SYMPOSIUM J

Micro- and Nanosystems–Materials and Devices

March 28 - April 1, 2005

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* Invited paper

TUTORIAL

BioMEMS–Materials, Fabrication, and Devices
Monday March 28, 2005
8:30 AM - 12:00 PM
Room 2003 (Moscone West)

Micro- and nanofabrication techniques are increasingly employed in the development of biosensors, fundamental biological studies, and tissue engineering. This broad field of research, which is quickly expanding, is commonly referred to as bioMEMS. In this tutorial, the basic fabrication techniques commonly used in bioMEMS will be reviewed, promising devices highlighted, and the development and processing of new materials for sensor and tissue engineering applications described.

The tutorial will begin with an overview of the fabrication technologies typically used in the construction of bioMEMS. While this will include a brief summary of traditional technologies, such as surface and bulk micromachining, an emphasis will be placed on methods for fabricating polymer microsystems and patterning cellular materials. The second section of the tutorial will highlight work in area of devices. Numerous biosensors and systems have been developed for a range of applications from protein and DNA detection to drug delivery. Several promising devices will be discussed in terms of their application, operating principle, and fabrication process. The final section of the symposium will cover the development and selection of materials for bioMEMS. This section will provide an overview of the important characteristics of materials for applications in this area and will review recent efforts aimed at developing materials for sensor and tissue engineering applications.

Instructors:
Rashid Bashir, Purdue University
David A. LaVan, Yale University
Kevin Turner, Massachusetts Institute of Technology

SESSION J1: Metrology and Materials Characterization
Chair: Somuri Prasad
Monday Afternoon, March 28, 2005
Room 2003 (Moscone West)

1:30 PM *J1.1
Application of FIB and EBSD to Characterize MEMS Materials and Devices. Joseph R. Michael, Somuri V. Prasad and Brad L. Boyce; Sandia National Laboratories, Albuquerque, New Mexico.

Microstructural characterization of Microelectromechanical systems (MEMS) devices is a challenging task. Here, the samples are often too small to handle using conventional metallographic sample preparation techniques. In recent years, focused ion beam (FIB) has become a novel tool for preparing samples for electron microscopy. The ability of the FIB to produce samples from specific regions of a specimen, including those from microscopic regions of a test specimen or a device, is well suited for MEMS characterization. Electron backscatter diffraction (EBSD) is an ideal technique for linking microstructure and crystallographic texture. In this study, we have successfully applied FIB microscopy to prepare samples for TEM and EBSD analyses from MEMS devices and materials to develop a better understanding of device reliability. Many MEMS devices have relied on silicon, silicon oxides and nitrides as structural load-bearing members. There is an increasing need to use more conventional and damage-tolerant materials such as nickel or other metals in MEMS applications and there is a need to understand the mechanical limits and reliability of metallic MEMS devices. Currently, one path to produce metallic MEMS devices is through the electrodeposition of metals into deep x-ray photolithography formed molds. This process is called LIGA after the German acronym for Lithographie, Galvanformung, Abformung. This paper gives an overview of our current efforts on the application of FIB microscopy and EBSD techniques to characterize both silicon and metallic MEMS materials. We shall present two specific examples of our ongoing efforts to understand the role of fatigue and wear in MEMS materials using these two novel techniques.

2:00 PM J1.2
Electrical Characteristics of 1T/1R RRAM Device using ZrOx. Hyejung Choi, Dongsoo Lee, Yunik Son and Hyunsang Hwang; Department of Materials Science and Engineering, Gwangju Institute of Science and Technology, Gwangju, South Korea.

RRAM (Resistance Random Access Memory) is considered as new candidate for future memory device. The principle of RRAM is switching using the resistance difference. The resistance is changed by voltage sweep or voltage pulse and this phenomena is reported for many thin films such as chalcogenide glasses, PCMO, NiO and etc. Resistance switching mechanism is also studied for different models like defect filament model, charge trap model, and interface model. For most cases they have a MIS structure as substrate-thin film-electrode. In this study, we report on the fabrication of 1T/1R RRAM using non-stoichiometric zirconium oxide (ZrOx) and its electrical characteristics. 1T/1R RRAM structure has one resistor on the source part of the MOSFET, which can control drain current. Its advantage is amplification of role of RRAM. ZrOx is deposited in source part of MOSFET by RF reactive magnetron sputter at atmosphere of oxygen and argon mixture and annealed in oxygen condition. The $5\mu m$ and $0.3\mu m$ MOSFET is used and silicon oxide is used as gate oxide. Positive DC voltage sweep and voltage pulse is used as switching method. Reset voltage and set voltage is 1.0$\sim$1.2V and 1.4$\sim$2.8V. At pulse switching, pulse time is 100ns and this time is in reverse proportion to voltage. There is a 6 order of magnitude difference of drain current for high and low resistance condition. They showed good characteristics at retention and cyclic test. ZrOx RRAM has low cost compared to others, low power due to nonvolatile memory and high current ratio at 1T/1R structure.

2:15 PM J1.3
Modification of Deposition Process of Piezoelectric Polycrystalline Film by Hydrothermal Method - Improvement of the Deposition Process by Pre-Treatment Using Hydrogen Peroxide. Akito Endo[1], Norimichi Kawasima[1], Shinich Takeuchi[1], Mutsuo Ishikawa[2] and Minoru Kurosawa[2]; [1]Department of Biomedical Engineering, Toin University of Yokohama, Yokohama, Japan; [2]Tokyo institute of Technology University, Yokohama, Japan.

We deposited ferroelectric poly-crystals with perovskite structure on the titanium substrate processed using hydrothermal method, and have tried to develop ultrasoud probes using the ferroelectric poly-crystal films with thickness of $10\mu m$-$50\mu m$.We reported these results at 2003 MRS fall meeting in Boston and 2004 IEEE UFFC 50th anniversary joint congress in Montreal. We will report the pre-treatment method of the titanium substrate by corrosion with hydrogen peroxide solution in order to obtain more stable PZT poly-crystal nuclei for hydorothermal method on the substrate in this symposium. However, it was problem that elements in the ultrasound probes had unstable properties in spite of keeping constant concentration of source materials, constant synthesizing temperature and constant synthesizing time.The nucleation of PZT poly-crystals depends on the conditions of heterogeneous nucleation on the titanium substrate. Therefore, difference between the individual deposited elements depends on the surface condition of titanium substrate.The chemical cleaning process is employed as the cleaning treatment of titanium substrates before deposition in the conventional hydrothermal method. However, impurities or contaminations were removed from the surface of the substrate with the chemical cleaning process. This process can not control the roughness and chemical condition on the surface of titanium substrate.Therefore, it is important for suppression of the differences between individual elements to form poly-crystal nuclei with high quality stably.The surfaces of the titanium substrates with anticorrosion were corroded as pre-treatment with hydrogen peroxide solution.The surfaces of PZT poly-crystal films deposited on the titanium substrates with and without pretreatment were observed with SEM and compared.We could obtain the excellent quality deposited PZT poly-crystal films without pinhole on the titanium substrate with pre-treatment using hydrogen peroxide solution.When crystal structure was measured by XRD, the peaks of high diffraction intensity corresponding to PZT were observed on the PZT poly-crystal films deposited on the titanium substrates with pre-treatment.It confirmed that the good poly-crystal nuclei is formed.When the composition rations between Zr and Ti were measured on the deposited PZT films with EDS.These results were independent on the titanium substrates with and without pre-treatment.Thickness of the deposited PZT poly-crystal films on the substrate with the pre-treatment was about 65% of thickness of those without pretreatment.The density and Young's modulus were increased to about165%, and the piezoelectric constant d31 was increased to about 250% by pre-treatment.The standard deviation of the thickness of deposited PZT film was suppressed to about 40%, and that of the density was about 50% by the pre-treatment. Consequently, we confirmed the validity of pre-treatment of titanium substrate using hydrogen peroxide solution.

2:30 PM J1.4
Micromirror Arrays for High Temperature Operation. Mahmoud Fuad Almasri and A. Bruno Frazier; Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, Georgia.

This paper describes the design, modeling, fabrication, testing and the associated electronics for electroplated electrostatic torsion micromirror arrays. The goal of this research was to develop novel micromirror arrays optimized for high temperature operation for use in epitaxial systems such as MOCVD and MBE to define device structure and hence eliminates the need for etching and lithography. Metallic micromirror arrays of 5×5 and 16×16 elements were fabricated with an approximate array area of 0.5×0.5 mm2 and 1×1 mm2, respectively. The micromirrors were structurally composed of primarily electroplated nickel, a mechanically durable material with a high glass transition temperature with controllable residual stress. The micromirror elements were designed with a hexagonal geometry to provide a high fill factor and uniform stress distribution. Two circular dimples (actuation stops) were designed into the micromirrors to control the maximum tilt angle and to prevent shorting of the actuation electrodes. The torsion beam was designed with three different shapes, straight bar, serpentine shape and rectangular shape in order to optimize the voltage necessary to tilt the micromirror. Each pixel in the 5×5 array was operated individually by entering the data into Labview interface, while in the 16×16 arrays each pixel was controlled via row and column. The actuation signal was sent to the micromirror array via a microcontroller for toggling the appropriate micromirror. The microcontroller output was amplified by a voltage converter. Electrostatic driving force was used to actuate the individual micromirror elements in the array providing relatively large rotation angles of ±10 oC for incident beams of light. The use of electrostatic actuation provides a stable, relatively temperature independent method for controlling the tilt angle of every pixel. Furthermore, finite element analysis using ANSYS/Multiphysics simulation package has been employed to determine the micromirror geometries and to provide accurate prediction of the mirrors performance such as the voltage required to rotate the mirror by 10oC, resonance frequency, stress distribution, and structural displacements in the Z-direction, and. A voltage in the range of 120-200 volt was required to rotate the small micromirror by 10oC. In addition, the micromirror was operated at a resonance frequency between 550-600 Hz. A comparison between the experimental and simulated results showed excellent agreement. In addition, the micromirror showed high reflectance of 100%, the measurement was performed with an FTIR. Finally, the nickel electroplated micromirror surface has a smooth and very flat surface. The surface roughness was measured by atomic force microscope (AFM).

2:45 PM J1.5
Recent Development of the Surface Nanocrystallization by SMAT (Surface Mechanical Attrition) and the Effect on the Mechanical Behavior. Jian Lu[1] and Ke Lu[2]; [1]LASMIS, Mech. Syst. Engg, UTT, Troyes, France; [2]SYNL, Institute of Metal Reserach CAS, Shenyang, China.

This talk will summarize the recent work related to a kind of new nanomaterials produced by the SMAT(surface mechanical attrition treatment).The concept of surface nanocrystallization of metallic materials will be presented. In terms of the grain refinement mechanism induced by plastic deformation, a novel surface mechanical attrition (SMA) technique was developed for synthesizing a nanostructured surface layer on metallic materials in order to upgrade the overall properties and performance. The different process of SMA technique and the nanostructure of the SMA-treated surface layer will be described. The grain refinement mechanism of the surface layer during the SMA treatment will be analyzed in terms of the nanostructure observations in several typical materials (Fe, Cu, Stainless steels, Ti, etc.). The nanostructured layer with a grain size of 10 to 15 nm was generated on the surface of material up to a depth of 50 micrometer. Significant enhancements in mechanical properties of the nanostructured surface layer in different materials will be analyzed. The evidence obtained so far has already indicated that a nanostructured surface layer synthesized by means of SMAT on metallic materials provides many unique opportunities in terms of both basic scientific research and technological applications. Very high yield stress (5 times of the base material) on the surface layer of the material obtained by the SMAT has been observed in stainless steel 316L. The effect of surface nanostructures on the mechanical behavior and on the failure mechanism of metallic material shows the possibility to develop a new strength gradient composite. The role of residual stress induced during the treatment will be investigated and discussed. The developed materials are also porosity free materials which can be used as reference material for the local mechanical behavior investigation technique such as the nanoindentation. The first results show that the SMAT is a new efficient process for increasing the wear and corrosion behavior of the materials using the hybrid treatment. So many industrial applications including the development of high performance materials for MEMS applications using the nanostructured surface layer (10 to 50 micrometer)as a base material for small size components can be anticipated. New diffusion properties of the nanostructured surface show a high potential new route for the nanomaterial development. The so-called concept of the nanostructure selective reaction will be explained.

SESSION J2: Surfaces and Interfaces
Chair: Cengiz S. Ozkan
Monday Afternoon, March 28, 2005
Room 2003 (Moscone West)

3:30 PM *J2.1
Electrodeposition of High Aspect Ratio Microstructures Through Thick Resist. James Kelly, Steve Goods and Alec Talin; Sandia Natl Labs, Livermore, California.

Electrodeposition through thick resist such as polymethylmethacralate (PMMA) or SU8 has enabled the fabrication of metallic high aspect ratio microstructures. The most commonly deposited metal for this purpose is nickel, usually electroplated from a sulfamate electrolyte. When the electroformed microdevice is to perform a mechanical function (such as in the case of an actuator, for example), the mechanical properties of the electrodeposited nickel are of interest. For example, the material may need to possess a certain yield strength for the device to function properly, or the modulus must be known to design for a desired elastic response. In order to obtain the required mechanical properties, the grain size and texture of the electrodeposit must be controlled. In this presentation, the various electrolyte parameters that may be used to influence deposit structure and properties will be considered. The grain size of electrodeposited nickel is often refined by codepositing other elements, such as Fe, Co, or Mn. These approaches for depositing high strength Ni alloys will be compared and contrasted with emphasis on the unique challenges posed by electrodeposition into deep, high aspect ratio cavities. The texture, unique for each alloy, will be presented as well. The through-thickness and across-wafer uniformity of the deposited material will be discussed. Other, often unintended electrolyte parameters (such as pH, temperature, and breakdown species) that may affect grain size and texture will be presented; often, these unintended aspects may govern the deposit nucleation and growth process, resulting in deposits with unacceptable morphologies despite the presence of other intentionally added species that would otherwise lead to a desired result. Finally, the application of low-friction coatings on electroformed microdevices will be considered. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

4:00 PM J2.2
Anchoring of Organic Molecules on Cu(001) Surface through S-Headgroup. Patrizia Monachesi[1], Letizia Chiodo[2], Fabio Bussolotti[3], Maria Grazia Betti[4] and Carlo Mariani[5]; [1]Dipartimento di Fisica, Universita' dell'Aquila and INFM, L'Aquila, Italy; [2]Dipartimento di Fisica, Universita' di Roma "Tor Vergata" and INFM, Roma, Italy; [3]Dipartimento di Fisica, Universita' di Modena and INFM CRS-S3, Modena, Italy; [4]Dipartimento di Fisica, Universita' di Roma "La Sapienza" and INFM CRS-SOFT, Roma, Italy; [5]Dipartimento di Fisica, Universita' di Roma "La Sapienza" and INFM CRS-S3, Roma, Italy.

An important topic of molecular electronics is the functional characterization of self-assembled monolayers of organic molecules, on the nanometric scale, grown on traditional materials, like noble metals. Recent experiments [C. Mariani et al, Phys. Rev. B 66, 115407 (2002)] of angular resolved high-resolution UV photoelectron spectroscopy (AR-HRUPS) involving the aromatic molecule C_7H_5NOS on the Cu(001) surface have focused on the formation of dispersive molecule-substrate electronic states. Theoretical calculations performed 'ab initio' in the Density Functional Theory [P. Monachesi et al, Phys. Rev. B 69, 165404 (2004)], have well reproduced the spectral density of the S-metal electronic states, allowing for the assignement of the structures observed experimentally. Recent AR-HRUPS measurements [F. Bussolotti et al, Surf. Sci. 2004, in press] yield density of states and dispersion of the electronic states of the system CH_3S-metal, whose S-headgroup is again functionally devoted to the chemisorption of the whole molecule. Here we focus on the adsorption on Cu(001) of C_7H_5NOS and CH_3S. The surface reconstruction is different in the two cases and also depends critically, in the case of CH_3S, on coverage and on adsorption temperature. The observed reconstructions are p(2×2) (S/Cu(001), C_7H_5NOS, CH_3S at low coverage and room temperature), c(2×2) (CH_3S at low coverage and low temperature), and c(2×6) (CH_3S at high coverage and room temperature). The interface we theoretically model is formed by the S overlayer and the Cu subsurface layer. The S-Cu hybrids are reproduced quantitatively by present theoretical calculations performed 'ab initio' in the Density Functional Theory. In particular, we reproduce quantitatively the width of the dispersion of the S-Cu hybrids and the fingerprint of the bonding states in the DOS for the p(2×2) and c(2×2) reconstructions. In conclusion, we have characterized experimentally and theoretically the electronic properties of the S/Cu interface in two molecule-metal systems and shown that the S-headgroup realizes the anchoring of these molecules to the Cu(001) surface.

4:15 PM J2.3

In-Situ Pretreament Approach for Surface Deterioration Alleviation Amidst Thermal Desorption of Si (100).

Arthur Pun[1], Xu Wang[1], Jamie Meeks[1], Steve Durbin[2] and Jim Zheng[1]; [1]Electrical and Computer Engineering, FAMU-FSU College of Engineering, Tallahassee, Florida; [2]MacDiarmid Institute for Advanced Materials and Nanotechnology, University of Canterbury, Christchurch, New Zealand.

Forgoing to silicon-based device construction, manufacturers typical discard wafer native oxide layers utilizing thermal desorption as the favored means over ion bombardment and chemical etching due to simplicity, usage ease, and minimal contamination. However, as the thermally driven chemical reaction necessary for oxide reduction transpires, the wafer surface rapidly deteriorates requiring the necessity for homoepitaxial growth of micro-meter thick buffer layers to restore surface integrity. This customary procedure is undesirable due to the time and material utilized and furthermore without the assurance of eliminating stacking faults. Thus, it is highly beneficial to develop a method to frustrate the chemical reaction from etching the wafer surface, with such secondary goals as expedient implementation, readily integratable into existing systems, and financially beneficial. Within this article, a novel in-situ method is proposed as a modification of thermal desorption utilizing pretreatment which can be applied to systems subject to material deposition, substrate heating, and creation of non-oxidizing environments (vacuum or inert atmosphere). Following the theoretical development of this proposed method, involving the fueling of the oxide-reduction reaction with segregated sacrificial material, the method is demonstrated experimentally on Si (100) wafers utilizing ex-situ atomic force microscopy for resulting surface topography analysis and in-situ reflective high-energy electron diffraction for crystalline information during the modified thermal desorption progression. Experimental results utilizing pretreatment durations under 60 seconds indicate a significant reduction in surface roughness of 75%, from an average value of 2.20 nm to 0.56 nm, while resulting in crystalline surfaces indicative of suitability for further epitaxial growth. Furthermore, results yield indirect information regarding initial chemical information of the native oxide as well as insight into thermal desorption surface kinetics.

4:30 PM J2.4

Interface Phenomena in MEMS Switches and Relays.

Lior Kogut and Kyriakos Komvopoulos; Department of Mechanical Engineering, University of California at Berkeley, Berkeley, California.

Microelectromechanical systems (MEMS) technology has the potential to replace traditional solid-state devices, in response to demands for broader operating temperature range, higher breakdown voltage, and much higher off-state resistance. Interest in MEMS switches and relays has surged recently, principally due to the enhancement of the switching performance with radio-frequency (RF) signals. However, various complex interface phenomena often limit the performance and lifetime of microswitches and microrelays. Therefore, the development of reliable, high-performance MEMS switches and relays requires basic understanding of the dependence of the functionality and longevity of these microdevices on interface behavior controlled by different mechanisms that depend on the material properties, applied voltage, and operation environment. One of the principal objectives of this study was to provide a critical appraisal of the role of various interface phenomena on the stable operation and long-term use of MEMS switches and relays. Emphasis is given on the dependence of pull-in voltage on surface topography, enhancement of the electric field at surface asperities and its effect on trapped charges, electrical breakdown across microgaps and its role on surface erosion and microdevice failure due to permanent adhesion (stiction), limitations in switching frequency range and microdevice longevity due to contact bouncing, electrical contact resistance, and implications of power dissipation at the contact interface in thermal softening and/or microwelding of the interacting surfaces. The analysis of the various interface phenomena is accompanied by a description of the operation modes of RF microswitches and ohmic microrelays. In view of the importance of surface topography in surface interaction, special MEMS devices for measuring the topography of top and bottom surfaces are discussed, in conjunction with a scale-invariant method based on fractal geometry, appropriate for unbiased surface topography description. Surface topography effects on the capacitance of closing-gap actuators lead to important phenomena, which are ignored when the surface are assumed to be smooth. For example, when surface topography is taken into consideration, intense electric fields are produced at surface asperities, and the enhanced electric field can be two orders of magnitude higher than the smooth-surface electric field. An excess electric field may increase the density of trapped charges through charge injection or electrical breakdown of the gas between the electrodes, hence increasing the likelihood for stiction of the microswitch. Surface topography, mechanical properties, and adhesion forces influence contact bouncing. This degrades the microdevice performance by increasing the transition time between the instant that the control voltage is applied and the instant that the signal is allowed to flow without interruption.

4:45 PM J2.5

Crystallization of Amorphous Sputtered NiTi Thin Films.

Ainissa G. Ramirez, Hoo-Jeong Lee, Hai Ni and David T. Wu; Mechanical Engineering, Yale University, New Haven, Connecticut.

Sputtered NiTi thin films require a crystallization step, since the as-deposited state is amorphous. The overall crystallization process is driven by nucleation and growth, and the resulting microstructure dictates the martensitic transformation behavior and its actuation properties. Using in situ transmission electron microscopy, we directly observed the crystallization of amorphous NiTi and present the full kinetic description using the Johnson-Mehl-Avrami (JMA) theory. Thin films were sputtered onto micromachined silicon-nitride membranes and subjected to in situ heating and cooling conditions. The electron-transparent membranes constrained the NiTi films and rendered it possible to observe the complete transformation cycle, which includes: the crystallization of the amorphous phase to austenite with heating; and the conversion of austenite to martensite with cooling. With this analysis we are able to correlate the resulting microstructure to temperature. Such insights contribute to the development of materials with optimal (actuation) properties.

SESSION J3: Reliability and Packaging

Chair: Roya Maboudian
Tuesday Morning, March 29, 2005
Room 2003 (Moscone West)

8:30 AM J3.1

A Detailed Study of Hydrogen Annealing Process Effects on Silicon (011) Nano Structures.

Rownak Jyoti Zaman[1], Weize Xiong[2], Andrea Franke[1], Rudy Quintilla[1], Nirmal Chaudhury[3], Thomas Schultz[3], Rinn Cleavelin[2], Rick Wise[2], Mike Pas[2], Shaofeng Yu[2], Klaus Schruefer[3] and Sanjay K. Banerjee[4]; [1]ATDF, Inc, Austin, Texas; [2]SiTD, Texas Instruments Inc, Dallas, Texas; [3]Infineon Technologies, Munchen, Germany; [4]University of Texas at Austin, Austin, Texas.

In this paper we report, for the first time, a systematic study of the impact of hydrogen (H_2) annealing process conditions (temperature, pressure and time) on rectangular silicon nano wires (surfaces in the (011) planes by Reactive Ion Etch (RIE)) suitable for MugFET as well as the significant and crucial role of surface preparation prior to the annealing. Using scanning electron microscope for top down profile, AFM for 3D line profiles and AFM technique [1], we studied the surface roughness changes with various H_2 anneal conditions. Temperature plays important role in the Fin-shape transformation. Temperatures 700^{0}C and above, for the same ambient pressure and time in H_2 cause significant silicon atom diffusion. All narrow bulk silicon lines without any hardmask (HM) disappear for high temperature anneals (900-1000^{0}C) in 15Torr (T) H_2 due to high surface self-diffusion of silicon atoms. Wider lines survived with corner rounding, consistent with the published literature [2]. However, narrow structures with a hardmask trim the lines to the hard-mask width. It has been observed for the first time that 700^{0}C anneals for SOI wafers cause topside rounding. The presence of Buried Oxide (BOX) tends to work like a catalyst and expedites the rounding process. Anneal at 15T on bulk silicon results in more shape transformation. Higher pressure anneals (600T) showed less curvature in base profile for narrow lines and less silicon loss. Anneals at and above 800^{0}C also cause pronounced faceting of the silicon lines of various lengths and rounded cross-section on SOI substrate. Source-drain faceting is more pronounced with longer anneals. Anneal at 800^{0}C, 30s 600T in H_2 is sufficient to result in improved sidewall surface roughness from RIE for small 3-D features of 60nm. The RMS value of the sidewall roughness for the 800^{0}C, 30s annealed sample is 0.76A and better than cleaned polished silicon wafer. Anneals at 700^{0}C and below show no SD facets, and even a 300s anneal has too low a thermal budget to reduce the surface roughness. For the first time, we observed that a clean before a H_2 anneal plays a significant role in silicon loss in the presence of SOI oxide. The surface preparation is critical since the hydrophobic surface helps H_2 anneal to keep the silicon loss to a minimum level. Surfaces cleaned with "HF last" process with "Marangoni dry" creates a thin layer of chemical oxide. The presence of chemical oxide causes lifting of narrow lines and rapid silicon loss. To create a good hydrophobic surface, wafers are cleaned by Piranha, HF, SC1, SC2, DI, Spin Dry, and Vapor HF, dilute HF in the Spin Dry cycle and can prevent extra silicon loss.

The anneal temperature does not affect the narrow silicon lines on SOI substrate as much as the clean before anneal. Reference: 1.Fin sidewall micro-roughness measurement by AFM- C. Gondran, et. al, MRS 2004 2.Shape transformation of silicon trenches during hydrogen annealing- H. Kuribayashi, et. al, JVS, 2003

8:45 AM J3.2
Layer-by-Layer Metallic and Ceramic Photonic Crystals Fabricated by Soft Lithography for Optical Regime.
Jae-Hwang Lee[1,3], Chang-Hwan Kim[1,3], Yong-Sung Kim[1,3], Henry Kang[2,3], Wai Leung[3], Rana Biswas[1,3], Cha-Hwan Oh[4], Kristen Constant[2,3] and Kai-Ming Ho[1,3]; [1]Department of Physics and Astronomy, Iowa State University, Ames, Iowa; [2]Department of Material Science and Engineering, Iowa State University, Ames, Iowa; [3]Ames Laboratory DOE, Ames, Iowa; [4]Department of Physics, Hanyang University, Seoul, South Korea.

We present fabrication methods and optical data of 3D metallic and dielectric photonic crystals. The fabrication methods are based on soft lithographic techniques that include layer-by-layer template fabrication, structure alignment and ceramic infiltration. These methods can be easily extendable for introduction of defects in 3D photonic crystals. With these techniques, freestanding metallic crystals and titania crystals on a silicon substrate have been fabricated. Since the crystals have systematical spatial deviations in their structures, structure-dependent optical properties were investigated in a single sample by means of an infrared spectral imaging. We will present the effect of alignment errors on the optical signature in the 3D photonic crystals fabricated by these methods. The tolerance of alignment for both metallic and dielectric 3D photonic crystals will also be discussed.

9:00 AM J3.3
Temperature and Solution pH Effects on Cohesive and Adhesive Fracture of Silica/Adhesive/Polyimide Thin Film Systems. Louise Y. Wang and Reinhold H. Dauskardt; Materials Science and Engineering, Stanford University, Stanford, California.

Epoxy resins blended with silane coupling agent are widely used as adhesives between passivated substrates and polymeric films. Although such adhesive layers have high fracture toughness with fracture energies in excess of 500 J/m2, the silica/adhesive interface and the adhesive itself may be susceptible to environment assisted fracture. In this study, the effects of temperature and pH on the adhesive and cohesive fracture behavior of silica/adhesive/polyimide thin layered structures are examined under different loading mode mixities typical for a range of microelectronic device packages. The relationship between the debond growth rate (da/dt) and the applied strain energy release rate (G) in mode I was evaluated using fracture mechanics techniques. As expected, the thin film system exhibited higher crack growth rates with increasing temperature due to faster crack tip reaction kinetics. In addition, at higher temperature, the debond path moved from the adhesive to the silica/adhesive interface. Similar behavior was also apparent for very low crack growth rates approaching the threshold loads for crack growth. This resulted in two distinct regions of behavior observed on the da/dt vs. G curve. Furthermore, the crack path was also sensitive to the pH character of the testing solution. Neutral and basic solutions favored debonding of the silica/adhesive interface. The effect of loading mode mixity and possible mechanisms for the subcritical crack growth process and debond path selection are described in terms of competing reaction mechanisms.

9:15 AM J3.4
Detection of Residual Stress in Silicon Carbide MEMS by μ-Raman Spectroscopy. John C. Zingarelli[1], Michael Marciniak[1] and Jason R. Foley[2]; [1]Department of Engineering Physics, Air Force Institute of Technology, Wright-Patterson AFB, Ohio; [2]Munitions Directorate, Air Force Research Laboratory, Eglin AFB, Florida.

Micro (μ)-Raman spectroscopy is used to measure residual stress in two silicon carbide (SiC) poly-types: single-crystal, hexagonally symmetric 6H-SiC, and polycrystalline, cubic 3C-SiC thin films deposited on Si substrates. Both are used in micro-electro-mechanical-systems (MEMS) devices. The 6H-SiC structures are bulk micro-machined by back etching a 250-μ-thick, single-crystal 6H-SiC wafer (p-type, 7 Ω-cm, 3.5-degrees off-axis) to form a 50-μm thick diaphragm. A Wheatstone bridge, patterned of piezoresistive elements, is formed across the membrane from a 5-μm, 6H-SiC (n-type, doped 3.8 x 10^{18} cm^{-3}) epilayer; the output of the bridge is proportional to the flexure of the MEMS diaphragm. For these samples, the μ-Raman spectroscopy is performed using a Renishaw InVia Raman spectrometer with an argon-ion excitation source (λ = 514.5 nm, hν = 2.41 eV) with an approximate 1-μm^2 spot size through the 50x objective. By employing an incorporated piezoelectric stage with submicron positioning capabilities along with the Raman spectral acquisition, spatial scans are performed to reveal areas in the MEMS structures that contain residual stress. Shifts in the transverse optical (TO) Stokes peaks of up to 2 cm^{-1} along the edge of the diaphragm and through the piezoresistors indicate significant material strain induced by the MEMS fabrication process. The phonon deformation potential in both SiC poly-types is measured to quantify the material stress as a function of the shift in the Raman peak position. The line center of the TO Stokes peak is shifted by applying a uniform stress to the sample using a four-point strain fixture and monitoring the applied stress using a strain gauge, while the μ-Raman spectrum is being measured. A spectral analysis code tracks the shift of the Raman peak position with respect to the line center of the Rayleigh peak to account for any thermal drift of the spectrometer during the time of the area scan. 3C-SiC films, with thicknesses ranging from 1.5-5 μm and are deposited by CVD on (100) Si substrates, are also investigated to determine their residual stress via their Raman spectral characteristics. An ultraviolet excitation source (λ = 325 nm, hν = 3.82 eV) is determined to be more effective for the detection of Raman shifts in these thin films than the 514-nm source, since the absorption coefficient in SiC at 300 K at 325 nm is 3660 cm^{-1}, while that at 514 nm is less than 100 cm^{-1} (dependent on doping level). In addition, the Si substrate is less Raman active at 325-nm excitation, leading to a lower relative amplitude than that at 514.5 nm and increasing the signal-to-noise ratio (SNR) of the SiC Raman spectrum. Since SNR is also increased by increasing absorption length, the thicker films of the 3C-SiC are preferable for measuring Raman spectra. The phonon deformation potential of thin-film 3C-SiC is determined using the same method described for the bulk 6H-SiC samples.

