Flat Panel Displays Topical Conference
Room 604 - Session FP+VT-MoM

Field Emission Displays and Vacuum Packaging Issues

Moderator: W. Weed, Sandia National Laboratories

8:20am **FP+VT-MoM1 A New Field Emission Device with Improved Vacuum Features**, ***V.P. Mammana***, Instituto de Física - Universidade de São Paulo, Brazil; *F.T. Degasperi,* Faculdade de Tecnologia de São Paulo - FATEC/SP, Brazil; *O.R. Monteiro,* Lawrence Berkeley Laboratory; *J.H. Vuolo, M.C. Salvadori,* Instituto de Física - Universidade de São Paulo, Brazil; *I.G. Brown,* Lawrence Berkeley Laboratory

We introduce in this article a novel geometry that can be used in the manufacturing of field emission displays that combines superior vacuum conductance and field enhancement factors. A theoretical model is developed for the calculation of the upper limit of the electrostatic field at the emitting regions, and these values are compared to those calculated for the actual geometry. The vacuum conductance of the proposed geometry is also calculated, and we show that conductances up to an order of magnitude higher than other schemes are readily achievable.

8:40am **FP+VT-MoM2 Fabrication of a Well-Type Field Emission Device with a Tungsten Doped Zinc Oxide Thin Film Phosphor**, ***V. Bhatia***, *J.B. Sobti, L.D. Karpov, M.H. Weichold,* Texas A&M University

Interest in the area of the field emission displays (FEDs) exists because of combination of the positive features of a cathode ray tube with flat panel display technologies. High resolution at low cost, power efficiency at low voltage operations, wide viewing angles, and operation under variable temperatures are some of the important features of an FED. This paper reports the fabrication of a monochromatic display of blue light from a lateral edge well emitter. A high-resolution display has been fabricated using a blue phosphor developed at TAMU@footnote 1@ in conjunction with a well type edge field emission device designed by Karpov et al.@footnote 2@ The FED has been formed by constructing arrays of wells, having sides of a dielectric material above a matrix of anode lines. The anode lines lie underneath the phosphor. In the diode design of the device, cathode lines are fabricated by depositing metal-carbon-metal layers, atop the well sides, hanging slightly over the well edges. The FED design reported here provides an extra measure of brightness to the display by reflecting the light from anode lines out of well towards the viewer. Since the device eliminates the fabrication of microtips, the display involves simpler fabrication steps, more ruggedness, and stability than conventional FEDs. The phosphor being used in this display, has been fabricated by co-depositing zinc oxide and tungsten (ZnO:W). This phosphor has been reported to emit blue light at 490 nm when excited at 300 V.@footnote 3@ This paper presents ongoing research in integrating the ZnO:W phosphor in the well type edge field emission display. The fabrication steps involved in making the display device are presented as are emission properties and current-voltage characteristics to determine the performance of the display. @FootnoteText@ @footnote 1@Technology Disclosure to TAMU Technical Licensing Office (1993). @footnote 2@L. D. Kapov et al. 7th Int'l Vacuum Microelectronics Conf., France 1994. @footnote 3@J. B. Sobti et al. MRS meeting, Spring 1998.

9:00am **FP+VT-MoM3 Effects of Residual Gas Exposures on the Emission Characteristics of Field Emission Arrays**, ***R.M. Wallace***, *B.E. Gnade,* University of North Texas; *B.R. Chalamala,* Motorola Flat Panel Display Division **INVITED**

Field emitter arrays have been introduced as a potential component for flat panel display technologies. A key issue for reliable performance includes the consideration of the device vacuum ambient in the course of packaging the display. In this paper, we review the effects of residual gas species on the emission characteristics of field emitter arrays under carefully controlled UHV conditions. We also examine recent work in the community on controlling the tip morphology, the tip surface chemistry, and the sources of residual gas species in displays.

9:40am **FP+VT-MoM5 Pressure Field Detailed Calculations for a New Field Emission Device with Improved Vacuum Features@footnote 1@**, ***F.T. Degasperi***, Faculdade de Tecnologia de São Paulo - FATEC/SP - Brazil; *V.P. Mammana,* Instituto de Física da Universidade de São Paulo, Brazil

The vacuum characteristics are an important consideration for field emission devices, mainly because of the high area/volume ratio presented in these devices. Dessorption associated with relatively small conductances can degrade the device performance over its lifetime, if small distances between the cathode and the anode are set. The proposal of a novel geometry for these devices@footnote 1@ seeks superior vacuum conductance, while maintaining a high electric field enhancement factor. It is of great importance to determine the pressure distribution along the emission chamber of the proposed device, since the emission performance is strongly dependent on this pressure. The usual vacuum technology approach considers a vacuum system made up of discrete elements. This approach is very useful, but leads only to the knowledge of the average pressure, and not to the detailed pressure distribution. In this article we calculate the pressure distribution considering the degaseification effect from several surfaces of the device, which allows us to predict its vacuum behaviour in a more realistic situation. @FootnoteText@ @footnote 1@ see "A new field emission device with improved vacuum features".

10:00am **FP+VT-MoM6 Cathodoluminescent (CL) Degradation Mechanism for ZnS-Based Phosphors and the Impact on Field Emission Displays (FEDs)**, ***B.L. Abrams***, *W. Roos,* University of Florida; *H.C. Swart,* University of the Orange Free State; *P.H. Holloway,* University of Florida

The surfaces of ZnS powder and thin film phosphors have been subjected to electron beam bombardment.Simultaneous acquisition of CL brightness data and Auger Electron Spectroscopy(AES)data have revealed a correlation between surface chemical reactions and CL degradation.The data were collected in a stainless steel UHV chamber.In the presence of a 2kV primary electron beam in 1e-6 Torr of H2O,the amounts of C and S on the surface decreased while the O concentration increased.XPS data showed that ZnO formed on both the samples.This change in surface chemistry coincided with a decrease in CL brightness.Our model of electron beam stimulated surface chemical reactions(ESSCR)for this degradation process postulates that the primary electrons dissociate physisorbed molecules to reactive atomic species. These atomic species remove surface S and C as volatile SOx and H2S species allowing formation of a non-luminescent ZnO layer in 1e-6 Torr water.However,in a vacuum of 1e-6 Torr dominated by hydrogen and with a low water content, there was no decline in S,no rise in O,but the CL still degraded.These effects are still attributed to ESSCR due to hydrogen assisted by thermal effects.Hydrogen is postulated to dissociate under the electron beam and remove S as H2S while Zn volatilizes due to a high vapor pressure and elevated temperatures from electron beam heating.The desorption of various ions or molecules from the surface of the phosphor caused by surface chemical reactions contaminate the vacuum inside the display tube and create a reactive environment.These reactive atoms or molecules may adsorb,react and consequently form an absorbed or coated layer(sulfide or oxide)on the field emitter tip on the cathode side of the FED.It is thus suggested that the ESSCR mechanism is important to degradation both of the phosphor on the anode and the field emitter tips on the cathode.This work was supported by Darpa Grant MDA 972-93-1-003 through the Phosphor Technology Center of Excellence.

10:20am **FP+VT-MoM7 A Novel Electron Emission Flat Panel Display Using Cesiated Amorphous Diamond Planar Emitter Structure**, ***S. Kim***, *M.H. Sohn, Y.S. Park, N.W. Paik, B. Lee,* SKION Corporation; *Y.H. Lee,* Sung-Kyun-Kwan University, S.Korea, Korea; *D.H. Lee, Y.J. Sung,* Sung-Kyun-Kwan University, S.Korea; *G.Y. Yeom,* Sung-Kyun-Kwan University, S.Korea, Korea

Oxidized cesiated amorphous diamond films have been developed for electron emitters. The work function of the surface is as low as 1.05 eV. The work function, chemical composition and structure are found to be stable even after annealing at temperatures up to 700 degree C. A very low turn-on field of 5-7 V/µmm is obtained by a planar geometry field emission measurement. A unique Pierce-type planar electron extraction geometry has been developed for flat panel display applications. Unlike field emission from a sharp point, the structure produces a long focal length beam of the order of few centimeters. In this paper, the fabrication procedure of the emitter structure and its emission properties will be presented.

