch1,2 and Mary McNamara1,2. 1Focas Research Institute, D.I.T., Dublin, Ireland; 2Chemistry, Focas Research Institute, D.I.T., Dublin, Ireland; 3Physics, Focas Research Institute, D.I.T., Dublin, Ireland.

A series of π conjugated systems were studied by absorption and photoluminescence spectroscopy. As is common for these systems, a linear relationship between the positioning of the absorption and photoluminescence maxima plotted against inverse conjugation length is observed. The relationships are in good agreement with the simple particle in a box method, one of the earliest descriptions of the properties of one-dimensional organic molecules. In addition to the electronic transition energies, it was observed that the Stokes shift also exhibited a well-defined relationship with increasing conjugation length, implying a correlation between the electron-vibrational coupling and chain length. This correlation is further examined using Raman spectroscopy, whereby the integrated Raman scattering signal was shown to behave superlinearly with chain length. There is a clear indication that the vibrational activity and thus nonradiative decay processes are controllable through molecular structure. The correlations between the Stokes energies and the vibrational structure are also observed in a selection of PPV based polymers and a clear trend of increasing luminescence efficiency with decreasing vibrational activity and Stokes shift is observable. The implications of such structure property relationships in terms of materials design are discussed.

M3.19
Fully Mass Printed Integrated Circuits. Florian Doetz1, Ingolf Hennig1, Peter Eckerle1, Arved C. Hubeler2,4, Heiko Kempa3,4, Howard E. Katz2, Matthias Bartsch2, Njole Brandt2, Uta Fuegmann2, Subramanian Vaidyanathan2, Jimmy Granstrom2, Sen Liu2, Tino Zilliger2, Georg Schmidt2, Elsa Reinachmus3, Thomas Weber3, Franke Richter3, Thomas Fischer2, Ulrich Hahn2, 4BASF AG, Ludwigshafen, Germany; 4Institute for Print and Media Technology, Chemnitz University of Technology, Chemnitz, Germany; 3Lucent Technologies Bell Labs, Murray Hill, New Jersey; 4Printed Systems GmbH, Chemnitz, Germany; 2Johns Hopkins University, Baltimore, Maryland.

Additive mass printing of functional electronic materials is considered to provide a powerful path to low-cost manufacturing of integrated transistor circuits. Such a high-speed approach requires successive in-line capable solution deposition of each layer on flexible substrates. Typical strategies reported include printing techniques such as screen and pad printing or ink jet. However, to be useful in mass production the final process must allow high throughput rates and high resolution. Therefore, offset and gravure printing represent attractive deposition techniques since they are commonly used for the production of newspapers and packaging with printing speeds ranging from 2 to 15 m/s. Meeting printing requirements (formulation and rheology of inks, adhesion) and device performance is a key challenge for an efficient production process. We report the first fully mass printed ring oscillator consisting of 7 inverter stages proving the logic capability of each top gate organic field effect transistor (FET). The substrate used was a commercially available, corona treated PET foil, the source and drain electrodes were made of poly(3,4-ethylenedioxythiophene) : poly(styrenesulfonate) (PEDOT:PSS), which was re-formulated to make it offset-printable. As the active semiconducting layer we used commercially available poly[(3,4-ethoxyfluorene-co-bithiophene)] (F8T2) which was deposited by a carefully adjusted gravure printing process resulting in high quality, structured layers. For the gate dielectric, we chose a double layer structure of a low k (low permittivity) and a high k material (high permittivity). The gate k material is a hydrogenterminated polymer of butadiene and styrene formulated in long chain alkane, especially designed to be processable by gravure printing into very thin and smooth, structured layers. As high-k material we used a re-formulation of a commercially available, printable BaTiO3 suspension, flexo printed on top of the low k layer. Finally, the gate electrodes were made by flexo printing a silver ink. The channel length of the FET was L = 0.1 mm, the channel width W = 30 mm and W = 6 mm for the load and driver transistors, respectively. When a supply voltage VDD ≤ 40 V is applied, the ring oscillator started oscillating, the frequency increasing with VDD up to 3.9 Hz at 80 V. The mobility of a single FET was 4 x 10–3 and with an on/off ratio of about 2300. Further work is focusing on optimizing the process to enable the manufacturing of RFID tags and flexible backplanes for displays.

SESSION M4: Emerging Patternning Techniques
Chair: L. J. Guo
Tuesday Morning, November 29, 2005
Room 306 (Hynes)

8:00 AM *M4.1 Nano-scale Electric Lithography. Yong Chen, Mechanical Eng, UCLA, Los Angeles, California.

In previous research, scanning probe microscopy (SPM) has been used to generate nanoscale patterns by electrochemical reaction between the probe and a resist. Although this technique can reach sub-10 nm resolution, it cannot be used for mass production due to its slow speed. A new nanoscale lithographic technique: nanoscale electric lithography (NEL) is demonstrated. In NEL, nanoscale patterns a mask are transferred to a resist layer on a substrate by an electrochemical process in which the resist is configured by the electric field generated between the mask patterns and the substrate. The basic NEL process is simple and straightforward. A layer of resist is spin-coated onto a substrate, and then a mask with conductive metal patterns that are separated by insulating materials is pressed down toward the resist. After the top layer is brought into contact with the resist, an electric field is applied between the top and bottom electrodes. The resist residing under the mask conductive patterns will be configured due to an electrochemical reaction (e.g. by solvating). After the mask is removed, the resist in masked areas can be developed selectively from the substrate by further chemical process. We have demonstrated that the NEL can have a sub-10 nm resolution, high manufacturing rate, and scale-up capability. By using specific dynamic masks, the NEL can also be used to fabricate on-demand patterns.
8:30 AM M4.2
The Physics and Limits of Femtosecond Laser Nano- and Micromachining
Micromanufacturing and Micro-systems Engineering, University of Michigan, Ann Arbor, Michigan; 2Center for Ultrafast Optical Science, University of Michigan, Ann Arbor, Michigan.

Damage produced by optical breakdown becomes very precise for pulse durations less than a picosecond; while nanosecond laser ablation results in an uncertainty of 10-20% shot to shot, femtosecond ablation is repeatable to 1% or less. This precision is particularly evident when using a breakdown in the application of optics at critical intensity (OCI) for reproducible laser machining of sub-diffraction limit features on surfaces. We have recently demonstrated precise OCI machining even at the nanoscale by using the features as the order of 100 nm on a wide variety of materials. This competes with the resolution of e-beam lithography, but is more straightforward and less material-specific. The production of nanoscale features raises fundamental questions about the mechanism of OCI optical breakdown. Foremost from the viewpoint of practical applications and theory are the ultimate physical limits in respect to size, wavelength, and material. Applying OCI nanomachining we can produce regular features that are more than an order of magnitude smaller than the wavelength of light that produced them. This indicates that optical breakdown is critically dependent on a material property that exhibits little spatial variability down to the nanoscale. We argue that material damage occurs only after all valence electrons are ionized, thus the valence electron density provides the requisite homogenous material property, and constitutes a material-dependent limit on feature size and reproducibility. Although the physics of optical breakdown plays a central role in predicting the limits of material nanomachining, in practice machining is often limited by a less subtle difficulty: the ultimate destination of ablated materials. Ablated materials may be redeposited at or near the site of breakdown, creating unintended structures or debris at the machining site. We have investigated using unusual long-lived bubbles that are produced during machining as a mechanism to extrude fluid entrained debris. During higher-energy microscale machining, bubbles can diminish the accuracy due to uncontrolled extrusion associated with the violent collapse, but we find a low energy regime exists in which highly damped and surprisingly long-lived microbubbles gently extrude debris. These results demonstrate the efficacy of OCI nanomachining for creating submicron structures in arbitrary materials and in three dimensions in transparent dielectric materials. We have also tested the same method to machine solid 3D objects such as cones, spheres, and cantilevers. OCI nanomachining of analytical devices in hard materials enables rapid “art to part” construction of micro and nanofluidic devices, with potential to dramatically accelerate development of micro-TAS applications such as integrated HPLC devices, micro scale sensors, and integrated nanopores for patch-clamp studies of cells.

9:00 AM M4.3
The Direct Nanoscale Deposition of Molecular Electronic Materials via Dip Pen Nanolithography
Paul E. Sheehan1, Minchul Yang1, Arnauld R. Larancunet1, Brent A. Nelson2, William P. King2, and Lloyd J. Whittman2; 1Chemistry, Naval Research Laboratory, Washington, District of Columbia; 2Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, Georgia.

We have developed a new technique, called thermal Dip Pen Nanolithography (tDPN), where a heated atomic force microscope cantilever controls the deposition of a solid “ink.” The heated cantilever becomes a nanoscale “soldering iron” or “glue gun” which has been successfully used to deposit semiconductors, insulators, and metals. tDPN has several demonstrated advantages over conventional DPN. First, control over writing is much greater-deposition may be turned on or off and the deposition rate changed without breaking contact with the surface. Secondly, imaging with a cool tip does not appear to change the surface, thereby leaving intact the confirmation of the deposited pattern. Thirdly, because the ink is solid at room temperature, the deposits can be highly three-dimensional. Finally, tDPN expands the range of useable inks. One material that is easily deposited but which is chemically unstable is poly(3-dodecylthiophene), or PDDT. PDDT is a conducting polymer that shows great promise as an active component in organic electronic devices. Using tDPN, well-ordered PDDT nanostructures have been deposited on oxidized silicon and gold substrates with thickness control. By adjusting the tip heating power and the writing speed, we can vary the polymer thickness from a single monolayer (~2.0 nm) to tens of monolayers with lateral dimensions below 100 nm. Unlike conventional DPN inks, this low vapor pressure polymer may be deposited in UHV, thereby allowing integration with CMOS processing. With the recent demonstration of metallic indium deposition by tDPN, we now have all the requisite elements for the direct deposition of electronic circuitry by DPN.

9:15 AM M4.4
Non-Lithographic Subtractive Micropatterning of Thin Crystalline Films and Films via Hydrogel Stamping
Stoyan K. Smoukov, Christopher J. Campbell, Kyle J. M. Bishop and Bartosz Gryzbowksi; Chemical & Biological Engineering Dept., Northwestern University, Evanston, Illinois.

Anisotropic Solid Microetching (ASOMIC) – a subtractive printing process we have developed – uses hydrogel stamps patterned in bas relief to create patterns and devices of various functional thin metal, metaloxide, and crystalline materials. The stamp is soaked in a solution of a desired reagent(s) to deliver this reagent(s) onto, and remove products from, a solid substrate. ASOMIC is a 1-step alternative to traditional lithographic patterning procedures (involving 5 or more steps) of deep bulk etching of glass and metals produces microlens arrays, micromolding, and microfluidics applications. ASOMIC and the more general Wet Stamping (WETS) method overcome many limitations of soft-lithographic techniques, e.g., reagents can penetrate through 300 mm thick polyimide substrates. Besides etching, control over reaction geometries and fluxes allows allowing reactive patterning on the micrometer and even hundreds of nanometers scales to produce diffraction gratings, optical elements, and microfluidic devices. We have recently extended the process to 1-step etching of curvilinear depth profiles. Several applications in deep etching of materials will be discussed in detail. 1-step etching of functional device prototypes is will also be highlighted.

10:00 AM M4.5
Rigiflex Lithography: Nano-Patterning and Printing
Hong H. Lee, Dongchul Suh, Daeh-Young Kang, Hyunsik Youn, Young Park and Joon Kim; School of Chemical Engineering, Seoul National University, Seoul, South Korea.

We introduce rigiflex lithography as opposed to hard and soft lithographies. The lithography is based on a rigiflex mold that is rigid enough for high resolution as with a hard mold for imprinting but is flexible enough to mimic a soft mold for soft lithography that allows for an intimate contact over large area. This rigiflex lithography is demonstrated for the transfer of metal nanostructures and the patterning by capillary force. When the lithography is applied to imprinting, a reduction by orders of magnitude in the pressure needed is realized. Continuous printing is also made possible.

10:30 AM M4.6
Cou Lomb-Force Directed Assembly and Transfer of Nanomaterials
Chad R. Barry1, Aaron M. Wolfe1, Thomas J. Hatch2, Uwe Kortshagen1, Stephen A. Campbell2 and Heiko O. Jacobs1; 1Department of Electrical and Computer Engineering, University of Minnesota, Minneapolis, Minnesota; 2Department of Mechanical Engineering, University of Minnesota, Minneapolis, Minnesota.

This talk will review recent results in the use of long-range electrostatic forces to direct the assembly of nanomaterials. Concepts will be presented to adjust and control forces both locally and globally. Local patterns are used to direct self-assembly of nanomaterials onto charged surface areas (receivers) with 40 nm resolution. We report on a gas-phase process that uses a transparent porous assembly module to direct and monitor the assembly of nanoparticles from the gas phase as well as a new electro spraying system to print organic and inorganic materials from polar solutions. First patterns of bio-molecules will be presented. A computer model will be discussed to analyze and the deposition process. Currently, the Cou Lomb force directed assembly of sub 10 nm sized proteins, 10 - 100 nm sized metal, 40 nm sized silicon nanocubes, and 30 nm - 3000 nm sized carbon nanoparticles has been accomplished. The application to nanoparticle devices and first results on a nanoparticle transistor will be discussed.

11:00 AM M4.7
Direct-Write Assembly of 3-D Micro-Periodic Silicon Structures
Gregory Gratson1, Flore Garcia-Santamaria2, Mingjie Xu1, Virginie Louis3, Paul V. Braun1, Shauliu Fan2 and Jennifer A. Lewis1; 1University of Illinois, Urbana, Illinois; 2Stanford University, Palo Alto, California.

We have developed a novel approach for patterning 3D micro-periodic structures via direct-write assembly (DWA). Central to our approach is the creation of a concentrated polyelectrolyte ink that flows through fine deposition nozzles and then “sets” almost instantaneously to facilitate shape retention of the as-patterned structures. By combining direct-write assembly and chemical vapor deposition, we demonstrate the fabrication of 3D silicon structures with micron-sized features. First, polymer woodpile structures are created by direct writing a polyelectrolyte ink. These structures are then coated using a room temperature silicon CVD method and followed by bulk oxidation to produce 3D hollow-woodpile and inverse woodpile
structures. The optical properties of the resulting structures are measured after each processing step to identify the effects of their geometry and analyze if the anticipated optical performance is achieved. These devices can be fabricated on a silicon substrate using standard photolithography techniques, which is critical for future applications in micro-nanotechnology, optoelectronics, and photovoltaics.

11:15 AM M4.8
Optical-Maskless Lithography for Fast, Flexible Patterning of Complex Geometries at the Nanoscale. Rajesh Menon1
1 MIT, Cambridge, Massachusetts; 2LumArray Inc., Somerville, Massachusetts.

The primary mode of imparting spatial information in the nanoscale is lithography. Although several variants of lithography are used in manufacturing, they almost always share the use of a patterned photomask, whose demagnified image is recorded in a photore sist layer on a substrate. In order to print patterns close to the diffraction limit imposed by the illuminating wavelength and the imaging optics, a large variety of resolution-enhancement techniques and illumination techniques are employed. As a result of these techniques, the geometries of all practical patterns are highly constrained, for example to periodic lines (gates in transistors) and “Manhattan” geometries. These constraints ensure that the designs are overly conservative, and experimentation is restrained, since the price of first-time failure can be extremely high. The case we described here is for the semiconductor industry. For all applications outside the realm of conventional CMOS, there is a large variety of fields that require patterning of very complex geometries. Various forms of nanoinprint and soft lithography have been used for such applications. These techniques involve the use of a pre-patterned template. Here, we present a form of optical-maskless lithography that can achieve the highest resolution for patterns of all geometries, and may also be used to pattern templates for other lithographies. In Zone-Plate Array Lithography (ZPAL), an array of high-numerical-aperture zone plates is used to create an array of tightly focused spots on the photoresist-coated surface of a substrate. The array of zone plates is illuminated by an array of pixels in a spatial-light-modulator (SLM). The substrate is scanned on a high-precision stage, while the pixels in the SLM are modulated to achieve grayscale intensities in the focused spots. Thereby, patterns of arbitrary geometries may be written in a single step. In this technique, the patterning of curved features, for example, is shown by using the platform described above. We will describe the alpha–prototype system at MIT and the commercialization effort underway at LumArray Inc. We will also illustrate a number of novel devices being fabricated using ZPAL.