9:30 AM J3.5
The Electrical Contact Resistance and Adhesion of Intermixed Metal Thin-Films for Use in MEMS Contact Switches. Daniel J. Dickrell, Michael T. Dugger, Paul T. Vianco and Ron S. Goeke; Sandia National Laboratory, Albuquerque, New Mexico.

The performance and reliability of MEMS Ohmic contact switches is strongly influenced by the material properties of the interface. Contact material selection is an important decision in the device design process that affects electrical resistance and surface adhesion. These attributes are of particular concern, since the functional degradation of electrical contact MEMS devices is often dependent on electrical contact resistance and adhesion. Traditional MEMS electrical contact materials, most often noble metals like gold and platinum, have shown to be moderately capable at satisfying the electrical resistance requirements of MEMS switches but are often highly adherent and proficient adsorbents of contaminants, which negatively affects device performance. A proposed method to reduce the adhesion and maintaining acceptable electrical conductivity is to form multiple layer contact metal films in situ by controlled annealing and diffusion processes. The goal of this controlled diffusion process is to tailor the surface properties of an electrical MEMS contact in order to address as many degradation mechanisms as possible. AuGe and AuCo intermixed thin-film systems were identified as potential candidates for new MEMS electrical contact materials. Direct contact testing at typical MEMS device applied force and electrical loads were conducted for both noble metal and intermixed thin film material pairs using a nano-indentation apparatus. Electrical contact resistance and adhesive pull-off force measurements were recorded during cyclic surface contact for all materials. Current-voltage sweeps were also performed to asses the Ohmic nature of the contacts. Relative contaminant adsorption ability and cleaning effectiveness of noble and intermixed thin films was also determined by surface analytical techniques. All results are discussed in terms of the needs for MEMS electrical contacts and how the new films satisfy those needs in comparison to traditional contact materials.

9:45 AM J3.6
Strain Sensitivity in Conductor-Modified Polymers.
Eerik Hantsoo[1], Yanan Zhao[1], Vanessa B. Chial[1], Kevin Chan[1], Kenneth Wu[1,2] and Beth L. Pruitt[1]; [1]Mechanical Engineering, Stanford University, Stanford, California; [2]Materials Science and Engineering, Stanford University, Stanford, California.

This study evaluates the mechanical and electrical properties of conductor-modified polymers. Specifically, it addresses 2 types of polydimethylsiloxane (PDMS) modified for conductivity: PDMS coated with gold film and PDMS coated with graphite-based ink. Owing to the low modulus (1.2 MPa) and ease of processing PDMS, the material has great potential for soft-tissue sensors and implantable medical devices. We present recent progress in this new class of polymeric high-elongation strain sensors, and we continue to optimize the fabrication process and characterize the materials. This paper addresses fabrication process, testing procedures, and resulting electromechanical properties. Fabrication Dow Sylgard 184 Silicone Elastomer, mixed 10:1 by mass with crosslinker, was degassed and cured in a micromachined SU-8 mold. Samples were 250μm thick with a gage length of 20mm. 2 types of composites with conductive films were fabricated. Gold-modified samples were coated with a 5nm chromium adhesion layer by e-beam evaporation, followed by a 100nm layer of gold. Graphite-modified samples were squeegeed with Creative Materials, Inc.'s 123-27 Electrically Conductive Silicone Ink and dried. Testing Samples were loaded in uniaxial tension on an MTS Bionix 200 tensile tester. We modified the tensile tester to monitor electrical resistance in addition to stress and strain, to obtain data on "piezoresistance" and gauge factor. Resistance data were collected with a Keithley 487 Picoammeter and logged in LabVIEW. Results Particularly in the carbon-modified sample, large strains (up to 100%) are possible with a sustained resistance signal. A clear, linear trend up to 65% strain dominates its resistance vs. strain plot. Resistance rises more sharply above 65% strain, losing linearity. The conduction path breaks at 100% strain and the substrate yields shortly thereafter. In hysteresis plots of 5% strain-relaxation cycles, stress fluctuates ±10% from its baseline vs. strain. Resistance fluctuates ±1.8% from its baseline vs. strain. The sample exhibits a gauge factor of 4.2. In the case of gold, strains above the ultimate strain of a freestanding 100nm film (1.53%, Haque and Saif, PNAS, 27 April 2004) are not achieved. At high strains the gold film itself fractures, breaking electrical continuity. These findings are not in line with another study reporting finite resistance up to 23% strain in gold-modified PDMS (Lacour et al., APL, 14 April 2003). According to Lacour, the mechanism that allows extension beyond the ultimate strain of freestanding gold is unfolding of residual stress from evaporation in the gold film. Thin trace geometry forms anisotropic ripples in the gold, which unfold at high strain; however, the blanket film geometry tested in our work to date does not induce the same buckling. Work on replicating these results will continue in the coming months, employing shadow masks to generate conduction paths of different geometries.

SESSION J4: Tribology

Chair: Mihri Ozkan
Tuesday Morning, March 29, 2005
Room 2003 (Moscone West)

10:30 AM *J4.1

Surface and Materials Issues for High Reliability MEMS.

Roya Maboudian, Chemical Engineering, UC Berkeley, Berkeley, California.

This presentation will consist of two parts. In the first part, the tribological issues in MEMS are discussed. Despite much progress in surface micromachining technology, adhesion, friction and wear (tribology) remain key issues, severely limiting the reliability of many MEMS devices. I will describe the use of molecularly thin organic films as anti-stiction coatings for MEMS. The various classes of organic films explored for MEMS are briefly reviewed. Current shortcomings of these coatings include the serious constraints that they put on MEMS packaging processes, and their susceptibility to wear and charge build-up. Many applications impose demanding requirements, such as high resistance to wear and elevated temperatures. In the second part of my presentation, I will describe the integration of silicon carbide as a hard coating as well as structural material for high reliability MEMS.

11:00 AM J4.2

Characterization of Ti/TiN and TiN Conductive Layers for High Temperature MEMS Devices.

Peter Lange[1], Birger Ohlsen[2], Sebastian Puls[1] and Joerg Syre[1]; [1]MST, FhG-ISIT, Itzehoe, Germany; [2]FH-Westkueste, Heide, Germany.

New thin film conductive layers for heating and sensing in MEMS devices operated at high temperatures are reported. In applications such as calorimetric and anemometric flow sensors, thermopiles and gas sensors the resistors have to withstand temperatures of several hundreds degree of Celsius. Thereby degradation effects have to be prevented, otherwise the external/interal signal conditioning circuit could not work properly. Ti and TiN thin films are state of the art technology in MOS devices as diffusion barrier between Si and Al or Cu. Because of this proven compatibility with front end MOS technology we have investigated these films for the application as heating and sensing elements. The Ti films were covered with thin TiN layers for the protection against interdiffusion/oxidation effects. These layers are deposited on a membrane (SiO2/Si3N4) of 1 micron thickness in a reactive sputtering process. After structuring the film the resistor lines are meanderlike with lines and spaces of 5 micron. Subsequent a passivation layer of 1 micron thickness is deposited. The response to elevated temperatures, the temperature coefficient (TC), the resistivity and the crystallographic structure were examined. The achieved temperature was calculated using the TC value. In addition temperature measurements were carried out by thermography. The Ti /TiN thin film consists of a sandwich of 25nm TiN, 650 nm Ti and 50 nm TiN. The TC of this stack was measured with 3830 ppm/K. This value agrees well with reported data of 3800 ppm/K. The resistivity was measured via sheet resistance with 44 micro Ohmcm and fits also to reported data in the range of 40 to 54 micro Ohmcm. The structure is a polycristalline hexagonal closed packed alpha-phase with grainsizes of 0.2 to 0.5 micron. So far these properties of thin film Ti reveal no significant difference from those of bulk Ti. The temperature stability of the resistance exceeds 380 C. Above this point a distinct degradation of the resistance (hysteresis) could be observed. The TC of a TiN layer with 500 nm thickness was measured with 750 ppm/K (fig. 5) and is reported for the first time. The resistivity was measured with 115 micro Ohmcm in agreement with reported data. Temperature stressing was possible until 600 C, at higher temperatures a degradation in the passivation layers occured. Up to this point no hysteresis was observed. Overall these two materials show excellent characteristics. Both are compatible with CMOS technology and can easily be converted from standard processes. If a high TC is desired the Ti/TiN stack can be selected for temperatures of max T = 380 C. This is usefull for sensor systems related to temperature measurements in moderate hot environments. For heating purpose only, the material of choice is the pure Titaniumnitride layers since it withstands temperatures of at least 600 C without material degradation.

11:15 AM J4.3

Exchange Spring Type Magnet Realized in FePt/Fe Multilayers Deposited by Magnetron Sputtering.

Yousong Gu, Dayong Zhang, Zhen Ji and Yue Zhang; Department of Material Physics and Chemistry, University of Science and Technology in Beijing, Beijing, Beijing, China.

FePt/Fe multilayers have been deposited on Si substrates by magnetron sputtering and post annealing. Series of FePt/Fe multilayers with different layer thicknesses have been prepared and annealed at different temperatures and durations. The prepared multilayers have been characterized by x-ray diffraction(XRD), scanning electron microscope(SEM) and vibrating sample magnetometer(VSM). In [FePt(4min)/Fe(t_{Fe})]10 multilayers, after annealing at 500C for 1 hour, samples with $t_{Fe}<$4min transformed from fcc disorder phases to tetragonal ordered phases, while thess with thick Fe layers remain as fcc phases. However, after annealing at 600C, all the samples (1min$\leq t_{Fe} \leq$5min) transformed into tetragonal ordered phases. However, the degree of order decreases as Fe layer thickness increased. The lattice constant a decrease as Fe layer thickness increases, while c dose not change very much. After annealing at 500C, the samples with thick Fe layers (tFe$\geq$4min) remain as fcc phase and a, c value are the same. However, all those values are smaller than those of bulk value, indicating that the FePt phase is Fe rich. The grain sizes of samples annealed at 500C are less than 70nm and are less dependent of Fe layer thickness. The grain sizes of samples annealed at 600C increase as Fe layer thickness decrease and reach 76nm for Fe layers deposited for 1 minute and 86nm for single layer. Magnetic measurements show that for samples annealed at 500C and 600C, the coercivities decease and the saturated magnetizations increase as Fe layer thickness increase. Therefore, there are peaks in magnetic energy product (BxH)max at tFe=3 min, 17 MG Oe for the samples annealed at 600C. Searching the wider range for the best layer thickness show that for samples annealed at 500C, $[\mathrm{FePt(8min)/Fe(4min)}]_8$ shows the highest (BxH)max value, 4πMs=12.6kGs, Hc=5.81kOe. and (BxH)max=15.2MG Oe. Quick annealing (10 minutes) experiments show fine grain size and close coupling between soft and hard magnetic phase. The decrease rate of Hc with Fe layer thickness is much slow than conventional annealing. Grain growth is small is quick annealing while fcc to tetragonal transformation is realized. The use of Ag underlayer is to inhabit Si diffuse and raise saturation magnetization. Results on FePt/Fe multilayers with Ag buffer layers show similar magnetic behavior but fine grain size. The small magnetization value (less than FePt bulk value) is not related to Si impurities.

11:30 AM J4.4

Atomic Layer Deposited Tungsten Disulfide Films for LIGA Microsystems: Syntheis and Tribological Behavior.

Somuri V. Prasad, Thomas W. Scharf, Michael T. Dugger and Thomas M. Mayer; Sandia National Laboratories, Albuquerque, New Mexico.

Microelectromechanical systems (MEMS) fabricated by LIGA utilize electrodeposited metals and alloys. Although many of these metallic materials meet structural requirements (e.g. strength, modulus and fracture toughness), self-mated contacts typically exhibit high coefficients of friction (COF=0.6-1.0), unacceptable wear and debris generation during sliding contact. In a number of microsystems applications such as gear trains, comb drives and transmission linkages, tribological (friction and wear) considerations, particularly sliding contacts amongst sidewalls, is of paramount importance. With the increasing number of MEMS fabricated using LIGA and other thick resist electroforming processes, there exists a need for the development of suitable coatings to combat the tribological issues. In view of the miniature nature of the LIGA MEMS parts and their unique sidewall morphologies, applying friction-reducing coatings conformally by conventional physical vapor deposition techniques is a challenging task. Chemical vapor deposition, though conformal in nature, is a high temperature process that will alter the microstucture of the base alloys. In the current study, we have developed an atomic layer deposition technique to coat the LIGA NiMn alloy parts with tungsten disulfide (WS_2) solid lubricant films by using WF_6 and H_2S gas precursors in a viscous flow reactor at 300°C. A new catalytic route was established to promote nucleation and growth of WS_2 films on NiMn substrates. In situ quartz crystal microbalance (QCM) measurements showed that WS_2 did not grow on bare substrates, and thus needed a nucleating agent. We discovered that a ~3 nm layer of Zn grown by ALD served as a catalyst and facilitated the growth of ALD WS_2. This catalytic action of Zn in WS_2 growth appears to be critical for the ALD process. The films were characterized by Raman spectroscopy, XRD, high resolution SEM, and TEM. Friction measurements were made using a ball-on-disk tribometer in load regimes relevant to LIGA microsystems applications. Cross-sections of wear scars for TEM analysis were prepared by focused ion beam microscopy techniques. Raman spectra and X-ray diffraction measurements confirmed that the WS_2 films were crystalline with hexagonal structure. The basal planes (0002) were oriented predominantly parallel to the substrate for films grown at 300°C. This is typical of transition metal dichalcogenides, which exhibit easy shear basal planes necessary for low friction and wear. The films exhibited extremely low coefficients of friction (0.02) in dry nitrogen environments. The mechanisms of nucleation and growth of ALD WS_2 films on NiMn substrates, and their friction behavior will be discussed. * Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

11:45 AM J4.5

Sliding Wear In Polysilicon Microelectromechanical Systems.

Daan Hein Alsem[1,2,3], Eric A. Stach[2,3,4], Michael T. Dugger[5] and Robert O. Ritchie[1,3]; [1]Material Science and Engineering, University of California Berkeley, Berkeley, California; [2]National Center for Electron Microscopy, Lawrence Berkeley National Laboratory, Berkeley, California; [3]Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California; [4]School of Materials Engineering, Purdue University, West Lafayette, Indiana; [5]Materials and Process Science Center, Sandia National Laboratory, Albuquerque, New Mexico.

Wear is a potential failure mode in microelectromechanical systems (MEMS). The presence of wear particles is potentially catastrophic for applications where debris may inhibit electrical contact or motion. Therefore, it is necessary to understand the initiation of wear processes in MEMS in hopes of prolonging life. Since silicon is the most widely used material on the micron-scale and it is inherently brittle, conventional wear models for bulk materials may not be applicable for characterizing MEMS reliability. Although surface characterization of structural thin films has received much attention of late, the physical mechanisms associated with micron-scale wear in silicon are still uncertain. To address this issue, we have used sidewall friction and wear test devices in combination with electron microscopy to study active mechanisms in sliding wear in polycrystalline silicon. In situ experiments in the scanning electron microscope were performed, as well as transmission electron microscopy (TEM) of the worn MEMS parts. After performing the wear tests, samples were prepared for TEM using a dual-beam focused-ion beam system. Analytical TEM was conducted on wear debris and worn parts to investigate their morphology and micro-structural evolution. Amorphous debris particles were observed, varying in size from below 100 nm to agglomerates larger than 500 nm and consisting primarily of amorphous silicon dioxide. Furthermore, an oxygen-rich sub-surface layer with a polycrystalline core was found. Our observations of ploughing wear tracks (caused by loose debris particles), as well as surface cracks perpendicular to the wear direction, with no evidence of plastic deformation, suggest a mechanism of micron-scale wear in polysilicon governed by local oxidation and fracture.

SESSION J5: Materials and Mechanics
Chair: Ainissa Ramirez
Tuesday Afternoon, March 29, 2005
Room 2003 (Moscone West)

1:30 PM J5.1

Comparison of Suspended versus Clamped Aluminum Nitride Acoustic Resonators.

Lori Ann Callaghan[1], Vanni Lughi[2], Michael V. Requa[1], David R. Clarke[2,1], Noel C. MacDonald[1,2] and Kimberly L. Turner[1]; [1]Mechanical Engineering, University of California, Santa Barbara, Santa Barbara, California; [2]Materials, University of California, Santa Barbara, Santa Barbara, California.

To meet the demand for lighter weight and more power efficient portable communication devices, research efforts have been focused on replacing solid state and Surface Acoustic Wave (SAW) filters with smaller, higher quality mechanical filters [1]. The mechanical filters we are investigating are aluminum nitride (AlN) thin Film Bulk Acoustic wave Resonators (FBARs). Each FBAR device is designed to resonate at a particular frequency in the UHF regime with the piezoelectric AlN layer converting an electrical signal to a mechanical vibration and then back to an amplified electrical signal at the resonant frequency. AlN is compatible with silicon micro processing; therefore, known thin film and MEMS bulk fabrication techniques are used to produce the FBARs. Our novel FBAR design uses a (0001) textured AlN layer, ranging from 1.5 to 2.5 microns in thickness, sputtered directly on <100> silicon wafers. The geometry consists of a suspended circular membrane of AlN, 300 microns in diameter, sandwiched between metal electrodes that activate the piezoelectric layer in the [0001] direction. A chlorine etch and a titanium dioxide mask are used to pattern the chemically inert AlN film. Reactive ion etching is used to create air cavities below the AlN film and to create a suspended resonator structure. The suspended membrane is supported by non-electroded AlN beams whose purpose is to reduce the damping and possible spurious frequencies when the AlN film is attached to the substrate in a conventional FBAR configuration. The reflection coefficients, S11, of the single port devices were measured and the resonators displayed a series and parallel frequency pair with a quality factor of 200 and an electromechanical coupling factor of 4.6% at 1.342 GHz. The Smith chart plot was also smooth in the UHF regime exhibiting no spurious frequencies. Solidly clamped resonators were also tested and all failed to exhibit a frequency pair. [1] R. Aigner, "RF-MEMS filters manufactured on silicon: key facts about Bulk-Acoustic-Wave technology," 2003 Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems IEEE, pp.157-61. Piscataway, NJ, USA

1:45 PM J5.2

Fabrication of Electrical Nanocontacts to Nanometer-Sized Materials and Structures using a Focused Ion Beam.

Francisco Hernandez[1], Olga Casals[1], Mohamed Abid[2], Sima Valizadeh[3], Jordi Rodriguez[1], Anna Vila[1], Juan Ramon Morante[1] and Albert Romano-Rodriguez[1]; [1]Department of Electronics, University of Barcelona, Barcelona, Spain; [2]Laboratoire de Physique des Materiaux Nanostructures, Ecole Polytechnique Federale de Lausanne, Lausanne, Switzerland; [3]Angstromlaboratoriet, Univeristy of Uppsala, Uppsala, Sweden.

Nanometer-sized materials, like nanoparticles, nanotubes, nanowires, ... and nanometer-sized structures, like beams, cantilevers, ..., are strongly gaining interest in the last years due to the new and, sometimes, unexpected properties they present, which makes them potentially interesting as building blocks in different types of devices, as, for example, mechanical, chemical and biological sensors. The fabrication procedures for these types of materials and structures are being developed and, in some cases, are relatively well controlled. However the extraction of the electrical parameters of the individual materials or structures is not trivial, because of the difficulties in producing electrical connections between them and the electrical measuring systems. Focused Ion Beam (FIB) is a powerful technique for the patterning and deposition of materials and for the rapid prototyping, with resolution in the range of tens of nanometers. It is based on the scanning of the sample's surface by a focused ion beam that sputters the material of the exposed area. When introducing a metalorganic compound in the beam path, the secondary electrons, generated in the sample by the ion beam and exiting its surface, dissociate the precursor and a part of the compound can be deposited on the sample's surface (ion-assisted deposition), while the volatile components are removed by the vacuum system. If the FIB is equipped, simultaneously, with an electron beam (which constitutes the so-called Dual-Beam) and the metalorganic compound is introduced in the electron beam path, dissociation also occurs and, similarly, deposition can be achieved, giving rise to electron-assisted deposition. In this work the procedure for fabrication of Pt contacts to access different nanometer-sized materials and structures, both using electron- and ion beam-assisted deposition in-situ in a Dual-beam machine and with PtC_9H_{16} as precursor, will be presented. Contacts with widths and heights ranging between tens of nm and few microns, and lengths between 500 nm and several microns have been fabricated using this procedure and have been analyzed both structural and electrically, being more resistive than metallic Pt due to strong carbon contamination. The study of the structural stability and change of the electrical parameters of the contacts after annealing at temperatures up to 800°C will also be presented. The feasibility of this method will be shown by contacting different nanometer-sized materials and devices, from which the electrical parameters will be extracted, including nanowires and nanoparticles. The advantage of using electron or ion-assisted deposition will be discussed as a function of the chemical composition and surface state of the material to be contacted and of the thermal treatment of the contacts. This work has been partially supported by the EU through the project NANOS4 of the VI FPM.

2:00 PM J5.3

Surface States of the Wirtzite Type Nanowires. Natalia Malkova and Cun-Zheng Ning; NASA Ames Research Center, Moffett Field, California.

We study the surface states at the lateral facets of the wurtzite type nanowires. As particular example we consider nanowires with the same symmetry for all the lateral facets. Our approach is based on the transfer matrix technique within the semi-empirical tight-binding approximation. We calculate the surface states at $1\bar{1}00$, $1\bar{2}10$ and (0001) surfaces of the semi-infinite crystal first. Then using the cyclic boundary conditions, depending on the radius of the nanowire, we find the quantized spectrum for the surface states in question. We present the result for the surface states of GaN, ZnO, CdS, CdSe and AlN wirtzite nanowires with the $1\bar{1}00$ and $1\bar{2}10$ lateral surfaces. The dangling bonds are shown to give a set of the states inside the band gap of the semiconductors studied. The orbital character and decay length of the states are calculated. We analyze the symmetry of the quantized surface states and possible optical dipole transitions between them.

2:15 PM J5.4

Mechanical Integrity of Polymer/Inorganic Interfaces for Micro and Nanosystems. Bree M. Sharratt[1] and Reinhold H. Dauskardt[2]; [1]Aeronautics and Astronautics, Stanford University, Stanford, California; [2]Materials Science and Engineering, Stanford University, Stanford, California.

The mechanical integrity of polymer/inorganic interfaces is of considerable importance for a range of micro and nanosystems. For example, both MEMS and NEMS are hermetically sealed and bonded to substrates using thin polymer layers. Physical and chemical sensors also incorporate thin polymer layers both in the sensor structure and in the packages. The functional reliability of such structures during processing and in service depends critically on the integrity of the polymer interfaces. Even though interfacial debonding associated with thermomechanical fatigue, vibrational loading and moisture attack are of considerable technological importance, a fundamental understanding of the debonding mechanisms and their relationship to interfacial chemistry, environmental factors and loading parameters is lacking. We address these issues using a technologically relevant bisphenol F polymer layer bonded by weak secondary bonding to SiN_x passivated silicon substrates. We present evidence of a significant mechanical fatigue effect, which translates to dramatic reductions in predicted device lifetimes. More importantly, however, we show that anomalous threshold behavior develops under both monotonic and cyclic fatigue loading conditions, resulting in debond growth rates that are almost independent of the applied loads. This surprising behavior has profound implications for the reliability of devices that incorporate thin polymer layers. We discuss the mechanisms associated with the debonding phenomena in terms of the interfacial chemistry, and the effects of moisture and applied loads. By comparing device lifetime predictions for interfaces that exhibit anomalous threshold behavior to those that have well-defined debond growth thresholds, we reveal the dramatic impact of weak secondary bonding on device reliability. Significant implications arise for micro and nanosystems that incorporate thin polymer films.

2:30 PM J5.5

Through-Wafer Polysilicon Interconnect Fabrication with In-Situ Boron Doping. Ismo Luusua, Kimmo Henttinen, Panu Pekko, Tapani Vehmas and Hannu Luoto; Microelectronics, VTT Information Technology, Espoo, Finland.

Bulk micromachining technology can be used to produce conducting through-wafer polysilicon interconnects, i.e., polysilicon via plugs. This paper presents the process fabrication steps of polysilicon via plugs with in-situ boron doped polysilicon material in order to develop fast one-step doping process, without additional diffusion. The via holes can be processed by high-aspect ratio silicon etching with inductively coupled plasma (ICP). Only one deep ICP etching is required if the wafer is mechanically ground (from the backside) to reduce the wafer thickness of 500 microns to a typical of 400, in order to overcome deep etching sidewall profile problems. After hole formation with ICP the via plug fabrication process continues by growing an insulating thermal oxide layer with a thickness of the order of a micron, followed by an in-situ boron doped LPCVD polysilicon growth to fill the holes with sufficient step coverage. The polysilicon growth temperature at 680°C ensures sufficient step coverage, reasonable furnace process time and enables planarization processing, such as grinding and chemical-mechanical polishing (CMP). The subsequent planar processing typically requires planarization of the polysilicon layer down to the original silicon (or oxide) surface with CMP, and some doping activation step, which usually can be performed together with some additional oxidation step. Applications of the via plugs in the field of silicon-based sensors or actuators enable significant reduction of the front surface wiring density, which opens additional space for denser packing or other desired components.

2:45 PM J5.6

Degradation of Monolayers Coatings Used in Silicon Microsystems. Michael T. Dugger, Joshua S. Wiehn and James A. Ohlhausen; Sandia National Laboratories, Albuquerque, NM, New Mexico.

Chemisorbed monolayers are employed in silicon surface micromachined (SMM) microelectromechanical systems (MEMS) to reduce the surface energy after removal of the sacrificial oxide layer and thereby prevent movable structures from adhering during manufacturing, handling or operation. These films also reduce static and dynamic friction between movable structures. Although these films nominally react with the surface to form a single monolayer, the degree to which they bond with the surface, and hence coverage, can be affected by the ability to generate a clean surface in high aspect ratio gaps between structures as well as on surfaces directly exposed to the cleaning and coating processes. Mechanical stress as well as exposure to other adsorbates, including water vapor, can affect the chemistry and structure of the films and change device operating characteristics. Surfaces examined using time-of-flight secondary ion mass spectroscopy (TOF-SIMS) reveal differences in coverage based on location, whether in an occluded region or a free surface. Coverage is depleted in narrow gaps compared to exposed surfaces. Coated surfaces have also been exposed to a variety of environments including a packaging process and controlled water vapor concentration at elevated temperature. The tribological behavior of the surfaces has been investigated using atomic force microscopy and specially constructed SMM tribometers for measuring friction under MEMS operating conditions. Results show that contaminant adsorption can occur preferentially at locations of prior mechanical contact, and that this adsorption can increase the static friction coefficient between movable surfaces. In addition, exposure to water vapor is shown to result in an increase in adhesion and friction between coated surfaces even though the surfaces remain hydrophobic. The tribological behavior of MEMS interfaces will be discussed in terms of the composition of the surfaces determined from TOF-SIMS measurements, and the chemical stability of the monolayers.

SESSION J6: Process and Device Modeling

Chair: James Kelly
Tuesday Afternoon, March 29, 2005
Room 2003 (Moscone West)

3:30 PM J6.1

Elastic Self-Healing during Shear Accommodation in Crystalline Nanotube Ropes. Moneesh Upmanyu and Liang Haiyi; Engineering Division, Materials Science Program, Colorado School of Mines, Golden, Colorado.

We have performed rigid tube-based computations of transverse shear in (n,n) crystalline nanotube ropes (CNTRs). Our results show that shear modulus and strength increase and decrease with tube radius, respectively. High shear modulus to strength ratios suggest that dislocations play a minor during their plasticity. Computed shear modulii are in agreement with previous studies, although shape-change and rolling-based shear will modify low strain and low temperature behavior of large tube radius CNTRs. Instability past the shear strength is due to shear localization via interlayer sliding, wherein stress relief results in significant dissipation of elastic energy. During localization, large tube radius CNTRs accommodate large strains at minimal energetic cost, a direct consequence of increasing cohesive energy and short range nature of the inter-tube potential. Fascinatingly, the crystal aids its recovery (elastic self-healing), implying that CNTRs are promising materials for energy absorption and tribology.

3:45 PM J6.2

Pulse Testing of GaN/AlGaN HEMTs and Device Junction Temperature Measurement. YoungMin Kim, Albert G. Baca, Phil F. Marsh, Andrew A. Allerman, Mark E. Overberg, Joel R. Wendt and Carlos A. Sanchez; Sandia National Laboratories, Albuquerque, New Mexico.

GaN is considered as one of the most promising material for high power. The power density of GaN/AlGaN HEMTs can be ten times higher than that of GaAs based HEMTs at a given frequency. However, device self-heating will cause the junction temperature rise markedly and will limit practical power densities to somewhere near 5W/mm in large periphery power amplifiers. Pulsed I-V measurements are a good tool to separate the thermal effect from electrical characterizations. By using a very small pulse width and relatively long pulse period, thermal effects can be minimized. The GaN/AlGaN HEMT structure was grown by metalorganic chemical vapor deposition (MOCVD) on a semi-insulating SiC substrate. It has a 165 nm AlN nucleation layer, a 1.3 μm thick GaN buffer, and a 20 nm undoped AlGaN layer with 27% Al. The HEMTs were fabricated with a four-step process consisting of 1) mesa isolation with a Cl-based RIE (reactive ion etch) or ICP (inductively coupled plasma) etch 2) a Ti/Al/Mo/Au (30/100/15/40 nm) ohmic contact alloyed at 925°C for 30 s, 3) a Ni/Au gate defined by optical (for 1.0 μm gates) and ebeam (for 0.25 μm gates) lithography, and 4) SiN passivation by PECVD (plasma-enhanced chemical vapor deposition). The source-drain spacing was 4.5 μm. Pulse testing was performed with a DIVA D-265 tester. GaN/AlGaN HEMT I-V characteristics were measured from two finger devices which have 1.0 μm (or 0.25 μm) gate length and 75 μm gate width for each finger. The output current from static measurements decreased as the drain to source bias voltage increased while pulsed measurement data showed a constant saturation current. Because a very small pulse width of 0.2 μsec and 1 msec pulse period was used in the pulsed measurement, it is natural to assume that there is no self heating in pulsed I-V characteristics. Thus, current decreasing at high voltage in static measurement is believed to be mainly due to the self heating effect. The device junction temperature can be obtained by measuring this difference of two current levels. To see the current variation as a function of temperature, pulsed I-V characteristics were measured at several different ambient temperatures. A quite linear relation between the temperature and saturation current level was observed. As an example of this technique, junction temperatures were determined for representative devices under 20 V drain bias. Currents were measured at Vds=20V and Vgs= 1V, and the saturation current was quite constant up to Vds=20V. The static current value at Vds=20V, Vgs=1V was 108.1 mA for 1.0 um gate length device and 123.5 mA for 0.25 um gate length device. The device junction temperatures can be calculated from the relation between temperature and saturation current and were found to be 90°C and 126°C for each device.

4:00 PM J6.3

Lock-and-Key Effect in the Surface Diffusion of Large Organic Molecules Probed by STM.

Roberto Otero Martin[1], Fernando Sato[2], Peter Thostrup[1], Sergio B. Legoas[2], Erik Laegsgaard[1], Ivan Stensgaard[1], Douglas S. Galvao[2] and Flemming Besenbacher[1]; [1]Department of Physics and Astronomy, University of Aarhus, Aarhus, Denmark; [2]Universidade Estadual de Campinas, Campinas, Brazil.