10:40am **FP+VT-MoM8 Field Emission Properties of Conformal and Non-Conformal Diamond Film Coatings on Si Microtip Electron Emitters**, *M.Q. Ding,* Beijing Vacuum Electronics Research Institute, China; ***A.R. Krauss***, *O. Auciello, D.M. Gruen, Y. Huang,* Argonne National Laboratory; *V.V. Zhirnov,* Semiconductor Research Corp.; *E.I. Givargizov, A. Stepanov,* Institute of Crystallography, Russia

Non-conformal and conformal nanocrystalline diamond films were deposited on single needle-shaped Si tip emitters, using hot filament chemical vapor deposition (HFCVD) and microwave plasma-enhanced chemical vapor deposition (MPECVD), respectively. The HFCVD diamond was deposited in the form of large single crystal grains at the end of the

microtips, whereas the nanocrystalline diamond films were uniformly thick conformal coatings. The threshold voltages for cold cathode electron emission were measured for Si microtips as a function of both the thickness of the diamond coating and the radius of the Si tips. The threshold voltages for the single crystal HFCVD coatings were found to vary with both the tip radius and diamond film thickness. For the nanocrystalline films, the threshold fields were found to be significantly lower than the uncoated tips, and nearly independent of both Si tip radius and film thickness. In this case, the behavior is consistent with field emission that is determined largely by local electric field enhancement associated with intrinsic film properties. A model is presented in which the field enhancement occurs at sp2-bonded grain boundaries. Work supported by the U.S. Department of Energy, BES-Materials Sciences, under Contract W-31-109-ENG-38, and ER-LTR CRADA No. C9501501 with SI Diamond Technology, Inc., Austin, TX, and DARPA/ONR under Contract N00014-97-F0305 The submitted manuscript has been created by the University of Chicago as operator of Argonne National Laboratory under contract no. W-31-109-ENG-38 with the U. S. Department of Energy. The U. S. Government retains for itself, and others acting on its behalf, a paid-up, non-exclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the government.

11:00am **FP+VT-MoM9 Fabrication of Aligned High-density Diamond Needles by Dry Etching of Diamond Substrates**, *E.S. Baik,* Myong Ji University, Korea*; Y.J. Baik,* Korea Institute of Science and Technology, Korea*;* ***D. Jeon,*** Myong Ji University, Korea

Densely packed diamond needles aligned in the same direction are formed by air plasma etching of diamond substrates. Diamond substrates were coated with a thin layer of Mo and then etched by RF or DC plasma with the substrate biased at negative several hundred volts. The shape and the density of the diamond needles could be reproducibly controlled with the etching parameters such as the substrate temperature, pressure, bias voltage, power, and the amount of Mo. If the substrate temperature was high, for example, the needles became thick. Mo acted as an etch-resistant mask for the needle formation. Mo was sometimes self-supplied by the sputtering of the Mo substrate holder during the etching, but the uniformity of the needles could be best controlled by coating small amount of Mo before etching. If the amount of Mo or the pressure was not adequate, the needles did not form or formed only along the edge of the diamond grains. With the optimum condition, we could fabricate sharp diamond needles whose pillar diameter and height were 0.1 µm and 3 µm, respectively. The density was 30 needles/µm@super 2@. Since the needles were highly aligned and always formed in parallel with the field, the direction of the needles could be chosen by tilting the substrate. Not only the polycrystalline diamond films but also the high pressure/high temperature diamond and the natural diamond could be etched to form needles. Our diamond needles can be utilized as the field emission cathode tips, diamond fiber for composite materials, highly efficient heat sinks for their large surface area, and sensors.

11:20am **FP+VT-MoM10 Hermetic Sealing and Evacuation of Candescent's ThinCRT@superTM@**, ***T.S. Fahlen,*** Candescent Technologies Corporation **INVITED**

Candescent has developed a full color, full video, power efficient display, the ThinCRT@superTM@ based on Spindt-type field emitters with very low voltage switching (<10.5 volt), and "high voltage" (6 KV) aluminized phosphors. Because of the high voltage used, the faceplate (anode/phosphor screen) and backplate (cathode) of the display are separated by 1.25 mm. This talk describes two methods used to hermetically seal the perimeter and evacuate ThinCRT displays. In both methods, the faceplate and backplate are sealed to a frame made of glass frit placed between them following an accurate, room temperature and atmospheric pressure alignment procedure. One sealing method uses a laser to first seal the frit frame to the faceplate, and then to hermetically seal the backplate to this assembly in a vacuum environment; no exhaust tubulation is required, and a non-evaporable getter is incorporated along one internal border of the display. A second method uses a laser to seal the frit frame to the faceplate, and the backplate to the frame/faceplate assembly but in a non-vacuum environment. An auxiliary chamber (AC) containing a getter and exhaust tube is then oven sealed to the rear of the assembly. Holes in the backplate allow the gases in the interior of the display to flow into the AC. The display assembly is then evacuated through an exhaust tubulation. The AC saves border space by allowing the getter to be removed from the display border to the rear of the display. The AC adds no additional thickness to the display because it protrudes no further than do the display electronics which are also attached to the rear of the display. In both sealing methods, the exact spacing between the faceplate and the backplate is determined solely by the internal support structure. The frit frame and sealing process have been designed so that during laser sealing, the frit expands to fill and seal the small gap left between the frit frame and the faceplate.

Organic Electronic Materials Topical Conference
Room 616/617 - Session OE+EM+FP-MoM

Organic Devices

Moderator: A. Kahn, Princeton University

8:20am **OE+EM+FP-MoM1 Invited Paper**, ***C.W. Tang,*** Eastman Kodak Company **INVITED**

NO ABSTRACT SUBMITTED.

9:00am **OE+EM+FP-MoM3 Ultrafast Electron Relaxation in Excited, DCM Doped Alq Films**, ***K. Read,*** University of Michigan*; H.S. Karlsson,* Royal Institute of Technology, Sweden*; M.M. Murnane, H.C. Kapteyn,* University of Michigan*; R. Haight,* IBM T.J. Watson Research Center

Electrons photoexcited into the lowest unoccupied molecular orbital (LUMO) of Alq (tris(8-hydroxyquinoline)aluminum) films doped with DCM (4-dicyanomethylene-2-methyl-6-p-dimethylaminostyryl-4H-pyran) have been studied using excite-probe laser photoemission. DCM doping, achieved by co-evaporation with Alq, is an important means of color tuning and enhancing Alq organic LED emission. In addition, DCM doped Alq films have been shown to lase at low photoexcitation thresholds. A detailed understanding of the involved relaxation mechanisms is beneficial to both applications. Using 3.14 eV excite, and 26.7 eV probe, 100 femtosecond laser pulses, we have observed the LUMO decay rate over the first 175 picoseconds, during which time diffusion is insignificant, and all dynamics occur in the absence of electron transport. We have found that the LUMO population fits to a model wherein the majority of the excitation rapidly transfers from the Alq to the DCM and decays via stimulated emission in the DCM, concentration quenching in the DCM, and bimolecular singlet-singlet annihilation in both the Alq and the DCM. Increasing either the DCM doping percentage, or the excitation intensity, is seen to significantly enhance the early, fast processes. The occupied to unoccupied molecular orbital energy gap shrinks as a function of excite-to-probe delay, in accordance with the expected energy relaxation within the excited states. Pure DCM yields a correspondingly smaller energy gap, and rapid LUMO decay. Analyzing the LUMO decay mechanisms allows an improved understanding of the functions served by DCM doping of Alq films.

9:20am **OE+EM+FP-MoM4 Unoccupied Molecular Orbitals in Organic Electroluminescent Materials Studied by Femtosecond Harmonic Photoemission**, ***H.S. Karlsson,*** Royal Institute of Technology, Sweden*; K. Read,* University of Michigan*; R. Haight,* IBM T.J. Watson Research Center

We have studied the lowest unoccupied molecular orbital (LUMO) in three organic electroluminescent materials using pump-probe harmonic photoemission based on a femtosecond laser system. The energy gap between the LUMO and the highest occupied molecular orbital (HOMO) in thin films of the blue-light-emitting molecules bis(2-methyl-8-quinolinolato)(para-phenyl-phenolato)aluminum (BAlq) and 1,4-bis(2,2-diphenylvinyl)biphenyl (DPVBi) was established and compared with the green-light-emitting molecule tris(8-hydroxyquinoline)aluminum (Alq). We have also studied the LUMO decay characteristics for the three materials and relate the differences in decay times to the morphology of the evaporated thin films. The effect on the electronic structure of the organics induced by deposition of metallic overlayers will also be shown and discussed.

9:40am **OE+EM+FP-MoM5 Femtosecond Charge Transfer Processes in Organic Molecular Heterostructures**, ***A.J. Mäkinen,*** *S. Schoemann, Y. Gao,* University of Rochester*; M.G. Mason, A.A. Muenter,* Eastman Kodak Company*; A.R. Melnyk,* Xerox Wilson Center for Research & Technology

The charge transfer (CT) process in organic semiconductor heterostructures is an important problem for applications such as photoreceptors and light-emitting devices. The operation of a photoreceptor structure is based on a CT process at the interface of a charge generator layer and a charge transport layer. We have investigated such a structure formed by vacuum grown thin films of two organic molecules, N,N'-diphenethyl-3,4,9,10-perylenetetracarboxylic-diimide (DPEP) and N,N'-diphenyl-N,N'-(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine (TPD), with femtosecond time-

resolved photoemission spectroscopy (TR-PES). By measuring the lifetimes of the excited electron states in the mixtures and in the bilayer structures of these molecules, and by recording the UPS spectra of the films we are able to determine the time-scale and the energy regime for the CT process. Our results show that the CT takes place in less than 10 fs between the DPEP and the TPD molecules. We also demonstrate the significance of the film interface in separating the charges upon CT.