11:30 AM M4.9
Novel Methods for the Direct Fabrication and Packaging of MEMS Devices using Sacrificial Polymers. Youngiu Ham and Clifford L. Henderson; School of Chemical & Biomolecular Engineering, Georgia Institute of Technology, Atlanta, Georgia.

A wide array of MEMS based devices have been designed and fabricated which are capable of accomplishing a variety of mechanical, electrical, and optical tasks. However, one major limitation is that the hindering more widespread adoption of MEMS devices is the difficulty in developing low cost and easily integrated packaging technologies. Over the past several years, we have developed a variety of sacrificial polymer materials and processing methods that can be used to build MEMS and microfluidic devices and which are compatible with conventional microelectronics fabrication techniques. Recently, we have developed new methods for producing air-infiltrated polymeric structures using sacrificial layer techniques. These new methods in some cases can be used to produce very high aspect ratio features without surface roughening, which is often a problem when using sacrificial polymer layers. In this paper, we describe some new methods for fabricating MEMS devices using sacrificial polymer materials and discuss some of the applications in which these new methods can be used.

1:30 PM M5.1
Inkjet Printed Backplanes for Displays: Polymer Based Screen Encapsulated TFTs. Amil Claudia Aria, Fred Eidtacott and Robert Street; Palo Alto Research Center, Palo Alto, California.

Polymeric materials have been studied in the area of low-cost, large-area electronics. The field of inkjet printing has shown itself to be a promising technology for the fabrication of active-matrix backplanes for liquid crystal displays. These backplanes can be used for both low-voltage, passive-addressed displays and for active-matrix displays. The use of inkjet printing as an alternative to other methods of backplane fabrication has several advantages. It is a low-cost, rapid method of fabrication. It allows for the use of a wide variety of materials, including organic and inorganic semiconductors. It also allows for the use of a variety of ink formulations, including inks that are tailored to specific applications. This technology is being developed for a variety of applications, including large-area electronic devices, displays, and electronic circuits.
biochemical or opto-mechanical response, which could allow the direct integration of electronic and functional polymer materials together to create new types of miniaturized chemical sensors and micro-machines.

2:15 PM M5.3

This paper focuses on our effort of developing novel oxide-polymer nanocomposite materials. A new approach, in situ nanocomposite, was proposed and realized to overcome the challenge in the make of nanocomposites. In this in situ nanocomposite synthesis, the oxide nanophase is formed in the presence of polymer matrix. Several different classes of nanocomposite materials are then made. Its shown that this approach yields novel nanocomposite materials with controlled optical properties such as refractive index, birefringence, chromatic dispersion and birefringence dispersion. The nanocomposites can also render functions such as UV absorption, improved mechanical properties such as stiffness, strength and hardness; improved thermal/thermal mechanical properties, such as dimensional stability and improved barrier properties to oxygen and moisture vapor.

3:30 PM *M5.4
Roll-to-Roll Manufacturing Technologies for Flexible Device Applications. Harri Kopela, VTT Electronics, Oulu, Finland.

Roll-to-roll fabrication of electrical, optical and optoelectrical structures and functional elements on the web will be described. Based on the monomers the potential of the roll-to-roll printing techniques for the volume-scale active device fabrication will be demonstrated.

4:00 PM M5.5

An aluminum-laminated polyethylene terephthlate (Al-PET) is used as the substrate for flexible organic light-emitting devices (OLEDs). The efficiency and luminance of the OLEDs are dependent on the Al-PET surface. An acrylic layer is formed on the Al-PET surface to improve the surface morphology and also the adhesion between the substrate and the anode. Poly(styrene sulfonate)-doped poly(3,4-ethylenedioxythiophene) was used as hole transporting layer. The light-emitting polymer is used in a phenyl-substituted poly(p-phenylenevinylene). Bilayer anodes of Ag/CFx and Ag/indium-tin-oxide and a semitransparent top cathode were used for the flexible polymer OLEDs. For a flexible polymer OLED with a 110-nm-thick light-emitting polymer, it exhibited a luminous efficiency of 4.56 cd/A at an operating voltage of 7.5V. The aluminum layer in the flexible substrate serves as a barrier to minimize the permeation of oxygen and moisture to the OLEDs. The robustness of this approach is also very good. The top-etching electroluminescent devices on Al-PET foil can be bent to a substantial degree without breaking.

4:15 PM M5.6

Low frequency noise characteristics of organic light-emitting diodes are investigated. Device conductive noise and noise from photodiode current which is related to fluctuation of the luminescence from organic Light Emitting Diodes (OLEDs) are measured. There have been several publications dealing with low frequency noise in both semiconductors and devices, however, there are very few studies on low frequency noise of OLEDs. First, two noise components were found in device low frequency conductive noise records: 1/f Gaussian noise from device bulk materials and an excessive frequency related part of noise related to device interfaces or defects and traps. 1/f noise is said to be related to carrier mobility. Degradation, especially photo-oxidation of the electroluminescence polymer is a possible reason to affect carrier mobility. Excessive part of noise is believed to be related to the carrier number which the fluctuation could be from the interface deterioration and defects and traps generation and furnish. Second, The luminance-time behaviors of organic light emitting device (OLED) was measured using photodiode and the low frequency time from photodiode current is also measured and investigated. Square impulses were observed in time domain. The square impulse is believed to be related to carrier number sudden change in the device. It shows that two dominant mechanisms take part to govern the photodiode noise levels. Degradation process pictures are given out to describe the corresponding noise change. This photonic noise observation is a direct reflection of polymer intrinsic degradation. Over the past months of experiment on the OLED device noise study, there are some new discoveries and we firmly believe this new discovery could greatly contribute the understanding of OLED degradation mechanism. With this submission of our findings on the research, we trust that your esteem materials research society (MRS) will find this information valuable. Thus, at this juncture, we seek to apply for an oral presentation on this research for this fall of 2005.

4:30 PM M5.7

For a variety of applications including high power density thin film solar cells, a polymeric substrate with temperature capability exceeding that of polyimide is highly desired. No polymer films currently available on the market meet this and other requirements such as optical performance and durability under long term radiation of a relevant wavelength range. Owing to their already oxidized backbone bonds (Si=O) and a higher bond energy of Si-O than C-C, highly crosslinked silicone polymers offer better thermal and radiation resistance than most other polymers. But their mechanical properties are less than satisfactory and films made from these polymers traditionally are not widely used as high temperature substrates. This paper will discuss several reinforcing approaches to mechanically strengthen free standing films prepared from these polymers without or with minimum compromise on the optical properties of the films. Many reinforced films have been prepared. The mechanical, optical, thermal, thermo-mechanical, electrical, and other physical properties of the films have been investigated. The properties of continuous process made films suitable for roll-to-roll processing have also been studied. These flexible films generally have very high strength and high modulus, although the strain to failure is relatively limited. Depending on the composition the optical transmission over the visible wavelength range can be as high as 90%. Surface properties can be engineered to suite specific applications. The temperature capability of the films, measured by an extended exposure to a certain temperature without observable dimensional change, mechanical cracking, and discoloration, ranges from 300 to 600 °C depending on the choice of resin compositions. Preliminary experiments show that useful devices can be fabricated on them through ultrahigh temperature processes.

SESSION M6: Poster Session: Light Emitting and Other Photonic Devices
Tuesday Evening, November 29, 2005
8:00 PM
Exhibition Hall D (Hynes)

M6.1
Fabrication and Characteristics of Organic Light Emitting Diodes and Photo Detectors Using Printable Silver Nanoparticles as an Electrode. Yutaka Ohno, Hideki Maki, Zenken Kin and Hirotake Kajii; Center for Advanced Science and Innovation, Osaka University, Suita, Osaka, Japan.

Polymer based light emitting diodes (PLED) and organic photo detectors (OPD) have been investigated utilizing silver (Ag) nanoparticles as a cathode by wet process. A printable polymer of poly(3-hexylthiophene) (P3HT) has been employed as an active layer fabricated by spin coating onto an ITO anode. As a cathode, Ag nanoparticles were employed and coated onto an active layer. The formation of the electrode was done heated upto 210 C, since we found that the Ag nanoparticles can be formed by wet processing onto the organic layer with an amorphous carbon nitride (a-C:N) buffer layer. The buffer layer act as a barrier layer to prevent Ag nanoparticles from penetrating into the organic layer. The a-C:N layer was formed by a damage free sputtering system, whose layer thickness was 10 nm. The P3HT device shows a red light emission at 700 nm in the forward bias condition as a PLED, whereas in the breverse bias it shows a photo-response by illumination of a red or a blue light as an OPD. The results demonstrate the realization of a PLED and an OPD fabricated by wet process utilizing Ag nanoparticles as an electrode.

M6.2
Ultra-High-Resolution Photolithographic Patterning Method for Organic Thin Films and Its Application to the Fabrication of Flexible Polymer Optoelectronic Devices. Jingsong Huang1, Xuhua Wang1, Oliver Hofmann2, Andrew J. de Mello2, John C. de Mello2 and Donal D. C. Bradley1; 1Physics Department, Imperial College London, London, United Kingdom; 2Department of
Chemistry, Imperial College London, London, United Kingdom.

There is considerable interest in patterning technologies that allow well-defined geometric features to be produced in organic thin film structures at micron resolution, reproducibly and at low cost. These techniques are of particular interest for electronic, optoelectronic and photonic applications on organic substrates. The ability to create densely packed regular arrays of components is important for many applications, including displays, imaging, communications and sensors. Patterned procedures that are compatible with multiple plastic substrates are especially attractive since they permit the use of roll-to-roll manufacturing techniques. We have recently patented a new, inexpensive, simple and reproducible lithographic patterning technique for organic thin films. The procedure allows the creation of intricate planar geometric features at near-micron resolution on a range of substrates without causing discernible degradation of the properties of the patterned material. This technique is very well suited to pattern a conducting polymer layer on a flexible plastic substrate to form a device contact replacement for ITO. Here, we report, for illustration, patterning of the well-known conducting polymer PEDOT:PSS on a PET substrate.

We demonstrate the effectiveness of the approach by fabricating flexible polymer light emitting diodes and photovoltaic devices. The light emitting diodes show very promising properties: peak power efficiency and current efficiency of 13.7 lm/W and 8.8 cd/A, respectively; 2V turn-on voltage and a maximum luminance greater than 7500 cd/m²; characteristics that are acceptable for flat panel display applications. The flexible polymer photovoltaic devices show a similarly impressive performance with external quantum efficiencies of 50% that are superior to conventional devices with ITO contact.

These results confirm that our new patterning method is well suited to the fabrication of high quality polymer optoelectronic devices on flexible substrates.


Organic light emitting devices (OLED) are promising for solid state lighting and display applications. In traditional OLED devices, transparent indium tin oxide (ITO) is the predominantly used choice for the anode material. However, the discovery of enhanced transmission in relatively thick nanostructured noble metal film[1] has motivated us to explore its potential application as a new type of anode for OLED. Using semi-transparent metal (e.g. Au) structure as anode could provide several advantages over conventional ITO: (1) it can potentially prolong OLED lifetime because for devices using ITO anode indium and oxygen can migrate from ITO to organic semiconductor causing device degradation[2] (2) Certain metal (e.g. Au) has higher work function which can better facilitate hole injection; (3) it is possible to fabricate top-emitting devices; and (4) one can potentially exploit metal-dielectric microcavity and surface plasmon resonance to enhance light extraction efficiency. In this work, we present a scheme to fabricate nanoscale perforated gold film by nanoimprint lithography that exhibits semi-transparent property. We also evaluate its potential as OLED anode. The semi-transparent anode structure consists of periodically perforated holes or gratings of various periodicities. The grid pattern for nanoimprinting was either directly written by electron beam lithography or by nanoimprinting twice using a grating mold, followed by reactive ion etching to create Si molds. The nanoscale grating or grid pattern is imprinted into a polymer thin film such as polyurethane, and then transferred into a thin metal film such as Au by metallization and lift-off in acetone. Transmission through such nanostructured metal film can be as high as 80%, while for a non-patterned metal film with the same thickness it is 10% or less. A polymer light-emitting diode is then fabricated using the periodically perforated metal film as the anode. After UV-ozone cleaning of the patterned film, thin layer of PEDOT:PSS is spin-coated onto the nanostructured metal surface followed by a vacuum baking. Finally, thermal evaporation of Cs/Al cathode bilayer through a shadow-mask completes the device fabrication. The device showed bright light emission under electrical biasing. The device characteristics are similar to those made with ITO anode.

Work on making top emitting OLED devices using such nanostructured semi-transparent metal film is currently underway.

Eindhoven University of Technology, Eindhoven, Netherlands; 2Dutch Polymer Institute (DPI), Eindhoven, Netherlands.

A solvent droplet inkjet printed on top of a polymer layer may leave a hole in this layer by dissolution of the polymer and subsequent redeposition at the contact line. This is a consequence of the capillary effect. The hole size does not depend strongly on the choice of solvent. The hole diameter increases with the number of droplets n printed at a spot as n0.5. Matter can be printed inside the holes in a second printing round. This demonstrates the possibility to use inkjet printing of holes for the formation of microarrays. Crystals of monodisperse colloidal particles are considered promising candidates for photonic bandgap materials. For the integration of such materials in a photonic circuit a technique is required that allows deposition of well-defined quantities of dispersion at a well-defined location, such as inkjet printing. It will be shown that inkjet printing of well-dispersed latex particles of several hundreds of nanometers in size is feasible. Depending on the choice of substrate ring-like or dot-like deposits form with a high degree of crystallinity. Printing techniques, such as inkjet printing, are interesting alternatives to conventional photolithography for the production of low-cost electronics. A typical application is inkjet printing of conductive tracks, using inks based on noble metal nanoparticles. A sintering step is needed to render the tracks conductive. The use of nanoparticles reduces the sintering temperature due to the large fraction of surface atoms. We will demonstrate the possibility to print tracks of silver nanoparticles on various types of thermoplastic substrates and sintering these to obtain a finite conductivity.


The deposition of highly conductive traces, typically metal, generally requires vacuum metallisation processes that often result in increased substrate temperature. While these methods are suitable for some applications, many polymeric substrates are far too sensitive for such means of conductive trace deposition. In addition, many applications involving polymeric substrates require conductive lines that are able to bend and flex without experiencing microcracking or pronounced changes in resistivity. To this end, the incorporation of single-walled carbon nanotubes (SWNTs) into a silver microparticle / polymer based ink is being investigated. This is expected to produce a composite with increased tensile and flexural strength and a tunable composite conductivity, and obviates the necessity of vacuum deposition techniques. The dispersion of SWNTs in the composite ink was characterized through both thermal and microscopic analysis, and the electrical conductivity was measured as a function of SWNT % w/w doping in the composite ink. A direct-write, stylos method of deposition was demonstrated using MicroPen® technology (Ohmcraft Inc.). The thermal and structural integrity of composite ink lines deposited on polyethylene terephthalate were also investigated, controlled deposition of electrically conductive inks using SWNTs offers the opportunity to develop robust conductive traces will aid in the advancement of polymer electronics.