A nano-scale understanding of the complex dynamics of large molecules at surfaces is essential for the bottom-up design of molecular nanostructures.Although a large number of previous studies has discussed the formation of molecular assemblies in terms of the molecule-molecule and molecule-substrate interactions, thus addressing the thermodynamic aspects of molecular assemblies, very few studies have addressed the dynamical processes that a large organic molecule can undergo when anchored on a solid surface. Here we address how the orientation and shape of large and complex organic molecules influence their dynamics (diffusivity). To this end, we have exploited the capability of the scanning tunneling microscope (STM) (i) to resolve the conformation and orientation of single individual molecules on the atomic scale, (ii) to manipulate the orientation of individual molecules by using the STM tip as a nano-scale tool to gently push molecules adsorbed on surfaces, and finally with the fast-scanning Aarhus STM (iii) to track the surface diffusivity of the different molecular configurations by acquiring dynamic STM movies at low temperatures. In this way, we will show that the diffusion coefficient of the complex organic molecule named the Violet Lander (VL, C108H104) on a Cu(110) surface can be changed by two orders of magnitude by purposefully manipulating the VL molecules, thereby modifying the molecular orientation with respect to the substrate. From an interplay with Molecular Dynamics simulations, we interpret the results within a lock-and-key model similar to the one driving the recognition between biomolecules: the molecule (key) is immobilized only when its orientation is such that the molecular shape fits the atomic lattice of the surface (lock); otherwise the molecule is highly mobile.

4:15 PM J6.4

Surface Chemistry and Electrical Properties of Germanium Nanowires.

Dunwei Wang and Hongjie Dai; Stanford University, Stanford, California.

Germanium is of renewed interest due to its high carrier mobilities and small carrier and optical bandgap, especially as Si based device scaling is approaching its theoretical limits. Lack of a stable native oxide has been a challenge that hindered the research progress on germanium in the past decades. We carried out systematic studies of the surface effects on the electrical properties of single crystalline Ge nanowires synthesized at temperatures below 300C via a chemical vapor deposition method. Complementary p and n-type field effect transistors (FETs) were built on as-synthesized and in situ doped Ge nanowires, and their performance was evaluated. X-ray photoelectron spectroscopy (XPS) revealed opposite band-bending and distinctive oxidation processes. It was found that p-type Ge nanowires tend to oxidize slower than n-type ones in ambient air through a different oxidation route. Its impact on nanowire electrical properties was discussed and correlated with p and n-type Ge nanowire FETs. A simple cleaning method was developed and it was integrated with high dielectric materials made by low temperature atomic layer deposition (ALD) to passivate devices. Finally, a general formula of surface effects on nanowire bulk properties was derived and it implied surface would play an important role as nanowires are small. Our result opens up opportunities to build high performance and ambient air stable transistors based on Ge nanowires. It also sheds lights on the understanding of nanowire electrical properties in general.

4:30 PM J6.5

Measurement of Faradaic Current in AFM Nano-oxidation of Semiconductor and its Dependence on Surface Conditions.

Naofumi Funakoshi[1], Tsutomu Yamada[1], Yasushi Takemura[1] and Jun-ichi Shirakashi[2]; [1]Electrical & Computer Eng., Yokohama National University, Yokohama, Japan; [2]Electrical & Electronic Eng., Tokyo University of Agriculture and Technology, Tokyo, Japan.

Nanofabrication technique using a atomic force microscopy (AFM) has attracted much interest. The AFM-based nanolithography is a promising approach for fabricating electron devices with nanometer-scale well-defined structures. Here, a quantitative study on the AFM nano-oxidation is studied. It is well known that the AFM and scanning tunneling microscope can be used to selectively oxidize the surface of various materials. The reaction mechanism of this nano-oxidation is considered to be an electrochemical reaction between the film materials and water adsorbed on their surfaces. The size of the fabricated nano-oxide depends on the applied voltage to the conductive cantilever, which can be explained by introducing the threshold electric field for promoting the oxidation [1]. The volume of the oxide can be theoretically calculated by integrating the reaction current, called Faradaic current specifically in this case, with time. Recently, it was reported that the current was successfully measured and that the volume of the fabricated oxide agreed with the integrated current value [2]. On the other hand, we have noticed the waveforms of the current-time sweeps, which strongly depend on surface conditions of the films. As for the surfaces covered with oxides, i.e. Si substrate with native oxide and metal surface capped with thin oxide layer, almost constant current was detected from the beginning of biasing the cantilevers. The over-current was observed immediately after applying the voltage in the oxidation of the surfaces with the less or without oxides. These results agree with previously reported discussion [3] that the residual oxide on the surface acts as a nucleation of the anodic reaction and that it promotes the initial oxidation. The mechanism and quantitative analysis of the AFM-based nano-oxidation are discussed in detail as well as nano-oxidation of metal films and fabrication of ferromagnetic devices in the presentation. [1] Takemura et al., JAP 93, 7346 (2003). [2] Kuramochi et al., Nanotechnology 15, 297 (2004). [3] Takemura et al., Nanotechnology 15, S566 (2004).

4:45 PM J6.6

Electrostatic (Plasmon) Resonances in Metallic and Semiconductor Nanoparticles and Their Applications.

Isaak Mayergoyz and Zhenyu Zhang; Electrical & Computer Engineering, University of Maryland, College Park, Maryland.

It is known that small dielectric objects can exhibit resonant behavior at certain frequencies for which the object permittivity is negative and the free-space wavelength is large in comparison with object dimensions [1]. This phenomenon usually occurs at nanoscale and at optical frequencies where the above two conditions can be simultaneously satisfied. These resonances are electrostatic in nature, and they result in powerful localized sources of light, which may find applications in nano-lithography, nanophotonics, surface-enhanced Raman scattering, biosensors, and optical data storage. These resonances in semiconductor nanoparticles are of special interested because they can be controlled through optical manipulation of carrier densities. This optical controllability can be utilized for the development of nanoscale light switches and all-optical transistors. Currently these resonances in nanoparticles are found experimentally (or numerically) by probing dielectric objects of complex shapes with radiation of various frequencies, i.e. by using a trial-and-error method. There has not existed any technique for direct calculation of the negative values of dielectric permittivities, and the corresponding frequencies of electromagnetic radiation at which these resonances occur. In the paper, we present a new technique for direct calculation of resonance frequencies and to study unique physical features of these resonances for 3D nanoparticles. It is demonstrated that the resonance values of permittivity, and hence the resonance frequencies, can be directly (i.e. without laborious probing) found by computing the eigenvalues of a specific boundary integral equation. Once the resonance permittivity is known, the resonance frequency can be obtained by invoking appropriate dispersion relations. This approach also reveals the unique physical property of plasmon resonances: resonance frequencies depend on dielectric object shapes, but they are scale invariant with respect to object dimensions, provided that they remain appreciably smaller than the free-space wavelength. It turns out that the integral operator in the integral equation is compact, and hence the plasmon spectrum is discrete. General properties of this spectrum have been studied along with the excitation conditions for plasmon resonances. A novel algorithm and robust codes have been developed to solve the corresponding eigenvalue problem. This algorithm and codes have been tested for spherical particles where exact analytical solutions are available (Mie theory). Our computations have also reproduced (with sufficient accuracy) the experimental results for golden nano-rings recently published in [2]. [1] D. R. Fredkin and I. D. Mayergoyz, Resonance Behavior of Dielectric Objects (Electrostatic Resonances), Phy. Rev. Lett, Vol. 91, No. 25, Dec. 2003 [2] J. Aizpura, P. Hanarp et al., Optical Properties of Gold Nanorings, Phy. Rev. Lett, Vol. 90, No. 5, Feb. 2003

SESSION J7: New Materials and Fabrication Methodologies
Chair: David La Van
Tuesday Evening, March 29, 2005
Golden Gate C1/C2/C3 (Marriott)

7:00 PM J7.1
Low Temperature MEMS Manufacturing Processes: Plasma Activated Wafer Bonding. Viorel Dragoi, Shari Farrens and Paul Lindner; Technology, EV Group, Schaerding, Austria.

Initially driven by the automotive applications, MEMS development is now driven mainly by portable consumer products. The new MEMS applications raised important challenges to the existing processing technologies and lead to the development of new technologies in order to fulfill the new demands. Some applications require special conditions, as long term high vacuum encapsulation, low temperature processing and wafer level packaging. Wafer bonding became a key technology in various processes related to MEMS devices manufacturing. MEMS devices packaging is a very important step for both the technological and also the commercial point of view: for some types of devices the cost of the package account for ~70% of the total cost of the device. Considering this aspect, wafer level packaging becomes very important for high volume manufacturing. In this respect, wafer bonding becomes a crucial technology as far as it enables not only 3D structure building but also wafer level packaging. Different wafer bonding approaches are currently used in the MEMS industry. Because Silicon Direct Bonding (SDB) processes require a high temperature annealing which is not always suitable for the devices, a high interest is focused on low temperature processes (maximum temperature of 400C). Plasma activated bonding is a surface activation method which results in decreasing the process temperature. By applying a plasma treatment to the wafers prior to bonding, the surface chemistry can be tailored in order to obtain maximum bond strength for low temperature thermal annealing. In the past decade some research groups reported results on plasma activated wafer bonding. The experimental setup was built usually on plasma etching equipment (barrel-type reactors or RIE tools). Most of the experiments on plasma activated wafer bonding were using plasma activation process followed by a deionized water rinse or even an RCA cleaning prior to bonding. The use of a rinse step between surface activation and bonding steps was justified for particle removal and improving the bond strength. Recently new tooling was developed specifically for plasma activated wafer bonding. For direct wafer bonding the surface quality is of very high importance, therefore this process chamber was designed to prevent any potential surface damaging effect during the plasma exposure. Another important aspect considered during process development was the need of numerous MEMS applications for a completely dry process. As wet processes can not be applied for substrates containing metals, etched features or mechanically fragile structures, dry processes are required. This paper introduces a new low temperature plasma activated wafer bonding process. The process is optimized for a maximum temperature of 400C and does not require any wet process prior to bonding step. Examples of plasma activated wafer bonding applications will be presented as an alternative to standard high temperature wafer bonding processes.

7:15 PM J7.2
Spontaneous Growth of Nickel Silicide Nanowires and Formation of Self-Assembled Nanobridges by the Metal Induced Growth Method. Joondong Kim[1], Wayne A. Anderson[1] and Young-Joo Song[2]; [1]Electrical Engineering, University at Buffalo, Buffalo, New York; [2]High-Speed SoC, Electronics and Telecommunications Research Institute, Daejeon, Yuseong-gu, South Korea.

Nickel silicide nanowires (NWs) have been grown on n-type (1 0 0) and p-type (1 1 1) Si wafers and self-assembled nanobridges (NBs) have been formed in a trenched Si wafer by Metal Induced Growth (MIG). Ni as a catalyst was first thermally evaporated on SiO$_2$-coated Si wafers. Si was then sputtered on the Ni layer by a D.C. magnetron at a substrate temperature of 575 °C. To form NBs, a dry etching system was used to make trenches in a Si wafer at a chamber pressure of 130 mTorr and power of 450 W. A 250 nm - SiO$_2$etch mask was thermally grown on a cleaned p-type (1 1 1) Si wafer at 1000 °C. The trenched sample was then processed in a D.C. magnetron sputtering system after Ni evaporation on a SiO$_2$-coated Si wafer similar to the NW growth process. The NWs have diameters of $20 \sim 80$ nm, length of $1\sim 10$ μm and surface coverage of about $35/10^{-12}$ m^2. NBs were formed in a trench as long as 4 μm. Self-assembled MIG NBs may be promising 1 dimensional building blocks in nanoscale connections and nanoelectronic applications. The MIG NWs and NBs satisfy the need of self and direct assembled bottom-up fabrication concepts.

7:30 PM J7.3
Size-Dependent Electronic Structures of ZnO Nanowires. Juan Wang, Xi Po An and Quan Li; Physics, The Chinese University of Hong Kong, Hong Kong, Hong Kong.

Recently one-dimensional (1D) nanomaterials have arisen much interest due to their dimensionality and the size related novel properties, which may lead to potential applications in various nanodevices. Fundamental understanding of the electronic structure of these 1D nanomaterials is therefore of great importance in order to investigate the feasibility of utilizing them as building blocks for the nanodevices. In this study, two different types of ZnO nanowires (circular vs. hexagon cross section) with a diameter distribution from 20 to 100nm were fabricated via simple thermal evaporation process. Their size dependent electronic structures were investigated using valance electron energy loss spectroscopy (VEELS). Several features in the loss function were observed to be surface related in both types of samples, including the increasing oscillation strength of surface plasmon resonance at ~11.2eV and the broadening of the bulk plasmon peak as the nanowire diameter decreases. These can be explained by the increased surface to volume ratio when the diameter of the nanowire decreases. Interestingly, we observed that the peak corresponding to the interband transition from O 2s to the conduction band splits into two peaks only in the nanowires with circular cross section at small diameter, which is attributed to the presence of oxygen dangling bonds on their rough surfaces. Such splitting always coincides with a red shift of the bulk plasmon peak, which can be explained by the coupling between the interband transition and the plasmon resonance. The experimental results strongly suggested that with careful control of the growth conditions (resulting in ZnO nanowires with hexagon cross section and low-indices termination surface), even the nanowires with 20 nm diameter are of high electronic quality, which can serve as effective building blocks for optoelectronic nanodevices.

7:45 PM J7.4
Combination of Soft Lithographic and Nonlithographic Methods of Nanofabrication for High-Tc Superconductor Systems. Sungwook Kim and John McDevitt; University of Texas at Austin, Austin, Texas.

In order to fabricate the nano-electronic device of High-Tc superconductors, especially organic molecule/superconductor devices, it is critical to develop the reliable lithographic methods and the interface control methods. Self-assembled monolayers etching methods and thermal annealing methods were developed to control the interface and recrystallize the structures of high-Tc superconductor nano-devices. The current state of the suitable methods for the fabrication of cuprate superconductor/conductive polymer nano-devices will be described as well as experiment results that could probe the proximity effects at such nanocomposites.

8:00 PM J7.5
Electrical and Optical Properties of Self-Assembled, Ordered Gold Nanocrystal/Silica Thin Films Prepared by Sol-Gel Processing. Kai Yang[1], Hongyou Fan[2], Sima La Fontaine[1], Daniel M. Boye[5], Kevin J. Malloy[1], Jeffrey C. Brinker[3,4] and Thomas W. Sigmon[1]; [1]Center for High Technology Materials, University of New Mexico, Albuquerque, New Mexico; [2]Ceramic Processing and Inorganic Materials Department, Advanced Materials Laboratory, Sandia National Laboratories, Albuquerque, New Mexico; [3]Self-Assembled Materials Department, Advanced Materials Laboratory, Sandia National Laboratories, Albuquerque, New Mexico; [4]Department of Chemical and Nuclear Engineering, University of New

Mexico, Albuquerque, New Mexico; [5]Physics Department, Davidson College, Davidson, North Carolina.

Nanometer-sized crystallites of metals, semiconductors, and oxides form a new class of "artificial solids" possessing electrical properties far different from those of either the corresponding isolated atoms or macroscopic solids. The ability to adjust the properties of such solids through control of the size, shape, composition, crystallinity, and structure leads to a wide range of potential applications. In this work, we report electrical and optical results on high ordered gold nanocrystal(NC)/silica films (Science, 304, 567-571, 2004). These films are synthesized through self-assembly of water-soluble gold nanocrystal micelles and soluble silica by sol-gel processing. The films are analyzed by X-ray diffraction, transmission electron microscopy, ellipsometry, ultraviolet(UV)-visible spectroscopy, and Fourier transform infrared spectroscopy to determine their microstructure and optical properties. Charge transport behavior of the films was examined using metal-oxide-semiconductor (MOS) and metal-insulator-metal (MIM) structures. MOS capacitor samples exhibit charge storage with discharge behavior dominated by electron transport within the gold NC arrays. Low temperature current-voltage measurements on MIM devices reveal electrical conduction with a thermal activation energy of ~90 meV. For temperatures less than 100 K, the I-V characteristics of the NC film exhibits a strong coulomb blockade effect, with a threshold voltage of ~0.5 V measured at 78K. Noble metal nanoparticles are known to possess large third-order nonlinear optical coefficients in the surface plasmon absorption region. The surface plasmon resonance (SPR) of metal nanoparticles in composites occurs in the UV-visible to near-IR spectrum region, depending on the metal species, shape, size, and dielectric medium. Typical nanocomposites studied are gold nanoparticles in glass or solution, which show the SPR band around 550 nm. In this work, we examined films having different gold NC/silica film thicknesses with fixed gold nanocrystal size of ~3 nm. Transmission and absorption spectra were measured for wavelengths from 200 to 2000 nm. The absorption spectra show a strong SPR absorption peak at ~525 nm for all samples. This is consistent with published results that the resonance peak exhibits a blue-shift with decreasing particle size. Nonlinear optical properties of our gold NC/silica films were examined by the Z-scan technique with a mode-locked, feto-second pulsed Ti-sapphire laser, and enhancements of the third-order optical nonlinearities are observed as a result of the enhanced local field around individual gold nanocrystal.

8:15 PM J7.6

Laser Micromachining Using F2-Laser - A Machine Concept for New Materials in R&D. Jens Haenel, Tino Petsch and Mathias Weber; 3D-Micromac AG, Chemnitz, Saxony, Germany.

The first part of the lecture will present the laser micromachining workstation with their characteristically optical and mechanical setup. The workstation using 157nm wavelength and 30 ns pulse duration. An all-new F2-laser beam guiding and shaping approach based on combination of reflective and transmission optics. The result is a much better efficient of the optical system as the conventional methods. The beam energy damage up to the workpiece is smaller. The workstation has many helpful mountings. How the scientists can use this equipment for good results of micromachining in vacuum. E.g. the four dimensional space workpiece handling is integrated in a warp resistent granit-house which can performed as vacuum box or flushed with nitrogen gas. The second part will present the first results of investigations on laser micromachining of different materials which is performed with the efficient f2-Laser-workstation.

SESSION J8: RF and Optical Applications
Chair: Mark McNie
Tuesday Evening, March 29, 2005
Golden Gate C1/C2/C3 (Marriott)

8:30 PM J8.1

Micro-Molded High Q Polymer Resonators for Optical Loss Determination. Andrea Martin, Deniz Armani, Bumki Min, Akil Srinivasan and Kerry Vahala; Applied Physics, California Institute of Technology, Pasadena, California.

Replica molding of silica ultra-high-Q toroidal microresonators can produce polymer replica microresonators with material-limited quality factors. The molding process consists of three simple steps: fabricating the silica toroidal resonator, forming the silicone mold, and casting the polymer resonator. This technique was previously used to micromold planar microresonator arrays using two thermally curing polymers, polydimethylsiloxane and Vicast, which resulted in microresonators with quality factors (Q) in excess of $10\hat{6}$. This was a 40x improvement over previous polymer microresonators. By measuring Q and the effective refractive index of the polymer microresonator, the optical absorption coefficient of a given polymer can be determined. This technique was applied to determine the material absorption of two previously uncharacterized polymers at wavelengths ranging from the visible (680nm) through the near-IR (1550nm). We also explored the effect of curing mechanism on the molding process. Two polymers were chosen which cure by two different mechanisms: thermal or ultra-violet exposure. No significant difference was found between the quality of the two types of polymer resonators produced. This demonstrates the flexibility of the molding process which is a result of the silicone molding material. Polymer resonators were tested using optical fiber taper couplers. Transmission spectra were taken through tapers coupled to ~70micron diameter polymer microresonators. Spectral bands near 680nm, 1300nm and 1550nm were scanned using single frequency tunable lasers. The full-width at half maximum (FWHM) of the resonances were measured under various taper-coupling conditions to infer the intrinsic Q factor of the devices. In all bands intrinsic Q factors in excess of 100,000 were routinely measured using Efiron, and Crystal Cast. The effective refractive index was determined from the free spectral range of the resonators. To prove this technique has merit as a rapid absorption test, in a previous work, the loss values published by the manufacturer of the PDMS polymer were compared with those measured using the microresonator. The values were consistent throughout the near-IR spectrum. Additionally, Metricon prism coupler loss measurements were performed on spun samples of Vicast and PDMS. These values were also consistent with the measured loss value of the polymer microresonators. Combining the effective refractive index and Q determined above, the material loss of Efiron and Crystal Cast, two previously un-characterized polymers, has been determined in the present work.

8:45 PM J8.2

Peculiarities of X-ray Beam Formation for Nanoscale Size Range. Vladimir Konstantinovich Egorov and Evgeniy Egorov; Analytical, Institute of Microelectronics Technology, Chernogolovka, Moscow District, Russian Federation.

Generation and formation of X-ray beams with nanoscale cross-section is not simple task owing to difficulties of direct influence on high energy photon fluxes and appearing of diffraction satellites at using of nanosize slit-cut systems. Application of the planar X-ray waveguide-resonators removes these problems. This device forms X-ray beams with width 10-200 nm without diffraction satellites and divergence $\Delta\phi$=0.1° and smaller [1]. Moreover, the waveguide-resonator condenses the radiation and transports it almost without attenuation. Planar X-ray waveguide-resonator (PXWR) represents the narrow extended slit formed by two planar polished dielectric plates (reflectors) located parallel to one other with small distance between them. The distance is defined by thickness of metallic strips deposited on edges of one reflector. Such geometry promotes to appearing of uniform X-ray standing wave interference field in all space of the slit when the slit width falls into the specific size interval. It's upper limit is defined by the magnitude of the coherence length of radiation transported by slit, and for the characteristic radiation generated by X-ray tube (at using of different anodes), it is varied from 90 to 200 nm. The lower edge is connected with the material density of waveguide-resonator reflectors. Usually, it is equal 10-20 nm. The radiation transportation in condition of the uniform interference field of X-ray standing wave is the new mechanism of the radiation propagation differed, in principle, from the mechanism of it's multiple total reflection. The waveguide-resonance mechanism is characterized arising of the interference field not only in the slit space but also in volumes of reflectors. But in the reflector volumes the field has the dropping characteristic. In the result, the reflector volumes are excited at the first total reflection of the flux and next reflections occur without energy losses, and we have the superstream type propagation. Moreover, the diffraction effect for any slit size can be appear for PXWR inlet, only. The PXWR emergent beam is formed together by slit outlet area and areas of reflector butt-ends, and it can not characteristic by diffraction effects. Some attention will be spared to discussion of the waveguide-resonator practical application for X-ray diffractometry and fluorescence spectrometry. Directions of waveguide-resonator technique development will be elucidated briftly. [1] V. Egorov, E. Egorov, MRS Proceeding, v716, 2002, pp. 189-195.

9:00 PM J8.3

Fine-Tuning of the Spectral Collection Efficiency in a Multilayer Junction through the LSP Technique. Manuela Carvalho Vieira[1], Alessandro Fantoni[1], Miguel Fernandes[1], Paula Louro[1], Guilherme Lavareda[2] and Carlos Nunes de Carvalho[2]; [1]DEETC, ISEL, Lisbon, Portugal; [2]CFM-IST, Lisbon, Portugal.

We report in this paper the recent advances we obtained in optimizing a color image sensor based on the LSP (Laser Scanned Photodiode) technique. A device structure based on a a-SiC:H/ a-Si:H pin/pin tandem structure has been tested for a proper color separation process that takes advantage on the different filtering properties due to the different light penetration depth at different wavelengths inside the a-Si:H and a-SiC:H absorbers. While the green and the red images give, in comparison with previous tested structures, a weak response, this structure shows a very good recognition of blue color under reverse bias, leaving a good margin for future device optimization in order to achieve a complete and satisfactory RGB image mapping. Preliminary results shows that device optimization for red detection can be obtained by reducing the thickness of the internal recombination junction while by increasing the thickness off the intrinsic layer of the bottom a-Si:H cell a better detection of the green color is also foreseen under appropriated applied voltage. The physics behind the device operation is explained by recurring to a numerical simulation of the internal electrical configuration of the device in dark and under different wavelength irradiations. Considerations about conduction band offsets, electrical field profiles and inversion layers will be taken into account to explain the optical and voltage bias dependence of the spectral response. Experimental results about the spectral collection efficiency are presented and discussed from the point of view of the color sensor applications. Our interpretation point out the cause of such effect to a self biasing of the bottom cell under certain unbalanced light generation of carriers and an asymmetric reaction of the internal electric fields to the externally imposed forward bias. The possibility to relate such a behavior to the light intensity and color, leave an open discussion on the possibility to use these structures and this effect for color recognition sensors.

9:15 PM J8.4

Characterization of Nanoscale Acoustic Vibrations in RF MEMS Resonators by Scanning Force Microscopy Methods.

Alvaro San Paulo[1], Xuchun Liu[1,2] and Jeffrey Bokor[1]; [1]BSAC, UC Berkeley, Berkeley, California; [2]School of Electrical and Computer Engineering, Cornell University, Ithaca, New York.

The development of radio frequency microelectromechanical resonators with improved characteristics such as higher quality factors, smaller lateral dimensions and optimized integration capabilities requires an accompanying development of characterization techniques that allow to understand and control the material and mechanical properties that govern the performance of these devices. The application of Scanning Force Microscopy (SFM) methods for the measurement of acoustic vibrations in RF resonators does not only allow the measurement of the magnitude of the vibration amplitude of the desired acoustic modes with sub-angstrom-scale sensitivity, but also provides valuable information about the excitation of spurious resonant modes around the main resonance frequency as well as parasitic modes excited together with the desired resonant mode at the main resonance frequency. The excitation of these undesired modes prevents an ideal frequency response of the resonators and it also represents an important source of energy dissipation and Q-factor limitation for its applications in wireless communication systems as filters, duplexers, etc. Our work is focused on the development of SFM methods for the measurement of both out-of-plane and in-plane acoustic vibrations in different types of RF resonators. Film Bulk Acoustic Resonators (FBARs) are based on the excitation of bulk acoustic wave modes in a piezoelectric thin film (typically AlN or ZnO), and are becoming extensively used in wireless communications due to their low cost, small size, high Q-values and good power handling capabilities. Our results show that SFM methods allow an extensive acoustic characterization of these resonators, including vibration amplitude mapping, decomposition of vibration images into acoustic modes, mode shape reconstruction and identification of different channels of energy dissipation such us thermal expansion or the excitation of undesired short wave-length Lamb wave modes. On the other hand, Silicon based resonators represent the most promising strategy for the CMOS integration of RF MEMS devices. These resonators are driven by the electrostatic excitation of bulk acoustic modes which imply in-plane vibrations of the resonating structure. We have successfully tested different SFM methods in order to detect and image in-plane vibrations of the order of a few nanometers in both Silicon and piezoelectric resonators. Other interesting effects, such us the coupling of in-plane vibrations to out-of-plane or bending modes, or mechanical losses in non-active parts of the resonators have also been observed in our experiments.

9:30 PM J8.5

Silicon Photodetectors with Self-Assembled Ge Quantum Dots for Near- and Midinfrared Operation.

Anatoly Vasilievich Dvurechenskii, Andrew I. Yakimov, Victor V. Kirienko, Alexander I. Nikiforov and Natalia P. Stepina; Institute of Semiconductor Physics, Novosibirsk, Russian Federation.

The potential advantages of the quantum dots infrared photodetectors (QDIPs) as compared with two-dimensional systems are (i) increased sensitivity to normally incident radiation as a result of breaking of the polarization selection rules, so eliminating the need for reflectors, gratings or optocouplers, (ii) expected large photoelectric gain associated with a reduced capture probability of photoexcited carriers due to suppression of electron-phonon scattering, (iii) small thermal generation rate, resulted from zero-dimensional character of the electronic spectrum, that renders a much improved signal-to-noise ratio, (iv) possibility of the narrow-band detection due to discreteness of the density of states. At present work we have developed a procedure and fabricated p-i-n and p-i-p photodiodes with embedded multiple arrays of Ge quantum dots on Si substrate for near-infrared detection (1.3-1.5 μm as electron transition from Ge QDs to Si conduction band) by molecular-beam epitaxy. To provide a high performance of QDIPs, the photosensitive region of detectors should consist of a dense array of QDs. For our case the dots have a lateral size of about 8-10 nm and a density up to 10^{12} cm^{-2}. The lowest dark current density reported in Ge/Si photodetectors at room temperature was achieved (2×10^{-5} A/cm^2 at reverse bias 1 V). An external quantum efficiency of 3% was obtained at 1.3 μm of wavelength at normally incident radiation. To increase the interaction length between the light and the QDs layers and to provide the intrachip interconnections, a vertical stacking of 36 layers of coherent Ge nanoislands was inserted into a waveguide obtained with a silicon-on-insulator structure. The sample was processed into ridge waveguide. Devices with lengths going from L = 0.1 to 5 mm were fabricated. The light is coupled through the edge of the detector. The maximum external room-temperature quantum efficiency achieved is 16% for 1.55 μm and 21% for 1.3 μm at L > 3 mm and reverse bias > 3 V. The photoconductivity associated with bound-to-bound transitions (hole transitions between discrete energy levels in Ge QD) was studied in a vertical p-i-p phototransistor in the wavelenght 10 -20 μm. The current flowing from emitter to collector is limited by space charge. The holes photoexcited from the ground to excited states change the space charge density in the base region. The room temperature photoresponse spectra measured at normal incident radiation conditions exhibit two distinct peaks: the low-energy peak corresponds to the hole transition from the ground to the first excited state, and the high energy peak is apparently associated with the transition to the second excited state. The highest peak detectivity is 1.7×10^8 cm Hz$^{1/2}$/W at room temperature. The work was supported in part by INTAS project 2001-0615.

9:45 PM J8.6

Mechanically Tunable Nanophotonic Devices.

Wounjhang Park[1], Ethan Schonbrun[1], Mark Tinker[2] and Jeong-Bong Lee[2]; [1]Electrical & Computer Engineering, University of Colorado, Boulder, Colorado; [2]Electrical Engineering, University of Texas, Dallas, Texas.

We report a novel tunable nanophotonic device concept based on flexible photonic crystal (PC), which is comprised of a periodic array of high index dielectric material and a low index flexible polymer. Tunability is achieved by applying mechanical force with nano-/micro-electron-mechanical system actuators. The mechanical stress induces changes in the periodicity of the photonic crystal, to which the photonic band structure is extremely sensitive. This consequently produces tunability much greater than that achievable by electro-optic materials such as liquid crystal. To demonstrate the concept, we theoretically investigated the anomalous refraction in the flexible PC structure made of a triangular array of Si pillars embedded in a polyimide film. At a normalized frequency of $\omega a/2\pi c$ = 0.39, the equi-frequency surface (EFS) was highly anisotropic with a star-like shape, resulting in a giant negative refraction effect in which refraction angle reaches -70 degree for an incident angle as small as 5 degree. As the structure is mechanically stretched, the EFS becomes significantly flattened, dramatically reducing the refraction angles. When stretched by 10%, the curvature of the EFS is reversed and the flexible PC begins to exhibit positive refraction. This enables dynamic beam steering over a range as wide as 75 degree. We have also demonstrated tunable focusing with sub-wavelength resolution by the negatively refracting PC structure. For experimental demonstration, we fabricated the flexible PC structures on Si-on-insulator substrates. The test structure was comprised of a 10x100 matrix of Si pillars embedded in polyimide thin film. The structures were released for mechanical tuning by etching the underlying SiO2 layer. SEM confirmed the precise fabrication of Si pillars with diameters ranging 400nm $\sim$ 2.5μm and aspect ratio of 1:1. For optical characterization, we co-fabricated a Si ridge waveguide through which 1550 or 1310nm laser beam was delivered to the flexible PC. The PC's refractive properties were then measured directly by imaging the light scattered out of the device or the light transmitted through the device. Our test structure was designed to exhibit nearly isotropic negative refraction at 1550nm. The experiments clearly showed the anticipated negative refraction in which the incident beam was refracted back to the side it was incident. To our knowledge, this is the first experimental demonstration of negative refraction in a Si-based photonic crystal structure. We have also successfully fabricated metallic and Si comb drive actuators with sub-micron feature sizes. We are currently working on integrating the actuators with the flexible PC for experimental demonstration of dynamic tunability, which will be presented at the conference. This new concept of tunable PC allows real-time, dynamic control of photonic band structure, thereby greatly expanding the utility of PCs and enabling novel advanced nanophotonic systems.