10:00am **OE+EM+FP-MoM6 A Comparison of Organic Light-Emitting Devices Using Transient Current-Transient Voltage, Transient Brightness-Transient Voltage, and Transient Brightness-Transient Current Analysis**, ***B.J. Norris***, *J.F. Wager,* Oregon State University*; J. Liu, Y. Yang,* University of California, Los Angeles

Four types of organic light-emitting devices (OLEDs) are compared using transient current-transient voltage [i(t)-v(t)], transient brightness-transient voltage [b(t)-v(t)], and transient brightness-transient current [b(t)-i(t)] analysis.@footnote 1@@footnote 2@ These analysis methods consist of obtaining the instantaneous brightness [b(t)], current [i(t)], and voltage [v(t)] of the device under test when it is subjected to a bipolar, piecewise-linear applied voltage waveform and then plotting these quantities parametrically. The four types of OLEDs considered are: two types of green OLEDs and a blue OLED, provided by the Eastman-Kodak Co., and a polymer light-emitting device (PLED) fabricated at the UCLA. The OLEDs are dual-layer heterostructures, involving an electron transport layer (ETL) and a hole transport layer (HTL). In contrast, the PLED is a single-layer device. The ETL and HTL capacitances of heterostructure OLEDs can be estimated from b(t)-i(t) curves. The b(t)-v(t) curves allow the conduction current to be estimated. Perhaps the most interesting aspect of this study is the existence of a small bump in the retrace portion of i(t)-v(t) curves of heterostructure OLEDs, which is not observed in single-layer PLEDs. This bump is ascribed to the removal of accumulated holes at the ETL/HTL interface. Hole accumulation at the ETL/HTL interface of OLED heterostructures is manifest as hysteresis in b(t)-v(t) curves. @FootnoteText@ @footnote 1@B. J. Norris, J. P. Bender, and J. F. Wager, "Steady-State Transient Voltage-Transient Current Characterization of OLEDs," SID Digest, in press. @footnote 2@ B. J. Norris, "Characterization of Organic Light-Emitting Devices," MS Thesis, Oregon State University, 1999.

10:20am **OE+EM+FP-MoM7 Organic and Polymer Transistors: Device Physics, Functional Blocks, and Circuits**, ***A. Dodabalapur***, *B.K. Crone, Y.Y. Lin, J.A. Rogers, S. Martin, R. Sarpeshkar, Z. Bao, W. Li, H.E. Katz, V.R. Raju,* Bell Laboratories, Lucent Technologies **INVITED**

This presentation will begin with a description of the basic physics of typical organic and polymer transistors and the factors which determine and influence the apparent mobility. The transient characteristics organic transistors with sub-microsecond switching speeds will be described. The integration of organic light emitting diodes and transistors is promising for emissive displays. We have developed designs for 'smart' pixels in which an analog circuit consisting of 6-7 transistors drives each LED. The simulated and experimental characteristics of such pixels will be presented. The development of air-stable n-channel organic transistors led to our demonstrating the first organic complementary circuits. The design considerations and characteristics of organic complementary circuits with > 100 transistors will be described. The noise properties of organic transistors and their use in gas sensors will be described.

11:00am **OE+EM+FP-MoM9 Sub-microsecond Switching of n and p-Channel Organic Field Effect Transistors**, ***B.K. Crone***, *A. Dodabalapur, Z. Bao, W. Li,* Lucent Technologies, Bell Laboratories

Steady state and transient electrical characteristics are presented for p-channel (@alpha@,@omega@-dihexyl quinquethiophene) and n-channel (copper hexadecaflourophthalocyanine) organic field effect transistors. The structure of the transistor is as follows. The gate electrode is a doped silicon wafer with a thermal oxide gate oxide. Gold source and drain contacts are evaporated and photolithographically defined on the oxide, and finally the active organic film is evaporated. The transistors measured had channel length of 4 µm and width 250 µm. Field effect carrier mobilities are determined for both the steady state and transient response using a simple model for the saturated drain current. The steady state mobility and threshold voltage were determined by a linear fit to the square root of the saturated drain current versus gate voltage. Steady state mobilities of 1.5x10@super -2@cm@super 2@/Vs for the p-channel and 3x10@super -2@cm@super 2@/Vs for the n-channel were measured. Transient mobilities were determined using the same model for the saturated drain current and the threshold voltage obtained in the steady state case. Transient mobilities were higher, 3x10@super -2@cm@super 2@/Vs for the p-channel and 1.5x10@super -1@cm@super 2@/Vs for the n-channel devices. The transient responses showed switching times less than 1 µsec for both p and n-channel devices.

Flat Panel Displays Topical Conference
Room 604 - Session FP-MoA

Luminescent Thin Films
Moderator: P.H. Holloway, University of Florida

2:00pm **FP-MoA1 Critical Issues Related to Processing and Properties of Laser Deposited Luminescent Oxide Thin Films**, ***R.K. Singh***, *K.G. Cho, D. Kumar, P.H. Holloway,* University of Florida **INVITED**

The performance of the powder-based field emission display devices can be improved significantly by using thin film phosphors due to their higher lateral resolution, better thermal stability, reduced outgassing, and better adhesion to the solid surfaces. A variety of growth techniques such as evaporation, spray pyrolysis, sputtering, metal organic chemical vapor deposition, and pulsed laser deposition, are employed for the fabrication of thin film phosphors. The pulsed laser deposition (PLD) technique is emerging as one of the most convenient techniques to fabricate complex thin films since it offers numerous advantages, including convenient reproduction of target stoichiometry onto the films, low contamination level, high deposition rate, atomically sharp step coverage, thickness control. However, the biggest hindrance in the use of thin film phosphors is their low brightness and efficiencies in comparison to those of bulk powder phosphors. In this talk, we will discuss some of the critical issues related to processing and properties of laser deposited Eu-activated yttrium oxide (Eu:Y @sub 2@ O @sub 3@) luminescent thin films. We will also present our results showing how brightness and stability can be improved significantly by changing microstructure, orientation, and crystallinity of Eu:Y@sub 2@O@sub 3@ films by changing the processing parameters during pulsed laser deposition. A theoretical model will be presented to account for the increase in brightness with an increase in film roughness which has been found to be a key parameter determining the light piping effect.

2:40pm **FP-MoA3 The Effect of Carbon Deposit on Electron Beam Degradation of Oxide Thin Film Phosphors**, ***C. Kondoleon***, *B.L. Abrams, J. Thomes,* University of Florida*; P. Rack,* Rochester Institute of Technology*; V. Krishnamoorthy, P.H. Holloway,* University of Florida

The cathodoluminescence (CL) brightness and spectral distribution from thin film Ta@sub2@Zn@sub3@O@sub8@ has been studied as a function of electron dose. Thin films of Ta@sub2@Zn@sub3@O@sub8@ were prepared by sputtered deposition followed by rapid thermal annealing (RTA). Under bombardment by 2keV electrons, the films produce a blue luminescence with a dominate wavelength of 386nm. These films were exposed to residual vacuum gas dominated by H@sub2@ and H@sub2@O at pressures ranging from 10@super-8@ Torr to 10@super-6@ Torr with <5% loss in CL brightness. However when hydrocarbons from colloidal graphite paint was introduced and raised the base pressure of the vacuum from 1 x 10@super-8@ Torr to 8 x 10@super-8@ Torr, the CL brightness was degraded to 5% of its original value after approximately 4 hours at 2.7 x 10@super-4@ A/cm@super2@ (corresponding to a dose of 3.9 C/cm@super2@). The electron beam stimulated degradation since when the beam was off, degradation stopped. In addition, on some samples the electron beam was blocked by a Cu grid over the surface and degradation only occurred when the electron beam struck the surface. Auger analysis showed a thick layer of carbon. It is speculated that the electron beam cracked hydrocarbons, resulting in deposition of a carbonaceous layer which attenuated primary electrons and absorbed luminescent photons. The significance of this phenomena in field emission displays will be discussed. This work is supported by DARPA Grant MDA 972-93-1-0030, through the Phosphor Technology Center of Excellence.