Micropen® Direct-write is a novel CAD-based 2-D fabrication technique, which is able to deposit patterns on a substrate through the use of a fully automated X-Y-Z motorized dispensing system. Although this technique has been widely applied to fabricate ceramic or polymeric electronics, its potential for photonic devices has not been fully exploited. The successful use of the Micropen® relies on developing suitable feedstocks that posses the right chemistry, rheology, surface tension, and stability. Our work was based on polyvinylmethacrylate (PMMA) or SiO2 nanoparticles, perfluorocyclobutyl (PFCB) polymer, and PFCB/SiO2 composites. These were developed and studied for their suitability as feedstock to fabricate passive and active optical waveguides. First, the PMMA/SiO2 was synthesized by the polymerization of TEOS in the presence of PMMA from the sol-gel process. The sols of PMMATEOS (w=80/20, wt%) were used for its high transparency, N,N-dimethyl (DMAc) was the co-solvent instead of the normal solvent (tetrahydrofuran, THF). Because the high boiling point solvents was found a critical factor in Micropen® deposition to avoid quick drying at the pen tip and to better control the viscosity. The patterns and multi-layer lines were successfully
deposited with the height up to 20μm and width up to 140μm. SEM revealed another interesting phenomenon of the disc shaped SiO₂ particles in Fig. 9(b) due to the biasing of the deposition. We also studied a commercial FFCB polymer because of its superb optical transparency in the 800-1600nm window in contrast to PMMA. This is because the substitution of fluoride in lieu of hydrogen increases the refractive index of the FFCB polymer. Additionally, this polymer increases the absorption band falling outside of the 800-1600nm window. After writing, the patterns were cured at 200°C for 2h under controlled atmosphere. The variation of line dimension as a function of writing parameters was extensively studied for them with the width decreased with increasing writing speed (WS). In regards to FPCB/SiO₂ composites, we have optimized the materials synthesis for Micropen 1,2,3 by studying the effects of organic-inorganic ratio, and a 50:20 ratio (wt%) was found to work the best. Also, tolune was found the best co-solvent to avoid the phase separation between the organic-inorganic moieties. In addition, silica-based nonequilibrium processed nanoparticles containing up to 1 wt.% Er³⁺ were doped into the FPCB/SiO₂ for active waveguides. The transmission at 1550nm were observed for both systems. Notably, the SiO₂ induced in the composites was helpful to prevent the agglomeration of nanoparticles compared with that in pure FPCB. We will also present the patterns based on the composites with/without the nanoparticles.

M6.7 Sol-Gel Inks for Direct-Write Assembly of 3-D Micro-periodic Titania Structures. Eric B. Duong 1, Mariusz Twardowski 1 and Jennifer A. Lewis 1,2,1, 1Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois; 2Chemical and Biomolecular Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois.

3-D micro-periodic titania structures have been patterned by direct-write assembly (DWA) for use as photonic crystals. Central to our approach is the fabrication of a continuous sol-gel based fluid that flows through a fine deposition nozzle as a continuous filament, and then rapidly solidifies to maintain its shape even as it spans gaps in the underlying layer(s). Face-centered tetragonal woodpile structures have been fabricated and thermally annealed to remove the organic phase. The resulting 3-D structures are comprised of TiO₂ (anatase), and exhibit a corresponding increase in their refractive index from 1.6 to 2.5. Preliminary optical measurements have been performed using a modified FTIR setup to characterize the fabricated and annealed structures. Current efforts are underway to extend this approach to finer feature sizes (<1 μm) and create 3-D photonic bandgap materials at commercially relevant wavelengths.

M6.8 Paste Inks for Electromagnetically Interconnecting Flexible RF Device Components. Sa Raahib Narayani 1, Samali Datta 1, Dustin Vaseelaar 1, Nathan Schuler 2, Rob Sailer 1, Aaron Reinholz 1, David Wells 2, Dean Webster 3 and Douglas L. Schultz 1.

1Center for Nanoscale Science and Engineering, North Dakota State University, Fargo, North Dakota; 2Industrial and Manufacturing Engineering, University of Nevada, Reno, Nevada; 3Department of Chemical & BioEngineering, Colorado State University, Fort Collins, Colorado; 4Coatings and Polymeric Materials, North Dakota State University, Fargo, North Dakota.

Radio-frequency identification (RFID) is a system that utilizes a single chip computer and an antenna to collect and communicate information. Emerging markets enabled by RFID (e.g., inventory tracking) are providing the need for advanced manufacturing routes to materials including conductors for use as interconnects and antenna. While Ag- and C-based systems are actively being engineered by major industrial entities for low-cost and high-throughput manufacture with acceptable performance at radio frequencies, there are niche opportunities that might be realized by alternative production formats. Towards this end, NDSU has developed an Ag-based zero-VOC paste ink system that remains tack-free and thermoplastic after UV curing. This novel formulation was designed to achieve high curing yields (e.g., via screen printing) and a conductor layer onto a web-based substrate followed by a UV treatment to render the composite tack-free and amenable to being rolled up. The residual thermoplasticity is targeted to allow a secondary component to be electrically and mechanically bonded to the web in a subsequent processing step. In this paper, an overview of the chemical formulation of the paste ink will be presented. Cure times of less than 15 seconds were typically observed when using a UV lamp of intensity of 15 W/cm². Electrical and optical parameters utilized with a Milura semiautomatic screen printer will be correlated to print quality parameters such as percent bleed. Electrical performance of the printed features were assessed by standard DC methods to give sheet resistance of 50 Ω/sq for UV-cured silver ink and 1.4 ohm/sq after UV cure and thermal treatment at 100°C in air. Preliminary AC impedance characterization of a microstrip transmission line prepared using an NDSU paste ink gave 0.52 Ω/sq and 0.63 Ω/sq at 900 MHz and 2.45 GHz, respectively, after UV cure with impedance decreasing slightly to 0.13 Ω/sq and 0.26 Ω/sq after an additional thermal treatment at 100°C in air. Scanning electron microscopy data will be illustrated to support the morphology of the composites. The effects of hot pressing and accelerated lifetime testing upon both electrical performance and microstructural development will be presented. In general, NDSU formulations provide slightly superior electrical and mechanical performance compared to commercially-available UV-curable paste inks with the additional advantage of remnant thermoplasticity.

M6.9 Polymer Blends with Applications in Photonics: Analyzed by Conducting Tip Atomic Force Microscopy. Elisabeth Holder 1,2, Dmitry Kozodoev 1, Martijn M. Wieneck 1,2, Veronica Marin 1,2, and Ulrich Schubert 1,1 1Laboratory of Macromolecular Chemistry and Nanoscience, Eindhoven University of Technology (TU/e), Eindhoven, Netherlands; 2Dutch Polymer Institute (DPI), Eindhoven, Netherlands; 3Laboratory of Molecular Materials and Nanosystems, Eindhoven University of Technology (TU/e), Eindhoven, Netherlands.

Functional polymer systems are in the focus for many potential applications in plastic electronics. A very attractive point is the multifunctional active layer fulfilling all necessary requirements in just one layer. In bulk heterojunction solar cells (BHSCs) [1] the active polymer layer combines all functions such as light absorption through the donor, exciton formation, electron transfer to the acceptor, exciton formation and charge separation, followed by the charge transport through the active layer to the respective counter electrodes of such a donor-acceptor BHSC. Therefore, the complete construction of the polymer BHSC can be similar than that of a traditional donor-acceptor solar cells. Wet-chemistry fabrication processes (spincoating and printing techniques) are used for applying polymers. They are giving access to cover also larger areas, which becomes important for cost-effective industrial production processes. The donor-acceptor couple in the BHSC described herein consists of a ruthenium(II) complex (donor) covalently linked to a poly(methyl methacrylate) (PMMA) [2] backbone and a PC60BM (acceptor). [3] On the other hand, the phase separation and resulting morphology is crucial to obtain working polymer solar cell devices. The charge transport through such a single active layer consisting of a polymer blend will only work if there are no isolated areas. Also the donor and the acceptor need to be connected to respective counter electrodes to obtain the desired solar energy. To obtain information of both the morphology of the films and the electrical behavior of the active layer after illumination conductive tip atomic force microscopy (c-AFM, Ti coated tip) serves as an optimal characterization and analysis tool. With our materials this approach lead to similar results as received with standard solar cell devices monitoring (the electrical response of the full area of the conductive layer). The I/V characteristics were found to be in the same range. However, some deviations were observed and can be ascribed to a slightly different measurement set-up (inert atmosphere, illumination source, etc.). In this presentation c-AFM is applied to characterize the morphology of conductive polymer blends on a nanometer level. This information cannot be used to complement the information obtained by standard device fabrication and characterization methods. Furthermore, it is less time consuming and cost intensive than usual device preparation methods. Therefore, the described method may find use as a characterization tool for novel materials. [1] M.M. Wieneck, J.M. Kroon, W.J.H. Verhees, J. Knol, J.C. Hummelen, P.A. van Hal, R.A.J. Janssen, Angew. Chem. Int. Ed., 2003, 42, 3371. [2] E. Holder, M.A.R. Meier, V. Marin, U.S. Schubert, J. Polym. Sci. Part B: Polym. Phys., 2004, 42, 2508. [3] J.C. Hummelen, B.W. Knight, F. LePeq, F. Wudl, J. Yao, C.L. Wilkins, J. Org. Chem., 1995, 60, 532.


The well-known and technologically useful properties of one-dimensional photonic crystals (1DPCs), in particular the presence of tunable optical band gaps for certain wavelength ranges and polarizations, are based on theoretical crystal models of perfect structures. However, the actual fabrication of such perfect structures is difficult to introduce interfacial roughness and other defects that were not treated in the models. Thus, the aim of this study seeks to answer three questions: (1) how tolerant are the optical properties of 1DPCs to imperfections; (2) what parameters/design conditions can be modified to improve tolerances; and (3) what is the physical reason behind the change in reflectivity of the imperfect structures? The first two questions have been answered by examining the optical reflectivity of 1DPCs with varying degrees of interfacial roughness using a two-dimensional
finite-difference time-domain (FDTD) code. We have found that the normal reflectivity of a roughened photonic crystal at the center of the band gap can decrease by more than 25% in some cases. However, this decreased optical performance can be mitigated by either increasing the number of bilayers in the structure or increasing the index contrast between the two constitutive materials in the 1DPC. The third question that has been applied is the homogenization approximation to the same imperfect structures, which produced results that are equivalent to the FDTD results. This suggests that the primary role of the roughness features is to grade the refractive index differently at each interface in the crystal, rather than diffusely scattering the incident light. Consequently, this also implies that the amount of incoherent reflected power from the roughened structures is smaller compared to the total amount of reflected power, even for extremely rough structures. This conclusion has been verified by extracting the amount of incoherent reflected power directly from the FDTD results, further strengthening the claims we put forth here.

M6.11 Fabrication of three-dimensional photonic crystals with aperiodic features using multi-beam holography and two photon polymerization: Br. S. A. Pruzinsky1, P. V. Braun2,3 and P. Wilutzki2,3, 1Department of Materials Science and Engineering, University of Illinois, Urbana-Champaign, Urbana, Illinois; 2Beckman Institute for Advanced Science and Technology, University of Illinois, Urbana-Champaign, Urbana, Illinois; 3Department of Physics, University of Illinois, Urbana-Champaign, Urbana, Illinois.

Holographic lithography is an attractive technique for the fabrication of larger and more complex three-dimensional photonic crystals. Various FCC based structures were formed in the photore sist SU-8, through concurrent exposure with 4 non-coplanar coherent beams of laser radiation. The dimensions of the fabricated structures closely matched those predicted by full intensity calculations for the beam parameters used. Prisms were employed prior to entry into the photore sist to yield the appropriate beam orientations for definition of FCC crystals. Aperiodic features were written within the crystals by using two-photon polymerization, directly into the undeveloped photore sist, thereby eliminating the need for any infilling step. In addition, the optical properties of the crystal were investigated via spectroscopy.

M6.12 Comparative Analysis of a One Dimensional Metal Dielectric Photonic with a Dielectric Photonic Crystal. Miguel Angel Basurto1, Jose Javier Sanchez-Mondragon2; Daniel May-arroyo2, 3 J. Jesus Escobedo-Alatorce3, and Alvaro Zamudio-Lara1; 1CHIC, Universidad Autonoma del Estado de Morelos, Cuernavaca, Morelos, Mexico; 2Optica, INAOE, Tonantzintla, Puebla, Mexico; 3Optica, CREOL & FPCE, Orlando, Florida, Orlando, Florida.

We discuss a one Dimensional Metal-Dielectric Photonic Crystals created by inserting ultra thin metallic layers between the dielectrics of a regular Photonic Crystal. We discuss the new band structure taking as a reference the underlying Dielectric Photonic Crystal and corresponding Metallic Photonic Crystal. In particular, we characterize the new metallic band gap that arise by the metal presence in two particular cases: keeping the periodicity of the Dielectric PC and by introducing new periodicities, that separate the periodicity of the PC as well as other that introduce new periodicities. We demonstrate that the changes introduced goes well beyond the perturbative corrections introduced by the metallic presence; in particular we discuss the properties of the new ultrathin metallic band gaps, that arise before the predominance of the metallic features. Work supported by CONACyT, Mexico, under grant 45667 and ALFA Project IPECA.

M6.13 Biestability, Chirping and Switching in a Linear Nolinear Photonic Crystal. Jose Javier Sanchez-Mondragon2, 3 J. Jesus Escobedo-Alatorce3, Margarita Trecqoyol-Torres2, Romeo Sulsav Aguilera2, 3, Isabel Torres-Gomez2, 3, and A. Martinez-Rios3; 2Optica, INAOE, Tonantzintla, Puebla, Mexico; 3Optica, CHIC, Cuernavaca, Morelos, Mexico; 4Optica, CIO, Leon, Guanajuato, Mexico.

Biestability, Chirping and Switching have been shown in a Stack, the simplest model of the fully nonlinear One Dimensional Photonic Crystals. These features have also demonstrated for the fully nonlinear Cylindrical fiber and the microsphere. However, these features do not occur in the in the case of the fiber and the linear case, there are hardly any information in the intermediate case, when only one of the dielectrics is linear or nonlinear. We present a comparative numerical analysis with the corresponding fully nonlinear PC and the linear PC. Work supported by CONACyT, Mexico, under grant 48667 and ALFA Project IPECA.

M6.14 Preparation of PVP-Protected Silver Nanoparticle for Conductive Patterns. Hyojin Cho1, Kwi Jong Lee1, Sung Il Oh2 and Jaewoo Joung3; 1Central R&D Institute, Samsung Electro-Mechanics Co., Ltd., Suwon, Gyeonggi-Do, South Korea; 2Manufacturing Engineering Team, Samsung Electro-Mechanics Co., Ltd., Suwon, Gyeonggi-Do, South Korea.

Recently metal nanoparticles have received considerable attention due to their applications to bio, optics and electronics. This study was attended to demonstrate synthesis of silver nanoparticles stabilized with polymer and their applicability to printed electronics. First, the silver nanoparticles were synthesized by reduction of silver nitrate in aqueous solution by N,N-dimethyl formamide in the presence of polyvinyl pyrrolidone (PVP) as a stabilizer and showed average size of 50 nm at molar ratio of PVP to silver below 8. The silver nanoparticles were redispersed in ethylene glycol at 25 wt% and then were printed on various substrates. The printed silver patterns were cured in the temperature range between 100 and 300 °C and showed low specific resistance (<10 μohm-cm) even at low sintering temperature below 250 °C.

M6.15 Sintering Behavior and Electrical Property of Printed Conductive Line with Silver Nano Particles. Jaewoo Joung, Young Ah Song and Sung Il Oh; Central R&D Center, Samsung Electro-Mechanics, Suwon, Gyeonggi, South Korea.

Silver nano particles are being widely used in electronic parts. The current line of electronic part has high electric conductivity and low sintering temperature. We have developed new suspension solutions consist of two different-size-distributed silver nano particles. In this study, we synthesized 5 to 20 nm and 70 to 150 nm of particles in aqueous phase, which were stabilized with MSA and PVP relatively. After mixing and dispersing each 2 different sized particle by another dispersant. We formulated suspension solutions with various contents. We make fine printed conductive line by a micro dispenser and then was sintered at 200 to 250 C for 30 to 90 minutes in air. We have found that small size particles have unique sintering property by SEM analysis. As a result, we could obtain 3 times higher electrical conductivity of 7.0 x 10^-6 ohm.cm than single size-distributed particles with sintered 200 C.