SESSION J9: Micro- and Nanfluidics
Chair: Cengiz S. Ozkan
Wednesday Morning, March 30, 2005
Room 2003 (Moscone West)

8:30 AM J9.1

CMOS Compatible Integrated Silicon Dioxide Microfluidic Tunnels for Fluidic Sample Delivery to Nanometer Scale Chemical Sensors. Ali Gokirmak and Sandip Tiwari; Electrical and Computer Engineering, Cornell University, Ithaca, New York.

Using the cutting edge semiconductor technology it is possible to make very small sensors for very fast sensing of chemicals. However, the fluidic sample is needed to be delivered to the sensor from the off-chip sources and is needed to be taken out. In order to interface an external pluming system with the on chip sensors, on chip microfluidic tunnels are needed to bring the sample from one end of the chip into the microfluidic sensors. Chemical sensors which use electrical detection schemes need to be electrically isolated from the microfluidic tunnels carrying the sample into the small openings of the sensors. The dimensions of the microfluidic tunnels need to be large enough to allow necessary throughput. Most of the CMOS based sensors and CMOS circuitry integrated with sensors have materials, process and temperature constraints for back-end of the line fluidics integration. We have developed a low temperature, CMOS compatible back end of the line process for making silicon dioxide microfluidic tunnels for sample delivery to CMOS based chemical sensors. Fabrication process of these tunnels involve removal of sacrificial photoresist, allow arbitrary tunnel widths with the use of the pillars and the maximum process temperature is 135 ° C. The semicircular ceiling of the fabricated tunnels are supported by pillars separated by 8 μ m. These microfluidic tunnels are compatible with cleaning steps involving strong base or acid solutions and can withstand anneal steps at higher temperatures. In the fabrication process 1.2 μ m photoresist is filled into lithographically defined shallow trenches of 0.3 μ m leading to the sensors and patterned by photolithography using the same mask and image reversal with ammonia bake. In order to increase structural strength and increased flow rate in the tunnels, the top surface of the photoresist filling is rounded using isotropic oxygen plasma in a spike heated chamber. Wafers are then are baked at 135 ° C in order to prevent outgasing of the photoresist during the subsequent steps. The bake step slightly reshapes the photoresist to properly fill into the trenches, eliminating possible problems due to misalignment in the lithography steps and enforces the continuity of the tunnels into the nanofluidic sensors. After this step a thin 0.25 μ m shell of SiO_2 is sputtered on the wafer followed by a 120 ° C PECVD SiO_2 deposition of 1 μ m thickness. The sputtered SiO_2 shell prevents both the reflow of the resist and SiO_2 deposition between the resist fill and lead openings of the sensors during the PECVD deposition. Irrigation holes are opened and the sacrificial photoresist is dissolved using acetone. It is possible to fabricate multiple levels of microfluidic tunnels crossing one over another to implement complicated chemical sensor and mixer networks by simply repeating the process steps after the irrigation holes are sealed. We will show the use of this technique for on chip fluidic delivery.

8:45 AM J9.2

Microfluidic Platform for the Generation of Polymer Particles. Zuzanna Cygan, Kathryn L. Beers and Eric J. Amis; Polymers Division, National Institute of Standards and Technology, Gaithersburg, Maryland.

We demonstrate a microfluidic platform for the synthesis of polymer particles of controlled size and composition. Rapid prototyping photolithography of a thiolene-based resin was used to fabricate microfluidic devices stable to organic solvents and monomers. Monodisperse droplets of monomer suspended in a water/surfactant matrix were formed and photopolymerized on chip to generate crosslinked polymer particles. In-line Raman spectroscopy was used to monitor extent of conversion and particle composition. Particles were isolated and size and shape were characterized by optical image analysis.

9:00 AM J9.3

Development of a Microfluidic Rheometer for Measuring the Complex Modulus and Complex Viscosity of Complex Fluids. Jai Pathak[1] and Kathryn Beers[1]; [1]Polymers Division, NIST, Gaithersburg, Maryland; [2]Polymers Division, NIST, Gaithersburg, Maryland.

The measurement of the rheology of complex fluids at the micro-scale is an important scientific and technical challenge in the evolving field of microfluidics. As part of the ongoing effort at the NIST Polymers Division to integrate synthesis of model polymers and the characterization of their physical chemistry and rheology on a lab-on-a-chip platform, we present results of our work on the development of a microfluidic rheometer based on the well-established metrology principle of magnetic particle rheometry. We are inspired by ideas from the bio-rheology field, with which we face a common experimental challenge: the availability of extremely small quantities (tens of microlitres) of fluid samples. We will discuss the design and fabrication of the instrument, and present results of oscillatory and steady shear rheometry on diverse fluids, including standards of known viscosities and a plethora of complex fluids.

9:15 AM J9.4

Novel Microfluidic Reactors for the Synthesis of Unconventional Materials. Kyung M. Choi[1,3], Abraham P. Lee[2] and Kenneth J. Shea[1]; [1]Department of Chemistry, University of California-Irvine, Irvine, California; [2]Biomedical Engineering, Mechanical and Aerospace Engineering, University of California-Irvine, Irvine, California; [3]Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois.

Microsystem technology offers us numerous active devices by fabricating small features on a variety of substrates to satisfy a set of our demands in miniaturization. Since we have been seeking precision microdevices with enhanced performance at small scale, here we introduced a 'microfluidic approach' for the synthesis of new materials, which hitherto have not been possible from conventional synthetic approach. The use of microreactors for synthetic chemistry offers a number of potential advantages over existing chemical technology. Chemical reactions run in microfluidic devices have high thermal and mass transfer rates with an opportunity to use more aggressive reaction conditions allowing for improved product yield. The overall goal is to carry out all operations normally performed in a chemical laboratory including synthesis, processing, purification and analysis on one microfluidic device efficiently and economically using minute amounts of solvents and reagents. For example, we demonstrated here a microfluidic synthesis of functional molecularly imprinted polymer (MIPs) particles by using a novel microfluidic reactor to produce 'monoclonal MIPs particles', which have only high affinity binding sites to achieve high performance molecular recognition function in chemical or bio-detective technology. We also synthesized nano-sized semiconductor particles by continuous, dynamic fusion method using a specially designed microfluidic reactor.

9:30 AM J9.5

High Resolution Parallel Microfluidic Arrays. Yu Xiang and David A. LaVan; Mechanical Engineering, Yale University, New Haven, Connecticut.

We describe a simple parallel microfluidic system that can produce an array of mixtures of 4 input compounds. A PDMS prototype device that is capable of producing 10^4 blends of 4 individual input compounds (named A, B, C and D) was designed, fabricated and tested. The prototype is composed of two micro-mixers and a 100x100 array. Each micro-mixer, a network of sub-mixers and meanders, can generate and mix 10 dilutions of compound A (or C) with 10 dilutions of compound B (or D), respectively, to deliver the 100 mixture combinations in separate outlet microchannels. The 10^4 array is generated by crossing the two sets of channels coming out of the two mixers, fabricated in two different layers. At every crossing, the channels are separated by a composite separator comprising a membrane, a microwell, and a second membrane. The fluidic networks have been carefully designed such that the flow rates are the same at all the outlets. The finest features of the prototype system are 50 micrometers wide. The devices described have broad potential in high-throughput synthesis of polymers along with drug-screening.

9:45 AM J9.6

Glancing Angle Deposition Thin Film Microstructures for Microfluidic Applications. Gregory K. Kiema, Martin O. Jensen and Michael J. Brett; Electrical and Computer Engineering, University of Alberta, Edmonton, Alberta, Canada.

Micro and nanometre-scale structures promise to be of great importance in the advancement of biotechnology. Recent studies have demonstrated the capabilities of these structures as artificial separation matrices for microfluidic devices. In comparison to conventional gels which have random pore size distribution, nanofabricated artificial gels have controllable and measurable porosity which make them easier to integrate with devices that sort, separate and analyze molecules based on size or mechanical properties. Most of the previous methods for fabricating artificial micro and nanometre-scale fluidic structures have involved lithography approach and etching processes.[1] As a result, most of the materials used to nanofabricate artificial fluidic structures has been on glass and selected semiconductors limited to standard microfabrication technology. This however limits the experimentation of artificial gels made of materials that would interact with individual molecules at nanometre-scale. In this work, we describe a new glancing angle deposition (GLAD) technique for fabricating three-dimensional artificial gels in a wide variety of materials with potential use in microfluidic analysis. Traditional GLAD technique involves physical vapour deposition of thin films onto substrates oriented at highly oblique angles to the incident vapour flux. Two competing mechanisms namely, self-shadowing and limited adatom diffusion dominate the film growth process.[2] The new GLAD method decouples the direction of incoming flux with the direction of film growth and this allows us to engineer the porosity of the film microstructures.[3] The fabricated microstructures were characterized by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). A digital camera with a short focal distance was used to record flow through the fabricated artificial gel. Results show that the new Glad method may be used to fabricate the entire microfluidic device as a monolithic unit which is an advantage. Observation of pressure driven flow through the fabricated high density microcolumn arrays indicate the feasibility of microfluidic analysis using devices made with the new Glad method. References 1 J. Han, H. G. Craighead, Science 288, 1026 (2000). 2. K. Robbie, M.J. Brett, U.S. Pat. 5,866,204, (1999). 3. M. O. Jensen, M. J. Brett, Appl. Phys. A. In Press (2004)

SESSION J10: Drug and Protein Delivery
Chair: David La Van
Wednesday Morning, March 30, 2005
Room 2003 (Moscone West)

10:30 AM J10.1
Novel Fluorescent Noble Metal Quantum Dots. Robert M. Dickson and Jie Zheng; Chemistry and Biochemistry, Georgia Institute of Technology, Atlanta, Georgia.

Highly fluorescent, water-soluble, several-atom gold and silver quantum dots have been created in dendritic and peptide matrices. These quantum dots behave as multi-electron artificial atoms with size-tunable, discrete electronic transitions between states of well-defined angular momenta. Correlation of Au nanocluster size with transition energy is well-fit by the simple relation, Efermi/N1/3, indicating protoplasmonic fluorescence arising from intraband transitions of free electrons (the jellium model). These conduction electron transitions are the low number limit of the plasmon-the collective dipole oscillations occurring when a continuous density of states is reached. Photon antibunching experiments further indicate that single electron transitions instead of collective oscillations are responsible for the size-dependent emission. Providing the missing link between atomic and nanoparticle behavior in noble metals, these highly fluorescent, water-soluble noble metal quantum dots offer complementary transition energy size scalings at smaller dimensions than do semiconductor quantum dots. The unique, discrete excitation and emission coupled with facile creation in aqueous solution open new opportunities for noble metal quantum dots as biological labels, energy transfer pairs, and other light emitting sources in nanoscale optoelectronics. References: 1. Zheng,J.; Zhang C.W., Dickson, R.M. Physical Review Letters, 2004,93, 077402. 2. Zheng, J.; Petty, J. T.; Dickson, R. M.; J. Amer. Chem. Soc., 2003,125, 7780-7781. 3. Zheng, J.; Dickson, R. M.;, J. Amer. Chem. Soc.,2002 124, 13982-13983

10:45 AM J10.2
Micro and Nano-Assembly of Devices. Mihri Ozkan, University of California, Riverside, Riverside, California.

Heterogeneous integration of devices made of different materials than the mother substrate requires creative ways of integration. In this presentation, a bio-assembly of both micro- and nano-size particles using linkers such as DNA, PNA and viruses will be discussed. Micro scale objects (polystyrene micro spheres) and inactive devices (silicon dioxide discs) are assembled on silicon substrate using DNA linkers. Similarly, single walled carbon nanotubes, CdSe quantum dots are assembled via PNA and viruses as linkers. Assembly of these hybrid systems are analyzed by Scanning electron microscope, Transmission electron microscope, and Fourier transformation infrared spectroscopy. Such hybrid systems offer controlled assembly of objects in the nano-scale for applications of electronics and bioengineering.

11:00 AM J10.3
High Density Chemical Delivery Arrays with Temporal and Spatial Control. Morgan Mager, Adam Freund and Nicholas A. Melosh; Materials Science, Stanford University, Stanford, California.

Controlled delivery of chemical species into an aqueous system is an important component of drug research, molecular conformation studies and cell interrogation. To advance the integration of biological systems with micro- or nano-scale devices, it is important to administer drugs, neurotransmitters, DNA fragments and other biomolecules exactly when and where they are needed. It would be useful to have a compact system able to interact in parallel with a number of local environments. We report the fabrication and testing of a system of electrically addressable nano-scale reservoirs that allows temporal control of seconds and spatial control of hundreds of nanometers. This system is comprised of a nano-scale reservoir of several microns with an aperture of about 100nm. The opening is covered with a continuous lipid bilayer which, at equilibrium, acts as a diffusion barrier to the species inside. Through the application of an electric potential, this species can be electroporated through the membrane and into the surrounding environment. Since it can be fashioned in a massively parallel array of independently controllable reservoirs, this technology has potential applications for directed cell growth.

11:15 AM J10.4
Electrokinetic Transport of Rigid and Soft Molecules in 2D and 3D Nanofluidic Geometries. Shengnian Wang, Xin Hu and Ly James Lee; Chemical and Biomolecular Engineering, Ohio State University, Columbus, Ohio.

Sacrificial templates imprinting (STI) is introduced and applied to the fabrication of polymer nanonozzle arrays. Nanonozzles with uniform conical fluidic channels can provide two important flow patterns: converging and diverging flow. Electric field enhanced transport is studied in both flow patterns with rigid nanospheres and flexible DNA molecules. Since the analytes always carry negative charges, both electrophoresis (EP) and electroosmosis (EOF) play important roles. The geometry of those nanonozzles create velocity gradient along the restricted taper regions. Therefore, the diverging flow showed self clean function while converging flow easily clogged for rigid colloid nanosphere transport. But for flexible polymers (i.e., DNA), converging flow can moderately stretch the DNA chain to achieve easy pass with equilibrium size of molecules much larger than the channel size. With the increase of analyte size, hindered transport became apparent until completely block when the channel size closer to the analyte size. To directly observe the conformations of DNA, 2D nanofluidic geometries are fabricated by e-beam Lithography (EBL), followed by soft embossing. The motion of DNA is studied in electrokinetic flow with different solutions, considering the effects of channel geometry and internal surface properties of nanochannels. Both steady state and dynamics of DNA conformation are investigated. To compare with experimental results, molecular model is employed to simulate DNA deformations in some cases. All of these findings are relevant in designing gene delivery strategies, and nanofluidic systems for biochemical analysis.

11:30 AM J10.5
Luminescence Enhancement and Inhibition Properties of Core-Shell Silica Fluorescent Nanoparticles. Carl Poitras[1], Michal Lipson[1], Andrew Burns[2] and Ulrich Wiesner[2]; [1]Electrical and Computer Engineering, Cornell University, Ithaca, New York; [2]Materials Science and Engineering, Cornell University, Ithaca, New York.

We present results on lifetime, photoluminescence enhancement and inhibition of bright and photostable silica fluorescent nanoparticles. These nanoparticles, come in a liquid solution. They are produced by encapsulating tetramethylrhodamine isothiocyanate (TRITC) fluorophores into a silica shell. These emitters have a brightness that is of the same order of magnitude as quantum dots, and their colloidal form enables their incorporation into optical structures for providing optoelectronic properties to passive devices such as oxides. Here we control the emission properties of the nanoparticles by incorporating them into light confining microcavities. The photoluminescence of the nanoparticles studied is centered at about 570 nm with a FWHM of 39 nm at room temperature under optical excitation at 496.5 nm. Other fluorophores can also be used in order to obtain different luminescence spectra. The photoluminescence properties of the nanoparticles were controlled in 1D by a microcavity formed between distributed Bragg reflectors (DBRs). The microcavity is formed by sputtering layers of SiO2 and TiO2. The cavity mode of the structure exhibits a relatively high Q of 110. The confinement of light in the plane of the structure was achieved by varying the effective cavity thickness along the sample. Due to the light confinement in the cavity we observe a strong photoluminescence enhancement and inhibition of the nanoparticles. We also observe a strong directionality due to the in-plane confinement. With conjugation chemistry that is well developed for silica, the silica-clad nanoparticles embedded in microcavities opens the door to a variety of applications ranging from biosensing to displays.

11:45 AM J10.6

Efficient Atomization Using MHz MEMS-Based Integrated Ultrasonic Nozzles. Shirley C. Tsai[1], Yue L. Song[2,3], Yuan F. Chou[4], J. H. Cheng[4] and Chen S. Tsai[3,5]; [1]Chemical Engineering, California State University, Long Beach, Long Beach, California; [2]Physics, National Taiwan University, Taipei, Taiwan; [3]Electrical Engineering and Computer Science, University of California, Irvine, California; [4]Mechanical Engineering, National Taiwan University, Taipei, Taiwan; [5]Electrooptical Engineering, National Taiwan University, Taipei, Taiwan.

At the 2003 MRS Fall Meeting, we reported simulation and vibration characterization of 0.5 MHz silicon (Si) MEMS-based ultrasonic nozzles using a novel design of multiple Fourier horns. In this paper, we report for the FIRST time on successful atomization using such high frequency ultrasonic nozzles and an integrated system for pumping and atomization. The MEMS-based integrated MHz ultrasonic nozzle is made of a piezoelectric drive section, a pump section, and a silicon-resonator with a central channel for liquid flow. As the liquid to be atomized is pumped into the central channel of a 0.5 MHz 3-Fourier horn nozzle, a liquid drop forms at the nozzle tip, but no atomization takes place when the frequency of the drive signal differs from the resonant frequency. In contrast, a thin film of liquid forms at the nozzle tip and a 0.4 mm-wide sheet of drops around 5 um in diameter is produced when a drive voltage as low as 6.5 V is applied at the actual resonant frequency of 484.5 kHz. A video photo of the atomization clearly shows the softness of the resulting spray sheet. Due to the resonance effect of multiple Fourier horns, the electric drive power required for atomization using the 3-horn nozzle is only 1/4 of that using a single horn nozzle. For the same reason, the drive voltage required is one order of magnitude lower than that required in conventional ultrasonic atomization using nebulizers. Furthermore, the narrow bandwidth associated with resonance facilitates production of uniform droplets. A high degree of correlation between the atomization results and the impedance analysis and the longitudinal vibration at the nozzle tip has been accomplished. Some of the advantages of such MHz MEMS-based ultrasonic nozzles are microfabrication technology for mass production, much higher ultrasonic frequency and thus much smaller uniform droplets, and much lower elctric drive power requirement. These advantages enable the silicon-based MHz ultrasonic nozzles to overcome the 120 kHz frequency limitation of the conventional ultrasonic nozzles. Among the potential applications are: (1) spray pyrolysis for nanoparticles synthesis, (2) spray coating of polymers and bio dispersions for nano- and micro-electronics processing, and (3) use in pocket-size nebulizers for alveolar delivery of medicines. Some results of such applications will also be reported.

SESSION J11: Actuators for BioMEMS
Chair: Somuri Prasad
Wednesday Afternoon, March 30, 2005
Room 2003 (Moscone West)

1:30 PM J11.1

Abstract Withdrawn

1:45 PM J11.2

Thin Film Silicon Microbridges for DNA Detection. Teresa Adrega[1], J. Gaspar[1], F. Fixe[1,2], V. Chu[1], D. M. F. Prazeres[2] and J. P. Conde[1,3]; [1]INESC-MN, Lisbon, Portugal; [2]Center of Biological and Chemical Engineering, Instituto Superior Tecnico, Lisbon, Portugal; [3]Department of Chemical Engineering, Instituto Superior Tecnico, Lisbon, Portugal.

There has been growing interest in using microelectromechanical systems (MEMS) as biological sensors. Microresonators, in particular, have been proposed as sensors to detect and quantify the presence of specific compounds. Recently, thin-film silicon MEMS were developed in order to benefit from the advantages of thin-film technology. The use of low temperature processing ($< 150^\circ$C), allows the use of substrates such as glass, plastic and stainless steel. In addition, thin-film MEMS are CMOS compatible enabling the monolithic integration of MEMS with its control electronics. This work presents a DNA sensor based on doped hydrogenated amorphous silicon (n^+-a-Si:H) fabricated on a glass substrate. The sensor works by the measurement of the resonance frequency shift induced by specific oligonucleotide immobilization on a resonating microbridge. The sensor is fabricated using surface micromachining and consists of a n^+-a-Si:H/ aluminum bilayer microbridge with silicon dioxide patterned on the top. The silicon dioxide is a material suitable for DNA covalent binding after chemical functionalization by silanization. An aluminum gate underneath the bridge allows the electrostatic excitation of the microbridge. The width of the microbridges is 18 microns, the air gap is 1 micron and the length ranges from 20 to 70 microns. The oligonucleotide molecules are labeled with fluorescein-5-isothiocyanate (FITC) at the NH_2 terminated 3′ end to allow detection of the immobilization by fluorescence microscopy. For resonance frequency measurements the bridges are electrostatically actuated by applying a voltage with both DC and AC components between the bridge and the gate counter electrode. The resulting deflection is detected optically. Using fluorescence microscopy it was confirmed that the DNA molecules were immobilized specifically on the area of the bridge surface coated with silicon dioxide. The resonance frequency of the microbridges is in the 1-10 MHz range, and is inversely proportional to the square of its length. Quality factors are of the order of 1000. DNA immobilization on the microbridge induces a resonance frequency shift. From previous experiments, we expect the density of DNA immobilized in this process to be around 30 pmol/cm^2. Observed shifts in resonance frequency of around 2% are consistent with these results. Quantitative studies for the detection of DNA immobilization and hybridization will be presented. In particular, the variation of resonance frequency with the area of silicon dioxide on top of the microbridge available for DNA immobilization and also the effect of using oligonucleotides with different length are studied. A model discussing this sensing method will also be presented.

2:00 PM J11.3

Fabrication and Electromechanical Properties of Conductive Polymer Microbridge Actuators. Guandong Zhang[1], J. Gaspar[1], V. Chu[1] and J. P. Conde[1,2]; [1]INESC-MN, Lisboa, Portugal; [2]Chemical Engineering, Instituto Superior Tecnico, Lisboa, Portugal.

Polymeric materials are of great interest for electronic devices and MEMS applications due to their relative low cost and simple processing. Polymers are flexible, biocompatible, and available in many varieties. Their structure can be modified to achieve different functionalities. In this work, all-polymer suspended microbridges incorporating a conductive polymer are fabricated on glass substrates using surface micromachining, and their electromechanical properties are characterized. A blended conductive polymer material of polymethyl methacrylate (PMMA) and Baytron P (a waterborne dispersion of the polymer complex PEDOT and PSS) is investigated for the preparation of the microbridges. A silane-based adhesive agent that works as a crosslinking agent is added to the mixed polymer solution to improve the strength and binding of the polymer film. In the fabrication process, a Cr gate is first deposited and patterned on a glass substrate. Then, an Al film is deposited and patterned on the Cr gate to function as the sacrificial layer. Next, the conductive polymer film is spin coated. After hard-baking the polymer film, a thin Al layer is deposited and patterned to function as a mask for defining the polymer bridge during the subsequent polymer plasma etching process. Finally, the Al sacrificial layer and the bridge mask are selectively removed by wet etching. The pull-in voltage of the polymer structure is electrically measured by applying a voltage between the top polymer bridge and the bottom Cr electrode and measuring the current between the bridge and the gate. The structure bends due to the electrostatic force. The pull-in voltage increases as the length, L, of bridges decreases. A voltage V_G with DC and AC components is also applied to the gate electrode. In this case, the excitation frequency is in the Hz range, far below the resonance frequency. The movement of the microstructures is optically monitored. A quadratic dependence of the bridge deflection with the amplitude of the applied voltage is observed, in agreement with a simple electromechanical model. The polymer bridges show a high sensitivity to the electrical forces due to the low Young′s Modulus, E, of polymer material (for PMMA, $E \approx 3.5$ GPa). Therefore, the electrostatically induced deflection of the polymer structures is significantly higher than that of inorganic actuators with similar dimensions. The resonance response of the polymer microbridges is measured at different pressures. The resonance frequency of the bridge shows a length-dependence between $1/L$ and $1/L^2$ and is in the MHz range. The quality factor in vacuum of the microresonator is of the order of 100. Although the values of the pull-in voltage, quasi-DC deflection and resonance frequency are compatible with those expected from the low value of E for the polymer structural layer, they are strongly modified by the addition of the crosslinking agent and by the effect of residual stresses as will be discussed.

2:15 PM J11.4

Low-cost and Chemical Resistant Microfluidic Devices based on Thermoplastic Elastomers for a Novel Multiple Parameter Biosensor System. Ivan Stoyanov, Stefan Glass, Michael Tewes, Eckhard Quandt and Markus Loehndorf; Nano- and Microstructures, Research Center Caesar, Bonn, Germany.

Up to now the most crucial part for the development of a complete analytical biosensor system is the technology for the integration or combination of the microfluidic components and the sensor device. In our approach we have developed a modular multiple parameter biosensor system where the microfluidic device can be easily exchanged when different sensors chips used in order to adjust for the active sensor surface area. The modular, flexible microfluidic device is then positioned over the active sensor cell and a spring-loaded mechanical force is applied to assure the proper sealing prior to any bio-analytical measurements. The multiple parameter biosensor system [1] is equipped with fluidic connectors, high frequency electronics and data acquisition for bio-analytical measurements. 5-channel surface acoustic wave (SAW) sensor arrays with a limit-of-detection of 800 femtogramm/square mm [2] and high frequency nanogap impedance sensors [3] are used for bio-analytical measurements such as protein-antibody binding in real-time. In order to allow for real-time measurements concentration rise times on the order of 1-3 sec within the microfluidic cell have to be realized. Therefore, the total volume of the fluidic cell is 2 microliter/channel for the SAW sensor and about 0.2 microliter/channel for the impedance sensor. The microfluidic devices have to fulfil certain requirements, such as excellent sealing properties, high chemical resistance and compatibility with the other fluidic handling components and in addition a low price of the material and the possibility for an easy exchange of these devices should enable the use as fluidic disposables. Therefore, we have used commercial available thermoplastic elastomer foils based on polyurethane (PU) in a thickness range of 100-600 μm. Prior to the fabrication of the microfluidic devices by means of hot embossing we have analysed the chemical resistance for a wide range of standard biological buffer solutions and cleaning fluids. Double-sided hot embossing with an alignment accuracy of +/- 3 micrometer created systems of channels, reservoirs and holes for the tube connections. Closed channel structures were produced by an additional chemical bonding process of the embossed devices with a sealant foil. The influence of the shape and the total volume of the microfluidic device as well as the concentration gradient distribution within the fluidic cell are discussed in detail in view of real-time kinetic measurements of protein-antibody and protein-aptamer interactions. [1] S-sens analytics (www.s-sens.com) [2] M. Schlensog et al. Sensors and Actuators Vol. B101/3, 308 (2004) [3] M. Loehndorf et al. Proc. of μ-TAS 2004, Vol.2, 431 (2004)

2:30 PM J11.5

Multi-Layer Photopolymer Micromachining. Jiunn-Ru Jeffrey Huang[1], Bo Bai[2], Jeffrey Shaw[1], Thomas N. Jackson[2], Ching-Yeu Wei[1], Venkatesan Manivannan[3] and Kevin M. Durocher[1]; [1]Micro- and Nano-Structures Technologies, GE Global Research Center, Niskayuna, New York; [2]Center for Thin Film Devices, Electronic Materials and Processing Research Laboratories, Department of Electrical Engineering, Pennsylvania State University, University Park, Pennsylvania; [3]Ceramic and Metallelurgy Technologies, GE Global Research Center, Niskayuna, New York.

We report on a novel approach to create micromachined devices and high aspect-ratio (height-to-width ratio) micro-structures in which the microstructures are built up using multiple layers of photopolymer film and/or viscous solution. Very high aspect-ratio 2- and 3-dimensional (2-D and 3-D) microstructures were fabricated by stacking photo-imagable polymer dry films and/or viscous solution by lamination and/or bar coating and photolithography. We demonstrated a 2-D, 12-layer array of high aspect-ratio deep trenches (greater than 180 mm deep and 25 mm wide), and a 2-layer, micromachined SU-8 micro-trench array structures of an aspect ratio of greater than 25 on glass substrates. This method has the potential to create functional large-area micro-devices at low-cost with increased device flexibility, durability, and reduced process complexity for applications in optoelectronics, integrated sensors, and bio-devices. The novel multi-layer photopolymer dry film and solution process also allows micro-electro-mechanical systems (MEMS) to be built and provides the functionality of MEMS integration with electronic devices and integrated circuits (ICs).

2:45 PM J11.6

A Novel Latching Relay Fabricated using a Oxide Molded Tungsten Process. Jim Fleming, Michael Baker and David Luck; Sandia Nat Labs, Albuquerque, New Mexico.

Here we describe a new MEMS process for fabricating metallic structures based on molded tungsten. Micro-molding avoids the generally severe out of plane stress problems associated with blanket, chemical vapor deposited tungsten films. However, in our process there remains a tensile stress associated with the mismatch in thermal expansion coefficient between the silicon substrate and the tungsten structural material. We have successfully demonstrated a latching relay which takes advantage of this high residual tensile stress. The device employs thermal actuation, however, since the state can be latched, the average power usage of such a device can be small for applications where the state of the latch is changed infrequently. The novel actuator design, which takes advantage of the inherent tensile nature of the released tungsten components can generate milli-Newton level forces and avoids problems associated with buckling which can limit the force exerted by the device. Without any noble metal coating of the contacts we have demonstrated contact resistances as low as couple of ohms. While the major structural component of the parts is tungsten, there is a thin layer of TiN inherent to the fabrication process that forms the contacting surface on both electrodes. We believe that while this application is useful in its own right, it does not exploit the main potential advantage of this process, its compatibility with back end CMOS processing. The processes we have employed have been taken directly from the different process modules used in traditional CMOS back-end-of-line metallization. This potentially would enable the straightforward addition of complex metallic MEMS structures onto completed CMOS circuits. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

SESSION J12: Process and Device Modeling
Chair: Mark McNie
Wednesday Afternoon, March 30, 2005
Room 2003 (Moscone West)

3:30 PM J12.1

Helical Oligothiophenes As Spring-like Electromechanical Actuators. Adah Almutairi and Michael J. Marsella; Chemistry, University of California Riverside, Riverside, California.