3:00pm **FP-MoA4 Blue Luminescence Properties of Zinc Oxide Doped with Low Concentration of Tungsten**, ***J.B. Sobti***, *V. Bhatia, P.M. Babuchna, M.H. Weichold,* Texas A&M University

Research in developing high quality thin film phosphors for field-emission displays (FEDs) has gained momentum over the last decade. From the aspect of low voltage applications, cost and durability, efficient red and gren phosphors are now available. However, phosphors for blue light still need improvement. An investigation conducted at Texas A&M University showed that tungsten doped zinc oxide (ZnO:W) emits blue light at 490 nm when excited at 300V.@footnote 1@ Results for this phosphor preparation, its luminescence and material characterizations, and potential use in fabricating a FED are prsented in this paper. Using ion mill, thin films of ZnO and W were co-deposited. The films with varying W concentrations (10%, 30%, and 50%) were annealed at 450°C, 650°C, and 850°C for 4, 8, and 12hrs in the presence of argon and oxygen. Luminescent characterization of these films indicated that phosphor having 10% W, annealed at 850°C for 12 hrs. in pure argon emitted the brightest blue light.@footnote 2@ Continuing research involves studying the effect of even lower W concentrations under above-mentioned conditions. Radiance data for ZnO:W phosphor will be measured and compared with the efficiencies of other blue phosphors. X-ray diffraction studies and infrared spectroscopy of the films showed formation of zinc tungstate (ZnWO@sub 4@), which has been reported to exhibit photoluminescence at 490 nm. This led us to conclude that ZnWO@sub 4@ is the source of blue light from our phosphor.@footnote 3@ This paper also presents results from Stokes shift measurements to understand mechanisms for blue light emission. Research is underway in determining a material chemically compatible with the phosphor to form anode lines for the display. Results from this research will also be reported. @FootnoteText@ @footnote1@Technology Disclosure to TAMU Technical Licensing Office (1993). @footnote 2@J. B. Sobti et al, April 1998, AVS Texas Chapter meeting. @footnote 3@J. B. Sobti et al, Spring, 1999, MRS meeting.

3:20pm **FP-MoA5 Progress in TFEL Technology**, ***S.-S. Sun***, Planar Systems, Inc. **INVITED**

This paper will review the basic operation of inorganic TFEL displays. Recent progress in monochrome and color TFEL phosphors including the new efficient blue TFEL phosphor will be presented. The application of these improved phosphors in direct view and active-matrix TFEL displays, both monochrome and color versions, will be described.

4:00pm **FP-MoA7 Multicolor Emitting TFEL Devices using Ga@sub 2@O@sub 3@ Phosphors Co-doped with Mn and Cr**, *T. Minami,* ***T. Nakatani***, *T. Miyata,* Kanazawa Institute of Technology, Japan

This paper introduces newly developed TFEL devices consisting of Mnand Cr-co-doped Ga@sub 2@O@sub 3@ phosphor thin-film emitting layers combined with a thick BaTiO3 ceramic sheet insulating layer. The co-doping effects of Mn doped into Ga@sub 2@O@sub 3@:Cr thin films and Cr doped into Ga@sub 2@O@sub 3@:Mn thin films on their electroluminescent properties have been investigated. Ga@sub 2@O@sub 3@:Mn,Cr phosphor thin films were prepared using a solution coating technique. The Mn and Cr dopant contents (Mn/(Mn+Ga) and Cr/(Cr+Ga) atomic ratios) were varied from 0 to 20 atomic%. In order to improve the EL characteristics, all deposited Ga@sub 2@O@sub 3@:Mn,Cr phosphor thin films were post-annealed in an Ar atmosphere for 1 h at 1020@super o@C. The emission from Ga@sub 2@O@sub 3@:Mn,Cr TFEL devices was more strongly dependent on the Cr content than on the Mn content doped into the phosphor emitting layers. A high luminance above 100 cd/m@super 2@ was obtained in all TFEL devices using Ga@sub 2@O@sub 3@:Mn,Cr thin films co-doped with a Cr content from 0 to 20 at.% and a Mn content of 0.3 at.% when driven at 1 kHz. The emission color from these Ga@sub 2@O@sub 3@:Mn,Cr TFEL devices changed from green to red emission as the co-doped Cr content was varied from 0 to 20 at.%. In addition, the emission color changed from green to red as the applied voltage was increased. Thus, Ga@sub 2@O@sub 3@:Mn,Cr TFEL devices would be useful in color indicators and displays, with color controlled by the applied voltage.

4:20pm **FP-MoA8 Effect of Ce@sub 2@O@sub 3@ and Ag/Cu Codoping on the Brightness and Efficiency of RF Magnetron Sputtered ZnS:TbOF Alternating Current Thin Film Electroluminescent Displays**, *J.P. Kim,* ***D.J. Moorehead***, *K.E. Waldrip, B. Speck, M. Davidson,* University of Florida*; P.H. Holloway,* University of FLorida*; Q. Zhai,* University of Florida

ZnS:TbOF has shown promise as a green electroluminescent phosphor, but it still lacks the performance necessary to incorporate it into a commercially viable ACTFEL device. Many codopants have been shown to improve the performance of such devices. This study reports the results of Ce@sub 2@O@sub 3@ and Cu/Ag codoping on the brightness and efficiency of ZnS:TbOF thin film EL devices. As-deposited Ce codoped ZnS:TbOF films showed no significant change in brightness. Annealing of low Ce concentration half-stack (no top dielectric) devices improved EL brightness by 65% over the best undoped samples. Scanning electron microscopy shows no significant morphology changes in annealed films. Ag/Cu codoping did not dramatically effect the brightness of as-deposited films, but there were significant improvements in BV characteristics of annealed samples. Half-stack data show a much sharper turn-on and B20 improvement from 32 cd/m2 to 70 cd/m2. Samples annealed at high-temperature (850°C) demonstrated severe degradation in brightness and

efficiency, while SEM micrographs show that grain size significantly decreased, possibly due to precipitation of another phase.

4:40pm **FP-MoA9 A Comparison of the Short Wavelength Performance of ZnS and SrS Thin-Film Electroluminescent Devices via a Rare Earth Doping Study**, *P.D. Keir,* ***C.M. Maddix****, B. Baukol, J.F. Wager, B.L. Clark, D.A. Keszler,* Oregon State University

The short wavelength electroluminescent (EL) performance of SrS and ZnS phosphors for thin-film EL flat-panel display applications is compared. This is accomplished by measuring the EL spectra of ZnS and SrS EL devices doped with various rare earth luminescent impurities: Dy, Er, Ho, Tb, and Tm. All of the SrS EL devices tested have more intense EL emission at short wavelengths than corresponding ZnS EL devices. Additionally, all of the SrS EL devices operate at smaller average phosphor fields. The superior EL performance of SrS appears to be due to a hotter electron distribution and to the presence of positive space charge in SrS EL devices. The ZnS devices show a distinct EL cut-off at ~440-460 nm. This is attributed to an inadequately heated electron distribution which is unable to excite high energy transitions in the luminescent impurity. Collectively, these results indicate that efficient blue emission from a ZnS phosphor is unlikely.

5:00pm **FP-MoA10 Role of Cations and Anions in Donor Doping of ZnS:Mn Thin Film Electroluminescent Phosphors**, ***K.E. Waldrip****, J.S. Lewis, III, Q. Zhai,* University of Florida*; M. Puga-Lambers, M. Davidson,* University of Florida, Microfabritech*; P.H. Holloway,* University of Florida*; S.-S. Sun,* Planar Systems, Inc.

Alternating current thin film electroluminescent ZnS:Mn phosphors have been deposited by RF magnetron sputter deposition on glass substrates coated with indium tin oxide (ITO) transparent conductor and an alumina-titania (ATO) composite dielectric. A co-dopant was introduced by an ex-situ diffusion method. The top dielectric and contact layers were deposited to complete the device. Control samples were processed exactly the same, with the exception that the co-dopants were not introduced. Co-doping ZnS:Mn thin film electroluminescent phosphors with potassium chloride resulted in a 50% increase in brightness and efficiency (150fL, 1.9L/W vs. 100fL, 1.3L/W), a 5% increase in threshold voltage, and an improvement in brightness vs. voltage stability. Electrical analysis revealed increases in the amount of transferred charge, leakage charge, internal phosphor field, and in the overall symmetry of the electrical characteristics with respect to applied voltage pulse polarity with KCl co-doping. The observations to date of the improved performance in co-doped ZnS:Mn can be explained by a donor doping mechanism in which chlorine acts as the shallowest and most abundant donor in the phosphor film. Interstitial potassium also behaves as a donor, and the theory rests on the assumption that there are more activated donors than acceptors. The purpose of the work presented here is to elucidate the role of the cation and the anion in the improved performance of co-doped ZnS:Mn phosphors. KF, KCl, KBr, LiCl, NaCl, ZnCl@SUB 2@ and K@SUB 2@S were tested as dopants to deconvolute the roles of the anion and the cation. The brightness and efficiency vs. voltage and threshold voltage for each sample will be reported against the control samples. SIMS and XTEM, as well as spectral distribution and electrical analysis will also be presented and correlated with the donor doping theory.