M6.16 Biodegradable Surfaces on Titanium and Some of its Alloys for Orthopaedic Implants. Agustin Santana Lopez1, Julia Claudia Mirza Rosca1, Heinz Sturm2, Paula Drob3 and Ecartera Vasilcescu4; 1Mechanical Engineering, Las Palmas de Gran Canaria University, Las Palmas de GC, Spain; 2Federal Institute of Materials Research, BAM VI 2001, Berlin, Germany; 3Institute of Physical Chemistry "I.G. Morucalev", Bucharest, Romania.

Titanium and its alloys are largely used because of their good biocompatibility, superior mechanical strength and high corrosion resistance. But the artificial materials implanted are, generally, encapsulated by a fibrous tissue isolating them from the surrounding bone. Recently, it was demonstrated that the chemical treatment of the titanium implants produce some proteins useful to living bone. In this study, following alkali treatment, a dense bone-like apatite layer is formed on titanium and Ti-5Al-4V in simulated body fluid (SBF). Further studies have shown that the release of Al ions from the well known Ti-5Al-4V produces potential neurological disorders. Different alloys were primarily developed in response to concerns of these health problems and one of them is Ti-5Al-4V. Optical, microhardness and electrochemical impedance spectroscopy determinations were made on Ti and Ti-5Al-4V before and after the alkali treatment. The ESEM technique was used to observe the evolution of the surface appearance in the SBF: it results that the first nuclei appeared after 3 days of immersion; once the first nuclei had appeared, the growth of the apatite layer was very rapid. The nature of the deposited layer on the metallic surface is characterized by EDX. The observed Ca/P atomic ratio was 1.65 which is equal to that of bone apatite. This means that bone-like apatite had formed on the surface of both materials.

SESSION M7: Printed OTFTs
Chair: Arokia Nathan
Wednesday Morning, November 30, 2005
Room 306 (Hynes)

8:00 AM - MT.1
Integrated electronic systems built up from the combination of printed organic insulators, semi-conductors, conductors and electrolytes for electronic lab-on-a-chip applications and photonic integrated circuits. Printed batteries power these labels, touch buttons and electrochromic displays provide for communication and electrochemical transistor systems offer simple computing. A more in-depth description will be devoted to these non-planar analogue circuit design. New integrated circuits and a review of the printing steps needed to achieve these all-integrated circuits on paper labels. The electrochemical transistors utilized function in equivalence to a p-type depletion mode FET-transistors which require then a non-conventional approach in designing digital circuits. Printing electro-active organic polymers, new opportunities arise from a patterning point of view. We describe a novel subtractive patterning technique for coatings of PEDOT:PSS on paper-based printed circuit boards. This layer-by-layer printing technique has successfully been implemented in a traditional rotary screen-printing station. In addition, we report results from flexo-printed conducting polymers on paper. Printing speeds beyond 50 m/min have been achieved.

8:30 AM M7.2
Novel Contacts for Flexible Electronics: Amorphous TCO’s and Direct Write Metals and Polymers. David S. Ginley1, Alex Miedaner1, Lee Smith1, Andrew Leenher2, John Perkins2, Tanya Kadayanova1, Maike Van Hest1, Rubin Collins2, Sean Shaheen2, Matthew Taylor2, Dana Olson2, Matthew Dabney3 and Calvin Curtis1, 1Process Technology and Advanced Concepts, NREL, Golden, Colorado; 2Colorado School of Mines, Golden, Colorado.

There is an increasing interest in developing flexible and non-planar electronics on low temperature substrates such as plastics, glass and flexible foils. To be able to build circuits on these substrates requires contacts that can be processes at low temperature (<200°C) and ideally in a non-contact fashion. We have been developing new and improved contacts specifically address these needs. These include amorphous transparent conducting oxides (TCOs) based on In-Zn-O that can grow at room temperature with electrical and optical properties similar to InSnO (Sn > 3000 ohm cm-2) but with stability in air to nearly 600°C. We have also investigated ink-based approaches for direct write contacts by inkjet for metals and polymers. In metals we have developed inks for Ag, Cu and Ni that produce on deposition near vacuum quality metalizations (i.e. for Ag 5 x 10-5 S/cm) for polymers we have focused on PEDOT:PSS, where we have observed conductivities as high as 120 S/cm for jet ink printed films subsequently treated with DMSO or ethylene glycol. The inkjet printable contacts are suitable for a wide variety of applications and can be deposited in a non-contact approach with high material utilization and no additional patterning. These contacts point the way towards new atmospheric processing specifically suited to flexible and 3D electronics. This work was supported by the DOE through the NCPV and DARPA under the OPV program.

9:00 AM M7.3
Room-temperature deposited high-k gate dielectrics for low-voltage flexible electronics. Il-Doo Kim1,2, YongWoo Choi1,2, Akitunde I. Akinwande3 and Harry L. Tuller1. 1Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; 2Microsystems Technology Laboratory (MIT), Massachusetts Institute of Technology, Cambridge, Massachusetts; 3Optoelectronic Materials Research Center, Korea Institute of Science and Technology, Seoul, South Korea.

Transistors using organic semiconductors (OTFTs) have received intensive interest for applications requiring low cost, large area coverage, and especially flexibility. Such applications include digital logic devices, electronic paper and books, wearable electronics, and flexible large area display. Recently, gate insulators for OTFTs have received increasing attention because OTFTs switching voltages can be reduced by using high-k dielectrics or ultrathin gate dielectric layers. Generally, high operating voltage results in high power consumption, a potential critical barrier for portable, battery-powered applications. Thus, some combination of lower permittivity gate dielectric and reduced dielectric thickness is desired to achieve lower voltage operation. However, the use of ultra-thin gate insulators leads to significant manufacturing problems (pinholes, significant leakage current, and low manufacturing yields) due to the surface roughness which is of the order of the thickness of the insulators. Therefore, flexible polymer substrates, often characterized by rough surfaces (RMS roughness ~ 3 nm), would benefit from the use of high k dielectrics because high electric fields could be applied (thicker films are needed to increase operating voltage). As new candidates, we developed pyrochlore structured Bi4+2ZrO3+Na2O5+O2 (BZN) and various acceptor doped (Ba,Sr)TiO3 thin films deposited at room temperature providing the requisite high dielectric constant coupled with excellent leakage current characteristics, while remaining compatible with the processing requirements of flexible OTFTs. Here we report the successful fabrication of low voltage (< 5 V) organic transistors using a 200 nm thick gate oxides by an all room temperature process. The introduction of an extremely thin organo- and inorganic films between high-k gate oxide dielectric and the pentacene semiconductor markedly shifts the threshold voltage, making possible both enhancement (E) and depletion (D) TFTs. Based on these results, it becomes possible to demonstrate the ability to co-fabricate a number of key OTFT-based circuit elements on flexible substrates.

9:15 AM M7.4

Organic Field-Effect Transistors (OFETs) based on molecular and polymeric semiconductors need substantial performance and processibility improvement for utilization in commercial devices. Furthermore, OFETs typically operate at very high voltages and exhibit shift of key device parameters upon continuous operation. We report here our latest results on a new crosslinked polymeric gate insulator family exhibiting high capacitance and excellent insulating properties. Furthermore, these dielectric layers are compatible with a variety of p- and n-type organic semiconductors allowing fabrication of complementary circuits. The corresponding devices perform at exceptionally low operating voltages (~1V) with minimal shift of operational parameters. Finally, we will present our latest results on the optimization of these insulating materials via design/synthesis of new polymeric and crosslinking building blocks. This study provides a new evidence of the fundamental importance of an optimized organic dielectric layer, besides the organic semiconductor, to strengthen OFETs performance and meet the market expectations.

10:00 AM M7.5
Nano-transfer Printing as a Method for Fabricating Organic and Carbon Nanotube Thin-Film Transistors on Flexible Substrates. Daniel Hines1,2, Sergey Mezhzherin1,2, Michaela Breban1, Vinod Sangwan2,1, Ellen Williams2,1, Vince Ballarotto2,3, Gokhan Esem1 and Michael Fuhrer2. 1Laboratory for Physical Sciences, University of Maryland, College Park, Maryland; 2Department of Physics, University of Maryland, College Park, Maryland.

Nano-transfer printing has been developed as a method for fabricating high quality organic based devices onto flexible substrates. This is a non-lithographic process for the sequential assembly of device components such that an entire device can be fabricated without exposure to incompatible processes. As a demonstration of nano-transfer printing we have assembled a gold (Au) gate electrode, a poly(methyl methacrylate) (PMMA) dielectric layer, Au source/drain (S/D) electrodes and three semiconductor films from different materials classes onto a single high-k dielectric tetraphthalfulvalene (PET) substrate. The three semiconductor materials are pentacene (Pn) from the small-molecule class, poly(3-hexylthiophene) (P3HT) from the polymeric class and carbon nanotube mats (CNTs) from the nanotube class. The CNT and P3HT films have all resulted in high performance transistors devices.1 The details of the transfer printing method using Au electrodes and a PMMA dielectric layer as model components will be presented. The use of other dielectric layers such as polyvinyl phenol (PVP) with also be discussed. 1. D. R. Hines et al., Appl. Phys. Lett. 86, 163101 (2005). * Work supported by the Laboratory for Physical Sciences.

10:15 AM M7.6
Micron-scale Organic Thin Film Transistors with PEDOT Electrodes Patterned by Polymer Inking. Dawen Li and L. Jay Guo; Electrical Engineering and Computer Science, The University of Michigan, Ann Arbor, Michigan.

We report a simple, low-cost, and parallel fabrication of pentacene or thin-film transistors (OTFTs) with conductive PEDOT electrodes that are patterned by a special “polymer inking and stamping” technique. In this technique, A PDMS stamp with source/drain electrode patterns was first made by casting and curing PDMS against a Si Master. Conductive polymer PEDOT was spun-coated on the PDMS stamp. Next the PEDOT coated stamp was placed on Si/SiO2 substrate or deposited pentacene film without additional force, and the PEDOT on top of the stamp protrusion regions were in conformal contact. Subsequently, the PDMS stamp was removed and PEDOT patterns were left on the substrate having identical dimensions as the source/drain patterns on the stamp. We found that success of pattern transfer depends on both substrate surface and PEDOT solution, and pattern transfer took place when a certain amount of glycerol was added into PEDOT.
aqueous solution. OTFT channel length of 2μm for both top contact (TC) and bottom contact (BC) configurations has been achieved. During the patterning for TC, pentacene at the device region can also be defined simultaneously due to adherence of pentacene material that surrounds source/drain pads to the PDMS stamp. This naturally created the device-to-device isolation, without additional pentacene patterning steps. Electrical characteristics of TC pentacene TFTs with PEDOT electrodes is superior to those with gold electrodes. This is due to a lower energy barrier between the PEDOT and pentacene. Field-effect mobility and on/off current ratio in saturation regime as large as 0.75 cm²/Vs on the pentacene TFTs were obtained. On the other hand the electrical performance of BC pentacene TFTs with PEDOT electrodes is very similar to OTFTs with Ti/Au electrodes. This is because for BC OTFT configuration, interface morphology between the electrode and the pentacene deposited on top limits the carrier injection efficiency. We have quantified that the contact resistance (Rc) of TC OTFTs with PEDOT electrodes is an order of magnitude smaller than those with gold electrodes. Therefore, for both BC and TC pentacene TFTs, Rc has the same order of magnitude as channel resistance (Rch) per micron meter. Electrical performance can be further improved by reducing channel length. While Rc of BC OTFTs is in about two orders of magnitude greater than Rch, scaling down channel length will not effectively improve OTFTs performance. Reduction of Rc is the only way for further improvement of OTFTs electrical performance. The authors have developed a new polymer inking and stamping technique not only provides much higher resolution than the thermally evaporated gold electrodes via shadow mask, but also is much more cost effective. This technique can be potentially developed as a rapid, reel-to-reel patterning technology for conductive polymers.

10:30 AM M7.7
Monolayer Formation in Oligothiophene Based OTFTs.
Paul Chang1, Amanda R. Murphy2, Jean M. J. Frechet2 and Vivek Subramaniam1; 1Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, California; 2Department of Chemistry, University of California, Berkeley, California.

Recent work has shown oligothiophenes deposited via inkjet printing can undergo a thermosolvin driven organization that results in films a single monolayer thick between adjacent source and drain electrodes. This work studies the mechanisms behind such film formation, including the surface mobility of deposited molecules and the effects of substrate surface energy. Oligothiophenes of different size are studied in order to better examine the kinetic tradeoff in observed the surface rearrangement. Molecules are verified to have a preferential affinity for gold surfaces and the ability to diffuse >5 um over the surface. Under specific processing conditions and electrode configurations, resulting films using particular oligothiophenes are seen to form continuous or/and percolative films with channel length up to 10 um long. Compared to aggregated, thicker film devices, monolayer devices films show significantly reduced trapping behavior, resulting in improved performance and consistent low bias behavior. Overall, for printed interconnects, field-effect properties over 400 μA/cm² are measured, with peak inverse subthreshold slopes <200 mV/dec.

10:45 AM M7.8
Organic Thin Film Transistors from Uniaxially Aligned Films of Hexa-peri-hexabenzocoronene (HBc).
Jason Christopher Plinto1, Richard Friend1, Henning Sirringhaus1, Wojciech Pilsula1, Tadeusz Pakula2 and Klaus Mueller2; 1Optoelectronics Group, Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom; 2Max Planck Institute for Polymer Research, Mainz, Germany.

Recent interest in polymeric systems for optoelectronics has been motivated by the many advantages polymers offer over traditional inorganic semiconductors. Ease of processing through room temperature solution deposition is one of these key advantages. This makes polymers inexpensive and craftily adaptable to flexible substrates. Polymeric semiconductors, however, suffer from a lack of long-range order which is thought to be the major cause of low mobility in polymer thin film transistors (TFTs). Disordered liquid crystals (DLCs) present an alternative approach to flexible organic electronics. Conjugated core DLCs are disc shaped molecules that have the ability to self-organize into columnar aggregates. The self-organization of these molecules produces a highly ordered system where columnar pathways for charge transport paths. These pathways can be exploited for high mobility field-effect transistors (FETs) if the columns lie in plane with the transistor channel and span the source and drain contacts. We report here the use of a novel disordered liquid crystals cast as uniaxial aligned films of hexa-peri-hexabenzocoronene derivatives. These films were used to fabricate field-effect transistors that demonstrated the highest observed charge-carrier mobility for these materials. These devices also showed high mobility anisotropy when devices made parallel and perpendicular to the coating direction were compared. The temperature dependence of charge transport in these films was investigated for insight into the prevalent mode of carrier transport parallel and orthogonal to the column direction. We also performed spectroscopic studies on these highly aligned materials.

11:00 AM M7.9
Fused thiophene semiconducting polymers for OFETs: Solutions to high mobility and stability.
Clare Bailey, Kristjóns Genevics, Martin Heeney, Iain MacDonald, Ruth Rawcliffe, Richard Sisters, David Sparrow, Maxim Skunurov, Weimin Zhang and Iain McCulloch; Merck Chemicals Ltd., Southampton, United Kingdom.

The emergence of organic field-effect transistors (OFETs) for incorporation into lightweight flexible electronic devices has generated interest in the development of solution-processable organic semiconductors. Novel semiconducting polymers containing thiophene[2,3-b]thiophene and thiophene[2,3-b]-1,2,5-thiadiazole moieties were prepared via a fast highly reproducible microwave-assisted reaction. These polymers were solution-processed to form the active semiconducting element of an OFET. Processing parameters including surface treatment, annealing temperature, and device architecture were optimised in order to maximise thin-film morphology and charge transport in the polymers. Field-effect mobilities higher than 0.1 cm²/Vs are reported for thiophene[2,3-b]-1,2,5-thiadiazole co-polymers and thiophene[2,3-b]-1,2,5-thiophene co-polymers. Excellent air-stability is also reported for thiophene[2,3-b]thiophene co-polymers in an OFET.