Electromechanical actuation (EMA) is the conversion of electrical to mechanical energy. Conducting polymer EMAs (CP-EMAs) generate stresses that exceed those of mammalian muscle by at least an order of magnitude. Materials capable of emulating the action of natural muscle have been proposed for use in a variety of applications, such as muscle augmentation, and prosthetics. During oxidation, traditional CP-EMAs expand and contract by intercalation of counter ions. This non-intrinsic, bulk process can be augmented by designing polymers with redox induced intrinsic dimensional changes. We reported that 2,3-linked sexithiophene (1) and 3,3'-diaryl-2,2'-bithiophene (2) reliably exhibit helical motifs in the solid-state. The concept of using helical compounds as a spring-like CP-EMA stems from our computed and theoretical predictions that delocalization of charge generated by a redox event will cause the S-C-C-S dihedral angle to decrease in order to maximize pz-orbital overlap in non-neutral states. This action results in a compression of the oligothiophene spring, furthering opportunities for charge delocalization via face-to-face thiophene pz-orbital interaction. Compound 2 undergoes anodic electrochemical polymerization at the free terminal alpha-positions. The resulting poly(2) is electroactive, exhibiting both oxidation and reduction. The latter redox state is an order of magnitude more electrically conducting than the former, as determined by in-situ conductivity measurements (relative conductivity). Theoretically, in the oxidized state, the intrinsic length of the polymer remains constant (polythiophene axis), while its width (tetramer long helical axis) contracts. Real-time EMA measurements of bulk poly(2), show a 1.5% contraction, of the polymer film, prior to the critical point when inter-chain contraction typically dominates ion intercalation. This is comparatively an augmentation from the 0.5% contraction that poly (3-methyl) thiophene exhibited. Advantages to actuation in the light-doping regime include lower voltage requirements and faster response times (given that the flux of counterions will be at a minimum). We have demonstrated 3,3'-diaryl-2,2'-bithiophenes as well-defined and predictable helical systems, capable of augmenting traditional bulk CP-EMA actuation with intrinsic molecular contraction analogous to compression and expansion of a spring. Current work will focus on manipulating the electrolyte solution/solid to increase the inter-chain contraction phenomena. Results to date will be presented.

3:45 PM J12.2

Hot Embossing Lithography: Release Layer Characterization by Chemical Force Microscopy. Neil S Cameron[1], Arnaud Ott[2,1], Helene Roberge[1] and Teodor Veres[1]; [1]IMI, National Research Council Canada, Boucherville, Quebec, Canada; [2]Ecole Superieure D'Ingenieurs de Recherche en Materiaux, Dijon, France.

High cost, slow serial throughput and resolution issues often handicap traditional micro and nanofabrication techniques. To meet the challenges of the micro-electronics, optics, MEMS, BioMEMS, and related industries, researchers look to next generation lithography. Among the technologies being re-invented to this end is hot-embossing lithography (HEL), an example of nano-imprint lithography (NIL). HEL facilitates the fabrication of miniaturized devices with several advantages: high resolution, low long-term cost, flexibility, near-perfect pattern replication, and minimum dimensions in the sub-10 nm range. HEL is promising for optical, biological and data-storage devices as well as semiconductor integrated circuits. We have employed chemical force microscopy (CFM) to quantify interfacial effects for nano-imprint lithography. In its crudest form, a textured, but raw wafer is pressed into a thermoplastic polymer heated above its Tg. As the stamp progresses into the material, the displaced polymer is pushed into the bulk reservoir for relatively thick thin-films. As the stamp motifs reach the end of the stroke, the film remaining between the stamp and the substrate can approach the tribological regime where surface effects from both the stamp and the substrate act on the highly confined polymer. A greater understanding of the surface interactions is thus required with model systems including the perfluoro surface described below both for the embossing stroke and for failure-free de-embossing. Wafers and SPM tips were first silanized with perfluoro- and alkyl-silanes, and model CFM experiments were developed to explore the effect of the various release layers on the embossing process. Contact angle measurements confirmed the chemical process (18.2 MΩ.cm water on SAM) and tip/SAM adhesion forces underscored the importance of the perfluorosilanes with a four-fold decrease in tip-adhesion to perfluorosilanized surfaces. Adhesion forces were measured with a bare, used-as-received SPM tip on silane-functionalized silicon [1 1 1] wafers. The surfaces were imaged by AFM to characterize surface roughness. Subsequently, the silanized-tip/polymer interaction was studied over a temperature range spanning the Tg of the polymer. The adhesion force for the perfluorosilane-functionalized tips was observed to decrease with increasing concentration of surface perfluoromethyl groups. Variable temperature CFM measurements were accomplished by silanizing AFM tips and conducting contact-force experiments on 1 micron polycyclic olefin films (Zeonor 750R on silicon) at various temperatures on our Veeco NanoScope IV MultiMode SPM. Adhesion between a saturated hydrocarbon-decorated tip (OTS) and PCO was comparatively strong (170 nN) above the Tg of the polymer (348 K). Adhesion among the perfluorinated tips decreased to 120 nN at 373 K with a relative increase in perfluoromethyl groups (w/w).

4:00 PM J12.3

Stochastic Frequency Signature for Chemical Sensing via Noninvasive Neuronelectronic Interface. Cengiz Sinan Ozkan and Mo Yang; Mechanical Engineering, University of California at Riverside, Riverside, California.

The detection of chemical agents is important in many areas including environmental pollutants, toxins, biological and chemical pollutants. As smart cells, with strong information encoding ability, neurons can be treated as independent transducer elements. A hybrid circuit of a semiconductor chip with dissociated neurons formed both sensors and transducers. Stochastic frequency spectrum was used to differentiate a mixture of chemical agents with effect on the opening of different ion channels. The frequency of spike trains revealed the concentration of the chemical agent, where the characteristic tuning curve revealed the identity. Fatigue experiments were performed to explore the refreshing ability and memory effects of neurons by cyclic and cascaded sensing. Neuronelectronic noses such as this should have wide potential applications, most notably in environmental and medical monitoring.

4:15 PM J12.4

Carbohydrate-Carbohydrate Recognition Promotes Membrane Adhesion. Christine Gourier[1], Eric Perez[1], Yongmin Zhang[2] and Pierre Sinay[2]; [1]Laboratoire de Physique Statistique, Ecole Normale Superieure, Paris, France; [2]Departement de Chimie, Ecole Normale Superieure, Paris, France.

Recently, carbohydate-carbohydrate recognition has emerged as a new type of interaction in cell adhesion processes. One of these carbohydrates, the LewisX determinant (LeX), has been shown to be involved in murine embryogenesis. Useful information has been obtained on a calcium dependent LeX-LeX recognition with model systems far from the native cellular context. However, nature imposes to the LeX several constraints which may turn out to be decisive for a possible LeX-LeX recognition in a cell environment. One of them is the orientation provided to the LeX through the ceramide (the LeX natural bearing lipid). Therefore the calcium mediated homotypic recognition between natural LeX molecules inserted in a membrane still needs to be proven. For this purpose, natural LeX bearing lipids were inserted in giant vesicles whose adhesion energy was measured. In the experiments, the vesicles, in tight contact, mimic reasonably well the geometry of cells during the compaction stage of the embryo. The measurements not only demonstrate the calcium dependent recognition between two LeX borne by these natural molecules, but also show that ceramide favors recognition. Moreover the choice of a control molecule very alike the LeX has allowed to show the high level of sensitivity of the LeX-LeX bond to molecular structure.

4:30 PM J12.5

Fabrication of Microfluidic Channels with Integrated Transducers for Fluid Pumping. Mary Elizabeth Anito[1,2] and Goksen G. Yaralioglu[2]; [1]Materials Sci. and Engineering, Johns Hopkins University, Baltimore, Maryland; [2]Electrical Engineering, Stanford University, Palo Alto, California.

The ability to fabricate miniaturized channels for the handling of biofluids is helping to advance the biomedical field. To further develop the use of these channels, we incorporated transducers, which allowed for pumping of fluids throughout the system. After etching channels into a double side polished silicon wafer, the wafer was placed between two quartz wafers. Once this construction was completed, transducers were added on top. Transducers serve to convert electrical energy into sound waves. The generated sound waves in the channel will serve the purpose of exerting radiation pressure on the fluid, allowing for the mixing of the fluids and pushing the liquid though the channel. We tested the use of sound radiation to facilitate the movement of fluids through the channels. The overall layout we used was a modification of a previously used design. We attempted to consolidate the fabrication of our system into a more compact device that's channels were formed in a complex geometric layout. Once constructed, we monitored the movement of fluid throughout the channels by taking pictures with a CCD camera. By knowing the time between pictures and the trajectory of the particles in the channel, we were able to measure the fluid velocity. Our success was measured by whether or not a liquid flow was present in the system. Eventually, through use of these developed channels and transducers, advancements in the field of microfluidics can be made.

4:45 PM J12.6

The Nano Pulverization of Liuwei Dihuang. Peiyan Ma[1], Zhengyi Fu[2] and Yanli Su[3]; [1]State Key Lab of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology, Wuhan, China; [2]State Key Lab of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology, Wuhan, China; [3]State Key Lab of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology, Wuhan, China.

In this paper, we proposed that the nano technology could be applied to the Chinese traditional medicine in order to improve the drug effect. HSCS pulverizer is a newly developed apparatus and has an entirely different construction compared with existing media agitating mills or ball mills. On the sub axis,there are a number of rings shaped grinding media, which can move freely. With the rotation of the axis and the autorotation of the rings,they can produce powerful centrifugal and cutting force to obtain nano-sized particles within a short time. The casting is equipped with a jacket, which is used to keep room temperature during milling by sending chilled water into the jacket. So the effective content of the medicine can't be destroyed during pulverization. The nano particles of Liuwei dihuang were prepared by HSCS pulverizer. The appropriate process parameter is: 1200r/min,50min and 3.8%.The microscopic characteristics were studied by ZetaPALS light scattering granulometric analyzer and optical microscope. Exprimental results show that the average diameter is 161.9nm and the great majority of the plant cell wall is broken into pieces after nano pulverization. The effective content can dissolute directly. The dissolution of 80 mesh -particles test maker,Paeonol has line relation with time, but nano particles have no line relation. After 45 min,the accumulative dissolution of nano particles is higher than that of 80 mesh'. Results indicate that c(max)of pseonol in rats taking nano medicine is higher than that in rats taking 80 mesh- particles and t(max) of nano particles is less than that of 80 -mesh particles. So the absorption of nano particles is quicker than that of 80-mesh particles. The absorbing degree of the medicine is also increased obviously after nano pulverization. Attachment: Liuwei Dihuang is a Chinese medicine compound herb composed of six herbs and noted in TCM as a drug with nourshing effect of the kidney. It has been used in treatment of diabetes mellitus for thousands of year. In China,the anti knub of the medicine was reported recently. Acidic polysaccharose extracted from the medcine has been drawn attention for immuneoregulation. But lower dissolution rate held up the progress of the patent medicine.

SESSION J13: Poster Session
Chairs: David La Van and Cengiz S. Ozkan
Wednesday Evening, March 30, 2005
8:00 PM
Salons 8-15 (Marriott)

J13.1

Fabrication of Nanopillars by Nanosphere Lithography. Chin Li Cheung[1], Rebecca J. Welty[2], Catherine Reinhardt[2] and Tzu-Fang Wang[1]; [1]Chemistry and Materials Science, Lawrence Livermore National Laboratory, Livermore, California; [2]Center for Micro and Nano Technology, Lawrence Livermore National Laboratory, Livermore, California.

Device physics is known to change when the dimension of the device is reduced down to the nanometer scale. However, extreme UV photolithography and e-beam lithography conventionally used to generate such small features are very costly, and thus are prohibitive to general research community. Nanosphere lithography (NSL) is an economical technique that applies large planar ordered arrays of nanometer-sized latex or silica spheres as lithography masks to fabricate sub-micron sized particle arrays. Though NSL has been reported to generate nanowells arrays by conventional reactive ion etching, high aspect ratio features are yet been demonstrated. Here we present the application of NSL to generate high-aspect-ratio silicon and gallium arsenide nano-pillars with high density plasma etching. Oxygen plasma reactive ion etching and nanospheres of different sizes were used to tailor the pattern of "nanosphere resist" to control the size and separation of nanopillars. Effect of chemical species, radio frequency power, and substrate bias on etching rates of Si and GaAs and anisotropy of etched profile have been investigated by scanning electron microscopy. This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48

J13.2

Synthesis of BaCrO4 Nano-Crystallites within Thermally Evaporated Sodium bis-2-ethylhexyl-sulfosuccinate and Stearic Acid Thin Films. Kaustav Sinha[1], Debabrata Rautaray[2] and Murali Sastry[2]; [1]Department of Materials & Metallurgical Engineering, University of Nevada, Reno, Reno, Nevada; [2]Department of Materials Chemistry, National Chemical Laboratory, Pune, Maharashtra, India.

The growth of barium chromate nano-crystallites occurs within thermally evaporated thin films of stearic acid and sodium bis-2-ethylhexyl-sulfosuccinate by a process of Ba2+ ion entrapment followed by in-situ reaction with CrO4 2- ions. Dense spherical assemblies of BaCrO4 nano-crystallites of very uniform size ($\sim$ 50 nm) were obtained within the two different host matrices. The spherical assemblies were composed of smaller (ca. 5-10 nm size) BaCrO4 crystals indicating that efficient size control over crystal size may be exercised by the matrix. Contact angle measurements of the BaCrO4-stearic acid and BaCrO4- sodium bis-2-ethylhexylsulfosuccinate films indicated that they were hydrophobic, thus pointing to the possible role of hydrophobic interaction between the stearic acid and sodium bis-2-ethylhexyl-sulfosuccinate monolayer-covered BaCrO4 crystals in the assembly process.

J13.3

Characterization of Benzocyclobutene and Chromium-gold Film Interface for Application in Silicon Micromachining. Nima Ghalichechian[1], Alireza Modafe[1], Paolo Lazzeri[3], Victor Micheli[3], Mariano Anderle[3] and Reza Ghodssi[1,2]; [1]Electrical and Computer Engineering, University of Maryland, College Park, Maryland; [2]The Institute for Systmes Reserach, University of Maryland, College Park, Maryland; [3]ITC-irst Centro per la Ricerca Scientifica e Tecnologica, Trento, Italy.

We report the interface study of Benzocyclobutene (BCB) polymer and chromium/gold (Cr/Au) films with emphasis on adhesion improvement. Strong adhesion between BCB and Cr/Au layer enables the fabrication of deep anisotropically etched grooves in silicon using potassium hydroxide (KOH) in presence of BCB films. BCB is a polymer with low dielectric constant (k=2.65). Integration of thick, low-k dielectric BCB film with deep etched structures in silicon allows the fabrication of microelectromechanical devices with low parasitic loss. In order to protect the low-k film during the highly corrosive, long, high-temperature KOH etching process, Au is used as an etch mask and Cr as an adhesion layer to improve the adhesion of Au to the underlying BCB layer. Metal-BCB adhesion is the key parameter in this masking design. A fabrication process is developed for integration of 1-μm-thick BCB and 200-μm-deep anisotropically etched grooves in silicon using KOH. Partial cure of BCB at 210 °C for 40 min with appropriate surface treatment (adhesion promoter) prior to metallization and full cure at 250 °C for one hour after metallization improves the adhesion dramatically. In order to understand the mechanism of the adhesion improvement, the interfaces between BCB and the Cr/Au layer were studied. Several samples were prepared with different film layers and processing parameters, i.e. cure temperature and surface treatment. Time of flight secondary ion mass spectroscopy (ToF-SIMS) was used to investigate the Cr diffusion into Au after Au deposition and cure at 250 °C for one hour. The quantitative value for Cr concentration at the gold film was obtained using Auger electron spectroscopy (AES). Using tabulated sensitivity factors, Cr concentration at the gold layer was estimated to be on average about 1 at. %. To investigate the lateral distribution of Cr inside the Au layer, high lateral resolution ToF-SIMS images was acquired. It was found that Cr diffusion (after curing) into Au layer is not homogeneous. Chromium-enriched grains of 2 μm or smaller were detected close to pure Au grains. Positive and negative ToF-SIMS depth profiling were performed on two samples and depth profiles of Si, SiO, SiH, and SiOH, as well as, Si, SiO_2, CrC, C, CrO, and CrO_2 were obtained respectively. Adhesion improvement which is mainly due to cure management and use of adhesion promoter is associated with (1) the diffusion of silicon and carbon from the polymer structure into the Cr layer, and (2) the chemical interaction of BCB/adhesion promoter and Cr at the interface mainly in the form of the oxidation of Cr. The integration of BCB and the KOH etching process obtained by improving the adhesion of metal etch mask to the BCB film, together with the study of the interfaces, allow us to use thick low-k BCB film for fabrication of microelectromechanical devices with low parasitic loss.

J13.4

Fabrication and Evaluation of Conducting Polymer Nanowire Heterostructures. Yevgeny Berdichevsky and Y.-H. Lo; Electrical and Computer Engineering Department, University of California, San Diego, La Jolla, California.

Conducting polymer nanostructures such as nanofibers and nanotubes have potential uses in a variety of applications including electronic and photonic devices and sensors. In this work, a method for fabricating polypyrrole and gold nanorod heterostructures is demonstrated. Template synthesis is used to alternatively electroplate gold and electropolymerize polypyrrole in the pores of alumina and polycarbonate membranes. Polypyrrole was electropolymerized in an aqueous solution containing sodium dodecylbenzenesulfonate (NaDBS), resulting in a polymer doped with DBS ions. Individual gold-polypyrrole nanorods are then isolated, and electrical connections are established lithographically. Nanorod conductivity and mechanical activity are then evaluated in various electrolyte environments to establish suitability of these heterostructure nanorods for use as pH and biological sensors and as nanoactuators.

J13.5

Composition Influence on the Properties of Titanium-Doped Gamma Iron Oxides Nanoparticles Prepared by Laser Pyrolysis. Ion Morjan[1], Rodica Alexandrescu[1], Florian Dumitrache[1], Ion Sandu[1], Monica Scarisoreanu[1], Lavinia Albu[1], Iuliana Soare[1], Ion Voicu[1], Bohumil David[2] and Victor Ciupina[3]; [1]Laboratory of Laser Photochemistry, National Institute for Laser, Plasma and Radiation Physics, Bucharest, Romania; [2]Institute of Material Physics, Brno, Czech Republic; [3]Ovidius University, Constanta, Romania.

The aim of this work is the compositional and sensing characterization of titanium-doped gamma iron oxide nanomaterials, in order to obtain stable materials for gas sensing.The properties of nanostructured materials are determined by the size, morphology, and crystalline phase of nanoparticles. Particularly in the case of nano-compounds, these properties are strongly dependent on the synthesis conditions. Titanium-doped gamma iron oxide or iron/iron oxide compozite nanopowders were synthesized by he laser pyrolysis technique. This is a versatile method that allows for the preparation of a large variety of nanosized bodies (with diameters ranging from a few nm to about 50 nm) by promoting IR laser-induced reactions in the gas phase. It is based on the resonance between the emission of a CW CO2 laser line and the infrared absorption band of a gas (vapour) precursor. The reactant gases are heated by laser absorption in a small, well-confined irradiation volume, defined by the intersection of the laser beam with the inlet gas flow. Basically, sensitized iron pentacarbonyl- and titanium tetrachloride-based mixtures were used as gas-phase reactants. The compositional characterization of the obtained nanostructures is performed by means of different analytical methods (such as TEM, SAED, XRD, and Moessbauer spectroscopy. Introducing Ti in the Fe2O3 network in very small quantities ($\sim$1%) seems to have little influence on titanium doped powder morphology (mean grain size: $\sim$ 1.5 nm) due to the fact that titanium could simply penetrate the iron oxide network. First attempts to increase the Ti content of gamma-Fe2O3 oxide indicate the formation of metastable compounds (to pressure-temperature) and a shift of the reaction route towards chlorinated by-products. Electrical measurements were performed in the presence of some gases of interest in polluting area (C2H2), in breath analysis (ethanol) and in food control (ethylene).

J13.6

A Systematic Study of the Formation of Nano-Tips on Silicon Thin Films by Excimer Laser Irradiation. D. G. Georgiev[1], R. J. Baird[1], I. Avrutsky[1], G. Auner[1], G. Newaz[2] and N. Tokranova[3]; [1]Dept. of Electrical and Computer Engineering, Wayne State University, Detroit, Michigan; [2]Dept. of Mechanical Engineering, Wayne State University, Detroit, Michigan; [3]Institute for Materials, SUNY at Albany, Albany, New York.

Recently [1], we reported conditions for controllable, direct laser fabrication of sharp conical tips with heights of about one micrometer and apical radii of curvature of several tens of nanometers. An individual cone is formed when a single-crystal silicon film on an insulator substrate is irradiated in air environment with a single pulse from a KrF excimer laser, homogenized and shaped to a circular spot several microns in diameter. In this work, we present a systematic study of the formation of such tips as a function of the laser fluence, the film thickness, and the diameter of the irradiated spot. Atomic force microscopy and scanning electron microscopy were used to study the topography of the structures. Auger electron spectroscopy will be used to follow any laser-induced chemical transformations. A simple mechanism of formation based on movement of melted material is proposed. The predictions of this model for the tips formation fluence threshold values are compared with threshold values obtained by extrapolation of the experimental results. The model also predicts that the two-dimensional pattern of heat dissipation in the film is essential for formation of sharp cones in the re-solidification process. The experiments confirm that the film thickness must be below the thermal diffusion length to observe the cone formation. We have also studied structures (nano-ridges) that resulted from irradiation with narrow lines (width of several microns) instead of circular spots. [1] D.G. Georgiev, R.J. Baird, I. Avrutsky, G. Auner, G. Newaz, Appl.Phys.Lett., 84 (2004) 4881

J13.7

Functionally Engineered Carbon Nanotubes Peptide Nucleic Acid Nanocomponents. Krishna Veer Singh[1], Cengiz S. Ozkan[3], Roger Lake[2], Alexander Balandin[2] and Mihrimah Ozkan[2,1]; [1]Chemical & Environmental Engineering, University of California, Riverside, Riverside, California; [2]Electrical Engineering, University of California, Riverside, Riverside, California; [3]Mechanical Engineering, University of California, Riverside, Riverside, California.

Carbon Nanotubes (CNTs) conjugation with bio-molecules is a very exciting research area, which finds its application in various fields like pharmaceuticals, drug delivery, nanoelectronics, novel materials and many others. The biomolecule under investigation here is Peptide Nucleic Acid (PNA). PNA is a nucleic acid analog in which the sugar phosphate backbone of natural nucleic acid has been replaced by a synthetic peptide backbone usually formed from N-(2-amino-ethyl)-glycine units, resulting in an achiral and uncharged mimic. Due to their unique yet highly functional structure they show a tremendous improvement in the properties with respect to their counterpart nucleic acids. PNAs form highly stable structures with Watson-Crick complementary DNA, RNA or PNA oligomers. The uncharged backbone facilitates the synthesis of shorter PNA probes unlike the nucleic acids, which require longer probes to overcome their mutual repulsion. Higher sensitivity, specificity, faster and stronger hybridization are few of many other advantages that PNA offer. These better chemical, physical and biological properties of PNA make it a strong candidate for its application at the interface of biology and engineering. We are able to form a controlled CNT-CNT network with the help of PNA, which acted as a linker between them. Glutamate modified ends of PNA and predominantly end functionalized CNTs resulted in high yield of CNT-PNA-CNT conjugates. These conjugates are further characterized by SEM (Scanning Electron Microscope), TEM (Transmission Electron Microscope) & FTIR (Fourier Transform Infrared) Spectroscope. Results indicate that these nanocomponents are thermally, electrically and physically very stable and have excellent self assembly properties, which can be utilized for building more complex structures.

J13.8

Investigation of Electric Characteristics of Nanoscale Composite A1B5C6 Semiconductors: Experiment and Numerical Simulation. Halyna M. Khlyap[1], Ludmila Panchenko[3], Violetta Bilozertseva[4] and Petro Shkumbatiuk[2]; [1]Physics, University of Technology, Kaiserslautern, Germany; [2]Physics, State Pedagogical University, Drohobych, Ukraine; [3]Physics, Sumy State University, Sumy, Ukraine; [4]National Technical University, Kharkiv, Ukraine.

Compounds of A1B5C6 group (Ag3SbS3, Tl3SbS3, Ag3AsS3 and others) are seemed to be among the most promising materials for manufacturing detectors of ionizing radiation [gamma-Ray Detectors Based on Composite A1B5C6 Semiconductors, H. Khlyap, L. Panchenko, M. Andrukhiv, MRS Proceedings 792 (2004), R3.4.1]. Electric properties of these wide-gap semiconductors are almost not studied. The abstract reports first experimental results on electric field-induced effects observed in these nanoscale semiconductor structures under room temperature. Thin films with thickness up to 800 nm were grown by means of pulse laser deposition technology on KCl substrates at the room temperature. The time of deposition was from 300 to 1120 s. SEM studies of the film surface revealed inhomogeneous relief. The experiments carried out on the bulk material as well as on the thin films under applied electric field up to 700 V/cm showed current-field characteristics typical for multi-step tunneling of charge carriers. In order to clarify the carriers transport features the model of disordered potential was used for numerical treatment of the experimental data obtained for the films. Results of the field-current characteristics of the bulk materials were analyzed and modeled according to the semiclassical theory of tunneling in solids.

J13.9

Etching Silicon through an Effective Nanomask: An Electrochemical way to Nanomachining. Stefano Borini, Andrea M. Rossi, Luca Boarino and Giampiero Amato; Nanotechnology and Microsystems, IEN Galileo Ferraris, Torino, Italy.

The fabrication of Nano-Electro-Mechanical Systems (NEMS) requires the ability of nanostructuring bulk materials in a controlled and flexible manner. Here we present a novel approach to silicon nanomachining, based on the electrochemical etching of the material through a nanopatterned mask. Combining a porous silicon (PS) buffer layer with cross-linked poly(methyl methacrylate) (PMMA) we have obtained masks which show high resistance to the electrochemical etching. PMMA is normally dissolved in a HF/EtOH mixture, but it becomes resistant to such a solution after cross-linking of the polymer. This can be achieved by high-dose electron irradiation in a Scanning Electron Microscope (SEM), obtaining a mask for the subsequent electrochemical etching. Anyway, due to the strong electric field across the masking layer during the electrochemical process, time duration of such a mask is limited. We demonstrate that the presence of a highly porous silicon thin film lying under the resist is sufficient for an evident improvement of the masking power during the electrochemical process. A final PS removal in alkaline solution leads to the formation of silicon micro- and nanostructures in relief, such as microtips and nanomolds. Thus, we have at hand a simple silicon nanomachining process, where the nanofeatures written by the electron beam in the SEM are transferred to the bulk material through a short anodization step in acid solution. This may be a useful alternative method for fabricating nanodevice elements, such as nanofluidic channels or field emitter arrays.

J13.10

Characterisation of Thin Film Piezoelectric Materials by Differential Interferometric Techniques. Markys Cain and Mark Stewart; National Physical Laboratory, Teddington, United Kingdom.

Piezoelectric thin films are considered emergent materials for integration within Micro Systems Technology (MST) or MEMS devices. The development of suitable measurement facilities to characterise the materials functional properties is complicated by the fact that the film is often attached to a substrate which acts to clamp the film thus affecting the system performance. This presentation will describe a differential interferometer system based on common path Jamin optics and measurement lock-in techniques that is able to analyse the displacements of the thin film to sub-pm resolution. Results will be shown for ceramic monolithic materials, quartz single crystal material and sol-gel derived thin and thick films of PZT on Si substrates. Further metrological issues will be addressed and future plans described.

J13.11

An Optical Diffraction Microphone with Active Grating Diaphragm. Kazuhiro Suzuki, Hideyuki Funaki and Yujiro Naruse; Corporate Research & Development Center, Toshiba Corporation, Kawasaki, Kanagawa, Japan.

We have previously proposed a MEMS-based optical microphone with an innovative structure as a type of directional microphone that optically detects the vibration displacement of the grating diaphragm. This optical microphone replaces the displacement of the grating pattern on the photo detector with the magnitude of change in the optical intensity and detects the vibration changes in the diaphragm. This paper describes an advanced version of the MEMS optical microphone which realizes the frequency selection and phase detection. The diaphragm of the microphone is fabricated using 8-inch SOI. The diffracting grating is fabricated using the 0.25-μm CMOS process after circuit formation, and the grating diaphragm is finally released from the substrate.In this structure, the diaphragm is suspended by the elastic connectors and can be vibrated in the up and down direction defined as vertical direction of the diaphragm by receiving the acoustic wave. The diaphragm is formed a 2-D diffraction grating (Diaphragm dimensions: 4mm square, Lattice cycle: 30μm). This optical microphone can realize efficient detection using the diffraction spot without any optical components for concentration of the laser beam. This allows for construction of a simple and compact optical microphone system. The microphone system has a driving circuit which provides the driving voltage Vp, in which an arbitrary frequency signal is superposed on a fixed bias voltage based on the control signal transferred from the processor. The driving voltage Vp is applied across the cavity between the diaphragm and the substrate. By the bias voltage Vp, the electrostatic force is established between the grating diaphragm and the substrate, and the diaphragm is pulled down to the substrate. Consequently, while the diaphragm is actively vibrated by the driving voltage Vp, a passive vibration of the diaphragm induced by a sound pressure is superposed on the active vibration in the diaphragm.

While the diaphragm is actively vibrating with the waveform of a fixed frequency f0, the corresponding frequency component of the acoustic wave enhances the vibration of the diaphragm. The intensified vibration is processed as the amplified electrical sound signal by the photo detector and the processor. Hence, the selected frequency amplification of sound signal can be realized. Additionally, the selected frequency band amplification is possible by scanning the frequency fo. In additional to the selective frequency amplification, phase information of the sound can be obtained by changing the phase of the vibration of the diaphragm. The coupling strength between the sound wave and the diaphragm is a function of the phase difference of the two vibrations. The results of the verification experiments indicated that this active optical diffraction microphone could be used for filtering functions and detection of phase information. The details of the experiments and results will be reported at the meeting.

J13.12

A Theoretical Model for the CO Adsorption Kinetics on Cu(110) by Reflectance Anisotropy. Letizia Chiodo[1] and Patrizia Monachesi[2]; [1]Dipartimento di Fisica, Universita' di Roma "Tor Vergata" and INFM, Roma, Italy; [2]Dipartimento di Fisica, Universita' dell'Aquila and INFM, L'Aquila, Italy.

The optical response of the Cu surface upon CO deposition is investigated from the clean Cu(110) to the reconstructed CO/Cu(110)-p(2 x 1) geometry through 'ab initio' electronic structure calculations, performed within the Density Functional Theory using a FPLMTO code. As observed by Sun et al [Phys. Rev. Lett. 90, 106104 (2003)] and in good agreement with previous results, the 2 eV peak in the reflectance anisotropy (RA) spectrum, ascribed to surface states transitions in clean Cu(110), is found to decrease strongly non linearly at low CO coverage. We recognize this evolution as the signature of the CO molecule on Cu by ascribing the RA peaks to the formation of electronic surface states peculiar of the modified interface as also observed in larger molecular systems with carboxylic groups. We also show that CO adsorption affects profoundly the dynamics of the optical transitions with respect to the clean surface in the whole RA spectrum (0-6$\sim$eV). Most interestingly, we interpret the observed chemisorption kinetics [Sun et al] by devising a quantitative model for the RA spectra at three different regimes of CO coverage. The impurity regime, at very low coverages, is characterized by a critical coverage that enhances the actual one by a factor of $\sim$30, close to the value estimated experimentally. We therefore propose CO/Cu as a prototype for further investigations on the adsorption kinetics on metallic surfaces monitored by RAS.

J13.13

Fabrication of a Bimodal Ferromagnetic Nanosystem in an Etched Silicon Structure and its Magnetically and Magneto-Optically Behaviour. Petra Granitzer[1], Klemens Rumpf[1], Peter Poelt[2], Angelika Reichmann[2], Svetlozar Surnev[1] and Heinz Krenn[1]; [1]Institute of Experimental Physics, University of Graz, Graz, Austria; [2]Research Institute for Electron Microscopy, Technical University of Graz, Graz, Austria.