Organic Electronic Materials Topical Conference
Room 616/617 - Session OE+EM+FP-MoA

Transport and Nanostructures in Organic Films

Moderator: E. Umbach, Universität Würzburg, Germany

2:00pm **OE+EM+FP-MoA1 Generation and Transport of Charge Carriers in Conjugated Polymers**, *V.I. Arkhipov,* ***H. Baessler****, S. Barth, C. Im, D. Hertel, B. Schweitzer,* Philipps Universität, Germany **INVITED**

Upon photoexcitation of conjugated polymers, such as ladder-type poly-phenylene (LPPP) and substituted PPVs, both geminately bound electron-hole pairs and free charge cariers are generated. Evidence for geminate pair production in LPPP comes from electric field assisted delayed fluorescence. Intrinsic free charge carrier generation occurs via on-chain dissociation of vibrationally hot singlet excitations. Motion of positive charge carriers has been studied involving time of flight experiments. From the hole mobility in a sieres of substituted PPV as a function of temperature and electric field it will be concluded that transport is disorder controlled as it is in molecularly doped polymers. An exception of this rule is hole transport in LPPP. The question of intra versus inter chain transport will briefly be addressed. This work was supported by the Deutsche Forschungsgemeinschaft (Sonderforschungsbereich 383) and the Stiftung Volkswagenwerk.

2:40pm **OE+EM+FP-MoA3 Resistance of Individual Molecular Semiconductor Grains Measured by Conducting Probe Atomic Force Microscopy**, ***T.W. Kelley****, C.D. Frisbie,* University of Minnesota

Continued interest in organic electronics has underscored the need for better understanding of transport mechanisms in polycrystalline films of organic semiconductors. We are employing conducting probe atomic force microscopy (CP-AFM) to measure the electrical resistances associated with individual grains and grain boundaries in thin films of @alpha@-sexithiophene (6T). These measurements focus on single 6T grains that are several microns in length and width and 1 - 6 molecular layers (2-14 nm) in thickness. The 6T grains are vacuum deposited onto insulating substrates with lithographically patterned gold electrodes. A Au-coated AFM probe is used to image each grain, including any crystal defects, and to subsequently make point-contact electrical measurements at particular positions on the grain. Current-voltage (I-V) curves are recorded at each position as a function of probe-electrode separation. From these data, we estimate tip-grain contact resistance and conductivity of each grain. In general, we show that CP-AFM is a powerful approach to exploring the effects of microstructure on conductivity in organic semiconductor films.

3:00pm **OE+EM+FP-MoA4 Self-Assembled, Template-Based Nanolithography**, ***S.R. Cohen****, R. Maoz, E. Frydman, J. Sagiv,* Weizmann Institute of Science, Israel

The versatility of our recently developed technique@footnote 1@ for scanning probe microscope (SPM)-based, non-destructive nanolithography on an organized organic monolayer template is demonstrated here. By building on, rather than destroying the organic "resist", consisting of an ordered self assembled monolayer (SAM), it is possible to construct complex 3 dimensional structures which can ultimately lead to device formation. In the first step, applying a bias voltage between a conductive SPM tip and a silver thiolate-based monolayer surface site leads to "activation" of that site by the tip. The second step, deposition of metal (silver) from solution by interaction with an enhancing solution which specifically deposits silver on these sites, leads to in-situ formation of metallic features with sub-micron resolution. These features are chemically bound to the surface-altered monolayer, and comprise a three-dimensional structure of surface-bound silver. The fabrication of conducting nanowires is demonstrated, which could be extended to device or nanocircuit formation. The formation of complex, three-dimensional structures with order determined by the underlying monolayer has been demonstrated. Considering that the surface template exhibits molecular order, this technique has the potential of creating molecular-scale devices, using standard ambient application of SPM, and solution chemistry. @FootnoteText@ @footnote 1@ R. Maoz, S.R. Cohen, and J. Sagiv, Adv. Mater. 11, 55 - 61 (1999).

3:20pm **OE+EM+FP-MoA5 Fabrication of Organic Microstructures Using Soft Lithography**, ***G. Whitesides****,* Harvard University **INVITED**

Chemistry, with stimulus from biology, is beginning to develop a range of new concepts for fabrication of microsystems: these include self-assembly, non-covalent synthesis, microprinting, micromolding, microfluidic patterning, microelectrochemistry, and related techniques designed to make it possible to design complicated structures having electrical, optical, biological or magnetic functionality and to replicate these systems efficiently. These concepts suggest approaches to fabrication that are substantially different from photolithography in their areas of application. The phrase "soft lithography" encompasses one core set of techniques for replication. The techniques included in soft lithography include the formation of self-assembled monolayers, the patterning of these monolayers using microcontact printing, the fabrication of structures inside small channels using microfluidic methods, and the fabrication of small (< 50 nm) polymer structures using transfer molding and replica molding. The adjective "soft" in the phrase "soft lithography" refers to the elastomeric stamps or molds that are important in many of these techniques, and to the properties of organic materials in general. These techniques may use photolithography, but normally primarily during the step that fabricates the master. This talk will outline progress in this area: from homogeneous self-assembled monolayers (SAMs) to transistors, and from molecular self-assembly to the self-assembly of macro-scale objects. Areas of application in which soft lithography is promising include 3-D fabrication and pattern transfer to non-planar surfaces, large-area patterning, low-cost additive fabrication, rapid prototyping (especially of microanalytical and microfluidic systems), fabrication of systems where control of surface

chemistry is crucial (e.g., cell biology) and fabrication of MEMS. Key problems are defect densities, distortions in the elastomeric masks/stamps/molds, and fabrication requiring multiple registered levels of fabrication. Reviews: "Soft Lithography" Xia, Y. and Whitesides, G. M., Angew. Chem. Intern. Ed. Engl. 1998, 37, 550-575. "Soft Lithography" Xia, Y. and Whitesides, G. M., Annu. Rev. Mater. Sci. 1998, 28, 153-184.

4:00pm **OE+EM+FP-MoA7 Electron Beam Patterning of Amine-Functionalized Self-Assembled Monolayers**, ***C.K. Harnett***, *K.M. Satyalakshmi, M.G. Metzler,* Cornell University*; D.R. Medeiros,* IBM T.J. Watson Research Center*; H.G. Craighead,* Cornell University

Amine-functionalized self-assembled monolayers form a hydrophilic surface that can strongly attach other materials. Examples of materials that have been selectively deposited on patterned amine monolayers include nanoparticles,@footnote 1@ metals, fluorescent molecules, and biological cells.@footnote 2@ Nanopatterning of reactive monolayers is therefore of great practical interest. We have studied electron-beam patterning of 3-aminopropyltriethoxysilane (APTS) and other self-assembled monolayers. Submicron features that are difficult to achieve with UV lithography or microcontact printing are accessible with electron beams. Exposed patterns are examined with lateral-force microscopy (LFM) to determine pattern quality vs. electron dose. At 20 kV, a dose of 300 μC/cm@super 2@ is required to produce continuous 1-micron lines. Results from several electron energies will be presented, with the goal of using these monolayers in a low-energy (1-2 kV) electron-beam lithography system. Exposed areas are analyzed with grazing angle IR spectroscopy to determine possible exposure mechanisms. Subsequent deposition of metals, and use of protection-group chemistry to produce a tone-reversed pattern, will also be discussed. @FootnoteText@ @footnote 1@ T. Vossmeyer, S. Jia, E. Delonno, M. R. Diehl, S.-H. Kim, X. Peng, A. P. Alivisatos, J. R. Heath, Journal of Applied Physics 84, 3664-3670 (1998) @footnote 2@ C. S. Dulcey, J. H. Georger, V. Krauthammer, D. A. Stenger, T. L. Fare, J. M. Calvert, Science 252, 551-554 (1991).

4:20pm **OE+EM+FP-MoA8 Liquid Crystal Imprinting: A New Method for Preparing Uniformly Oriented Thin Films**, ***D.L. Patrick***, Western Washington University

A new synthetic strategy is presented for preparing nanostructured thin films possessing macroscopically-uniform organization. The method is based on the use of a thermotropic nematic liquid crystal (LC) solvent, which serves a growth medium for deposition of material onto a suitable substrate. Application of a magnetic field results in the formation of an oriented film whose directionality can be controlled externally. The method has been used to prepare several organic monolayer systems in which the orientation of the films' molecular constituents is highly controlled. We show that orientational order at the solid-fluid interface originates during film nucleation, and that the alignment mechanism is based on anisotropic anchoring interactions between surface adsorbates and the LC solvent. Details of the relationship between molecular-scale surface structure and bulk LC ordering were studied by combining scanning tunneling microscopy and polarized optical measurements of uniformly oriented cells. LC fluids exhibit anisotropic anchoring interactions with most crystalline surfaces, indicating that the method may be applicable to the synthesis of films and layered materials using a wide range of molecular and supramolecular building blocks.

4:40pm **OE+EM+FP-MoA9 Electro-Patterning of Conjugated Polymer Films on Conducting Surfaces Using the Precursor Polymer Approach**, *R.C. Advincula,* University of Alabama at Birmingham, US*; S. Inaoka,* University of Alabama at Birmingham*;* ***D. Roitman***, Hewlett-Packard Laboratories

Recently, a novel method of depositing ultrathin films of conjugated polymers on conducting surfaces has been investigated by the UAB and HP groups. We report the formation and patterning of conjugated polymer films by novel electro-deposition of materials on specific sites of substrates and sequences. We have investigated a range of feature sizes using this method with features below micron size. We have also investigated the formation of unique blend film structures, with emphasis on light emitting materials. Previous attempts in using electrodeposition resulted in 'brittle' and defective (pinholes) film surfaces. Our results indicate that the overall optical, mechanical quality and physical integrity of the films are superior compared to previously reported systems.