11:15 AM M7.10
Non-Volatile Memory Effect of Ferroelectric Field-Effect Transistors based on a Printed Polyethylene Film. Sei Uemura1, Manabu Yoshida1, Toshio Kikami1, Masahiko Kojima2, Takeshi Kondo2 and Takeshi Kawar2; 1AIST, Tsukuba, Ibaraki, Japan; 2Department of Industrial Chemistry, Tokyo University of Science, Shinjuku, Tokyo, Japan.

Biomaterial is one of the most attractive materials for the printed device due to its solubility and unique dielectric properties. Polyethylene is one of the typical biomaterials with unique dielectric phenomena, thus it can be a good candidate for the component of printed devices. It has been known that some kind of polyethylene shows ferroelectric phase such as its rigid rod-like structure. In this study, we have examined to prepare a printed thin film of poly (γ-methyl-L-glutamate) (PMLG), and investigated its film structure and ferroelectric behaviors. In the printed thin film, PMLG showed a rod-like α-helix structure. Its molecular axis was oriented to the parallel direction to the substrate surface. A ferroelectric field-effect transistor (FeFET) was prepared by using the printed PMLG thin film as a dielectric layer. Large hysteresis was observed in the I-V characteristics of the FeFET. The bistable states could be obtained. The obtained bistable states were very stable more than 10 days without any applied voltages. Then, it can be expected to be used as a non-volatile memory. Such phenomena were dependent on the molecular weight of PMLG. While the thin film of PMLG with large molecular weight (M. w. > 60,000) does not show the bistable state, that with small molecular weight (M. w. < 30,000) showed large hysteresis in the I-V characteristics. A.c. and d.c. current-voltage properties, spectroscopic measurements and morphology observation revealed that the observed phenomenon was dependent on the oxidation potential of main-chain and side-chain dopants. In the case of high molecular weight PMLG, the aggregation of the PMLG and change of the morphology was observed by applying voltage. However, in the case of the low molecular weight PMLG, such a drastic molecular motion was not occurred but dipole moment could be observed. Furthermore, we have also observed that the driving voltage was dependent on the concentration of the dipole in the dielectric layer. From these results, we have proposed that the memory effect is caused by the motion of the main-chain rather than the side-chain without morphological change.

11:30 AM M7.11
Organic Field-Effect Transistors with Suppressed DC Bias-Induced Degradations. Tatsuya Saito, Takayasu Sakurai1, Tatsuo Inoue1, Yoshiaki Seki1, Meiko Nakamura1, and Hideaki Kato1; 1Quantum-Phase Electronics Center, The University of Tokyo, Tokyo, Japan; 2Center for Collaborative Research, The University of Tokyo, Tokyo, Japan.

We report our observation that the DC bias stress-induced degradations of organic field-effect transistors (FETs) can be suppressed drastically by postannealing effects. Heat-resistant pentacene FETs were manufactured on polyimide films with polyimide gate dielectric layers and annealed at 140 degree Celsius for 12 hour in a nitrogen environment. When DC biases of VGS and VDS = -40 V are continuously applied to these FETs for 11 h, the change of source-drain current is as small as 3 ± 1 % and the threshold voltage
(Vth) shift is less than 0.4 V. Heat-resistant organic FETs were fabricated on a 75-µm-thick polyimide film with a polyimide gate dielectric layer. The gate electrode was formed by thermal evaporation of 5-mm-thick Cr and 100-nm-thick Au through a shadow mask. A 600-nm-thick polyimide gate dielectric layer was then prepared by spin coating and a 50-nm-thick pentacene layer was deposited by thermal evaporation. A 60-nm-thick Au layer was deposited using a shadow mask to form the drain and source electrodes. The nominal channel length and width of organic FETs were 100 µm and 1 mm, respectively. Finally, the base film with transistors was covered by a 4-µm-thick poly-para-xylylene (parylene) layer. Both the annealing experiment and the electric measurements were performed in a light-shielding nitrogen environment with less than 1 ppm oxygen and moisture. After the thermal annealing process, the mobility was enhanced from 0.3 to 0.4 cm²/Vs and the on/off ratio was improved from 10⁷ to 10⁸, where Vth was shifted from +4 V to −3 V. Furthermore, the annealed FETs showed no significant changes even after applying continuous DC voltage biases of Vg,2 = +6 V. In general, the mobility is enhanced by the organic transistor characteristics such as mobility. Vth, and IDSS under continuous DC bias stress, which is crucial in order to realize reliable and sophisticated integrated circuits comprising organic transistors.

This study is partially supported by the GT Program, MEXT, MEXT, and NEDO.

11:45 AM M7.12
High performance vertical-type organic transistors using a metal base structure. Ken-ichi Nakayama, Shin-ya Fujimoto and Masaaki Yokoyama; Graduate School of Engineering, Osaka University, Osaka, Japan.

The vertical-type organic transistor is a promising device structure that can make the channel length much shorter, leading to low voltage operation and high frequency response. So far, some vertical transistors have been reported, for example, an organic triode device and a static induction transistor. However, these devices need complicated processes to fabricate the third controlling electrode, such as a self-assembled polymer network or a fine-pitch striped pattern. In this letter, we report a very high performance vertical transistor having a simple layered structure composed of organic/metal/organic layers. This device could modulate a sheet current between the emitter and collector by a voltage applied to the thin metal base inserted. The base was fabricated by vacuum deposition. The first organic layer of perylenetetracarboxylic derivatives (Me-PTC) was deposited on an ITO of a collector electrode. The base electrode of aluminum was deposited with a thickness of 20nm. The second organic layer of Ag was deposited by vacuum deposition. Without the base voltage (Vb), the small current collector (Ic) was observed on applying the collector voltage (Vc = 5V). However, application of Vb markedly increased the collector current, which finally exceeded 300 μA/cm² for only 3 V of Vb. The value of the ON/OFF ratio was around 10⁶, rather high for vertical-type transistors. In addition, the value of current amplification factor (hFE) reached as high as 180. This indicates that the output current was much larger than that of the input current, which means that current amplification occurred like bipolar transistors. There are two requirements to observe a large amplification using the simple semiconductor/metal/semiconductor structure. One is the thickness of the metal electrode. The thickness more than 40 nm makes the device a simple series connection of two organic films. The other is the used material. So far, the best performance was obtained for the combination of C60 as an emitter and Me-PTC as a collector. The other electron donating materials show high amplification or no amplification. The mechanism of the current amplification is not clear, but we consider that the key should be the coverage of the base aluminum electrode, that is, whether the thin base electrode covered the organic film sufficiently or not. This mechanism for the amplification of the transistor would be proposed. Now, we are investigating the electrode structure using various microscopic techniques.

SESSION M8
Inkjet Printing
Chair: James W. Stasiak
Wednesday, November 30, 2005
Room 306 (Hynes)

1:30 PM M8.1
Inkjet Printing of Functional Polymers and Nanoparticles.
Ulrich S. Schuberg, Berend-Jan Gans, Esten Fokin, John Perelaer, Antje van den Berg and Elisabeth Holder; Laboratory of Macromolecular Chemistry and Nanoscience, Eindhoven University of Technology and Dutch Polymer Institute, Eindhoven, Netherlands.


2:00 PM M8.2
Enabling Desktop Inkjet Printers as a Tool to Pattern Conductive Polymers. Yuka Yoshikawa1 andGlassan E. Jabbour2.
1Flexible Display Center, Arizona State University, Tempe, Arizona; 2Chemical and Materials Engineering, Arizona State University, Tempe, Arizona.

We will discuss how to use desktop inkjet printers as tools to pattern and control the sheet resistivity of a conductive polymer on any substrate ranging from glass to paper. The adequate choice and proportion of the ink and the method for only position (printing) variables will be presented. Examples of several applications that benefit from this approach will be highlighted.

3:30 PM M8.3
Inkjet Printing for Flexible Electronics and Smart Textiles. Paul Calvert, Amit Sawhney and Aminesh Agrawal; Textile Sciences, University of Massachusetts, Dartmouth, North Dartmouth, Massachusetts.

Inkjet printing can be used to deposit electronic materials such as conducting polymers and metals. The printing of uniform PEDOT films onto hard surfaces, the printing of silver lines and piezoresistive sensors onto textiles and the printing of active optical layers onto textiles will be discussed. In many cases when building complex structures, it will be desirable to print a receptor layer and then print the active materials into this. This is of interest to explore printing into gels and porous substrates.

4:00 PM M8.4
Inkjet Printing of Polyimide Precursors and its Application to Organic Field-Effect Transistors. Yoshiaki Noguchi1, Tsuyoshi Sekitani1, Yusaku Kato1, Shingo Iba1, Takaya Sakurai2 and Takao Someya2,3; 1School of Engineering, The University of Tokyo, Tokyo, Japan; 2Center for Collaborative Research, The University of Tokyo, Tokyo, Japan.

Employing an inkjet printing machine, heat-resistant polyimide gate dielectric layers are patterned on plastic films and exploited to
manufacture high-quality pentacene field-effect transistors (FETs). The measured mobility of pentacene FETs with inkjet polyimide is 0.2 cm²/V·s at a grain size of 50-μm and the mobility of the inkjet processed polyimide is significantly lower. The surface smoothness of the inkjet-printed polyimide layers characterized by AFM is comparable to that of spin coated polyimide films (RMS=0.22 nm). A high-purity precursor (Kemite CF142 from Chemical) was patterned by an inkjet printer (J-35, Ricoh Printing Systems) with a stainless steel inkjet head (GENSEI), which is driven by multilayered piezoelectric and equipped with 96 linear array nozzles. A solution containing polyimide precursors was diluted by N-Methyl-2-pyrrolidone (NMP) so that its viscosity could be the vendor’s recommended value (11 mPa·s). Before manufacturing organic transistors, various kinds of dot and line polyimide patterns were prepared by inkjet printing using the newly revealed and nanoscale 50-μm-thick Au layer. The samples were cured at 180 °C for 1 hour in the nitrogen environment. We have controlled the discharge-voltage (30-40V) of the inkjet head. The minimum diameter of dots was 120 μm without surface rupture during the printing of polyimide at high spatial resolution of 200dpi. The variation in diameter was less than ±5% for measured 100 dots. The surface of the inkjet-patterned polyimide layer was characterized by AFM. Its smoothness is comparable to that of spin coating (RMS=0.22 nm). Pentacene FETs were fabricated with inkjet-printed polyimide gate dielectric layer. A gate electrode consisting of 3-μm-thick Cr and 50-μm-thick Au layer was evaporated through a shadow mask on the same polyimide film. A polyimide gate dielectric layer was prepared by inkjet, whose thickness was 510 nm after curing process. A 50-μm-thick pentacene was deposited by thermal evaporation. Finally, source and drain electrodes were evaporated through a shadow mask. The channel length and width of organic FETs are 100 μm and 500 μm, respectively. The mobility was 0.2 cm²/V·s in the saturation regime and the on/off current ratio was above 10⁵. Compared with spin coating, the present inkjet printing of polyimide is considerably faster than a roll process and does not require additional patterning process for via interconnection, thus it is potentially ultra low in manufacturing cost. Although the present precursor-type polyimide was dissolved in NMP-based solution, the bending of polyimide as we have shown in Fig. 1(b). We have fabricated high-quality pentacene FETs suitable for organic electronic devices. This study is partially supported by IT Program, MEXT, MHPT, and NEDO.

4:15 PM M8-5

**Organic FET Grown by Direct Printing of Pentacene Channel and Metal Contacts Using a Molecular Jet Printer.**

Jianglong Chen¹, Valerie Leblanc¹, Annie Wang¹, Marc A. Baldo², Paul J. Benning², Martin A. Schmidt¹, David M. Schur³ and Vladimir Bulovic¹. ¹Microelectronics Technology Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts; ²Hewlett-Packard Company, Corvallis, Oregon.

We recently demonstrated Molecular Jet (MoJet) printing technique for high-resolution printing (up to 800 dpi, 30μm features) of organic semiconductors and metals, and we applied the technique to printing patterned molecular organic LEDs. In contrast to the ink-jet printing of solutions, the MoJet technique employs a solvent-free and air-stable additive deposition process to enable low-voltage evaporation of thin films. In this work, we demonstrate the use of MoJet technique to fabricate high-quality pentacene FETs suitable for electronic devices. This study is partially supported by IT Program, MEXT, MHPT, and NEDO.

4:30 PM M8-6

**Inkjet Printed Inorganic Channel Materials for Thin Film Transistors.**

Yi-Min Chiang, Doo-Hyung Lee and Chih-Hung Chang. Chemical Engineering, Oregon State University, Corvallis, Oregon.

Low cost integrated circuits will enable many new applications for our daily life. Amorphous silicon (a-Si) is the current material of choice for low-cost thin-film transistors (TFTs) that are widely used as switching devices in active-matrix liquid-crystal displays. Organic (molecular crystals or polymeric) semiconductors with advantages of flexibility and potential low-cost processing are major candidates. Moreover, showing that the 10⁵ performance of inorganic materials is not acceptable for the active device. Inorganic compound semiconductors have advantages of higher carrier mobility and excellent long-term stability. We are exploring this concept by fabricating inorganic thin film transistors via inkjcet processes. Simple and low cost chemical precursors for a variety of metal oxide semiconductors that is suitable for inkjet printing were developed in our lab. Using these precursors, we have successfully fabricated working thin film transistors with inkjet patterned channel layers in a metal insulator semiconductor field effect transistor structure. The mobility values of these devices were higher than 5 cm²/V·s. The success of inkjet printable inorganic semiconductors opens the door for fabricating low-cost high-performance devices via inkjet printing.

4:45 PM M8-7

**A novel high-Q printed inductor technology for RFID applications.**

David Redinger and Vivek Subramanian. EECS, University of California, Berkeley, Berkeley, California.

Deposition of low-resistance materials is crucial to the fabrication of high-quality inductors necessary for power coupling in low-frequency RFID tags. There is great interest in using printing to realize these inductors since it lowers the cost of the tag; unfortunately, to date, printed technologies have not provided the requisite low resistance conductors required for high-Q inductors. Therefore, most low-frequency tags today are realized using conventional etch or cut-based techniques, which are more expensive. Copper is an ideal material for use in low-cost circuitry due to its low cost, good etchability, and relative abundance. Here, we demonstrate a novel high-quality inductor technology based on the use of inkjet-printed nanoparticles as an initial pattern, followed by subsequent electroless plating to deposit copper, resulting in excellent low-inductance copper films to a significant improvement (10-20X) in inductor quality factor over printed nanoparticles alone. Finally, therefore, performance levels required for inductively coupled RFID are realized via a low-cost plating technique. Several metals catalyze the electroless plating of copper. Gold or silver nanoparticles catalyze the electroless plating reaction when deposited with adequate concentration. The seed layer consisted of oleic acid-encapsulated silver nanoparticles in dilute alcohol solution, along with a palladium organic adhesion promoter. Using inkjet-printing, a seed pattern was printed onto conventional DuPont Melinex substrates, and annealed to drive off the nanoparticle encapsulant. The plating solution consisted of CuSO4, EDTA complexing agent, RE-610 surfactant, pyridine, acetic acid, paraformaldehyde reducing agent, and DI water. The pH was adjusted to 13.2 using potassium hydroxide. The bath was kept at 60 °C and aerated during the deposition. Line height increases linearly with plating time until a point where the plating solution becomes unstable, which happens after approximately two hours. Copper lines 3.5 μm thick are reliably grown, giving an aspect ratio up to 7.5 μm/square. At least 450 line frequencies were used to determine inductor quality, and therefore sheet resistance of the metal layer is a very important metric. Conductivity of the deposited copper was as high as 73 percent of bulk copper. A 3.2 μH inductor was manufactured that had a serial resistance of 1.1 mΩ, giving a quality factor of 28.3 at 13.56 MHz. This is expected to be good enough for the most common RFD tags. Therefore, this process represents an important step towards the fabrication of low-cost RFID systems.