Due to the low cost production of an array of nanowires mesoporous silicon was used. Using proper doping densities of the wafer as well as proper and well tuned electrochemical parameters like electrolyte concentration (5%-10% HF), current density (100 mA/cm2) and bath temperature (20 degrees Celsius) the mesopores with a narrow distribution of the porediameter in the range of 60 nm and a length between 10 micrometer and 30 micrometer are highly oriented. This selforganized porous system with a rather homogeneous spatial distribution of the pores is appropriate to be loaded with a ferromagnetic material (e.g. Ni) in an electrochemical way to achieve a perpendicular magnetic nanocomposit system. The distribution of both, the porediameters as well as the spatial distance of the pores can be figured out by FT-image processing. Under convenient loading conditions the magnetic system consists of nanowires as well as granules and shows a very interesting magnetic behaviour with a lot of potential applications. A high magnetic anisotropy with the easy axis perpendicular to the surface can be observed as well as an interesting bimodal behaviour showing two switching fields in magnetic hysteresis due to strong dipolar interaction of the needles. This twofold switching system with a steep slope at the switching fields of HSW1 = 0.05 T and HSW2 = 5.2 T is promising to be useable for magnetic field sensors with a steep characteristic especially in the high field range of a few Tesla. Further the zero field / field cooled curves with a broad splitting and the splitting point between 250 K and 300 K is an advantage for technical applications, like magnetic storage. Due to rather long spin-relaxation lifetimes in silicon the needles could be used for spin-injection into the silicon matrix and therefore it is also an interesting system for spintronics. Beside the sample characterization with SEM, EDXS and AES all magnetically and magneto-optically investigations were carried out with a SQUID-magnetometer (H = 7 T, T = 1.7 K - 300 K) and an IR-spectrometer (especially Kerr-rotation measurements), respectively.

J13.14

Nanocomposite Thin Film Coatings for Ageing Aircraft Skins. Ramazan Asmatulu, Richard O. Claus, Jeffrey B. Mecham and Sean G. Corcoran; FEORC, Virginia Tech, Blacksburg, Virginia.

The present study deals with nanocomposite thin film coating, analysis and application steps for the ageing aircraft skins. Several nanoparticles (100 nm) were incorporated into polymers, and then the obtained polymeric nanocomposites were sprayed on the Al coupons (2024-T3) by a nozzle sprayer at different thicknesses. The main purpose of nanoparticles in coating materials is to absorb/block unwanted ions/molecules (i.e., Cl-, OH-, H2O, etc.). An urethane top layer (approximately 1 mil) was also coated on some of initially coated surfaces. Several corrosion tests including electrochemical impedance spectroscopy (EIS) and salt spray were conducted on the prepared samples using 0.5 M NaCl solution. The corrosion test results showed that the Al coupons coated by nanocomposites and urethane top coating gave the excellent corrosion resistances (up to 109 ?-cm2) against the corrosion attacks. As a result, it is assumed that the nanostructured coating system will allow military, private companies and government agencies to effectively protect the aircraft surfaces against corrosions and flying objects.

J13.15

Thermal Stability of Ir/TaN Electrode/Barrier on Thin Gate Oxide for MFMOS Structure Application. Haogang Zang, Mechnical Engineering, North China Electric Power University, Baoding, Hebei, China.

The Metal-Ferroelectric-Metal-Oxide-Silicon structure has a metal electrode directly on top of thin gate oxide. This structure can be used in NEMS and MEMS systems. The gate oxide used in our present MFMOS structure is 3 nm SiO2. Ir was used the bottom electrode and TaN was used as the barrier layer. It is important in this structure that TaN is stable and will not react with the gate oxide during the ferroelectric material deposition, annealing and subsequent processing which usually was performed at high temperature oxygen ambient. In this paper, TaN barriers with different deposition conditions have been deposited on 3 nm gate oxide. 150 nm Ir was deposited on the TaN barrier layer. Capacitors of Ir/TaN/gate SiO2/Si were defined by dry etching. Series RTP anneaing were performed in oxygen from 500 to 650C with different annealing times. The capacitors were also annealed in nitrogen ambient at 1000C for 10s. CV and IV charactereistics were measured befrore and after anneaings. It shows that Ir/TaN/Gate SiO2 structure is very stable during the above annealing processes. The consumption and further oxidation of the gate oxide is negligible and would depend on the deposition conditions of the TaN barrier layer. With optimized deposition conditions, a 22 nm TaN barrier layer can effectively prevent any iridium silicide formation and will not degrate the gate oxide during annealing processes. The interfaces between the TaN and gate SiO2 and Si substrate can be further improved by forming gas annealing. It demonstrated that Ir/TaN/gate SiO2/Si is a good candidate for MFMOS structure applications.

J13.16

Conductive Nanocomposites Incorporating Polymer−Modified Carbon Black. Valtencir Zucolotto[1], Jamshid Avlyanov[2], Rinaldo Gregorio Jr.[3] and Luiz H. C. Mattoso[4]; [1]DFCM, University of Sao Paulo, Sao Carlos, SP, Brazil; [2]Eeonyx Co., Pinole, California; [3]DEMa, Federal University of Sao Carlos, Sao Carlos, SP, Brazil; [4]EMBRAPA, Sao Carlos, SP, Brazil.

Conductive composites incorporating poly(vinylidene fluoride) PVDF or triblock copolymer poly(styrene−b−ethylene−co−buthylene−b−styrene) SEBS and a novel conducting polymer-modified carbon black (CPMCB) additive were produced by melting process. CPMBC additive comprises conductive nanoparticles made via deposition of polyaniline or polypyrrole on carbon black particles. The composites were produced in a high temperature mixer and then hot pressed in the form of homogeneous flexible films. Electrical conductivity in the order of 10^{-2}S/cm could be achieved with low contents of the conductive filler. The addition of CPMBC is advantageous to the melt processing of the composites reducing the melt viscosity in comparison to the addition of pure carbon black. It was shown that for the SEBS based composites, both strength at break and yield point decreases with the increment of the polyaniline content on CPMCB formulation. The conductivity is quite stable at high temperatures, even when the samples are exposed to 150°C for several days. Thermogravimetric analyses (TGA) showed that the composites have an excellent thermal stability up to temperatures of about 350 °C, which is highly desirable during the melt processing. For PVDF-based nanocomposites, in particular, the incorporation of the nanostructured additive allows the achievement of PVDF−− b phase in an one−step process, when the nanocomposites are quenched from the melt.

J13.17

Spectroscopic Investigation of Ferromagnetic Co-doped TiO2. Jong-Pil Kim[1], Chae Ryong Cho[1], Mi-Sook Won[1], Jang-Hee Yoon[1], Kyung-Soo Hong[1], Se-Young Jeong[2] and Dong-Ho Kim[3]; [1]Busan Branch, Korea Basic Science Institute, Busan, South Korea; [2]School of nanoscience and technology, Pusan National University, Busan, South Korea; [3]Department of Physics, Yeungnam University, Gyeongsan, South Korea.

Diluted magnetic semiconductors (DMS) have attracted considerable attention because of their potential for novel applications in the rapidly evolving area of spintronics. Recently, room-temperature ferromagnetism has been observed in some wide-bandgap host semiconductors such as GaN, GaP, ZnO, and TiO2. Among them, Co-doped TiO2, discovered by Matsumoto et al.[1], has been actively investigated due to properties like a high Tc over 400 K, excellent optical transmittance in the visible and near-infrared regions, and high n-type carrier mobility without intentional doping. Chambers et al.[2] reported improved properties like higher magnetic moments of 1.26 μB /Co atom and larger remanence when activated oxygen, such as oxygen plasma, was used during the film growth process. The oxidation state of cobalt in the film was +2 from both Co 2p core level photoemission and Co L-edge X-ray absorption analysis. Chambers claimed that the ferromagnetism originated from the electron-mediated exchange interaction between Co+2 cations that substitute for Ti+4 in the lattice, arguing against the formation of cobalt metallic nanoclusters. Recently, the occurrence of room-temperature ferromagnetic (FM) in Co-doped TiO2 anatase films grown by the combinatorial laser molecular beam epitaxy is reported. Co-doped TiO2 anatase, grown by pulsed laser deposition (PLD), has recently been demonstrated to be weakly FM and semiconducting for doping levels up to $\sim$8 at.%, and temperatures of up to 400 K. In this study, we described the phase formation, ferromagnetic properties and interface effect of diluted magnetic semiconductor. The structural properties were analyzed by X-ray diffractometer (XRD), scanning electron microscope (SEM) and transmission electron microscope (TEM) and the magnetic properties were measured with a Physical Property Measurement System (PPMS). The curve of Ti0.97Co0.03O3 in annealing temperature 450°C shows hysteresis loop with coercivity (Hc) of about 90 Oe and the 7.6 % remanence (Mr) of the magnetization saturation. The Elemental distribution with depth of thin films is measured by Auger electron spectroscopy (AES) and chemical state of thin films measured by X-ray photoelectron spectroscopy (XPS). From AES depth profile, it was found that Ti and O concentration of Ti0.97Co0.03O2 thin film were nearly constant in the interlayer between surface and substrate. And, with increasing of Co doping, O concentration of films were decreased from surface. From the binding energy, the main peaks of Co 2p3/2 and shoulders may be indicated oxidation state of Co and shifter of main peaks may be due to CoTiO3 phase. This work was supported by the Korean Research Foundation Grant (KRF-2002-070-C00033). [1] Y. Matsumoto, et al. Science 291, 854 (2001). [2] S. A. Chambers et al. Appl. Phys. Lett. 79, 3467 (2001).

J13.18

Embedded Piezoresistive Microcantilever Sensors: Materials for Sensing Chemical and Biological Analytes. Timothy L. Porter, William Delinger, Randy Dillingham and Robert Gunter; Physics, Northern Arizona University, Flagstaff, Arizona.

Embedded piezoresistive microcantilever array (EPMA) sensors combine many of the positive features of coated-cantilever sensor designs and standard chemiresistor sensors. In the EPMA sensor design, a tiny microcantilever of approximately 200 microns in length is embedded or partially embedded into a sensing material. This sensing material may be polymeric, functionalized polymeric, biological, or a composite material combining a polymer with biological molecules. Depending on the sensing material, analyte molecules may adsorb on the surface, chemically partition into, covalently bond to, or otherwise incorporate themselves into the material layer. This chemical action results in a tiny change in the physical properties of the sensing material layer, which in turn results in a tiny strain in the piezoresistive microcantilever. Strains of only a few Angstroms may be measured. The piezoresistive cantilever strain is measured as a change in resistance; a simple multimeter or bridge circuit is sufficient to record this change. These EPMA sensors are tiny, only a few mm in size, and require only simple electronics to operate. They are also very robust, as the cantilever/sensing material form a single, rigid unit. We will discuss materials and composite materials to be used as the active elements in EPMA sensors. We have used polymeric, functionalized polymeric, and biomolecule/polymer composite materials to sense a wide variety of analytes. These analytes include volatile organic compounds (VOC's) in air or in liquids, and biological molecules in liquids and in aerosol. VOC's detected include industrial compounds such as toluene, hexane, ethanol, and others, gases such as carbon monoxide, environmentally sensitive compounds such as carbon tetrachloride, MTBE, and TCE, and biological molecules such as viruses (vaccinia), single-strand DNA, and proteins including bovine serum albumin. Future work on new compound materials will also be discussed. These new materials, based on hydrogel matrices, will be used in applications such as biological sensing, hydration level sensing in living hosts, and poison gas sensing.

J13.19

Fabrication of Nano-Gap Electrodes with Controlled Gap-Widths Using Atomic-Layer-Deposited Sacrificial Layers. Chan Woo Park, Jung-Wook Lim, Han Young Yu, Ung Hwan Pi and Sung-Yool Choi; Electronics and Telecommunications Research Institute, Daejeon, South Korea.

We have fabricated poly-Si/Au nano-gap electrode pairs for characterizing and utilizing electrical properties of single molecules or nano-particles, using atomic-layer-deposited (ALD) Al2O3 as a sacrificial layer. In this process, a nano-gap is formed by removing a sacrificial ALD Al2O3 layer pre-formed between the poly-Si and Au electrode regions, where the gap-width is determined by the thickness of the Al2O3 layer. As the ALD process is a layer-by-layer growth based on self-saturated surface reactions, the width of gaps can be controlled within the range of a few angstroms by varying the number of deposition cycles. Because no thermal or anodic oxidation process is needed for forming the sacrificial layer, we can freely choose the electrode materials suitable for the molecular species to be characterized. In addition, this method enables the massive formation of identical gaps in a single process, which should be very useful in fabricating integrated circuits of molecular electronic devices containing numerous nano-gap electrodes. Using this method, we successfully fabricated 10X10 arrays of poly-Si/Au nano-gap electrode pairs varying the gap-width in the range of 3-10nm, and confirmed that they had good insulating properties in room temperature. However, when functionalized Au nano-particles were trapped within the gap region, the current flow through the nano-gap electrodes increased significantly. It demonstrates that the nano-gap electrodes fabricated by the new process can actually be used for measuring the electrical properties of nano-sized molecular species.

J13.20

Comparison of Laterally Aligned InGaAs/GaAs Quantum Dots Grown by MBE and ALE Techniques. Sam K. Noh[1], S. J. Lee[1], J. C. Park[1], J. O. Kim[1], K. -S. Lee[2] and J. W. Choe[3]; [1]Materials Evaluation Center, Korea Research Institute of Standards and Science, Daejeon, South Korea; [2]Basic Research Center, Electronics and Telecommunications Research Insititute, Daejeon, South Korea; [3]Dept. of Physics, Kyunghee Univ., Suwon, South Korea.

Two kinds of growth techniques, conventional molecular-beam epitaxy (MBE) and atomic layer epitaxy (ALE), have been introduced for formation of laterally aligned InGaAs quantum dot (QD) structures, and the QD profiles and their optical characteristics have been investigated for comparison. In MBE-grown QDs, the order of alignment of QDs have been controlled by the number of stacks with growth interruption during the growth of GaAs spacer layer.[1] The length of alignment becomes longer with increase of the period of stacks as reported, and the QD chain with a length of $\sim$ 1 um can be obtained from the 15-layer stacked sample in this study. The thicknesses of InGaAs QD and GaAs spacer layers are 7.5 monolayers (MLs) and 60 MLs, respectively, and the growth interruption for 10 sec for every 3 MLs is applied for the first 30 MLs. On the other hand, the laterally aligned QD chain similar to that grown by MBE can be achieved without stacking of QD layers only by controlling the coverage of QD layer (2.5-25 MLs) or the number of cycles of species. Dissimilarly to MBE-grown QD chain, ALE-grown one shows very strong photoluminescence (PL) emissions even at room temperature with the thermal carrier transfer behavior, and the above-1.35-um PL emission which is applicable to 1.3 or 1.5 um QD laser diode is realized at x=0.5 and teq =7.2 MLs. The preferential alignment and the emission characteristics may be enhanced by a longer surface migration due to alternate source supply in ALE technique compared with conventional MBE. Comparative data between MBE- and ALE-grown QD chains will be presented together with the details. [1] Z. M. Wang, K. Holmes, Yu. I. Mazur, and G. J. Salomo, Appl. Phys. Lett. 84, 1931 (2004).

J13.21

Interpretation of the Phonon Frequency Shifts in ZnO Quantum Dots. Khan A. Alim, Vladimir A. Fonoberov and Alexander A. Balandin; Nano-Device Laboratory, Department of Electrical Engineering, University of California - Riverside, Riverside, California.

Nanostructures made of zinc oxide (ZnO), a wide-bandgap semiconductor, have recently attracted a lot of attention due to their proposed applications in low-voltage and short-wavelength (368 nm) electro-optical devices, transparent ultraviolet (UV) protection films, gas sensors, and varistors. Raman spectroscopy presents a powerful tool for identifying specific materials in complex structures and for extracting useful information on properties of nanoscale objects. At the same time the origin of Raman peak deviation from the bulk values is not always well understood for new material systems. There are three main mechanisms that can induce phonon shifts in the free-standing undoped ZnO nanostructures: (i) phonon confinement by the quantum dot boundaries; (ii) phonon localization on defects (oxygen deficiency, zinc excess, surface impurities, etc.); and (iii) the laser-induced heating in nanostructure ensembles. In this paper we report results of the combined non-resonant and resonant Raman scattering studies of an ensemble of ZnO quantum dots with diameter 20 nm. Based on our experimental data, we have been able to identify the origin of the observed phonon frequency shifts. It has been found that the phonon confinement results in phonon frequency shifts of only few 1/cm. At the same time, the ultraviolet laser heating of the ensemble was found to induce a large red shift of the phonon frequencies. It is calculated that the observed red shift of 14 1/cm corresponds to the local temperature of the quantum dot ensemble of about 700 degrees Celsius. The experimental results are in excellent agreement with the theory of the optical phonons in wurtzite nanocrystals developed by Fonoberov and Balandin [1]. The theory predicts that the asymmetry of the wurtzite crystal lattice leads to the quantum dot shape-dependent splitting of the frequencies of polar optical phonons in a series of discrete frequencies. The obtained experimental and theoretical results allow one to unambiguously identify phonon peaks in the Raman spectrum of ZnO nanostructures. This research has been supported through DARPA - SRC MARCO Center on Functional Engineered Nano Architectonics (FENA) and NSF Award to A.A.B. [1] V. A. Fonoberov and A. A. Balandin, Phys. Rev. B 70, in print, December 15, 2004; ibid, cond-mat/0405681.

J13.22

SnO2 Doping Effect in In2O3(ZnO)k Ceramics: Change in Electrical Characteristics and Solubility Limit.

Kyung-Han Seo, Joon-Hyung Lee and Jeong-Joo Kim; Inorganic Materials Engineering, Kyungpook National University, Daegu, South Korea.

Recently, multicomponent oxide of ZnO-In2O3 system has been found to have a low resistivity and a good average transmittance above 80% in the visible range. Researches on In2O3(ZnO)k (indium zinc oxide; IZO) ceramics reported that the system is known to have various homologous compounds with different k values (k=3∼9,11,13,15), and the electrical conductivity and carrier mobility greatly depend on the k values. It is also known that the solubility limit of Zn in In2O3 is very narrow which is close to 2 mol%. However, among the IZO composites, In2O3(ZnO)3 (k=3) is known to have the best electrical and optical properties, and high electrical conductivity of IZO was reported when 30∼40 mol% of Zn is contained. In these compositions where k=2∼3, it was thought that the addition of Sn4+ could expand the solubility limit of Zn2+ in IZO due to the charge compensation effect. In this study, therefore, Sn was added to In2O3(ZnO)k (k=2∼3) for an expanded solubility limit of both Zn and Sn in In2O3(ZnO)k (k=2∼3). In this case, since the cost of indium sources is very expensive, the more use of Zn and Sn as substitutes for indium in In2O3 is highly recommended. Phase and microstructure development and electrical characteristics of IZO as a function of Zn and Sn concentration were examined.

J13.23

Effects of e-Beam Annealing on Structural and Optical Properties of GaN Nanorods.

Deuk Young Kim[1,2], Chang Seok Han[1,2], Sejoon Lee[1,2], Sun Jae Hwang[1,2], Duck Nam Kim[1,2], Hye Sung Lee[1,2], Doo Soo Kim[1], Hosang Lee[2], Sungryong Ryu[2], Jinhyoung Cho[2], Hwa-Mok Kim[2] and Tae Won Kang[2]; [1]Semiconductor Science, Dongguk University, Seoul, South Korea; [2]Quantum-functional Semiconductor Research Center, Dongguk University, Seoul, South Korea.

GaN is the most promising wide-band-gap semiconductor for such potential applications such as blue LEDs, blue LDs, and high-power electronic devices, because of its outstanding properties including wide bandgap of 3.39 eV, high breakdown field of 5×10^{6} Vcm^{-1}, and high saturation drift velocity of 2.7×10^{7} cms^{-1}. Recently, the synthesis of one-dimensional GaN nano-structures has been achieved by various techniques such as laser-ablation, chemical vapor deposition, catalytic reaction process, and it is well established that these one-dimensional GaN nano-structures enhance and modify their optical properties. Unfortunately, one-dimensional GaN nano-structures have strains and point defects at their surface and/or interface. Recently, many researchers have reported that the e-beam annealing process could change the chemical potential in surface or interface and that the ion-beam irradiation process might reduce the residual stress. In this study, the effect of e-beam annealing on structural and optical properties of GaN nanorods grown by HVPE has been investigated. GaN nanorods were directly grown on the c-Al_2O_3 substrates at 500^{o}C without catalyst. In order to investigate the effect of e-beam annealing on structural and optical properties of GaN nanorods, we performed e-beam annealing for 5 hours with applying the acceleration energy of 30 keV. For measurements of XRD, it was observed that the FWHM of e-beam-annealed GaN nanorods became narrower than that of as-grown GaN nanorods. The Bragg's angle of e-beam-annealed GaN nanorods was slightly moved to the left-hand side. The peak position of the DCXD pattern was determined to be 17.27 ^{o}, and this value is very similar to that of GaN thin films having no significant strain. For CL measurements, the values of FWHM and intensities were significantly decreased and gradually increased with increasing the annealing time, respectively. Moreover, it was observed that the peak position of e-beam-annealed GaN nanorods is slightly shifted to lower energy region. The red-shifted value of CL peaks was estimated to be 48 meV. The observed peak position of e-beam-annealed GaN nanorods was 3.39 eV, and this value is closed to that of GaN thin films without considerable strains. These results indicate that the improvement of crystal quality might be induced by relaxation of the compressive strain due to e-beam annealing. The results of Raman showed that the peaks of A_1(TO), E_1(TO), and E_2(high) modes were changed into narrower shapes and that the peak position of A_1(TO) mode was slightly shifted to higher-frequency region. These behaviors suggest that the decrease in boundaries and/or disorders of crystallites. Therefore, it is considered that the e-beam annealing process might lead to induce the enhancement of the crystallinity in the GaN nano-rod surface and interface resulting from the relaxation of the residual strains in GaN nano-rods.

J13.24

Second Harmonic Generation Imaging of Micro-Array of Surface-Immobilized Gold Nanoparticle on Gold Surface.

Kazuma Tsuboi[1] and Kotaro Kajikawa[1,2]; [1]Japan Science and Technology Agency, Kawaguchi, Saitama, Japan; [2]Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology, Yokohama, Kanagawa, Japan.

Surface-immobilized gold nanoparticles on a gold surface with a gap distance of a few nanometers show strong activity of second harmonic generation (SHG). We prepared a micro array of the surface-immobilized gold nanoparticles using a patterned aminoundecanthiol self-assemobled monolayer (SAM) formed on a gold substrate. The micro array was characterized by absorption reflection spectroscopy and SHG microscopy. A red-shifted peak due to the gap mode was observed, indicating that there is strong interaction between the gold nanoparticles and the gold surface. The clear pattern image was observed owing to a large contrast of the surface susceptibilities between surface-immobilized gold nanoparticles on a gold surface and the bare gold surface. The SHG contrast is much more than that of the conventional linear optical technique such as extinction upon reflection taken in linear microscopy.

J13.25

Study of Contact between Carbon Nanotubes and Bulk GaAs Semiconductor.

Chen-Wei Liang and Siegmar Roth; Solid State Research, Max-Planck-Institute, Stuttgart, Germany.

Recently the contact between carbon nanotubes (CNTs) and semiconductors is coming into notice [1,2] and the electrical properties of such a heterostructure are also under investigation [3]. The present work is to connect a single carbon nanotube to a bulk GaAs material and study the electrical characteristics of the contact. Using a GaAs substrate patterned by insulating film, contact can be achieved as a CNT crosses the edge of the pattern so that one end of tube touches GaAs and the other is isolated. The electronic transport can be studied through temperature-dependant current-voltage measurement and the junction characteristics, like interfacial states and depletion width, can also be investigated by capacitance-voltage measurement. [1] W. Orellana, R. H. Miwa, and A. Fazzio, Phys Rev Lett 91, 166802, 2003 [2] Yong-Hyun Kim, M. J. Heben, and S. B. Zhang, Phys Rev Lett 92, 176102, 2004 [3] M. Tzolov, B. Chang, A. Yin, D. Straus, and J. M. Xu, Phys Rev Lett 92, 075505, 2004

SESSION J14: Materials and Devices
Chair: Rashid Bashir
Thursday Morning, March 31, 2005
Room 2003 (Moscone West)

8:45 AM J14.1

A Novel Photo-patterning Method for PHEMA Hydrogels.

Stephanie J. Bryant[1], Kip D. Hauch[1] and Buddy D. Ratner[1,2]; [1]Bioengineering, University of Washington, Seattle, Washington; [2]Chemical Engineering, University of Washington, Seattle, Wyoming.

Patterned hydrogel structures have potential application in a variety of uses including microfluidic devices and tissue engineering scaffolds. In traditional photolithography of liquid phase solutions, the patterned depth and resolution are limited due to diffusion of the propagating chains into the unexposed regions. We describe here a novel photo-patterning technique that enables patterning of hydrogels at greater depths by allowing the polymerization reaction to occur throughout the liquid phase, but at different rates. Crosslinked poly(2-hydroxyethyl methacrylate) (p(HEMA)) gels were formed from a solution of 80% (v/v) HEMA, 2 mol% tetraethylene glycol dimethacrylate and 1.5% (w/v) photoinitiator in ethylene glycol/water. Photomasks were generated on transparency film in which the opacity of the mask was varied from 0-100% corresponding to a decrease in incident light intensity (Io). The polymerization reaction was monitored under different masks using near-IR spectroscopy. Interestingly, it was found that polymerization under the 0% opacity mask (Io=850 mW/cm2) reached 95±5% conversion in 300s, while polymerization under the 93% opacity mask (Io=45 mW/cm2) required only 30s to reach 96±3% conversion. Although it was expected that an increase in Io would decrease the overall polymerization time, the reverse was observed. Gel permeation chromatography indicated that the 0% opacity mask resulted in 3-fold shorter kinetic chains (i.e., growing polymer chains) compared to the 93% opacity mask after a 10s exposure. During polymerization, the viscosity of the solution increases as the reaction proceeds and the kinetic chains grow. This increase in viscosity prevents the macroradicals from readily diffusing causing a decrease in chain termination, and ultimately, a buildup in radical concentration (i.e., autoacceleration). Differential scanning calorimetry indicated that the onset of autoacceleration was significantly delayed under the 0% opacity mask due to the shorter kinetic chain lengths compared to polymerization under the 93% opacity mask. In summary, this technique initiates polymerization throughout the liquid phase solution and consumes monomer. As a result of monomer consumption, the adverse effects of diffusion are minimized and patterning at greater depths is achieved. Based on these findings, a photomask was created in which the desired pattern was represented by 93% opacity and the regions where the reaction should be limited remained clear. After a 30s exposure, the mask regions under 93% opacity formed a crosslinked gel while the regions under 0% opacity were partially polymerized, yet remained soluble and were readily washed away. We have successfully patterned channels in p(HEMA) hydrogels with aspect ratios of $\sim$3 and with a depth of $\sim$700 μm. For tissue engineering applications, we have used this novel photo-patterning process to pattern open, parallel channels in a porous p(HEMA) scaffold for cardiac muscle tissue engineering.

9:00 AM J14.2

Fabrication of Microstructured Silicon (μs-Si) from a Bulk Si Wafer for Printable Thin Film Transistors.

Keon Jae Lee[1], Heejoon Ahn[2], Dahl Young Khang[1], Etienne Menard[1], John A. Rogers[1] and Ralph G. Nuzzo[2,1]; [1]Materials Science and Engineering, University of Illinois Urbana Champaign, Urbana, Illinois; [2]Chemistry, University of Illinois Urbana Champaign, Urbana, Illinois.

Printable or solution processable materials for thin-film transistors (TFTs), and the systems formed from them on plastic substrates, have attracted great attention due to their light weight, mechanical flexibility and potential for low cost. We recently reported the development of a new form of printable semiconductor -microstructured silicon (μs-Si) - that uses a "top down" fabrication approach to create free standing single-crystalline semiconductor objects that can be used to construct high performance TFT devices. Here we report an ultralow cost fabrication route to microstructured silicon (μs-Si) ribbons using a bulk single-crystalline Si wafer and the electrical properties of test devices formed from it. The process involves standard semiconductor process technologies -dry oxidation, standard photolithography, sequential RIE etching, and deep anisotropic wet etching - to form oblique single crystalline silicon ribbons with smooth sidewalls supported on a silicon wafer. A novel metal-assisted anisotropic wet chemical etching was used to selectively undercut the underlying Si to give μs-Si ribbons. These structures can be collected and used in solution casting techniques or printed by dry transfer onto plastic substrates to produce high performance TFTs. In this approach, we demonstrated that microstructured silicon (μs-Si) from bulk Si wafer provide a simple and efficient route to high performance devices for macroeletronics that are compatible with printing processes and direct integration on plastic substrates.

9:15 AM J14.3

In Vivo Behavior of Silicon Oxide and Silicon Nitride Films.

John M. Maloney, Sara A. Lipka and Samuel P. Baldwin; MicroCHIPS, Inc., Bedford, Massachusetts.

Implantable microfabricated devices have been used in a variety of biomedical applications, including neural stimulation, sensing of physiological conditions, and drug delivery. Many of these devices rely upon exposed conductive and dielectric films for operation. Sensing and stimulation implants, for example, have used low pressure chemical vapor deposition (LPCVD) and plasma enhanced chemical vapor deposition (PECVD) ceramic films, most commonly silicon oxide and silicon nitride, to selectively passivate electrodes against the in vivo environment. However, these films dissolve in the body over time, leaving electrodes unprotected from degradation mechanisms such as delamination and corrosion. Because a dissolution rate as low as one micron per year could be disastrous to the functionality of a microfabricated implant, biostability is a major concern for long-term applications. An understanding of how ceramic films behave in vivo is fundamental to extending the useful life of MEMS implants. There have been previous reports of the dissolution rate of CVD dielectric films in saline, and this type of in vitro testing is useful for ranking material candidates. However, saline immersion does not replicate complex in vivo effects such as wound healing and the formation of a fibrous capsule around subcutaneous implants. We report here on the in vivo behavior of silicon oxide and silicon nitride films deposited by PECVD and LPCVD. A 1-year biostability study was performed by implanting microfabricated devices in the subcutaneous space of a rat model. The samples consisted of unpatterned films deposited on silicon and a drug delivery microchip containing the same films patterned in a functional configuration. The LPCVD films were deposited at approximately 800C with dichlorosilane and ammonia as precursors. The PECVD films were deposited by using silane and nitrous oxide or ammonia in a parallel-plate reactor at 350C. Devices were explanted at 1-, 3-, 6-, and 12-month time points, and dissolution rates were obtained by optical methods and by SEM images of cross sections. The dissolution rate of LPCVD silicon nitride is estimated to be 9+/-1 nm/month, as measured by spectrophotometry and confirmed by SEM. We have shown that measurements are not affected by necessary sample preparation steps such as autoclave sterilization and enzymatic cleaning to remove organic material. We also present cross-section images acquired by focused ion beam (FIB) etching. FIB sectioning avoids the smearing and other damage associated with polished sections and is therefore more accurate when characterizing in vivo degradation. FIB cross sections further allow a comparison of dissolution rates in exposed and recessed areas and are well suited for monitoring the delamination of features. These results have led to an improved understanding of the possible degradation mechanisms of microfabricated devices in vivo.

9:30 AM J14.4

In-Situ Pretreament Approach for Surface Deterioration Alleviation Amidst Thermal Desorption of GaAs (100).

Arthur Pun[1], Xu Wang[1], Jamie Meeks[1], Steve Durbin[2] and Jim Zheng[1]; [1]Electrical and Computer Engineering, FAMU-FSU College of Engineering, Tallahassee, Florida; [2]MacDiarmid Institute for Advanced Materials and Nanotechnology, University of Canterbury, Christchurch, New Zealand.