Flat Panel Displays Topical Conference
Room 604 - Session FP-TuM

Novel Materials for Field Emission Displays and Technologies for Flexible Displays

Moderator: B. Gnade, DARPA

8:20am **FP-TuM1 Comparative Study of Field Emission from Microcrystalline Graphite, Nanostructured Graphitic Films, and Nanotubes**, ***A.A. Talin***, *K.A. Dean, B.F. Coll, J.E. Jaskie, M. Johnson,* Motorola Flat Panel Display Division

Electron emission at remarkably low electric fields has been reported from a wide variety of carbon films over the past decade. Although the precise mechanism of emission is still under debate, it is becoming clear that graphitic phases of carbon play a central role in the origin of the low-field emission properties of carbon-based cold cathodes. In this work, we use conventional diode type apparatus to measure broad-area emission characteristics, and field emission microscopy to investigate and identify the carbon phases associated with field emission. We demonstrate that purely SP2 carbon films can be excellent field emitters. We relate the differences in broad area field emission characteristics and in field emission microscopy images in terms of film morphology and the field emission physics of various carbon phases. .

8:40am **FP-TuM2 Demonstration of Low Work Function Cu-Li Alloy Coatings for Edge Field Emission Devices@footnote *@**, ***J.C. Tucek***, *A.R. Krauss, O. Auciello, D.M. Gruen, D.C. Mancini, N. Moldovan,* Argonne National Laboratory

Low work function alkali metals have been shown to significantly enhance field electron emission when used as coatings for microtip field emission arrays (FEAs). Maximum enhancement of electron emission is expected for alkali metal coatings 0.5-1 monolayer in thickness. However, alkali metals are both physically and chemically unstable in layers exceeding a few Å in thickness, and therefore, it is extremely difficult to fabricate and maintain, during operation, such thin layers on FEAs. We have recently demonstrated that lithium alloy coatings based on materials developed at Argonne National Laboratory provide very stable, low work function coatings with low threshold field (~ 3 V/μm) and enhanced electron emission for application to FEAs.@footnote 1@ These alloy coatings maintain a segregated monolayer of lithium on the surface of the alloy, even under adverse environmental conditions or ion bombardment. As an extension of this work, Cu-Li coated edge emitters are produced by coating Si posts, followed by ion beam sputtering of the alloy and a selective etching of Si, resulting in the formation of hollow cylinders with nanometer thick Cu-Li walls. It can be expected that Cu-Li edge emitters will provide a larger emitter area, and therefore should be more robust than the Si FEAs while maintaining a similar low field emission threshold. In addition, we have performed tests using a simulated flat panel display configuration, which provide information about the emission uniformity of these edge emitters. The emission characteristics of the new Cu-Li-based edge emitters will be discussed in relation to the alloy composition and the geometry of the emitters. Re abstract entitled "Demonstration of Low Work Function Cu-Li Alloy Coatings for Edge Field Emission Devices" by J.C. Tucek et. al., submitted for presentation at the 46th International Symposium of the American Vacuum Society, Seattle, Washington, October 25-29, 1999, please be advised that: The submitted manuscript has been created by the University of Chicago as Operator of Argonne National Laboratory ("Argonne") under Contract No. W-31-109-ENG-38 with the U.S. Department of Energy. The U.S. Government retains for itself, and others acting on its behalf, a paid-up, nonexclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government. @FootnoteText@ @footnote 1@ O. Auciello, et. al., J. Appl. Phys. (in press, 1999). @footnote *@ Work supported by the U.S. Department of Energy, BES-Material Sciences, under Contract W-31-109-ENG-38 and DARPA/ONR under contract N00014-97-F0905.

9:00am **FP-TuM3 Progress and Performance of FEAs using Zirconium Carbide Field Emitters**, ***W.A. Mackie***, *T. Xie, P.R. Davis,* Linfield Research Institute

Field emission arrays are finding many and varied applications from the present use in flat video displays to potential uses in microwave devices, and spacecraft charge dissipation and propulsion systems. Many of these proposed uses would require high currents per tip and operation in adverse vacuum conditions. These requirements necessitate robust cathode materials. Our work focuses on the use of transition metal carbides for field emission sources. Here, we report on vapor deposition of zirconium carbide emitter cones in the conventional field emission array geometry. Generally, we have used array blanks provided by others with 50,000 gates. We deposit these carbide emitters via physical vapor deposition from crystalline zirconium carbide sources. Use of this material has required changes in the array fabricating technique used by others due to the high temperature needed for evaporation. We will report on results of studies using several new materials for the lift-off layer and the processing steps needed for proper cone formation using zirconium carbide. The emission properties of arrays formed in this was will also be reported. In general, zirconium carbide has an electronic work function approximately 1 eV lower than molybdenum, a common FEA emitter material. This has translated into a measured lowering of turn-on voltages by 45% and an increase in emission stability. Extraction voltages in the 35-65 volt range are reported for solid carbide emitter cones in the FEA geometry. Emission at relatively high individual tip currents and at poor vacuum levels will also presented and discussed. These carbide cone arrays could lead to extremely robust electron sources and open the use of FEAs to a variety of applications. Work supported in part by DARPA High Definition Systems Initiative under ONR Grant No. N00014-96-1-1011.

9:20am **FP-TuM4 High-Speed Assembly of Flexible Film LCDs: Materials and Process Development**, *J.T. Richard,* Polaroid Corp.*;* ***W.K. Smyth***, Polaroid Corp., U.S. **INVITED**

Thin, flexible displays have long been considered ideal for portable display applications where weight, ruggedness and product packaging are critical performance criterion. Materials research and display assembly process development targeting flexible displays have resulted in low volume plastic display production using new materials on typical LCD production lines with comparable throughput. In order for flexible displays to become pervasive in the portable applications, new materials, equipment and processes which take advantage of high speed and low cost web assembly techniques will be required. As part of ongoing optical films research at Polaroid, new materials and processes have been developed which improve the performance of flexible displays as well as increase the potential throughput of production volume display manufacturing. A conductor film has been developed which incorporates a high temperature, low birefringence substrate and hard-coat with a thin film optical structure. The unique structure of the sputtered layers integrates high optical transmission, high electrical conductivity, and the ability to be directly patterned with commercially available, IR laser patterning equipment. This thin, durable film can be patterned in continuous rolls to enable web based display assembly. Conventional display assembly processes for edge seal and alignment layer curing and vacuum filling of liquid crystal have prohibitively long cycle times to be feasible for roll to roll display assembly. Fast curing edge seal adhesive and process conditions suitable for web based coating and drying of alignment layers have been developed. In addition, a novel display assembly process, which eliminates the need for vacuum filling, has been demonstrated.

10:00am **FP-TuM6 Growth of ITO and SiN@sub x@ Films on Polymeric Substrates For Flexible Displays**, ***P.F. Carcia***, *R.S. McLean, M.H. Reilly,* DuPont Central Research and Development

The discovery that classes of polymeric materials are electro-luminescent and the rapid progress in their development into a technology promise a revolution in future flat panel displays. Currently, the first devices are being manufactured on glass substrates. If, however, devices could be made on flexible polymeric substrates in a reel-to-reel process, this would reduce cost, improve ruggedness, and reduce weight. However, to achieve success on plastic substrates, barrier coatings are needed to exclude atmospheric gases that chemically degrade device performance, and low resistance transparent coatings are needed for efficient electro-optical performance. In this paper we investigate the relationship of the polymeric substrate and its surface morphology to the properties and structure of inorganic thin films, as examined by atomic force microscopy. Conducting ITO films were grown by rf magnetron sputtering and SiN@sub x@ films by both rf magnetron sputtering and ECR PECVD. ITO films had very small grain size, as deposited on unheated PET and PEN polymeric substrates, 2 mils thick , with sheet resistance of only about 15 ohms/square. These films were relatively thin (150-200 nm thick) with low stress and high optical transparency in the visible, and they were also surprisingly good barriers to oxygen transport. Because of their higher optical transparency, SiN@sub x@ films are more attractive in flexible polymer display devices as barriers for atmospheric gases. And SiN@sub x@ films 50 nm thick, synthesized by

ECR PECVD on PET and PEN film, were excellent barriers (<0.005 cc/m@super 2@/day-atm) to atmospheric gases. Finally, we will discuss a simple method to semi-quantitatively image defects in barrier films.