SESSION M8: Poster Session: Printed TFTs and Circuits

Wednesday Evening, November 30, 2005
8:00 PM

Exhibition Hall D (Hynes)

M9.1

Using a Flexographic Printer for Organic Field Effect Transistors. Henrik G. O. Sandberg and Tapani Palmela; Polymer Electronics, VTT Information Technology, Espoo, Finland.

Field effect transistors (FETs) are key elements in printed electronic applications. Electronics are expanding into new fields where cost of manufacture is critical, which has lead to the development of new methods for preparing devices. Such application areas are for example simple devices used in packaging and other “throw away” devices, where embedded electronics may give additional value. In this work, flexible organic FETs are studied, where the flexographic (flexo) printing method is used for manufacture of polymer elements in the device. The main component geometry used in this study is the thin film transistor and the flexographic printing method is used primarily for manufacture of semiconductor and dielectric layers using solutions of regioregular poly(3-hexylthiophene) and polyhydroxystyrene.
respectively. The use of flexographic printing methods for doublelayer polymer structures are investigated and the devices are characterized in various applications. The layers are initially made from metal thin films using standard methods, or by using a flexo printed etching mask, as the resolution and printing quality of high conductivity polymers using the flexo printing method is not as such ideal for transistor dimensions/geometry. The gate electrode is made using inkjet or flexo for conducting polymer electrodes or by metal evaporation. The flexographic printing method is chosen as it allows for low-cost fabrication using organic material in solution and the process is easily scaled for high volumes.

**M9.2 n-Type Organic Field Effect Transistor Prepared by Supramolecular Nanotransfer Printing**

Christian Albertus Nijhuis1,2, Jurjen Maat1,2, Maria Peter3, Marcel Wuesthol3,2, Cora Salm1,2, Jurriana Schmitz1,2, Bernard Boukamp1,1, Wilfred van der Wel1,2, Bart Jan Ravoo1,2, Jurriana Husken1,1 and David N. Reinhoudt1,2,1.

Universite de Twente, Enschede, Overijssel, Netherlands. 1Department of Applied Physics, Enschede, Overijssel, Netherlands.

Organic field effect transistors (OFETs) can have applications in identification tags, smart cards, and display drivers, but n-type semiconducting organic molecules are still relatively rare. Moreover, the preparation of organic electronic devices by conventional lithography requires expensive and elaborated equipment and/or high temperatures and wet chemicals which may cause degradation of the relatively fragile organic molecules. For these reasons, the development of other fabrication techniques is of current interest. 

Printing techniques are attractive due to their low cost and conventional patterning techniques, and only low cost tools are required. Especially nanotransfer printing is interesting for device fabrication, since a thin metal film is transferred from the stamp to the substrate. Small replicas rely on the formation of chemical bonds between the metal film and the substrate resulting in an effective metal transfer. In our group self-assembled monolayers (SAMs) of β-cyclodextrin (βCD) on gold and on glass have been extensively studied.2,3 The surface confined β-cyclodextrin moieties retain the ability to form host-guest complexes with different molecules from solution. Redox-active ferrocenyl (Fc) functionalized PPI dendrimers constitute a particularly interesting class of polyfunctional guest molecules that are confined onto the water-soluble dendrimers. These molecules form stable assemblies at βCD SAMs owing to the formation of multiple specific host-guest interactions with the host-surface. A βCD SAM was formed at thin Au films that were thermally deposited at PDMS stamps. Placing these functionalized PDMS stamps in conformal contact with a monolayer of the ferrocene dendrimers at a βCD SAM resulted in an effective transfer of the Au from the PDMS stamp to the substrate. The effective transfer is caused by the formation of multiple host-guest interactions of Fc-endgroups with the βCD SAM at the stamp. Nanotransfer printing at heavily p-doped Si wafers with 50 nm SiO2 on which βCD SAMs were prepared, resulted in three-terminal devices with two Au top contacts and a heavily p-doped Si substrate as a gate. The obtained OFETs showed n-type semiconductor behavior due to the redox-active ferrocene endgroups. The potential at which the FET switches to the conducting state is very close to the redox potential of the Fc-units and devices fabricated from low redox-functionalized dendrimers showed no FET behavior. References 1. Loo, Y.-L.; Willett, R. L.; Baldwin, K. W.; Rogers, J. A. Appl. Phys. Lett. 2002, 81, 651. 2. Beulen, M.-W.; Büger, J.; Lammerink, B.; Geurts, F.A.J.; Biemond, E. M. E. F.; Leerdam, K. G.‐C.; Van Veggel, F. C. J. M.; Engbersen, J. F. J.; Reinhoudt, D. N. Langmuir, 1998, 14, 6424. 3. Oonlin, S.; Mulder, A.; Husken, J.; Ravoo, B. J.; Reinhoudt, D. N. Langmuir, 2004, 20, 5400. 4. Nijhuis, C.A.; Husken, J.; Reinhoudt, D.N. J. Am. Chem. Soc. 2004, 126, 12266.

**M9.3 Printed Nanocomposite Dielectric Gate Insulator for Organic Field Effect Transistors.** Amjad S. Rasul1,2, Jie Zhang1, Dan Gamota1 and Christos Takoudis2.

Motorola Labs, Motorola Inc., Schaumburg, Illinois; 2Department of Chemical Engineering, University of Illinois at Chicago, Chicago, Illinois.

Printed high capacitance nanocomposite dielectric material was demonstrated as a gate insulator for organic field effect transistors (OFETs). A nanocomposite consisting of cross-linked Propylene Glycol Methyl Ether Acetate and Nanotitanate (BTO) nanoparticles was developed and utilized as the gate insulator. The high permittivity (k≈35), bimodal nanocomposite utilized had two different filler particle sizes: 200 nm and 1000 nm, diameter particles. Due to the nanosize of the BTO particles, they disperse well in the organic solvent, which makes it possible to use solution-processable methods, such as printing to fabricate the devices. Bottom contact OFETs were demonstrated using a combination of pad printing and spray coating technologies. An aluminum coated Mylar film was used as the flexible gate substrate. An amorphous organic semiconductor was utilized as the active layer to evaluate the dielectric properties of room temperature, solubilized OFET devices. The thickness of an amorphous semiconductor material enabled a more consistent nanocomposite gate insulator evaluation since morphology effect can be largely neglected. It was demonstrated that OFETs with the nanocomposite dielectric layer have higher field-induced current than that of conventional devices due to the high dielectric constant of the gate insulator.

**M9.4 Solvent annealing improves thin-film transistor performance of an anthrithiophene organic semiconductor.** Kimberly Dickey1, John Anthony2 and Yueh-Lin (Lynn) Loo1.

1Chemical Engineering, University of Texas at Austin, Austin, Texas; 2Chemistry, University of Kentucky, Lexington, Kentucky.

The development of organic semiconductors is driven by the promise of low-cost device applications. The success of reducing fabrication costs and creating low-cost, high quality, flexible devices has focused on the ability to deposit the organic semiconductor material from solution, a relatively inexpensive deposition method, as compared to thermal evaporation. To date, several solution-processable organic semiconductors have been developed. Devices built with these materials, however, tend to exhibit carrier mobilities that are several orders of magnitude lower than thermally evaporated pentacene, the quintessential organic semiconductor with an average mobility of the order of 1cm2/V-sec. One solution-processable organic semiconductor we have studied is triethytherithiophene (TET ADT), an anthrithiophene molecule that has been functionalized with bulky side groups to promote film formation and solution stabilizer. We have fabricated thin-film transistors on silicon substrates with spun-cast TES ADT thin films. The hole mobility of the spun-cast TES ADT transistors is significantly lower (0.005cm2/V-sec) than thermally evaporated anthrithiophene thin films (0.1cm2/V-sec). Annealing the spun-cast TES ADT thin film over a pool of toluene for a mere two minutes, however, significantly improves the device performance. Specifically, the current-voltage characteristics of these annealed devices exhibit significantly reduced hysteresis, increased hole mobility of several orders of magnitude (0.2cm2/V-s), and increased on-currents (100 fold). Annealing TES ADT thin films with dichloroethane produces similar effects, but annealing with other solvents, such as hexane and carbon tetrachloride, did not yield significant improvement over unannealed films. The marked improvement in device performance can be directly correlated with structural changes and macroscopic morphological transformations that are traceable by near edge x-ray absorption fine structure spectroscopy and atomic force microscopy, respectively.

**M9.5 Contact resistance in asymmetric pentacene thin-film transistors with polyaniline and gold electrodes.** Kwang Seok Lee1, Timothy J. Smith,1 Joung Eun Yoo1, Keith J. Stevenson2 and Yueh-Lin (Lynn) Loo1.

1Chemical Engineering, University of Texas at Austin, Austin, Texas; 2Biochemistry, University of Texas at Austin, Austin, Texas; Center for Nano- and Molecular Science and Technology, University of Texas at Austin, Austin, Texas.

The performance of organic thin-film transistors (TFTs) is frequently limited by contact resistance at the organic semiconductor and metal interface. Such contact resistance results in pronounced non-linear current-voltage (I-V) characteristics in the linear regime. We have recently fabricated bottom-contact pentacene TFTs with polyaniline (PANI) electrodes that function as effectively as TFTs with gold electrodes. Specifically, the saturation characteristics (hole mobility, on/off ratios, etc.) of PANI devices are comparable to those of Au devices. In the linear regime, however, PANI devices do not exhibit the typical non-linear “hooking” behavior that is characteristic of bottom-contact gold devices. We attribute this observation to induced contact resistance in the PANI devices. To quantify the contact resistance at the pentacene/gold and the pentacene/PANI interfaces, we have fabricated asymmetric pentacene TFTs with one PANI and one gold electrode. The asymmetric electrode configuration allows us to compare the two interfaces with the same pentacene channel. We have conducted surface potential measurements on these devices using Kelvin probe force microscopy (KPFM). KPFM simultaneously provides the surface topography and the surface potential distribution of pentacene TFTs during operation. Using this technique, we have been able to separate the potential drop at each interface. The contact resistance at these interfaces can then be quantified by normalizing the potential drop by the, the local, component. The asymmetric devices were tested in two configurations: PANI source/gold drain then PANI drain/gold source to characterize the nature of charge injection and drawing at each contact. Our results reveal a large potential drop at the gold/pentacene interface whether
M0.6 Fabrication of low-molecular weight molecule material films by using a cocktail spin coat technique. Takuya Kamibayashi, Hitoshi Wada, Takehiko Mori, Hideo Takeo and Ken Ishikawa; Organic and Polymeric Materials, Tokyo Institute of Technology, Tokyo, Japan.

Organic semiconductors have some advantages, such as flexibility, variety, and easiness of fabrication, over inorganic ones. For example, it means that organic thin films can be fabricated in lower temperature than inorganic ones can. Organic thin films are able to be fabricated by wet processes such as a spin coat and a drop cast technique. So, organic materials are promising candidates for future devices. Organic transistors and organic light emitting diodes. Usually, films of low-molecular weight molecules (LMWM) are fabricated by a vacuum evaporation technique as inorganic films are. The vacuum evaporation technique needs high vacuum condition, so this technique needs high cost and it is difficult to fabricate films with large area using this technique. While, the spin coat technique does not need high vacuum; moreover it is easy to fabricate films with large area. This technique has been generally used for polymer materials. Fabrication of LMWM films by using this technique is difficult, since the viscosity of LMWM solutions are too low for spin coating. If we can fabricate LMWM films by spin coating, fabrication process of organic devices would be easier and simpler. One organic material and a kind of solvent are usually used in the conventional spin coat technique. Uniform polymer films are fabricated by conventional spin coating. Recently, we developed the conventional spin coat technique into a new spin coat technique which is called a cocktail spin coat technique. Using this technique, we first prepare the solution which contains a few kinds of organic materials and solvents. Then we fabricate organic films from the solution. Using the cocktail spin coat technique, we can fabricate functional films as LMWM films and films having grated structure. In this work, we will demonstrate the fabrication of dibenzotetrafulvalene (DBTTF) films by using the cocktail spin coat technique. These films were composed of large crystals and large domains with 10-20 nm. We used poly (3-hexylthiophene) (P3HT) and DBTTF as source materials. First, we prepared two kinds of chloroform solutions (solution A, B); solution A, B were the P3HT solution (0.25 wt %) and DBTTF solution (0.5wt %), respectively. Using the cocktail of solution A and B, we fabricated films by spin coating (3000rpm/20sec). Obtained films were observed by AFM and XRD. I-V characteristics of films were measured by four-probe method. All experiments and analysis were done under air. The mixing ratio of the solution B being under 30%, conductivity of films were quite low. This low conductivity results from the nature of P3HT. High conductive films obtained in the mixing ratio of the solution from 30 to 90%. We could observe that DBTTF domains contacted with each other in AFM images of samples. Conductivity decreased as the mixing ratio exceeded 90%. In this case, films showed island morphology in AFM images.

M0.7 Fabrication of Organic Static Induction Transistors Using Colloidal Lithography. Takahi Hiroi1, Kiyoshi Fujimoto2, Masakazu Nakamura1,1, Electronic and Information Engineering, Chiba University, Chiba, Japan; 2Japan Chemical Innovation Institute, Chiba, Japan.

To improve the electrical characteristics of organic static induction transistors (SITs) [1], fabrication of nano-scale structures in the horizontal direction is strongly desired without introducing an electrical damage to functional organic materials. The size of the fine lateral structure must be in the same length scale as the thickness of an organic semiconductor corresponds to channel length of the vertical type transistors. We have therefore developed novel fabrication techniques for the organic SITs [2, 3] using ‘colloidal lithography’ which is developed in our lab. The basic procedure and features as follows: First, positively charged colloidal particles as a deposition mask were adsorbed on a glass surface via electrostatic self-assembly. The particle monolayer film with no aggregation could be formed by optimizing particle concentration. Second, a drain electrode, a bottom CuPC layer, and a Schottky gate electrode were deposited successively on the particle-adsorbed glass substrate. Third, the particles were removed using an adhesive tape. Thus, a large number of SITs were formed in one step. Then a top CuPC layer and a top source electrode were deposited onto the nano-porous layers. Details of the optimization of the particle adsorption process and device characteristics will be presented. This work was supported partly by NEDO/Silicon Technology Material Program ’Rizable Paper Project’ based on funds provided by METI and administered by JST, and by Grant-in-Aid for Scientific Research (No.15860014) from Ministry of Education, Culture, Sports, Science and Technology. [1] K. Kudo et al. Synth. Met. 111 - 112 (2000) 11. [2] N. Hirashima et al., Proc. Int. Symp. on Super-Functionality Organic Devices, IPAC Conference Series 6 (2005), in press. [3] Joseph M. C. et al. 2003 MRS Fall Meeting (Boston, USA), K10.37. [4] P. Haapar et al., Collids Surf. A 214 (2003) 23.

M0.8 Significant Controllability of Threshold Voltage (ΔV_T/VTH ≈ 0.85) of Pentacene Field-effect Transistors with Double-gate Structures. Shingo Ihb1, Tsuyoshi Sekitani1, Yusaku Kato1, Takayasu Sakurai2 and Takao Soneya1, Quantum-Phase Electronics Center, School of Engineering, The University of Tokyo, Tokyo, Japan; 2Center for Collaborative Research, The University of Tokyo, Tokyo, Japan.