As commonly subjected to thermal treatment with the intent of dislodging native oxide layers prior to epitaxial growth, gallium arsenide wafers endure surface deterioration characterized by the etched formation of surface pits. This pit generation has been the subject of much prior research, commonly characterizing such pits as 20-500 nm wide, 5-20 nm deep, and having surface densities of 108-1010 cm-2. The formation of surface pits is an undesirable affect in device construction instigating the necessity for the manufacturer to grow micrometer-thick homoepitaxial buffer layers intended to smoothen the surface. However, such as the currently used technique is employed, it suffers from several deficiencies, including the utilization of significant time and material to deposit the buffer layer, which ultimately does not maintain the guaranteed elimination of propagating stacking faults. Within this study, a novel in-situ pretreatment is proposed theoretically and demonstrated experimentally, in which the formation of surface pits is subsequently stifled during thermal desorption. The proposed method involves fueling the well reviewed chemical oxide reduction reaction with a segregated source of material other than that ordinarily utilized in pit formation. The proposed method is implementable in virtually all deposition systems subject to the constraints of providing material deposition, substrate heating, and the creation of non-oxidizing environments either via vacuum or inert atmosphere. Experimental results of the proposed pretreatment, implemented in under two minutes, verify the near elimination of surface pits and decrease in average roughness from 1.61 nm to 0.38 nm for epiready wafers (UV/Ozone formed native oxide) and 1.44 nm to 0.40 nm for non-epiready wafers(air-formed native oxide), respectively. Furthermore, in-situ reflection high-energy electron diffraction results indicate the resulting surface is adequate for subsequent epitaxial growth, which has also been demonstrated experimentally for homoepitaxy. Additionally, results indirectly yield information regarding initial native oxide chemical composition as well as native oxide desorption surface kinetics.

9:45 AM J14.5

Effect of Donor and Acceptor Dopants on the Band Structure

of Barium Strontium Titanate Thin Films. Yuebing Zheng, Shijie Wang and Cheng Hon Alfred Huan; Institute of Materials Research and Engineering, Singapore, Singapore.

We have investigated the effect of donors and acceptors on the band stucture of Ba0.5Sr0.5TiO3 (BST) thin films prepared by a pulsed-laser deposition method. We selected Mg/Al and La as acceptor and donor dopants, respectively. Based on x-ray photoelectron spectroscopy (XPS) and ultraviolet-visible spectrophotometer (UVS) data, the Fermi level, valence-band edge and conduction-band edge are calculated for BST films in which Mg/Al and La dopants have been added. The Fermi level depends strongly on the oxygen vacancy concentration in thin films. Stress and grain size of thin films play a key role in determination of valence and conduction-band edges. The effects of dopants on the oxygen vacancy concentration, stress and grain size are detailedly discussed.

SESSION J15: MEMS and Photonics
Chair: Mihri Ozkan
Thursday Morning, March 31, 2005
Room 2003 (Moscone West)

10:30 AM J15.1
Fabrication of GaN Photonic Crystal Membrane Cavities. Cedrik Meier[1], Elaine D. Haberer[1], Rajat Sharma[2], Kevin Hennessy[1], Kelly McGroddy[2], Shuji Nakamura[2], Steven P. DenBaars[2] and Evelyn L. Hu[1]; [1]California NanoSystems Institute, University of California, Santa Barbara, Santa Barbara, California; [2]Materials Deparrtment, University of California, Santa Barbara, Santa Barbara, California.

Photonic Cavities such as microdisks, micropillars and photonic crystal cavities provide the possibility to confine light into distinct, well-defined modes. By coupling emission from active layers such as quantum wells or quantum dots to these modes, the emission properties can be greatly modified, e.g., by the Purcell effect. This has possible applications in low-threshold lasing, quantum cryptography etc. To achieve efficient coupling, two figures of merit are of importance: the quality factor Q, namely the spectral linewidth of the mode, and the effective mode volume V, which determines the volume the mode is confined into. As the Purcell factor increases with Q/V, a high quality / small volume mode is necessary to achieve optimum coupling strength. Of all types of photonic resonators, photonic crystal defect cavities can provide the smallest mode volume while maintaining high (up to Q>10000 demonstrated in GaAs) quality factors. An effective way of forming such a cavity is to form photonic cavity membrane structures in which the light is confined in-plane by the photonic crystal and confined in the vertical direction by the index difference between the membrane and surrounding regions. While the formation of an undercut membrane can be achieved by selective wet etches in many material systems, this is more difficult for GaN as this material system has no conventional wet etch. We have used bandgap-selective photoelectrochemical (PEC) etch to selectively undercut a sacrificial layer while maintaining the active layer untouched. We demonstrate the successful formation of photonic crystal membrane cavities, using a triangular lattice / H2 defect with lattice constants between a=160nm and a=200nm, suitable for coupling to emitters in the range between 400nm and 520nm. We will also analyze our device performance using FDTD simulations. Finally, we will discuss the impact of lattice constant on the mode spectrum of the H2 defect.

10:45 AM J15.2
Photon by Photon Analysis of Single Quantum Dot Emission Dynamics. Hauyee Chang, Kai Zhang, Lucas P. Watkins and Haw Yang; Chemistry, University of California, Berkeley, California.

Semiconductor quantum dots (QD) possess enormous potential as single photon sources, nano-lasers, and luminescent reporters for biological processes, to name a few. To realize the full potential for Qds, especially in nano-scale design and engineering, a fundamental understanding of their optical property at the single-molecule / single-particle level is critical. Since the initial discovery of "on" and "off" intermittent emission of individual QDs, considerable efforts have been made in characterizing the statistical properties of such behavior. These endeavors, however, are hampered by the inability to locate accurately the time instance at which the emission intensities change. Here we report a new study using the recently developed change-point algorithm that allows quantitative recovery of the underlying QD emission dynamics photon by photon. The number of emissive states (greater than 2) was determined. Inter-state transition kinetics and state-resolved luminescence lifetime were measured. Their implication in rational design of optical probes using QDs will be discussed.

11:00 AM J15.3
Multi-band Terahertz Imaging System Design.
Liviu Popa-Simil, AFCI-D5, Los Alamos National Laboratory, Los Alamos, New Mexico.

Developing visualization device in far Infra red presents tremendous advantages and focused the research of space agencies, defense and security as well many other private companies oriented to science. The THz wave emitters and receivers are less developed, compared to its neighboring bands (microwave and optical). During the past decade, THz waves have been used to characterize the electronic, vibrational and compositional properties of solid, liquid and gas phase materials to identify their molecular structures. At the base of this development stays the possibility of achieving microstructures from conductive or supraconductive materials able to select by resonant criteria the emerging photons and drive into specialized detection devices. The problem to be solved is the ratio S/N because the energy of a single 1THz photon is 4.1 meV equivalent to a 47K temperature. A group of such highly selective micro-antenna can be grouped into a unit cell - called elementary multi-band detector. The development is in the development of resonant structures for frequency selectivity and directivity reasons coupled with the electrical field amplification and detection in low noise quantum transistors heterostructures. Such an electronic system might be integrated in a modular structure and by multiplicity to create 3D imaging sensors.

11:15 AM J15.4
Emission Properties from High Efficient InGaN/GaN MQW Nanorod Array. Hwa-Mok Kim[1], Ho Sang Lee[1], Seong Ryong Ryu[1], Jin Hyeong Cho[1], Chang Seok Han[1], Yong-Hoon Cho[2], Deuk Young Kim[1], Tae Won Kang[1] and Kwan Soo Chung[3]; [1]QSRC, Dongguk University, Seoul, South Korea; [2]Physics, Chungbuk National University, Cheongju, South Korea; [3]Electronic Engineering, Kyunghee University, Yongin, South Korea.

We demonstrate the emission properties of the high-brightness and high-efficiency light emitting diodes (LEDs) using dislocation-free InGaN/GaN multi-quantum-well (MQW) nanorod (NR) arrays by metalorganic-hydride vapor phase epitaxy (MO-HVPE). These MQW NR arrays (NRAs) grown on the sapphire substrate are buried in spin-on glass (SOG) for isolating individual NRs and for bring p-type NRs in contact with p-type electrodes. The MQW NRA LEDs has the electrical characteristics similar to those of a conventional broad area (BA) LED. However, owing to the lack of dislocations and the large surface areas provided by the sidewalls of NRs, both the internal and extraction efficiencies are exceedingly enhanced. Moreover, the fabrication processes of the MQW NRA LEDs are almost the same as those of the conventional BA LED. It is thus expected the total yield of these MQW NRA LEDs to be the same as the conventional BA LED. The present method of utilizing dislocation-free MQW NRA LEDs is applicable to super-bright white LEDs as well as other semiconductor LEDs for improving total external efficiency and brightness of LEDs. This work was supported by KOSEF through the QSRC at Dongguk Univ. and AOARD/AFOSR.

11:30 AM J15.5
A Wide Band Gap Boron-doped Microcrystalline Silicon Film Obtained with VHF Glow Discharge Method. Zhuf Feng, Nankai University, Institute of Photo-electronics, Tianjin, Tianjin, China.

A wide band gap microcrystalline silicon film for the window layer of microcrystalline silicon thin film solar cells was obtained with very high frequency (VHF) glow discharge technology. The materials were deposited on glass substrates. The optical band gap (Egopt), calculated from absorption coefficient, enlarged with the increasing of hydrogen dilution ratio. When SiH4/H2 was less than 1%, the Egopt could be wider than 2.10eV. Raman spectra showed that this material was highly crystallized, and no peak correlation with amorphous silicon was observed. The materials showed strong n type before any intentional doping. We considered that the unintentional doping of oxygen and unpurified gases. The doping performance of this material was investigated by introducing B2H6 into the reacting gas. As increasing the rate of B2H6/SiH4 from zero to 0.5%, the conductivities changed from 10-1 S.cm-1 (n type) to 10-8 S.cm-1 dramatically and than backed to 10-1 S.cm-1 (p type), which indicated that this material had excellent doping ability. Raman spectra also showed that the microstructure of these materials did not change obviously in this doping range. We gained the p-uc-Si:H film with thickness less than 30nm, whose conductivities was more than 10-2 S.cm-1, and crystalline volume fraction no less than 40%. Using this p window layer in microcrystalline silicon solar cells with no rear reflection, the conversion efficiency was exceeded 8%.

11:45 AM J15.6
Diode Laser Bonding of Planar MEMS, MOEMS, & Microfluidic Devices. James T. Clements[1], Jerry Zybko[2] and Jie-Wie Chen[3]; [1]NanoSciences, Inc., Aliso Viejo, California; [2]Leister

Technologies, LLC, Itasca, Illinois; [3]Leister Process Technologies, Sarnen, Switzerland.

As polymer-based microfluidic devices, MEMS/MOEMS, lab-chips and diagnostic platforms, are pushed towards increasingly smaller geometries, advances in diode laser technology allows for cleaner and more precise assembly. Additionally, the growing use of these devices in this format has led to designs requiring a film seal. New technologies integrating diode lasers now makes it possible to join plastic microfluidic structures, and sub-components, by using laser light to join the elements at the interface, producing bond areas as small as 30-40 microns. The assembly process is accomplished without adhesives, diffused heat, vibration, or the formation of particulate contamination, and has proven a superior alternative when facing concerns regarding biocompatibility. Laser welding is accomplished by passing laser light through a top, laser-transparent plastic material and onto a bottom, laser-absorbent material. The laser is absorbed and transformed into heat. With the parts clamped together, the heat is conducted into both components, where it softens both parts, creating a molecular bond, and a hermetic seal. This technique has demonstrated flexibility not only in the manner in which the laser light can be delivered, but also in the materials which can be joined: from impregnated thin-films to thicker substrate platforms. This paper will also address the growing use of nanomaterials which have been intercalated or integrated into a variety of polymer matrices. In addition, laser diode welding can now be achieved with either a moving spot seal or a masking process: The mask technique allows for freely definable geometries to be generated on a metal-coated glass using the photolithographic process. Where the metal is etched away, the laser light is allowed to pass, transferring the pattern onto the substrate. Dedicated masks allow for flexibility and an automatic alignment can precisely position the mask within +/- 1.0 microns.

SESSION J16: Sensors and Materials

Chair: Rashid Bashir
Thursday Afternoon, March 31, 2005
Room 2003 (Moscone West)

1:30 PM J16.1
Investigating Narrow Plasmons in Nanoparticle Arrays Fabricated Using Electron Beam Lithography.

Erin McLellan Hicks[1], Richard P. Van Duyne[1], Linda Gunnarsson[3], Bengt Kasemo[3], Tomas Rindzevicius[2] and Mikael Kall[2]; [1]Chemistry, Northwestern University, Evanston, Illinois; [2]Applied Physics, Chalmers University of Technology, Gothenburg, Sweden; [3]Chemical Physics, Chalmers University of Technology, Gothenburg, Sweden.

The improvement of nanofabrication is one of the driving forces behind advancements in the fields of electronics, photonics and sensors. Precise control over nanoscale architecture is an essential aspect in relating new size-dependent material properties. Direct writing methods such as Electron Beam Lithography (EBL), enable precise, user-defined writing of nanostructures in a wide range of materials. Using electrodynamics calculations, Schatz and coworkers have discovered one dimensional array structures built from spherical silver nanoparticles that produce remarkably narrow plasmon resonance spectra upon irradiation with light that is polarized perpendicularly to the array axis. In order to investigate these interactions, precise control of nanoparticle orientation, size, shape and spacing is necessary. If the overall structures have excessive defects then the effect may not be seen. To have the best control over array fabrication and to look at these interactions experimentally, EBL was used to construct lines of circular cylinders of varying interparticle spacings. Dark field microscopy was used to look at overall sample homogeneity and collect the single particle plasmon resonance spectrum. Additionally, a UV-visible spectrometer with a variable angle stage was used to look at the bulk line properties. With experimental verification of the theory will lead to not only a more thorough understanding of the underlying principles of nanophotonics, but also application in biosensing, that potentially improve on current technologies.

1:45 PM J16.2
Electrostatic Control of Ions and Molecules in Nanofluidic Transistors.

Rohit Karnik[1], Min Yue[2], Rong Fan[3], Kenneth Castelino[1], Christine Trinkle[1], Deyu Li[4], Peidong Yang[3,5] and Arun Majumdar[1,5]; [1]Mechanical Engineering, University of California, Berkeley, California; [2]Applied Biosystems, Foster City, California; [3]Chemistry, University of California, Berkeley, California; [4]Mechanical Engineering, Vanderbilt University, Nashville, Tennessee; [5]Materials Sciences Division, Lawrence Berkeley National Laboaratory, Berkeley, California.

Electrostatic effects control the ionic environment in fluidic channels when the channel size is comparable to the Debye screening length. We demonstrate a nanofluidic transistor- a nanochannel with a gate electrode- that exploits this effect. The nanofluidic transistor can be used to control ionic as well as biomolecular concentrations and hence control their flow. This effect is similar to the metal-oxide-semiconductor field effect transistor (MOSFET). Further, surface-bound biomolecules and bio-reactions, such as antibody-antigen binding or phosphorylation, will affect the electrical conductance of the nanochannels, enabling their use as a novel charge-sensitive biosensor. Nanochannels that were 30-40 nm thick and 1 μm wide were fabricated on a fused silica substrate. Gate electrodes were incorporated and microchannels were bonded to interface with the nanochannels. The nanochannel environment and gating control were characterized by a combination of electrical measurements and fluorescence microscopy. Electrical conductance of the nanochannels was measured for different electrolyte concentrations. For higher electrolyte concentrations the nanochannels exhibited bulk conductance. Interestingly, for low concentrations, the conductance was several orders of magnitude higher than bulk conductance. Fluorescence intensity of a negatively charged dye solution in various KCl concentrations showed that the dye was being electrostatically repelled out of the channel for low KCl concentrations. These results provide direct evidence that in the limit one can produce unipolar solutions where the counter-ion concentration depends on the surface charge density, while the co-ions are electrostatically excluded from the nanochannel. The unipolar nature of the electrolyte in the nanochannel can be exploited in a nanofluidic transistor. A gate voltage could control the concentration of a charged dye as well as 30-base DNA in the nanofluidic transistor. Further, under a voltage bias along the nanochannel, a gate voltage could induce controllable concentration gradients and up to a hundred-fold concentration enhancement. The gating voltage could also control the electrical conductance of the nanochannels. These results demonstrate the feasibility of ionic and biomolecular flow control in nanofluidics. We have demonstrated that surface charge and gating voltage can be used to control the nanochannel environment. Simple nanochannel networks are currently being fabricated to demonstrate switching of biomolecular flow and to study pH control for isoelectric focusing of proteins. The nanochannels have been successfully functionalized with DNA probes using silane chemistry and their use for biosensing is currently under investigation. This work illustrates the efficacy of electrostatic control in nanofluidics, which would have broad implications on integrated nanofluidic circuits for manipulation and sensing of ions and biomolecules in femtoliter volumes.

2:00 PM J16.3
Microchannel Arrays in Borophosphosilicate Glass for Photonic Device and Optical Sensor Applications.

Claire L. Callender, Patrick Dumais, Chantal Blanchetiere, Christopher J. Ledderhof and Julian P. Noad; Communications Research Centre, Ottawa, Ontario, Canada.

The fabrication of arrays of embedded microchannels on a silicon wafer and their integration with optical waveguides offer great potential for the realization of novel photonic devices and sensors. In this work we present the fabrication of two-dimensional uniform arrays of microchannels with circular cross-sections of 2-3 μm diameter in borophosphosilicate glass (BPSG) layers deposited by plasma-enhanced chemical vapor deposition (PECVD), and demonstrate the application of these structures in optical sensors. The microchannels are formed by depositing specific thicknesses of BPSG over periodic ridge/space templates etched into underlying silica layers using reactive ion etching (RIE). High temperature annealing results in reflow of the BPSG and the formation of uniform voids between the template ridges. We demonstrate how the size, shape and position of the microchannels relative to the ridge templates can be controlled through adjustment of the template geometry, the thickness of the deposited layers and the annealing conditions. The use of different templates to fabricate one- and two-dimensional arrays as well as novel interconnecting channel structures will be presented. The silica-on-silicon PECVD/RIE processing techniques used in this work offer the flexibility to engineer these microchannels in a number of different multilayer structures with tightly controlled physical and optical properties. By using the same BPSG material for the template and the void forming layers, silica-air microstructures in a single matrix material can be formed. Alternatively, by patterning the templates in Ge-doped silica layers, optical waveguides aligned in close proximity to microfluidic channels are formed. The evanescent field of the light guided in the waveguides can then be used to access the optical properties of the fluid in the channels. Sensor and device functionality will be demonstrated through absorption and fluorescence in the integrated structure, and the performance of a novel optical sensor sensitive to changes of refractive index in small volumes (< 1 x 10-^{12} m^3) of liquid will be presented.

2:15 PM J16.4

Polypyrrole-based Humidity Sensor Fabricated by Layer-by-Layer Nano-assembly. Razat Nohria, Yi Su, Rajneek Khillan, Rohit Dikshit, Yuri Lvov and Kody Varahramyan; Institute for Micromanufacturing, Louisiana Tech University, Ruston, Louisiana.

Conducting or semiconducting conjugated polymers show significant change in their electrical properties after exposure to humidity. A number of different techniques such as electrochemical polymerization, chemical and electrochemical deposition and spin coating have been applied for the fabrication of polymer humidity sensors. In this paper we report layer-by-layer nano-assembly for fabrication of highly sensitive and fast response humidity sensors using conducting polymer polypyrrole (PPy). Spin coating was also used for fabrication of PPy humidity sensor for comparison. Layer-by-layer nano-assembly of poly(styrenesulfonate) (PSS), and PPy was done on glass substrate. PSS was used as polyanion, while PPy was used as polycation. Five alternating precursor layers of (poly(allylamine)(PAH)/PSS)$_5$ were deposited before self-assembly of polymer sensing layers. A LbL self-assembled bi-layer thickness was measured to be 2.3 ± 0.1 nm. The change of electrical resistance in the sensing polymer was monitored when the sensing element was exposed to humidity. These LbL assembled nano-films produced a fast change in resistance when exposed to humidity. The change in resistance was monitored for humidity ranging from 50 % to 90%. The experimental results show 10% decrease in resistance for the LbL-based PPy and 8% resistance change for the spin coated PPy for every 5% increase in humidity. A comparison was made in terms of sensitivity and response time for the two different fabrication techniques. LbL-based sensors showed higher sensitivity and fast response than those from spin coating. The response time is tested to be 25 seconds for the LbL-based sensor, while it is around one minute for the spin coated sensors. The degradation was noted when the sensors were exposed to air environment for 7 days. LbL based humidity sensor showed less drift in sensor baseline resistance than that from spin coated humidity sensor. Such PPy humidity sensors can be used as disposable handheld humidity detectors due to low cost and easy fabrication. Reference: 1. K. I. Arshak, et al. ″Investigation into a novel humidity sensor operating at room temperature″, Microelectronics Journal, Vol33, Issue 3, 2002, 213-220. 2. Shilpa Jain, et al., ″Humidity sensing with weak acid-doped polyaniline and its composites″, Sensors and Actuators B: Chemical, Vol96, Issues 1-2, 2003, 124-129. 3. R. K. Khillan, et al., ″Layer-by-Layer Nanoarchitecture of Ultrathin Films Assembled of PEDOT-PSS and PPy to Act as Hole Transport Layer in Polymer Light Emitting Diodes and Polymer Transistors″, Polytronics 2004, IEEE Intl Conf. On Polymers and Adhesives, Sept. 3-5, 2004, Poltland, OR. 4. M.K.Ram, et al., ″Physical Insight In The In-Situ Self Assembled Films Of Polypyrrole″, Polymer, 2000,Vol41, 7499-7509.

2:30 PM J16.5

Stabilized Pd-Alloy/AlN/Si Hydrogen Sensor. Linfeng Zhang[1], Ibrahim Al-Homoudi[2], Md H. Rahman[3], Eirk F. McCullen[1], Lajos Rimai[1], Ron J. Baird[1], Ratna Naik[4], Golam Newaz[2], Gregory W. Auner[1] and K. Y. Simon Ng[3]; [1]Electrical and Computer Engineering, Wayne State University, Detroit, Michigan; [2]Mechanical Engineering, Wayne State University, Detroit, Michigan; [3]Chemical Engineering and Materials Science, Wayne State University, Detroit, Michigan; [4]Physics and Astronomy, Wayne State University, Detroit, Michigan.

A metal-insulator-semiconductor (MIS) type sensor, utilizing a Pd-Cr or Pd-Ni /AlN/n-Si(111) structure are being developed to measure hydrogen concentration. This MIS type sensor works as a capacitor, the Capacitance-Voltage (CV) curve would shift in the presence of hydrogen. At a constant capacitance, the voltage shift is a function of hydrogen concentration. The alloy gates were deposited in a magnetron sputtering chamber and the AlN was grown using Plasma Source Molecular Beam Epitaxy (PSMBE). Samples with Cr concentration from 4-10% and Ni from 4- 20% were fabricated. Addition of Cr and Ni would suppress the phase transition of palladium and provide a more stable film, as revealed by Atomic Force Microscopy (AFM). The alloy gates not only extended the dynamic range of the response to hydrogen concentrations from 100 ppm to 50,000 ppm, but also showed a faster turn on/off response time. Moreover, the device with Pd-Cr gate has a negligible baseline and turn-on response drift, and is much stable than that from Pd-Ni device. The chemical composition of the film was analyzed by X-ray Photoelectron Spectroscopy (XPS). Surface segregations of Cr and Ni were found. Furthermore, in Pd-Cr alloy, Cr was oxidized on the outer surface while Pd was oxidized in the metal/insulator interface. However, no similar result was shown in the Pd-Ni alloy film. The work function of the Pd was different depends on the concentration of Cr and Ni. The effect of this difference on the sensor performance is still being studied. Several operating parameters including temperature, flow rate and ac signal frequency were investigated, the larger response could be obtained with measurements made at a low temperature and with a low ac signal frequency.

2:45 PM J16.6

Templated Growth and Overgrowth of Organic Nanofibers. Edward Kintzel[1], Frank Balzer[2] and Horst-Guenter Rubahn[3]; [1]Spallation Neutron Source, Oak Ridge National Laboratory, Oak Ridge, Tennessee; [2]Institut für Physik/ASP, Humboldt-Universität zu Berlin, Berlin, Germany; [3]Fysisk Institut, Syddansk Universitet, Odense, Denmark.

Organic nanofibers made from para-hexaphenyl molecules on the surface of mica exhibit distinctive dimensions, while growing in a well-tailored self assembly process. Due to their nanoscale widths and heights and macroscopic lengths, their use as optical waveguides is attractive. Additionally, the extraordinary luminescence efficiency, high dichroism and nonlinear optical response of these nanofibers opens up possible applications for polarized light emitting devices, miniaturized frequency converters, and lasing elements. Several of these uses imply the incorporation of the nanofibers within more complex optical or optoelectronic devices. In the present work we investigate, using a combination of atomic force and fluorescence microscopy, the possibility for additional growth of the original organic nanofibers after transfer as well as the ability to direct the growth of new nanofibers using the existing ones. Both growth processes are significant for future implementation strategies.

SESSION J17: Nanosystems and Devices

Chair: Kevin Turner
Thursday Afternoon, March 31, 2005
Room 2003 (Moscone West)

3:30 PM J17.1

Microfluidic Integration of Ultramicroelectrode Cells for Direct Electronic Detection of Biomolecular Signals in the Picoampere Range. Napat Triroj and Roderic Beresford; Engineering, Brown University, Providence, Rhode Island.

Biomolecular responses to stimuli are extraordinarily sensitive, specific, and efficient. If these unique attributes of biomolecules are combined with nanoelectronics, a wide range of new opportunities are opened up in information and medical technologies, laying the foundation for future 'biology-to-digital' sensing and control systems. This work reports the initial implementation of a microscopic cyclic voltammetery cell, which is being integrated with innovative sensors based on the development of molecular linkers between biological systems and nanoscale electrodes such as nanotubes and nanoparticles. Ultramicroelectrodes in electrochemical sensors require only small sample volumes, have small ohmic drops, increased limiting current density, rapid response, and flow insensitivity. We report a microfluidic/microelectronic fabrication process that yields identical, highly uniform and geometrically well-defined ultramicroelectrodes for picoampere current electrochemical detection. We have fabricated multiple copies of a three-ultramicroelectrode system on a glass substrate. Each cell consists of an Au working electrode with surface area of 9 μm^2, a Cl-plasma-treated Ag/AgCl reference electrode, and an Au counter electrode. The electrode pattern on glass is aligned and irreversibly bonded with a polydimethylsiloxane (PDMS) microchannel network. The electrokinetic properties of a background electrolyte in our microchannels were tested using a TBE 0.5x buffer with electrical conductivity of 0.7 mS/cm. The sample volume (channel) is 72 nL. For different channel widths, the mass-transport-limited currents detected at "large"-area (mm scale) electrodes are proportional to the channel widths and close to the theoretical values. Under pressure-driven flow rates between 80 nL/s and 1 nL/s, we observe a transition from transport-limited current to transient current, as expected. Use of such channels housing the ultramicroelectrode cells will be reported. We will show the functionality of our micro cyclic voltammetery cell as calibrated with redox standard species (Fe^{3+}/Fe^{2+}) and discuss novel linker systems for biomolecule sensing. This work is supported by the AFOSR under the MURI award F49620-03-1-0365.

3:45 PM J17.2

Biocompatible Polymer Matrix for Oriented Protein Insertion and Optimal Functionality. Hyeseung Lee, UCLA, Los Angeles, California.

As the technology approaches the new era of device miniaturization, a compact and more efficient power source to drive these devices are in demand. In this respect, it is worth exploring the potential of nanometer-scale hybrid organic/inorganic devices as an alternative to conventional batteries which have obvious limitations in size miniaturization. Our device is a demonstration of lighter and renewable energy source. It will show the potential for the next generation energy which is biocompatible and generates higher power per density. We are engineering a biocompatible fabric embedded with energy converting proteins and detecting their activity in bacteriorhodopsin (BR) and cytochrome oxidase (COX). The system converts optical energy to electrical energy, eventually allocating the derived energy to an external source. There are two different types of energy converting proteins embedded in artificial polymer membrane. Bacteriorhodopsin is a natural proton transporter being activated by light. Cytochrome oxidase, in its reversed action, is an electron transporter. When light is illuminated on this assembly, bacteriorhodopsin starts pumping protons from one side to the other creating the proton gradient across the membrane. This proton gradient will drive cytochrome oxidase in reversed action so then cytochrome oxidase would transport electrons. The transported electrons are detected and harvested to the electrode placed in the vicinity of the protein embedded in artificial biomimetic membrane. In this study, we have tested our choice of proteins in phosphatidyl choline based lipid membranes as well as in block copolymers. Artificial lipid membrane system made in the study is more stable than naturally occurring membranes. However, a more durable membrane system is needed for industrial and commercial applications. ABA triblock polymers (PMOXA-PDMS-PMOXA) form self-assembled stable structures which can be hybridized with biological molecules. We investigated on the pH directed orientation of bacteriorhodopsin and its wavelength dependency for activation in polymer membranes of different compositions. For the industrial applications, it is necessary to design more bendable polymer system, which makes flexible yet, robust fabric. A well-known hydrogel, TMOS (tetramethyl orthosilicate), was the choice of the solution to cast the assembly in a semi-dry environment. The study on the TMOS coated biosolar fabric showed the possibility of moving the device to the dry environment.

4:00 PM J17.3

Field and Fluorescence Modification by Colloidal Gold Nanoparticles. Kai Zhang and Haw Yang; Chemistry, University of California, Berkeley, Berkeley, California.

Gold metallic nanoparticles have great potential as biological probes due to their unique optical properties. Knowledge of the field distribution around gold nanoparticle is extremely important because it will guide applications of gold metallic nanoaprticles in biological systems. Our electromagnetic calculations show that scattering field is not homogeneously distributed around the gold particle. It can be either enhanced or quenched at different regions. Factors affecting field distribution include particle size, excitation wavelength, and light polarizations. Dye molecules located close to the particle surface therefore experience modified excitation fields such that their optical properties are changed. Results of three dimensional scattering field distribution, spatially dependent fluorescence modification will be discussed. Comparison of experimental results to theoretical calculations will be presented.

4:15 PM J17.4

Gate Effects for a Molecule-Nanoparticle Network Device. Shinichiro Kondo, Ryoichi Yasuda, Daisuke Hobara, Yuuki Ishioka, Shintaro Hirata, Masaru Wada and Jiro Kasahara; Fusion Domain Laboratory, Materials Laboratories, Sony Corporation, Ota-ku, Tokyo, Japan.

Despite varieties of intra-molecular electrical transport studies in the past, there is no previous experiment that showed gate effects with high reproducibility [1]. We report here for the first time that p-type gate effects were clearly observed for conjugated oligo-phenyldithiol molecules incorporated in a nanoparticle array. While most of previous works utilized some forms of nanogaps for single-molecule connections, our molecule-nanoparticle network was formed by a macroscopic number of inter-connected metal-molecule-metal junctions between μ-sized channel regions. This structure is an excellent template that makes it possible to study intra-molecular transport and provides highly reliable measurement results. The network consists of a densely packed gold nanoparticle monolayer array and dithiol linker molecules that chemically bridge pairs of nearest-neighboring nanoparticles. The particle array was prepared over a cm-order area by a modified Langmuir-Blodgett method and transferred, without damaging the array quality, to an insulating surface with interdigited metal electrode patterns on it. The array was submerged in a solution of linker molecules and subsequently rinsed well in a solvent. The substrate has a gate electrode on the back for three-terminal measurements. Source-drain current measurements were carefully carried out with or without gate voltage. Conjugated oligo-phenyldithiols and non-conjugated alkanedithiols were used in our study as linker molecules. After connecting the nanoparticles by any of the conjugated linker molecules used, two-terminal current measurements (that is, at zero gate voltage) exhibited a hundred-fold increase [2]. For either type of molecules, the current was found to decrease exponentially with molecular length. But the decay constants are distinctly different for conjugated or non-conjugated molecules. These observations strongly support the formation of molecule-nanoparticle network. The three-terminal measurements for the conjugated molecules all evidently showed p-type gating behavior with transconductance on the order of 1 nS (Wg/Lg = 8 mm/50 μm; 150 nm thick SiO_2 as a gate insulator). On the other hand, within the range of experimental uncertainties, only negligibly small gate modulation was seen for the non-conjugated molecules as well as the original gold array. To the best of our knowledge, this is the first observation of clear gate effects with satisfactory reproducibility on intra-molecular transport for conjugated molecules. [1] For example: A weak gate effect was observed with an only small probability for 1,3-benzenedithiol self-assembled monolayer in: Jeong-O Lee *etal.*, *Nano.Lett.* 3, 113 (2003). [2] D. B. Janes *etal.*, *Superlatt.Microstruct.* 18, 283 (1995).