10:20am **FP-TuM7 Transparent and Conductive Ultra-barrier Coatings for Flexible Plastic Displays**, ***C.I. Bright***, Delta V Technologies

One of the major issues limiting fabrication and lifetime of flexible displays is the moisture and oxygen permeability of the polymeric substrates. The acceptable value of permeation depends on the sensitivity of the particular display technology. Another flexible displays issue is the low temperature capability of optical quality plastic substrates. This restriction on process temperatures has many implications in display fabrication. One example is the low conductivity of the Transparent Conductive Oxide (TCO) used for the necessary transparent electrode layer. An organic layer deposited by the Polymer MultiLayer (PML) process for vacuum evaporation of organic monomers and in-situ e-beam or UV polymerization has demonstrated excellent smoothing of substrate surfaces. When dielectric layers of Al@sub 2@O@sub 3@ or SiO@sub 2@ are combined with PML deposited organic polymer layers; outstanding barrier properties are achieved on flexible plastic film substrates. A PML base coat layer also should provide a clean smooth surface for bonding and nucleation of a deposited TCO. In this work, we combined a PML base coat and a TCO layer to form a transparent conductive barrier where the TCO functions as both the moisture and oxygen barrier, and the required transparent electrode for the display. Multiple pairs of polymer/TCO layers can be used to increase both barrier performance and conductivity, as needed, for a particular display technology. The experimental results for ITO sputtered directly onto a PET substrate, and with a PML acrylic base coat, in a roll-to-roll (web) coating process are reported. The optical, electrical and barrier properties for both constructions were measured and compared. Very preliminary barrier results show permeation values of 0.05 - 0.005 O@sub 2@ cc/m@super 2@/day, H@sub 2@O g/m@super 2@/day, for single layer ITO on a PET (0.007" thick) substrate.

10:40am **FP-TuM8 Fabrication of OLED Devices on Flexible, Ultra-barrier Plastic Substrates**, ***G.L. Graff***, *M.E. Gross, P.A. Mounier, M.K. Shi, M.G. Hall,* Battelle Pacific Northwest National Laboratory*; J.J. Brown, J.K. Mahon,* Universal Display Corporation*; C.I. Bright,* Delta V Technologies*; P.E. Burrows,* Princeton University

To develop displays on flexible polymeric film substrates, transparent ultra-barriers to oxygen and moisture must be provided. The acceptable value of permeation will depend on the sensitivity of the particular display technology. A multilayer film structure with alternate layers of organic polymer and metal oxide, has demonstrated oxygen and moisture permeation rates below the measurement limit of commercial instrumentation (<0.005 O2 cc/m2/day, H2O g/m2/day). This highly transparent, multilayer ultra-barrier coating was deposited by roll-to-roll compatible, vacuum deposition processes. The Polymer MultiLayer (PML) process for vacuum evaporation of organic monomers and in-situ polymerization, was used to deposit the organic layers. DC reactive magnetron sputtering was used to produce the aluminum oxide barrier layers. A transparent conductive coating of ITO was sputter deposited over these ultra-barrier layers to provide a transparent electrode for display construction. Typical performance for a 135 nm thick ITO layer, deposited on a double hardcoated PET (7 mil thick) substrate with ultra-barrier layers, was = 85%T and = 70 ohms/square. OLED devices have been fabricated using the flexible, ultra-barrier substrates, and preliminary device performance will be reported.

11:00am **FP-TuM9 Photoisomerization and Photo-induced Alignment of Azobenzene Containing Dyes and Polymers in Ultrathin Films Fabricated by the Alternate Polyelectrolyte Deposition (APD): Application for LC Displays**, *R.C. Advincula,* University of Alabama at Birmingham, US*;* ***M.-K. Park***, University of Alabama at Birmingham*; A. Baba, F. Kaneko,* Niigata University, Japan

The incorporation of a photochromic moiety in polymers is very attractive due to the possibility of creating new light-sensitive materials and optical devices. Ultrathin films containing photoisomerizable moieties, e.g. azo dyes are excellent materials for inducing control in LC molecules (command layer effects), holographic surface relief gratings, optical storage media, nanoscale applications, etc. In this work we have employed the alternate polyelectrolyte deposition (APD) on solid substrates to fabricate ultrathin films containing photoactive azobenzene groups. We investigated the combination of polymer containing azobenzene dye (PAZO)/ polycation (PDADMAC or PDDA) system and the small molecule dye Direct Red 80/PDADMAC system at various layer thicknesses. The uniform layer by layer assembly of the films was determined by UV-vis spectroscopy, ellipsometry, X-ray reflectivity, QCM, AFM, and SPS. The complex photoisomerization behavior reveals the importance of layer ordering, azobenzene mobility, and aggregation states in determining the future utility of these films. We utilized polarized UV-light to induce photoisomerization and photo-alignment of these ultrathin films. Hybrid LC Cells reveal in-plane homogeneous alignment. Correlation was made on the effect of film formation parameters to the overall film quality and layer ordering. We observed high anisotropies dependent on the dye, layer preparation, thickness, etc. LC Cells made from 5 CB reveal read/write capabilities dependent on the thickness and irradiation parameters. Future possibilities for LC and Large area display device modifications are envisioned.

11:20am **FP-TuM10 Plastic Liquid Crystal Displays from Conducting Polymer**, ***R. Shashidhar***, Naval Research Laboratory*; L. Huang, C. O'Ferrall,* Geo-Centers Inc./Naval Research Laboratory*; W. Fritz, J. Doane,* Liquid Crystal Institute **INVITED**

In a conventional liquid crystal display device (LCD), glass substrates coated with an indium tin oxide (ITO) layer are typically used for the application of an electric field to the liquid crystal material. For many applications, there is a need for a LCD with a plastic substrate. Polypyrrole is a well known conducting polymer for its high conductivity and chemical stability. Compared with the currently used ITO conducting layer, polypyrrole is more compatible mechanically with plastic. Because it is an organic material, it should be able to bend and flex with the substrate. Here we describe the preparation of polypyrrole films on a polyethylene terephthalate (PET) substrate by an in-situ solution deposition process and their patterning by conventional photolithography techniques. We will discuss their important physical properties, such as surface resistance and optical transmission and their suitability as a substitute for ITO as an electrode for a plastic reflective Cholesteric reflective LCD. We have demonstrated for the first time the operation of a fully multiplexed plastic (LCD) using conducting polymers (on plastic) as the substrates and the reflective cholesteric display technology. The resultant display has several features like lightweight, low power consumption, increased ruggedness, bistability, sunlight readability and flicker-free operation. The functioning of the conducting polymer-based LCD is demonstrated and the features that make it attractive for many applications are discussed.

Flat Panel Displays Topical Conference
Room 604 - Session FP+OE+EM-TuA

Thin Film Transistor Materials and Devices

Moderator: G.N. Parsons, North Carolina State University

2:00pm **FP+OE+EM-TuA1 Nanoprobing Electrical Transport in Organic Semiconductors*, C.D. Frisbie,*** University of Minnesota **INVITED**

Commercial interest in mechanically flexible plastic electronics is the key motivator behind efforts to fabricate transistors, light-emitting diodes, and lasers from organic thin films. Continued development depends on increasing comprehension of factors affecting charge carrier mobility. In particular, the importance of film microstructure on transport in organic films has been recognized, but is currently not well understood. In this talk, I will describe experiments designed to address microstructural effects on conductivity in polycrystalline organic films. Our approach is to probe transport in individual grains, or even small collections of grains, which we characterize by atomic force microscopy (AFM). Experiments have focussed on crystalline grains of the molecular semiconductor sexithiophene (6T). Isolated grains of 6T are grown by vacuum sublimation onto SiO2/Si substrates. The crystals range from 1-6 molecular layers (2-14 nm) in thickness with diameters on the order of a micron. In one approach, these thin crystals are contacted with source and drain electrodes fabricated by electron-beam lithography; heavily doped Si underneath the SiO2 serves as a gate electrode. The resulting transistor structures are used to probe field effect conductance and carrier mobility as a function of temperature (5-300K) and the number of discrete molecular layers in the crystals. The second experiment uses a conducting AFM probe as a positionable electrical contact to grains contacted by a fixed electrode at the other end. This configuration allows variation of the tip-electrode separation, yielding the single grain resistivity and an estimation of the organic-metal contact resistance. Resistances associated with defects, e.g., a single grain boundary between adjacent crystals, may also be measured. In both types of experiments, the conjunction of AFM imaging with transport measurements is critical to correlating transport properties with specific microstructures.