We have unambiguously controlled threshold voltage of flexible pentacene field-effect transistors (FETs) with novel double gate structures, where the top- and bottom-gate electric fields can independently apply voltage biases to channel layers [1-3]. The threshold voltage (VTH) is shifted systematically by as much as -26 V when the voltage bias of the top-gate electrode (VTOP) is varied by +40 V. The value of the slope (ΔVTH/ΔVTOP) is equal to the ratio of areal capacitances of top and bottom gate dielectric layers. We have compared FET with top-gate electrodes that cover the entire channel layers as well as source and drain electrodes and an FET with top gate that covers only a part of channel layer. The results show that top-gate bias mainly affects the channel part rather than the contact part. A 60-nm-thick polyimide gate dielectric layer (5.4 nF/cm²) is formed on a 75-μm-thick polyimide film coated by a 50-nm-thick Au layer as gate. The channel layer is a 50-nm-thick pentacene. 50-nm-thick Au drain and source electrodes are evaporated through a mask layer. The channel length L and width W are 100 μm and 1 mm, respectively. The transistors are uniformly coated by a 60-nm-thick polyimide layer (4.1 nF/cm²). Finally, 50-nm-thick Au layer is deposited to form top-gate electrodes. In one of the devices, source-drain electrodes and channels are completely covered by a 300–1000 μm² top-gate electrode, while other wafers with narrowed width of top gate electrodes are also investigated. The device characteristics were measured in the ambient air. When the top-gate electrode is in the floating state, the DC characteristics in the saturation regime exhibit a VTH shift of about 60 V and a ON/OFF ratio of 10⁶. The characteristics were measured at VTOP of -60 V to +60 V, and characteristics in the linear regime showed systematic changes. The change in VTH is very small when VTOP is varied from -60 V to +20 V, but VTH decreases from -17 V to -43 V when VTOP is varied from +20 V to +60 V. The value of slope (ΔVTH/ΔVTOP) is 0.85, which is equal to the ratio of areal capacitances of polyimide and polyimide insulation layers4. Such a large slope becomes possible in organic transistors with careful optimization of structural parameters, although similar structures have been investigated recently both in silicon and organic transistors [1-4]. We also examined FET with identical structures except the size of top-gate electrode, which is 80 x 80 μm² square covering the entire channel area. There was no significant differences between those two FETs, indicating that top-gate bias mainly affects the channel part rather than the source-drain electrode part. This study is partially supported by IT Program, MEXT, MIPPT, and NEDO. [1]T. IJiri et al. et al. 2005 Jpn. J. Appl. Phys., B34 (2005); [2]R. Coehoorn, etal. 2005 Jpn. J. Appl. Phys., B34 (2005). [3]C. H. Gelinck, etal. SID, 3.1.1, (2004). [4]J.-P. Colinge, Silicon-on-insulator technology, Chap. 5. (Kluwer Academic Publishers)

M0.9 Investigation into the DOS of States within Organic Semiconductors. David Donaghy1, Naer Sediq1, Munira Rajj1, Sun Badriya2, Simon Higgins3 and William Eccleston1. 1Electronic Engineering, University of Liverpool, Liverpool, United Kingdom; 2Chemistry, University of Liverpool, Liverpool, United Kingdom.

It has been generally accepted that charge transport in organic dispersed semiconductors occurs via variable range hopping (VRH) multiple trapping among localized states. The density of states (DOS) in organic materials is commonly believed to be described by a Gaussian distribution of energy sites [1] but there has been a wide range of papers published where the density of states has been modelled as an exponential distribution [2-5]. The value of σ’s controls the width of the DOS while the Fermi energy level, EF, specifies the range of energy levels on the DOS curve that the majority of the carrier concentration, n(E), are situated in. The abstract continues to the trends in n(E) and also the error from substitut-ing a DOS with an exponential function. It should be remembered that the total current in a polymer device is primarily equal to the product of the carrier concentration, n(E) and the hopping rate. As the state of increase in the gradient of the DOS decreases with energy and as the rate of decrease in the gradient of the Fermi-dirac function is constant with energy the carrier concentration should reach a peak at some energy
level, Entmax. However, the latter is only correct if the increase of gradient of the DOS is greater than that of the Fermi-Dirac function, i.e., a stronger localization of the carrier concentration. This might be explained by the hygroscopic nature of PEDOT/PSS films. Actual values for Young's Modulus were in a range from 2 to 2.7 GPa and for the tensile strength in a range from 20 to about 44 MPa. Additional preliminary experiments showed a Poisson’s ratio of 0.36 for highly energy states above EF are responsible for the current conduction (since those below EF are all occupied and therefore do not take part in the hopping process) then only n(E) above EF is of any interest. Dependence of EF on n(E) is not a Gaussian distribution (EF \text{min} > \sigma^2/2kT). The point of inflexion for the DOS is equal to \sigma. For \sigma < kT and EF > \text{Max} the carriers reside at states above the point of inflexion. In this region the DOS is not exponential. The carrier concentration is plotted against EF for various values of \sigma. The carrier concentration is exponentially proportional to EF for below \text{EF} min. Above this value the carrier concentration becomes proportional to EF and after \text{EF} max the concentration saturates before decreasing. The explanation for charge transport within a TFT polymer device should become clearer when the concentration is multiplied by the hopping rate which is the next part of this study. Ref: [1] R. Schmechel, Phys. Rev. B, 66, 235206 [2] D. Monroe, Phys. Rev. Lett. 14 Jan 1985, p416. [3] S. Boranowski, et al, J. Non-Cryst. Solids, 198-200, 222. [4] M. Visschenberg, M. Matters, Phys. Rev B, Vol. 57, No. 20, p57. [5] S. Boranowski et al, J. Non-Cryst. Solids, 190, p 281.


Metal-organic ink systems targeted for low-temperature, atmosphere-pressure deposition of metal chalcogenide electronic materials are described. The approach was designed to allow direct write of active electronic components (i.e., diodes, transistors) for application as field effect transistors and x-ray detectors. The inks were comprised of metal chalcogenocarboxylates in non-aqueous solvents where the metal-organic was envisioned to transform at low-temperature (i.e., < 350 C) into a targeted chalcogenide phase with concomitant conversion of volatile components. The synthetic route to five cadmium selenocarboxylates, four cadmium tellurocarboxylates and four zinc tellurocarboxylates will be described. Thermogravimetric analysis of these complexes indicates appreciable vapor pressure at ambient pressure, however, a complete transformation of the metal-organic complexes into volatile bis(acyl)chalcogenide plus the targeted metal chalcogenide was not observed for all complexes. While one cadmium selenocarboxylate complex exhibited the anticipated mass loss, thin films of CdSe produced from this precursor did not exhibit a field effect either as a consequence of the use of non-optimum source and drain electrodes (i.e., Au). More recent results that utilize this chemistry will be presented as available.

M9.11 Mechanical Properties of Thin Films of Poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate)(PEDOT/PSS). Udo Lang and Juerg Dual; Center of Mechanics, ETH Zurich, Zurich, Switzerland.

In recent years there have been vast efforts to establish organic electronic devices. A key property of such devices is the possibility to fabricate them on flexible substrates. As the layers are mechanically stressed during bending, the knowledge of mechanical properties of the materials used will become very important. At the Center of Mechanics at ETH Zuerich a tensile test setup had already been established and applied to experiments on silicon [1] and on thin copper foils [2]. Motivated on a movable setup to which the specimen is glued. The other end of the specimen is glued to a weight. This weight stands on a balance and is being pulled on vertically during testing. By measuring the reduction of weight the force acting on the specimen can be calculated with a resolution of 0.1 N. The dimensions of the specimens are measured using a UBM laser profilometer with a resolution of up to 100nm. The strain is determined by a least-square-template matching algorithm with a resolution of 10^-4 [1]. BAYTRON P (PEDOT/PSS) was chosen for the experiments due to its widespread applications [3, 4, 5]. The fabrication of the specimens started off with pipetting 10ml of Baytron on a 3” polystyrol (PS) petri dish and then letting it air dry. After-24 hours the metal-organic layers obtained. It could then be easily peeled off the substrate. Afterwards 150mm thick gold lines were evaporated on as markers for strain measurement. Finally the specimens were laser cut. The tensile tests showed two important results: PEDOT/PSS is not stable when exposed to UV radiation for a longer period of time and it exhibits a strong dependence of its mechanical properties on relative humidity. The higher the relative humidity was, the lower was Young’s modulus and tensile strength. This might be explained by the hygroscopic nature of PEDOT/PSS films. Actual values for Young’s Modulus were in a range from 2 to 2.7 GPa and for the tensile strength in a range from 20 to about 44 MPa. Additional preliminary experiments showed a Poisson’s ratio of 0.36 for highly energy states above EF are responsible for the current conduction (since those below EF are all occupied and therefore do not take part in the hopping process) then only n(E) above EF is of any interest. Dependence of EF on n(E) is not a Gaussian distribution (EF min > \sigma^2/2kT). The point of inflexion for the DOS is equal to \sigma. For \sigma < kT and EF > \text{Max} the carriers reside at states above the point of inflexion. In this region the DOS is not exponential. The carrier concentration is plotted against EF for various values of \sigma. The carrier concentration is exponentially proportional to EF for below \text{EF} min. Above this value the carrier concentration becomes proportional to EF and after \text{EF} max the concentration saturates before decreasing. The explanation for charge transport within a TFT polymer device should become clearer when the concentration is multiplied by the hopping rate which is the next part of this study. We are investigating the variations in microstructure and physical properties of a family of functionalized pentacene of interest for making organic electronic devices such as thin film transistors. These pentacenes have been modified with alkyl acrylate or alkyl silyle groups with systematic variations in the alkyl spacer length. This modification disrupts the herringbone packing seen in neat pentacene, promoting face-to-face arrangements between the acene rings and providing for solubility in a variety of convenient solvents. Thin films can be readily formed by solution casting from toluene and other organic solvents. We have investigated the structure and properties of the functionalized pentacenes using high stage optical microscopy, differential scanning calorimetry, transmission electron microscopy, and electron diffraction. The results show that these materials exhibit their thermal behavior and macroscopic properties as the chemistry of the side-group substituent changes.


The design and synthesis of new oligophiophenes functionalized with a variety of phenacyl, alkylcarbonyl, and perfluorokylcarbonyl is presented. These semiconducting materials exhibit low-lying LUMOS which allows efficient electron injection/transport. Field-effect transistors fabricated by conventional methods exhibit on/off mobilities as high as \text{2 cm}^2\text{ V}^{-1}\text{ s}^{-1} \text{ for vapor-deposited film and 0.25 cm}^2\text{ V}^{-1}\text{ s}^{-1} \text{ for solution cast films with current modulation of 10}^5. Furthermore, these materials perform optimally when integrated with a new crosslinked polymeric dielectric family developed by our group. These dielectric layers are fabricated via spin-coating of a polymer-crosslinker mixture, exhibit very low leakage currents (J < 10^{-9} \text{ A/cm}^2), very high breakdown fields (> 3 MV/cm), and are fully compatible with both electron- and hole transporting materials allowing fabrication of complementary circuits.


The tuning and controlling the architectures of macromolecules is an important goal to determine materials structure-property relationship. Various polymers have been incorporated into metal-organic frameworks with supramolecular linkers giving rise to a metallo-supramolecular materials[1-3] that can be selectively complexed with a wide range of transition metal precursor complexes. This approach allows the construction of smart materials with tunable optical and electrical properties. Moreover, the electrochemical and photochemical
properties of the utilized complexes can be engineered by choosing the appropriate ligands, metal ions and counterions. Iridium(III) complexes are known for potential applications mainly in device and display technology but they may find also use in molecular electronics as well as in sensing technology.[4,5] Desired are phosphorescent emitters that favorably have high quantum yields and show lifetimes in the region of several microseconds. Furthermore, they need to be easy to process and do not aggregate. The chosen deposition methods as well as the conditions have also a strong influence on the film morphology and the obtained device performance. It was found that spincoated films showed different morphologies compared to inkjet printed films.[6] To analyze these differences atomic force microscopy (AFM) and conductive tip atomic force microscopy (c-AFM) was found to be a strong and complementary analysis tool. AFM is useful to obtain morphological and electrical information on a nanometer scale giving also rise on information regarding the structure-property relationship. Titanium nitride (TiN) coated tips worked best to achieve the desired information about the electrical performance (e.g. UV characteristics) and the electrical property of the respective metall-sulphonamolocule film. This presentation highlights in detail the role of the deposition method for charged iridium(III) complexes. Optical features of the materials are briefly summarised. The processing properties using spincoating and inkjet printing are described and evaluated. The different morphology of the obtained films is shown comparing the two wet-processing methodologies (spincoating and inkjet printing) with respect to the resulting film quality and electrical conductivity using c-AFM.[1] E. Holder, V. Marin, M.A.R. Meier, U.S. Schubert, J. Polym. Sci., Part A: Polym. Chem. 2004, 42, 2785.[2] B.G. Lohmeier, U.S. Schubert, J. Polym. Sci. Part A: Polym. Chem. 2003, 41, 1413.[3] E. Holder, V. Marin, D. Kozodaev, M.A.R. Meier, B.G.G. Lohmeier, U.S. Schubert, Macromol. Chem. Phys. 2005, 206, 989.[4] E. Holder, U.S. Schubert, V. Mater. 2005, 17, 1109.[5] E. Tekin, E. Holder, V. Marin, B.J.-de Gans, U.S. Schubert Macromol. Rapid Commun. 2005, 26, 293.

M9.15  High-Speed GaAs Transistors and Circuits on Plastics. Yugen Sun and John A. Rogers; Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois. This presentation introduces a novel process for fabricating bendable GaAs transistors and circuits with high speed response on low-cost plastic substrates. In a typical process, arrays of micro/nanowires of GaAs, one of the most important semiconductor materials with high carrier mobility, have been fabricated through a ‘top-down’ process including both traditional photolithography and wet chemical etching. The aligned GaAs wires with organization similar to the layout defined by lithography can be transferred to unconventional flexible substrates (e.g., plastics, paper, etc.) using a ‘dry transfer printing’ technique, which requires elastomeric PDMS stamps as transfer elements. Then, thin films deposited on plastics can serve as unique channel materials for building metal-semiconductor field-effect transistors (MESFETs), which have the essentially same performance as wafer-based MESFETs. For example, MESFETs with channel length of 50 microns and channel width of 2 microns exhibit high-speed response as high as 1.55 GHz. A series of typical circuits elements are also demonstrated by integrating GaAs MESFETs with specific parameters. Mechanical characterization of the resultant devices and circuits on plastic substrates reveals that they can withstand surface strain of ~1% without substantial degradation of performance. The results indicate promise for the applications of the devices and circuits in consumer and military electronics systems.

M9.16  Ladder Oligo(para-aniline) for Electronic Applications: Design, Synthesis, and Characterization. Salem Wakin, Nicolas Drolet, and Marco E.G. Caballero; Department of Chemistry, Laval University, Quebec city, Quebec, Canada;*Institute for Microstructural Sciences, National Research Council of Canada, Ottawa, Ontario, Canada. Organic field-effect transistors have received a great attention over the last 10 years because of their potential applications in low-cost fabrication devices. However, novel electroactive molecules are still required to solve remaining problems which are stability and processability together with good charge transport properties. One interesting approach is the development of ladder-type π-conjugated oligomers which show coplanar structure and favorable packing interactions with improved stability and processability. Starting from this point, we have developed a new class of semiconducting organic materials from phenyl-capped ladder oligo-p-aniline) derivatives. The synthesis of these soluble ladder oligo-p-aniline will be presented and the relationship between the chemical structure of these oligomers and their optical and electrochemical properties, as well as their performances as active material in a field-effect transistor configuration will be also discussed.

M9.17  Studies of Printing and Electric Properties of Conductive patterns Printed with Ag nanoparticles. Sung Il Oh*, Kwi Jong Lee, Tae Hoon Kim and Sung Nam Cho; Engineering Team, Samsung Electro-Mechanics, Suwon, Gyunggi-Do, South Korea;*Central R&D Center, Samsung Electro-Mechanics, Suwon, Gyunggi-Do, South Korea. Recently, in response to the request of low cost manufacturing process for electronic industry, printing technologies have been arousing many interests. Printing technologies, especially direct writing, when it is utilized to make certain patterns, conductive paths, complicated electronics etc., can eliminate some disadvantages of conventional technologies. Printing technologies, however to be applied to electronic industry featured as downsizing and high performance, should satisfy high printing quality and good electric properties. In this study, our group studied the features of printing quality and electric conductivity of conductive patterns printed with Ag nanoparticles. To proceed this study, we synthesized Ag nanoparticles with various particle sizes and formulated pastes dispersed in different kinds of solvents for printing on polyamide substrate. We could find out that dispersion media and sintering process affected printing quality and electric conductivity. By controlling the type of dispersion media, solid contents and sintering temperature, we could obtain a fine conductive line width of 100 μm as well as a high conductivity of 9.0×10-6 cm.

M9.18  Facile Synthesis of Silver Nanoparticles by Thermal Decomposition Method Useful for Metal Nano Ink. Youngil Lee, In Keun Shin, Kwi Jong Lee and Jae Woong Jang; R&D Center, Samsung Electro-Mechanics, Suwon, Gyunggi-Do, South Korea. Ag powders having a very fine and uniformly distributed sizes are desirable in many fields of industrial applications. One such example would be as the major constituent of conductive inks and pastes for various electronic components. In order to synthesize Ag nanoparticles with narrow particle size distribution was simply synthesized by thermal decomposition of various Ag-alkanoate(laurate, myristate, oleate)complex, which was prepared by a reaction with AgNO3 and sodium alkanoate in water solution. The resulting alkanoate stabilized Ag nanoparticles were produced by controlling the temperature and time. Transmission electron microscopic images of the particles showed a 2-dimensional assembly of the particles with a diameter 3~8nm according to a kind of alkanoate. Also Ag thin film spin cast from metal nano ink prepared by alkanoate stabilized Ag nano particles showed good electrical conductivity.

M9.19  Low Temperature Fabrication of Al2O3 on Cu for Embedded Capacitors. Jun Hee Bae, SooHyun Lyoo, Sang Tae Lim, Hyun ju Jin, Hwang-dong Kang and Yu-geo Chung; Central R&D Institute, Samsung Electro-Mechanics, Suwon, Gyunggi-Do, South Korea. Today’s electronic devices require increasing functionality and speed to respond to consumer demand. Consequently, we need more space and more passive along with powerful actives. The conventional surface mounting technique therefore faces the circumstance that the number of passives limits the size of the printed circuit board (PCB) and thus of the devices. One measure to handle this drawback is using the spaces below the surface to embed passives into the PCB. However, the process temperature limited up to 250°C due to the use of polymeric basis is still the main obstacle in the build-up of embedded passives. We prepared Al2O3 thin film capacitors using atomic layer deposition (ALD) at temperatures below 200°C. We used copper clad laminate (CCL) as a substrate, the material which serves as a substrate in the real fabrication process. The thickness of Al2O3 films was varied 50 to 100 nm. We estimated the film thickness from the TEM and showed the electrical properties of the dielectric films in dependence on both film and electrode structures. We measured the capacitance density of nearly 1 nF/mm2. Al2O3 films show an excellent leakage behavior and will be one of the best candidates for the embedded capacitor application. *Corresponding author: hyungdong.kang@samsung.com

M9.20  Organic field effect transistors using metal complexes. Tomohiro Taguchi, Hiroshi Wada, Takuya Kambayashi, Bunpei Noda, Masanao Goto, Takehiko Mori, Ken Ishikawa and Hideo Takezoe; Organic and Polymeric Materials, Tokyo Institute of Technology, Tokyo, Japan. Recently organic field-effect transistors (OFETs) have attracted a great deal of attention [1]. In particular, development of good N-type
materials is imperative because both P and N-type semiconductors are necessary to construct low power complementary circuits. [2] However, N-type organic semiconductors which work in air are very few. In this respect, we have explored OFETs using metal complexes because a wide range of reduction potentials is known in metal complexes, and stable anionic compounds are easily accessible. Bis(4-methyl-2-phenylendiaminobenzaldehyde) or triphenylamine or bis(4-hexylbenzyl) nickel [Ni(ttb),][4] were investigated. The oxidation potential of [Ni(mpa),] to a monocation (1+) was observed at 0.00 V vs Ag/AgCl. Whereas the reduction potential of [Ni(ttb),] to a monoanion (1-) was reported to be +0.12 V vs NHE. The former value is lower than the location of the HOMO level to be 4.44 eV, and the latter value indicates that the LUMO level of [Ni(ttb)] is 4.32 eV [6]. Therefore, [Ni(mpa),] is expected to work as a P-type semiconductor, while [Ni(ttb),] works as an N-type semiconductor. Bottom contact-type OFETs were fabricated on n-type Si substrates with thermally grown SiO2. Au (work function: 5.1eV) was used as source and drain electrodes for the [Ni(mpa),] transistor, whereas Al (work function: 4.1 eV) was used for the [Ni(ttb),] transistor. Organic semiconductors were thermally evaporated on the substrates. Transistor characteristics were measured by Keithley 4200-SCS semiconductor parameter analyzer. After thermal evaporation of the metal complexes, the substrates were once taken out from the evaporation chamber and transferred to a measurement chamber. Then field effect mobilities in air and under vacuum were compared. [Ni(mpa),] showed P-type transistor characteristics with 10^4 cm^2/Vs in air, and 10^6 cm^2/Vs (on/off ratio, 10^3) under the vacuum of 5.6 x 10^-5 Torr. By contrast, [Ni(ttb),] exhibited N-type characteristics with 10^-6 cm^2/Vs even in air, and the mobility increased to 10^-5 cm^2/Vs with the on/off ratio of 10^5 under vacuum. The present work demonstrates that some metal complexes, which are easily reduced to form stable monomers, are good candidates of N-type organic semiconductors used in OFETs. [1] a) B. C. Crone et al., Appl. Phys. Lett. 78, 2229 (2001). b) C. D. Dimitrakopoulos et al., Adv. Mater. 14, 99 (2002). c) A. Kraft, ChemPhysChem 2, 163 (2001). [2] B. C. Crone et al., Technical Digest of International Electron Devices Meeting 115 (1999) [3] S. H. Kim et al., Dyes and Pigments, 88, 381 (1987). [4] G. N. Shrauzer et al., J. Am. Chem. Soc. 87, 1483 (1965). [5] J. A. McCleverty, Prog. Inorg. Chem. 10, 49 (1968). [6] Hong Meng et al., Chem. Mater. 15, 1778 (2003).

SESSION M10: Soft Lithography and PDMs Applications
Chair: John A. Rogers
Thursday Morning, December 1, 2005
Room 306 (Hynes)

8:00 AM *M10.1
Optics and Microfluidics. George Whitesides1, Dmitri Vezenov2, Brian Mayers3, Richard Conroy4, Daniel Wolfe5, Mara Prentiss6, Piotr Garstecki7 and Steven Tang1; 1Department of Chemistry and Chemical Biology, Harvard University, Cambridge, Massachusetts; 2Department of Physics, Harvard University, Cambridge, Massachusetts.

The combination of “light” and “microsystems” provides many opportunities for new types of devices and capabilities. This talk will focus on three subjects in fluidic optical devices: i) liquid core/liquid cladding optical systems; ii) spectrometers for microfluidics; and iii) optical diffraction from flowing layers of bubbles.

8:30 AM *M10.2

The emergence of new forms and applications of electronics presents both opportunities and challenges for developing new approaches to materials patterning. This talk will explore these issues in the context of recent advances made in soft-lithography and materials assembly, methods that allow the removal of design rules for devices that are intrinsic to patterning protocols based on photolithography. New forms of materials for applications in electronics, processes for integrating them in complex functional arrays, and the development of a new model for fabrication based on both bottom-up and top-down approaches to large area patterning will be discussed.

9:00 AM *M10.3
Rate-controlled Transfer Printing of Solid Objects. Matthew Meit1 and John A. Rogers1,2; 1Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois; 2Department of Chemistry, University of Illinois at Urbana-Champaign, Urbana, Illinois.

In the context of printing materials with a rubber stamp, specific chemical interactions or nonspecific forces usually govern the transfer of inks. When the ink takes on solid character, the rate-dependent adhesive nature of the rubber stamp induces a solid-like stamp as another object that can facilitate or impede transfer. This talk will demonstrate that the stamping rate, or the speed at which a stamp separates from a substrate, can control the stamp’s ability to grab and release small solid objects. This phenomenon can be exploited to transfer arrays of micro objects between substrates without surface treatments or conformable glues and generate microstructured hybrid materials systems for optoelectronics, photonics, non-planar applications, and more. Examples of materials printed by this new rate-dependent stamping strategy will include silicon, III-V materials, silica microspheres, mica, graphite, and biological objects.

9:15 AM *M10.4
Patterned Flat Stamps and Catalytically Active Stamps for Improved Microcontact Printing. Juriaan Husken, Supramolecular Chemistry & Technology, University of Twente, MESA+, Enschede, Netherlands; 2Strategic Research Orientation "Nanofabrication", University of Twente, MESA+, Enschede, Netherlands.

Microcontact printing (mCP) is a versatile technique for the creation of patterned surfaces [1]. It commonly provides flexible, elastomeric relief stamps to transfer an ink (e.g. a thiol) onto a surface (e.g. a gold-coated substrate) thus forming a patterned self-assembled monolayer (SAM). Patterns of different thiols can be programmed by using self-assembly of a second thiol from solution, or the printed patterns can be used directly as etch resists allowing the structuring of the underlying substrate itself. Resolution of mCP is typically around 200 nm, diffusion during the printing stage and deformation of the elastomeric stamp features being the main limiting factors. Diffusion can be limited when heavy inks are used, such as high-molecular-weight thioethers, proteins, or nanoparticles. Stamp deformation can be controlled to some extent by using stiff mCP materials and hybrid stamps. The present study will show radical solutions to both problems. The first is the complete elimination of diffusion as an underlying principle of mCP. We have shown recently that nanoparticles can be coated with catalytically active acid groups to hydrolyze protecting silyl ether groups on a homogenous SAM when transferred onto this SAM by mCP [2]. This has led to patterned SAMs with an edge resolution below 100 nm. Based on this catalytic principle, we will show that oxidized [3] and catalyst-functionalized mCP stamps can catalytically cleave the same silyl ether groups of these SAMs in an ink-free mCP process, thus removing all possible ink diffusion. The stamp deformation problem is eliminated by the use of patterned flat stamps [4]. It is shown that patterned oxidation of flat mCP, followed by functionalization with silanes can lead to chemicochemical barriers for ink diffusion, thus on the stamp surface, rather than the commonly applied void barriers present in relief stamps. This allows high resolution mCP and the use of inks that cannot be applied in regular mCP. [1] Xia, Y. N.; Whitesides, G. M. Angew. Chem. Int. Ed. 1998, 37, 551-575; [2] Pokora, B.; Bernard, A.; Bietsch, A.; Delamarche, E.; Gierse, G.; Juncer, D.; Kind, H.; Renault, J.-P.; Rothuizen, H.; Schmid, H.; Schmidt-Winkel, P.; Stutz, R.; Wolf, H. IBM J. Res. Dev. 2001, 45, 697-719; [3] Li, X.-M.; Parashiv, V.; Husken, J.; Reinhoudt, D. N. Angew. Chem. Int. Ed. 2003, 12, 4279-4284. [4] X. M.; Pester, M.; Husken, J.; Reinhoudt, D. N. Nano Lett. 2003, 3, 1449-1453. [4] Sharpe, R. B. A.; Burdiski, D.; Husken, J.; Zandvliet, H. J. W.; Reinhoudt, D. N.; Poelsema, B. J. Am. Chem. Soc. 2005, 127, in press.

9:30 AM *M10.5
Charge Transport at Organic-Organic Heterointerfaces. Henning Serringhaus, Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom.

Polymer transistors offer new opportunities for the controlled manufacturing of active electronic circuits by a combination of solution processing and direct writing. We will review our understanding of their device physics with a particular emphasis on understanding the electronic structure of the interface between the organic semiconductor and the gate dielectric. Recent advances towards realizing ambipolar organic transistors through control of interface electronic structure will be presented. This has enabled realization of ambipolar light-emitting field-effect transistors, in which the position of the recombination zone can be moved to any position along the transistor channel by changing the applied gate voltage and source-drain voltages. We will also review recent progress towards manufacturing of organic transistor circuits by high-resolution printing techniques.
10:30 AM M10.6
Silicone for Advanced Lithography, Anne Shim¹, John Rogers²
and Ralph Nuzzo¹; ¹Dow Corning Corporation, Midland, Michigan;
²University of Illinois, Urbana-Champaign, Illinois.

Silicones are commonly used for a group of advanced lithography
techniques termed soft lithography and nanoimprint lithography. Soft
lithography can again be subdivided into techniques such as
micromolding, microcontact printing and replica molding. The silicone
material used in the process is enabling for all of these soft
lithographic techniques. Dow Corning desires to participate in the
emerging soft lithographic industry by supplying value added
materials to enable the process and the final device. To that end, Dow
Corning has established an Advanced Lithography project. This
presentation will discuss utilization of silicones to meet the emerging
needs of the advanced lithographic industry.

11:00 AM M10.7
The origin of large elastic stretchability of thin gold films on
elastomeric substrates. Stephanie Perichon Lacour¹, Donald
Chan¹, Sigurd Wagner¹, Teng Li² and Zhigang Suo²; ¹Electrical
Engineering, Princeton University, Princeton, New Jersey; ²Division
of Engineering and Applied Sciences, Harvard University, Cambridge,
Massachusetts.

Thin gold films patterned on soft elastomeric substrates produce
highly stretchable conductors. These can be used as interconnects in
elastic electronic circuits. Such circuits typically will be stretched and
relaxed reversibly. We studied the microstructure and electrical
resistance of 25nm thick gold films on elastomeric silicone substrates
during cyclic mechanical loading. Our films on silicone consists of a
contiguous gold network that contains micron scale cracks. The metal
network is well bonded to the silicone substrate. The cracks render
the gold film particularly stretchable and make the electrical
resistance change reversibly during cyclic mechanical loading. We
observed the morphology of the gold conductors prior to, during, and
after mechanical stretching using scanning electron microscopy
(SEM). 2cm long samples were elongated in a mechno-electrical
tensile test apparatus to a strain $\varepsilon_{\text{max}} = 32\%$ with strain increments
varying from 1, 4, 8, 16 to 32%. All samples remained electrically
conducting. The electrical resistance at $\varepsilon_{\text{max}}$ increases when the
strain is raised in large strain increments. A conductor was cycled 100
times to $\varepsilon_{\text{max}} = 32\%$ in strain increments of 8%. The variation in
electrical resistance correlated with the mechanical cycles. The
minimum and maximum values of the electrical resistance, at 0% and
32% strain respectively, remained essentially constant over the 100
cycles. During the first stretching cycle, several neighboring
micro-cracks merged to form $\sim3-10\mu m$ long scratches running
perpendicularly to the stretching direction. In situ SEM during the
second cycle and after 100 cycles revealed almost no further
development of the gold microstructure. The metallic film appears to
behave similarly to an accordion upon stretching and relaxation, and
deforms only elastically. Most of the elongation is then accommodated
by the out-of-plane deflection and opening of the micro-cracks. Our
observations suggest that highly stretchable electrical conductors for
elastic electronic surfaces can be designed of a variety of metals.

11:15 AM M10.8
Design Aspects of Multi-user 3D Displays using Deformable
Lenticulars. Mostafa El-Asry and Henry Daniel Young; Dept. of
Mech. and Mat. Eng., Wright State University, Dayton, Ohio.

A new optical technique to accurately steer the light beams to
demonstrate a virtual 3D picture for multi-users is presented. This
technique utilizes a deformable lenticular, fabricated from transparent
silicone elastomer-polydimethylsiloxane (PDMS), placed directly on
the LCD display. Different designs were explored where the elastomer
is deformed in a curved manner. The curved surface steers the beam
in different directions depending on the radius of the curvature and
the position of the light beam. Stress induced birefringence, time
response, mechanical properties and the effect of fatigue on the optical
properties for various compositions of the PDMS lenticulars are
investigated. This novel approach opens up the possibility of designing
and manufacturing of new type of 3D lenticular based displays.