2:40pm **FP+OE+EM-TuA3 Photolithographically Defined Pentacene Thin Film Transistors on Flexible Plastic Substrates*, D.J. Gundlach,*** *C.D. Sheraw, H. Klauk, J.A. Nichols, J-R. Huang, T.N. Jackson,* The Pennsylvania State University

We report photolithographically-defined pentacene thin film transistors (TFTs) on flexible plastic substrates with performance similar to hydrogenated amorphous silicon (a-Si:H) devices. Organic TFTs fabricated on flexible plastic substrates are of interest for mechanically rugged, low-cost broad-area electronic applications. Pentacene TFTs with performance similar to a-Si:H TFTs have been reported,@footnote 1@ however, such devices are typically fabricated on oxidized silicon or glass substrates. Since photolithographic processing of organic semiconducting materials is problematic, such devices, including more recent devices on polymeric substrates,@footnote 2@ typically use source and drain contacts deposited through a shadow-mask after the organic active layer deposition. We have fabricated photolithographically-defined pentacene TFTs on polyethylene naphthalate (PEN) and polyimide (PI) films. For ease of processing, the films were mounted to silicon wafers using a pressure sensitive silicone adhesive and pre-shrunk by heating to 150°C for 1 hour in vacuum. A 30 nm thick Ni gate electrode, 160 nm thick SiO@sub 2@ gate dielectric, and 80 nm thick Pd source/drain contacts were deposited by ion-beam sputter deposition. The TFTs were completed by thermally evaporating pentacene onto substrates heated to 60°C. All deposited layers were photolithographically-defined using a two-layer resist lift-off process. Field-effect mobility larger than 0.3 cm@super 2@/V-s was extracted for TFTs on both PI and PEN film, current on/off ratio was greater than 10@super 5@, and subthreshold slope was less than 1.5 V/decade, all obtained using drain-to-source and gate-to-source biases of -30 volts or less. @FootnoteText@ @footnote 1@ Y-Y. Lin, D. J. Gundlach, S. F. Nelson, and T. N. Jackson, IEEE Electron Device Lett., vol. 18, pp. 606-608, 1997. @footnote 2@ C. D. Dimitrakopoulos, S. Purushothaman, J. Kymissis, A. Callegari, and J. M. Shaw, Science, vol. 283, pp. 822-824, 1999.

3:00pm **FP+OE+EM-TuA4 Reduced Process Complexity Organic Thin Film Transistors*, H. Klauk,*** *D.J. Gundlach, M. Bonse, T.N. Jackson,* The Pennsylvania State University

The performance of organic thin film transistors (TFTs) has improved dramatically over the past few years and recently, pentacene TFTs with carrier mobility of 0.6 cm@super 2@/V-s were demonstrated on glass substrates.@footnote 1@ The TFT device structure used in this earlier work required 4 material depositions and 4 lithography steps: one each for the gate, the gate dielectric, the source/drain contacts, and the pentacene active layer. Patterning of the pentacene layer is important to avoid leakage since pentacene TFTs often have large positive threshold voltage. We report here a simplified device structure for depletion-mode pentacene TFTs. Only 3 material depositions and 3 lithography steps are required and the same metal deposition is used for the gate electrode and the source/drain contacts. Gate-to-source and gate-to-drain overlap are not required, since the pentacene layer is normally conducting, thus allowing a drain current to flow at zero gate bias; devices are turned off by applying a positive gate bias. Palladium was used for the gate and source/drain metal, and low-temperature (80°C) ion-beam sputtered SiO@sub 2@ was used as the gate dielectric; both layers were patterned by lift-off. To pattern the pentacene active layer, a double-layer photoresist technique was used to create a reentrant profile over which the pentacene was deposited by evaporation. Upon deposition, the pentacene layer breaks over the resist profile, leaving isolated TFT areas. At a relatively low drain-source voltage of -20 V, devices have carrier mobility as large as 0.3 cm@super 2@/V-s, on/off current ratio near 10@super 5@, subthreshold slope as low as 0.9 V/decade, and threshold voltage between +10 V and +17 V. @FootnoteText@ @footnote 1@ Hagen Klauk, David J. Gundlach, Jonathan A. Nichols, and Thomas N. Jackson, "Pentacene Organic Thin-Film Transistors for Circuit and Display Applications," IEEE Transactions on Electron Devices, vol. 46, no. 6, June 1999.

3:20pm **FP+OE+EM-TuA5 Soft Lithographic Patterning and Low Temperature Film Deposition: Methods to Fabricate Amorphous Silicon Thin Film Transistors at Low Temperature*, H.-C. Jin,*** *J.R. Abelson, M.K. Erhardt, R.G. Nuzzo,* University of Illinois, Urbana

We fabricate amorphous silicon thin film transistors on glass substrates at low temperature (125@super o@C) using "soft" lithographic patterning in place of traditional photolithography. In soft lithography, polymer templates are formed on the film by holding an elastomer block containing the desired pattern in contact with the substrate, flowing an uncured precursor into the micro-channels of the pattern, then curing the polymer. Such templates replace photoresist for all etch and deposition steps, and have been successfully used for the fabrication of multilayer device architectures with micron-scale feature resolution. It appears possible to pattern sub-micron features, as well as large area and curved substrates. In this talk, we show the patterning methodology, preliminary results for TFT devices on planar and curved substrates, and discuss future prospects.

3:40pm **FP+OE+EM-TuA6 Low Damage Etching Utilizing Activated Hydrogen Beam for ITO Transparent Electrode in Flat Panel Display*, T. Miyata,*** *T. Minami, M. Ishii,* Kanazawa Institute of Technology, Japan

Recently, low damage dry etching has become necessary for transparent electrode patterning in flat panel display fabrication. This paper introduces a newly developed low damage and high rate etching technique utilizing an activated hydrogen beam to etch Sn-doped indium oxide (ITO) transparent conducting films. The etching was carried out using an apparatus consisting of an etching chamber and an activating chamber interconnected with a 0.9 mm-diameter orifice; the pressure in the activating chamber was higher than that in the etching chamber. The hydrogen gas introduced into the activating chamber was first activated by applying microwave power and then introduced through the orifice into the etching chamber. The etching was accomplished by the activated hydrogen beam acting on patterned photoresist coated ITO films placed on a sample holder. The etching rate was strongly dependent on conditions such as sample temperature, orifice-sample separation and pressure in the etching chamber. It should be noted that the ITO film was only etched at sample temperatures above 160@super o@C and the etching rate increased as the sample temperature was increased. A maximum etching rate above 50 nm/min was obtained at a sample temperature of 220@super o@C. These results suggest that ITO films are mainly etched by chemical reactions.

4:20pm **FP+OE+EM-TuA8 Excimer Laser Processing for a-Si and poly-Si Thin Film Transistors for Imager Applications**, ***J.P. Lu***, *P. Mei, R.T. Fulks, J. Rahn, J. Ho, Y. Wang, J.B. Boyce, R.A. Street,* Xerox Palo Alto Research Center **INVITED**

Pulsed Excimer-Laser Annealing (ELA) has become an important technology to produce high performance Thin Film Transistors (TFTs) for large area electronics. The application of these advanced TFTs in flat pannel displays@footnote 1@ and flat panel imagers for two-dimensional X-ray imaging have attracted much interest. TFTs made from laser crystallized poly-Si thin films with mobility higher than 100 cm@super 2@/Vs can be consistently achieved and are well suited for the integrated driver circuits. Recently, leakage currents as low as 2fA/µm at 5V for these poly-Si TFTs have been achieved and enable one to consider making flat panel imagers using a full poly-Si process. Laser doping@footnote 2@ or dopant activation is another important application of the ELA process. Using a laser doping process, we have fabricated a-Si TFTs with self-aligned poly-Si source/drain contacts. These new devices have reduced source/drain parasitic capacitance and their channel length can be easily scaled down without stringent lithography requirements. Excellent DC performance, such as low leakage current (0.02fA/µm), sharp turn on (0.44V/decade) and high mobility of a-Si TFTs are preserved. In addition, good AC performance of these self-aligned a-Si TFTs has been demonstrated in four phase dynamic shift registers operating at 250kHz. In this talk, these two areas will be reviewed along with a report on the current status in developing poly-Si TFTs and self-aligned a-Si TFTs using ELA process for flat panel imager applications. @FootnoteText@ @footnote 1@ J. G. Blake, M. C. King, J. D. Stevens III, and R. Young, Solid State Technology, p151, May 1997. @footnote 2@ P. Mei, G. B. Anderson, J. B. Boyce, D. K. Fork, and R. Lujan, Thin Film Transistor Technologies III, Electrochemical Soc. Proc., PV 96-23, p51 (1997).

5:00pm **FP+OE+EM-TuA10 Solid-phase Crystallization of Hydrogenated Amorphous Silicon-Germanium Alloy Films**, ***O.H. Roh***, *I.H. Yun, J.-K. Lee,* Chonbuk National University, Korea

We have investigated the solid-phase crystallization of hydrogenated amorphous silicon-germanium alloy (a-Si@sub 1-x@Ge@sub x@:H) films by using electron spin resonance (ESR) and x-ray diffraction measurements. The films were deposited on Corning 1737 glass in a plasma-enhanced chemical vapor deposition system using SiH@sub 4@ and GeH@sub 4@ gases. The substrate temperature was 200°C and the r.f. power was 3W. The films were then annealed to be crystallized at 600°C in a N@sub 2@ atmosphere. The total spin density first increased with annealing time due to hydrogen evolution, and then rapidly decreased as the film was crystallized. The Ge dangling bond spin density increased faster with annealing time than the Si dangling bond spin density. However, it was observed that the H evolution from Si-H bond and Ge-H bond was strongly affected by the Ge composition of the films.

Author Index

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