4:30 PM J17.5

Multi-Technology Measurements of Amorphous Carbon Films. Stephen J. Morris, Eileen Clifford, Osman Sorkhabi, Xiaoping Liu, Jingmin Leng and Heath Pois; Therma-Wave Inc., Fremont, California.

We demonstrate that a multi-technology approach is essential for the accurate characterization of the thickness and optical properties of Amorphous Carbon (α-C) films used in semiconductor manufacturing. This is because the material tends to be highly birefringent, with its measured refractive index and extinction coefficient at any wavelength depending strongly upon the precise polarization and angle-of-incidence of the optical probe beam that is used. Conventional approaches for film characterization, based on single angle-of-incidence Spectroscopic Ellipsometry (SE), are bound to fail for this material because there is insufficient optical information to find a unique solution – the number of parameters that must be measured exceeds the number of independent data points that are available. The systematic errors introduced by this approach can be significant – up to 15% in some cases. This situation can be addressed in a number of different ways, such as adopting variable angle-of-incidence SE (VASE) or combining SE data with one or more complementary optical techniques. We show that Beam Profile Reflectometry® (BPR®) is particularly strong in this case because, unlike ellipsometry which measures the differences between the reflectances of p-polarized and s-polarized light at a particular angle-of-incidence, BPR measures the actual reflectances for both polarization components at multiple angles-of-incidence. Furthermore, the fact that BPR is a single-wavelength technique means that no assumptions must be made about the optical dispersion of the film and an absolute measurement can be made. Typically, thin α-C films on Silicon substrates are assumed to have uniaxial birefringence, with an "ordinary" refractive index for light polarized parallel to the substrate and an "extraordinary" refractive index for light polarized perpendicular to the substrate. We show that, to first order, this can often be modelled by assuming a single "anisotropy parameter", the ratio between the ordinary and extraordinary refractive indices (or, more correctly, the complex dielectric functions). However, there are cases where this approximation is insufficient and a wavelength-dependent function must be employed. In these cases, considerable advantages accrue from being able to combine SE, BPR and Broad-Band (BB), near-normal incidence spectrophotometry into the same measurement. A number of examples are supplied of α-C films characterized by these techniques, both singly and as components of more complex hard-mask filmstack structures. Three-sigma reproducibility results achieved for t, n and k at 193nm on single $\sim\sim 500\AA$ films are of the order of $0.7\AA$, 0.0020 and 0.0015 respectively.

SESSION J18: Poster Session
Chairs: Mark McNie and Somuri Prasad
Thursday Evening, March 31, 2005
8:00 PM
Salons 8-15 (Marriott)

J18.1

Hybrid Virus Networks with Quantum Dots and Carbon Nanotubes. Nathaniel Gerald Portney[1], Krishna Singh[1], Sumit Chaudhary[2], Giuseppe Destito[3], Anette Schneemann[3], Marianne Manchester[3,4] and Mihrimah Ozkan[2,1]; [1]Chemical and Environmental Engineering, University of California, Riverside, Riverside, California; [2]Electrical Engineering, University of California, Riverside, Riverside, California; [3]Molecular Biology, The Scripps Research Institute, La Jolla, California; [4]Center for Integrative Molecular Biosciences, The Scripps Research Institute, La Jolla, California.

Viruses are exemplary models in nanoassembly for their regular geometries, well characterized surface properties, and nanoscale dimensions. Armed with versatile tools aimed at site directed mutagenesis to modify the virion's surface, conjugation chemistry for capsid coupling, and manipulation of nanoparticles, we have demonstrated nanoscale assembly of inorganic carbon nanotubes and quantum dots with engineered viruses to produce an intimate array of hybrid structures. Network assembly has been achieved between a mutant insect Flock-House Virus (FHV-A205K) and single-walled carbon nanotubes (SWCNTs), and Plant Cowpea Mosaic Virus (CPMV) and quantum dots (QDs) through carbodiimide coupling chemistry. FTIR confirmed covalent amide linkages between each heterostructure, and SEM studies visualized large-scale network assembly. Fluorescence microscopy visualized how quantum dots were incorporated into micron-scale networks. To control quality of starting material, SWCNTs were separated by length using centrifugal fractionation to isolate a more monodisperse sample. Water soluble quantum dots were prepared by functionalizing them with mercaptoacetic acid. Such a hybrid system can be employed to fabricate novel biofilms with tunable pore sizes, 3-dimensional architecture for nanoelectronic device fabrication, a tool for biological probing, dynamic epitope expression systems, and drug delivery applications.

J18.2

Abstract Withdrawn

J18.3

Process Development of a Reconfigurable MEMs-Based Photonic Crystal Waveguide Device. Gerard Dang, Weimin Zhou and Monica Taysing-Lara; US Army Research Lab, Adelphi, Maryland.

We report on the progress of the development of a reconfiguarable MEMs-based photonic crystal waveguide device. The realization of this device requires overcoming a number of processing challenges, and the complexity of fabricating a three dimensional MEMs device is compounded with the nanometer scale features of the photonic crystal. The fabrication challenges will be illustrated by presenting the fabrication process, which includes e-beam lithography and various dry and wet etch techniques. The interdependence of the fabrication steps and how it affects the overall device will be examined. These devices can be a basic building block in optoelectronic integrated circuits, which can be used in a number of military applications such as signal processing for communication, radar, sensors, and imaging.

J18.4

Synthesis and Characterization of Chitosan-Fe_3O_4 Magnetic Nanocomposites. Patricia Lara, Marleth Mena, Moises Hinojosa and Virgilio Gonzalez; Div. de Ingenieria Mecanica, FIME-UANL, San Nicolas de los Garza, Nuevo Leon, Mexico.

Functional nanocomposites based on magnetic nanoparticles are becoming very popular in many fields finding applications in medicine and nanosystems. However, relatively few works have explored the use of chitosan in magnetic composites. We have developed a novel nanocomposite based on Fe_3O_4 nanoparticles embedded in a chitosan (CH3COOH) matrix. The magnetic nanoparticles were prepared by coprecipitation from $FeCl_3$ and $FeCl_2$ in NaOH, these particles were characterized by TEM, XRD and TGA, and were found to have sizes ranging from about five nanometers up to some one hundred nanometers. Chitosan was prepared from chitin (CHOOH), the nanoparticles are then embedded in the chitosan matrix by the use of different soft-chemistry methods. The characterization of the nanocomposite was performed by TEM, OM, XRD, FTIR, TGA, DSC and AFM. The possible applications of this composite in nanosystems is discussed.

J18.5

Negative Transverse Magnetoresistance Effect in Bismuth Nanowires. Dmitry Vasilievich Gitsu[1], Tito E. Huber[2], Leonid Alexandrovich Konopko[1,3] and Albina Alexandrovna Nikolaeva[1,3]; [1]Institute of Applied Physics, Chisinau, Moldova; [2]Department of Chemistry, Howard University, Washington, Washington; [3]International Laboratory of High Magnetic Fields and Low Temperatures, Wroclaw, Poland.

In Bi nanowires with diameters d<100nm for the first time the negative magnetoresistance effect at H⊥I at T=1.6-4.2K is found. Glass covered single crystal Bi wires of strictly cylindrical form with d=100÷50 nm were obtained by the liquid phase casting by the Ulitovsky-Tailor method. Orientation of the samples of all the diameters was the same: the wire axis made up an angle of ~20° with the bisector axis C_2 in the bisector-trigonal plane. The diameter was controlled with the help of SEM and AFM microscopes. It was found that with the wire diameter d decreasing the minimum on the TM shifted into the region of strong magnetic fields and its depth increased. Investigation of temperature and thickness dependences of the TMR allows us to conclude that two special points on the TMR (minimum of the negative polarity and the point of intersection with the axis x ($R(H_\perp)=0$) are connected to both size effect determined by the ratio $d=R_c=F_F{*}c/eH$ (R_c is the Larmor radius) and size quantization effect: $\omega_c=2.4h^2/2md^2$ In the first case this gives a possibility to estimate the Fermi pulse of the carriers in the direction H⊥I, and in the second - the size quantization value.

Acknowledgements This work is supported by Civilian Research and Development Foundation (CRDF), CGP # MO-E1-2603-SI-04.

J18.6

Towards Novel Light-Activated Shape Memory Polymer: Thermomechanical Properties of Photo-responsive Polymers. Emily Snyder and Tat Hung Tong; Cornerstone Research Group, Inc., Dayton, Ohio.

The basic principle for the operation of a thermally stimulated shape memory polymer (SMP) is a drastic change in elastic modulus above the glass transition temperature (Tg). This change from glassy modulus to rubbery modulus allows the material to be deformed above the Tg and retain the deformed shape when cooled below the Tg. The material will recover its original shape when heated above the Tg again. However, thermal activation is not the only possibility for a polymer to exhibit this shape memory effect or change of modulus. In this report, the results of an alternative approach to SMP activation are discussed. It is well known that the Tg of a thermosetting polymer is proportional to its crosslinking density. It is possible for the crosslinking density of a room temperature elastomer to be modified through photo-crosslinking special photo-reactive monomer groups incorporated into the material system in order to increase its Tg. Correspondingly, the modulus will be increased from the rubbery state to the glassy state. As a result, the material is transformed from an elastomer to a rigid glassy photoset, depending on the crosslinking density achieved during exposure to the proper wavelength of light. This crosslinking process is reversible by irradiation with a different wavelength, thus making it possible to produce light-activated SMP materials that could be deformed at room temperature, held in deformed shape by photo-irradiation using one wavelength, and recovered to the original shape by irradiation with a different wavelength. In this work, monomers which contain photo-crosslinkable groups in addition to the primary polymerizable groups were synthesized. These monomers were formulated and cured with other monomers to form photo-responsive polymers. The mechanical properties of these materials, the kinetics, and the reversibility of the photo-activated shape memory effect were studied to demonstrate the effectiveness of using photo-irradiation to effect change in modulus (and thus shape memory effect).

J18.7

Metallic Nanoparticles Embedded in Plasma Polymerized Matrix: TEM and XPS Measurements. Alexandre Felten, Carla Bittencourt and Jean-Jacques Pireaux; LISE, University of Namur, Namur, Belgium.

Polymer films with embedded metal nanoparticles are nanostructured materials of great interest due to their special structural, optical and electrical properties [1]. The possibility to tailor these properties by changing preparation parameters makes them promising materials for new applications, especially in optics and electronics. Combining metal nanoparticles in 2D or 3D arrays gives rise to materials with optical spectrum that will depend upon the nature of the metal and the matrix, the size and the shape of the particle, the interparticle distance. Moreover, the electronic structure of these materials is an important issue: as the size of metallic particles is reduced down to the nanometre range, the electronic structure will change from metallic (continuous energy bands) to free atom-like (discrete energy levels). These effects are still not well characterized and thus a good comprehension of the phenomena that occur can help in the development of applications such as nanoscale electronics. In this work we use plasma technology to create the nanostructured materials. Both gold and iron nanoparticles embedded in polymer matrix are studied. Transmission electron microscopy (TEM) measurements were performed in order to visualize the structure of the nanoparticles and X-ray photoelectron spectroscopy to analyse their electronic structure change. Gold incorporation in the polymer matrix was achieved by alternating evaporation of the metal and plasma polymerization of styrene in an inductive coupled rf (13.56 MHz) glow discharge. TEM showed changes in the shape and size of particles when varying deposition parameters (rate and time of evaporation, polymerization parameters). It was possible to control the mean diameter of the particles from 1.5nm to 5nm. At larger concentration, the gold islands begin to coalesce and form clusters with elongated-shapes. The binding energy shift and width of the Au4f line were studied by XPS with the aim to understand initial and final states effects in the photoemission process [2], that are intrinsically influenced by the size of the clusters. The iron incorporation in the polymer matrix was obtained by simultaneously plasma polymerization of styrene and of a solution of an iron-organometallic gas. Both TEM and XPS measurements were also performed on this material. 1 A. Heilmann, Polymer films with embedded metal nanoparticles, Springer series in material science vol. 52, 2002 2 D. Dalacu, J. E. Klemberg-Saphieha, L. Martinu, Surface Science, 2001, 472, 33-40

J18.8

Surface Modification and Neural Tissue Culture of Thin Film Electrode Materials. Sachin Suresh Thanawala[1], Saida P. Khan[3], Olena Palyvoda[2], Daniel G. Georgiev[2], Ibrahim A. Al-Homoudi[4], G. Newaz[4] and Gregory Auner[2,1]; [1]Biomedical Engineering, Wayne State University, Detroit, Michigan; [2]ECE, Wayne State University, Detroit, Michigan; [3]Chemical Engineering, Wayne State University, Detroit, Michigan; [4]Mechanical Engineering, Wayne State University, Detroit, Michigan.

Electrode materials and their surface topography influence the quality of neural interface. Good interfaces between electrodes and neural tissue are very important in chronic in vivo stimulation/recording. In order to study the effect of the electrode material and its surface structure on neural interfaces, we cultured neurons on thin films of biocompatible electrode materials such as platinum, and iridium oxide. We used both flat film surfaces and laser micro-structured ones. The laser micro-structuring consisted of creating regular arrays of micro-bumps with height of about $1\mu m$ and diameter of 2-3 microns. Recently, we found conditions for fabrication of such micro-bumps on platinum and iridium thin films on borosilicate glass substrate (Pyrex 7740) by mask-projection irradiation with single nano-second pulses from a KrF excimer laser (λ =248nm). To obtain micro-bump-structured films of iridium oxide, we deposited iridium oxide films on laser micro-structured iridium films using a pulsed DC reactive sputtering technique. Several types of iridium oxide films were studied including amorphous (reactively sputtered at low substrate temperature), polycrystalline (reactively sputtered at 300^oC), and electrochemically activated iridium metal films. Cortical neurons isolated from rat embryo brain were cultured onto these thin film surfaces. Cells were more than 98% viable as determined by trypan blue exclusion tests. Poly-D-Lysine coated surfaces were used as positive controls for cell growth and plastic surfaces served the purpose of negative controls. Regular optical and fluorescent microscopy techniques were used to image the cells after they were cultured. To differentiate between live and dead cells a viability test with fluorescein diacetate (FDA) and propidium iodide was carried out. Also, immunocytochemistry analysis of neuron cells was performed using antibody for neuron-specific enolase (NSE) staining. A qualitative and quantitative comparison was carried out between the different types of modified electrode surfaces to study the neuronal growth in order to explore the feasibility of micro-bumps as stimulating/recording neural interfaces. Electrical stimulation/recording experiments will be carried out on the best performing thin film electrodes by using a multi-electrode array setup.

J18.9

Atomic Force Microscopy Probe with Integrated Loop and Shielded Leads for Micromagnetic Sensing. Douglas Lagally[1], Abdolreza Karbassi[2], Charles Paulson[2] and Daniel van der Weide[2]; [1]Materials Science Program, University of Wisconsin-Madison, Madison, Wisconsin; [2]Electrical and Computer Engineering, University of Wisconsin-Madison, Madison, Wisconsin.

There is considerable interest in measuring and using electron spins, e.g. in quantum computing, magnetic resonance, and magnetic data storage. High spatial resolution is especially useful, which can be provided by the combination of magnetic-resonance imaging and atomic-force microscopy [magnetic resonance force microscopy (MRFM)]. Although sensitivity to a single spin has recently been achieved [1] there is benefit in developing probes that could be used in conventional atomic force microscopes to measure high-frequency magnetic-resonance (MR) effects. Toward this goal, we have fabricated a novel cantilever probe capable of measuring very small MR signals. The cantilevers have integrated conductive loop probes at their ends to act as sensors capable of high-spatial-resolution measurement of magnetic fields. Our new probe design is comprised of a $\sim$ 3/4 gold loop (variously with diameters of 6, 12, and 40 μm), with coplanar shielded feed lines. We fabricate our devices on (100) n-type 5000 Ω-cm single crystal silicon wafers etched 5-10 μm deep to define cantilever thickness, with the chip bodies defined by a backside deep RIE. Loops are patterned on the front side by thermal evaporation of Au to a thickness of 250 nm. Contact pads supply the shielded leads that terminate at the loop. Simulations of magnetic fields and mechanical characteristics are presented. In MRFM experiments, ferromagnetic resonance is detected by a modulation in the cantilever vibration frequency. With our probe, the sample can be placed in the center of the loop, at the maximum of its field, a feature that is important because the signal-to-noise ratio in MRFM is directly proportional to B1. We have demonstrated this experimental advantage for our sensor by sensing localized microwave resonance in yttrium iron garnet (YIG), a ferrimagnetic microwave resonator. Previous probes show spatially localized resonance detection, but are unshielded and thus susceptible to noise and induced fields in the feed lines. Our probes show higher sensitivity due to the shielding and more complete loop. The μm-level spatial resolution in magnetic detection of our probe also has important applications, such as examination of the currents in integrated circuits and magnetic thin films in recording heads. 1. D. Rugar, R. Budakian, H. J. Mamin & B. W. Chui, Single Spin Detection by Magnetic Resonance Force Microscopy, Nature 2004, Vol. 430, p. 329

J18.10

Functionalisation of Microfluidic Channels with In Situ Grown Carbon Nanotubes. Kjetil Gjerde[1], Tommy Schurmann[1], Ken B. K. Teo[2], William I. Milne[2] and Peter Boggild[1]; [1]Dept. of Micro and Nanotechnology, Technical University of Denmark, Kgs Lyngby, Denmark; [2]Dept. of Engineering, University of Cambridge, Cambridge, United Kingdom.

Modification of the surface properties in microfluidic channels may be achieved through in situ growth of multiwalled carbon nanotubes (CNT) by plasma enhanced chemical vapour deposition (PECVD). By distorting the electrical field we can control the inclination angle between the channel floor and the CNTs. Microfluidic channels with inclined nanotubes may be used as channels with anisotropic flow resistance (valves), for filters, or for separation and stretching of DNA. The growth direction of CNTs follows the direction of the electric field present in the plasma sheet. Recent works indicate that this is caused by the catalyst particle at the tip of the CNT [1,2]. Conductive substrate holders with special geometry allow us to distort the electrical field locally. By designing the substrate holder appropriately, the CNT forests can be grown inclined with respect to the surface, with an angle depending on the distance from the field-distorting feature. Finite element calculations confirm the experimental observations. We fabricated microliquid channels on Si wafers by conventional photolithography and KOH etch using SiO2 as an etch mask. Since KOH mainly etches the (100) plane, the resulting channels had flat floors with inclined sidewalls. Another lithography step was used to deposit (by evaporation) the catalyst material just inside the KOH etched channels. The CNTs were synthesised in a PECVD system at 5 mbar pressure and 650 °C with a discharge voltage of -600 V, using acetylene as carbon feed gas. A co-flow of ammonia was used to avoid formation of amorphous carbon. The elastic response of the CNTs depends strongly on the length and diameter, which can be controlled experimentally by growth time and catalyst film thickness. Ideal multiwalled CNTs have a Youngs modulus of order 1 TPa, but PECVD-grown nanotubes have more defects, and can be expected to be softer. Assuming CNTs with Youngs modulus of 0.1 TPa, diameter of 50 nm and lengths between 1 and 5 mm, the force required to deflect the nanotubes 10% of its length is of order 0.1 nN to 0.005 nN. Given a drag coefficient of 3 for the nanotube, and a viscosity of 1 mNs/m2 for water, deflecting the CNTs require fluid velocities between 50 to 0.5 mm/s. We suggest that flexible and inclined CNTs may, given certain conditions, bend down due to fluid flow in one direction and rise up for fluid flow in the opposite direction. Even moderate variation of length and diameter allows the flexibility of the CNTs to be matched to a large range of different flow conditions. Submitting author: K. Gjerde, Dept. of Micro and Nanotechnology, Technical University of Denmark, Bldg 345 east, DK 2800 Kongens Lyngby, Denmark; Tel +45 4525 5787; Fax +45 4588 7762; E-mail: kg@mic.dtu.dk References [1] Kim D-H., Cho D.-S. , Jang H-S., Kim C-D., Lee H-R., Nanotechnology 14, 1269-1271 (2003). [2] Merkulov V.I., Melechko A. V., Guillorn M.A., Lowndes D.H.,Simpson M.L., Appl. Phys. Lett. 79, 2970 (2001).

J18.11

Characterization and Processing of Vanadium Dioxide Thin Films for Advanced Optical and Electrical Switching Devices. Mohamed Soltani[1], Luc Stafford[2], Mohamed Chaker[1] and Joelle Margot[2]; [1]INRS-Energie, Materiaux et Telecommunications, Varennes, Quebec, Canada; [2]Departement de Physique, Universite de Montreal, Montreal, Quebec, Canada.

Vanadium oxide compounds (V2O3, V2O5, V6O13, etc.) present a first order phase transition, undergoing a transition from a semiconducting monoclinic phase at low temperature to a metallic tetragonal phase at higher temperature. This change is accompanied by an important modification of electrical resistivity, optical transmittance, and reflectance in the infrared region. Among these oxides, VO2 is the most interesting because its transition temperature Tt lies close to room temperature (Tt=68 deg. C). Thin films made of VO2 are thus very promising for various technological applications such as infrared uncooled bolometers, variable attenuators, optical, and holographic storage systems, fiber-optical switching devices, ultrafast switching, and smart radiator devices for spacecraft. However, the integration of VO2 thin films into specific devices requires optimizing simultaneously the semiconductor-to-metal phase transition and the patterning process. In this context, single phase VO2 layers have been deposited on quartz substrates by means of a reactive pulsed-laser-deposition technique. In this work, the potential of VO2 thin films for the fabrication of advanced optical and electrical switching devices is examined. In the first part, we investigate the optical and electrical switching properties of undoped, W-doped, and Ti-W co-doped VO2 thin films as a function of temperature using infrared transmittance and electrical resistivity measurements. Our results show that while the transmittance in the metallic state is not affected by W and Ti doping, the transmittance in the semiconductor state is significantly affected by these dopants. These results can be understood from the increase or the decrease of the carrier density whether the material is mainly acceptor-doped (Ti) or donor-doped (W). A closer analysis of the infrared transmittance and resistivity measurements also shows an hysteresis of about 5 deg. C for both undoped and W-doped VO2 films, such hysteresis being suppressed for Ti-W co-doped VO2. In the second part, the patterning characteristics of VO2 thin films are examined. Etching is performed using a magnetized high-density plasma in a pure argon atmosphere (sputter-etching). At low argon pressure (i.e., below 1 mTorr), highly anisotropic features are obtained with high etch rate and good selectivity over photoresist. As pressure increases, the redeposition rate of sputtered species is enhanced due to collisions with neutrals in the plasma sheath. This is found to significantly alter the profile verticality and thus the etching quality. Finally, our capability to control both the semiconductor-to-metal phase transition and the patterning process of VO2 thin films clearly indicates the strong potential of VO2 films for functional switching devices applications.

J18.12

Effect of Substrate Materials on the Electrical Behavior of Pd/AlN/Semiconductor Based Hydrogen Sensors.

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Pd/AlN/Semiconductor based devices were fabricated by a combination of plasma source molecular beam epitaxy (PSMBE) and magnetron sputtering techniques. Four different semiconductor substrates consisting of on- and off-axis 6H-SiC, on-axis 3C-SiC, and Si(111) were used for fabricating the devices. All of these substrates are n-type, where the net carrier concentration at room temperature was $\sim$2x10^{18} cm^{-3} for all types of SiC and $\sim$2x10^{15} cm^{-3} for Si(111). A typical device consisted of 60 nm of AlN deposited onto the semiconductor by PSMBE, then a circular 1 mm in diameter, 150 nm thick Pd dot was deposited onto the AlN by magnetron sputtering as catalytic electrode. Pt and Al film of 150 nm in thickness were deposited onto the back side of the SiC and Si based devices respectively to form the back contact. Details on the fabrication process and some experimental results from Pd/AlN/6H-SiC based devices are presented in our earlier work [1-2]. The electrical behavior of SiC based device is that of a rectifying diode [3], whereas the Si based device works as a MIS capacitor [4]. This work includes the results of a device made with free standing cubic silicon carbide (3C-SiC) wafer as a new material. The effect of AlN film thickness (on same substrate) on the electrical behavior of the device will be presented. The device on 6H-SiC shows an apparent barrier height of 1.5 eV whereas the device on 3C-SiC shows 0.8 eV in the absence of hydrogen. Result shows that the device made with thicker AlN on the same type of SiC has higher series resistance. For a forward current of 3 mA the required applied voltage is 1.6 V larger for the 90 nm thick AlN device than for the device made with 25 nm AlN layer, both on off-axis 6H-SiC. A comparison between the simulated and experimental I-V curves will also be presented. References: 1. F. Serina et al. Appl. Phys. Lett. 79, 3350-3352 (2001). 2. M.H. Rahman et al. Mat. Res. Soc. Symp.:J, Vol: 815 (2004). 3. L. Rimai et al. Mat. Res. Soc. Symp.:J, Vol: 815, (2004). 4. E.F.McCullen et al. J. Appl. Phys. Vol 93, pg 5757 (2003).

J18.13

Sonochemical and Microwave Synthesis Of ZnO Nanoparticles. Isi Umolu Abhulimen[1], Xiang-Bai Chen[2], John L. Morrison[2], Vijaya Kumar Rangari[3], Leah Bergman[2] and Kalyan Kumar Das[1]; [1]Department of Electrical Engineering, Tuskegee University, Tuskegee, Alabama; [2]Department of Physics, University of Idaho, Moscow, Idaho; [3]Center of Advanced Materials, Tuskegee University, Moscow, Alabama.

Zinc oxide, is a direct wide bandgap (3.37 eV) semiconductor with a high chemical and physical stability, is of interest for potential applications for the fabrication of high-frequency and optoelectronic devices. In this paper, we report the synthesis of ZnO nanoparticles by sonochemical and microwave techniques. Synthesized particles were characterized by photoluminescence (PL) study, scanning and transmission electron microscopy (SEM and TEM) and X-ray diffraction. A preliminary study of electrical conductivity was also performed using current - voltage (I-V) measurements employing photolithographically defined Au electrodes. For sonochemical synthesis 1g of zinc(II)acetate dihydrate was dissolved in a mixture of 12.5 mL of N,N-dimethylformamide(DMF) and 112.5 mL of deionized water. This reaction mixture was irradiated with a high-intensity ultrasonic horn (20kHz, 100 W/cm2) at room temperature for 3 hr. For microwave synthesis the reaction mixture was placed a microwave oven and allowed to boil for 22 min. The synthesized product obtained was washed with doubly distilled water and dried for 3hr. Samples for SEM examination and ultraviolet photoluminescence (PL) were prepared from a suspension of the product in absolute ethanol. Nanoparticles deposited on a Cu grid was used for TEM studies. XRD measurements were carried for the dried sample. It was observed that the diffraction peaks of the sample match that of Joint Committee for Powder Diffraction Standards, JCPDS 36-1451. Gold contact pads, photolithographically fabricated on a spin-on-oxide coated quartz substrate using a transfer length pattern mask, were used for electrical characterization of the ZnO nanoparticles. The quartz substrate with the fabricated Au TLM pattern was spin-coated (3000 rpm) with the ZnO suspension. Spin coating and drying was repeated thirty-five times. Current - voltage measurements were then performed using an HP4155A, Semiconductor Parameter Analyzer. The SEM images indicated the presence of Zno nanoparticles $\sim$160nm in diameter and also some agglomeration of particles was observed. Transmission electron microscopy, however, indicated the presence of platelets of $\sim$ 20 nm x 100 nm in dimension. The ultraviolet PL study showed a strong intensity and a significant blue shift relative to the PL of the bulk. Shifts up to 170 meV were observed and attributed to a confinement effect. From model calculations the average particle size corresponding to the observed shift was found to be $\sim$ 4 nm. Additionally the linewidth of the PL of the nanoclusters was found to be $\sim$ 154 meV which is much broader in comparison to the bulk value of $\sim$ 66 meV. The large linewidth observed for these clusters will be discussed in terms of the size distribution and impurity broadening. The I-V measurements indicated a highly resistive nature of the nanoparticles. It was speculated that carrier transport was obtained through chains of nanoparticles bridging the gap separating the electrodes.

J18.14

Focused Ion Beam Characterization of Materials with Varying Crystallinity. Jennifer Y. Lee[1], Jessica E. Bickel[1], Joanna Mirecki Millunchick[1], John F. Mansfield[2], Bongsup Shim[3], Nicholas A. Kotov[3], Tesfu Solomon[3], Michael J. Solomon[3] and Joerg Lahann[3,1]; [1]Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan; [2]Electon Microbeam Analysis Laboratory, University of Michigan, Ann Arbor, Michigan; [3]Chemical Engineering, University of Michigan, Ann Arbor, Michigan.

One approach to the formation of nanostructures is by fabricating them using a direct writing method. Focused Ion Beam (FIB) etching, with ion beam diameters on the order of 10 nm, is a promising technique for nanofabrication. In this work, ion beam-material interactions have been characterized for various materials, including single crystal Si and GaAs, polycrystalline Au, semicrystalline poly-p-xylylene, and amorphous glass. For all materials, arrays of square holes were etched using a 1 or 10 pA 30keV Ga ion beam as a function of dwell time per feature. The depth of the features initially scales with dwell time. However, as the etching time increases, the apparent depth of the features etching in the crystalline and polycrystalline material decreases due to redeposition of the sputtered material. In addition, excess material is deposited around the feature, resulting in a lip around the hole. In the case of the single crystal material only, the redeposited material occupies the lowest energy close-packed planes, thus altering the geometry of the features. Only in semicrystalline poly-p-xylylene and amorphous glass does the redeposition not occur in the same manner. We have used FIB patterning to direct the self assembly of compound semiconductor quantum dots and the sedimentation of colloidal crystals. Furthermore, this technique can be used to pattern a single-walled carbon nanotube-polymer composite in order to confine the attachment and growth of neuronal cells in selected areas.

J18.15

Low Dose Ionizing Radiation Detection using Luminescent Polymers. Rodrigo Fernando Bianchi[1,2], J. Borin[3], E. A. B. Silva[3], P. Nicolutti[3], T. Guilhardi Neto[3] and C. F. O. Graeff[3]; [1]Departmento de Fisica e Ciencia dos Materiais, Universidade de Sao Paulo, Sao Carlos, Sao Paulo, Brazil; [2]Departamento de Sistemas Eletronicos, Escola Politecnica da Universidade de Sao Paulo, Sao Paulo, Sao Paulo, Brazil; [3]Departamento de Fisica e Matermatica, Universidade de Sao Paulo, Ribeirao Preto, Sao Paulo, Brazil.

In this work we present a novel application of luminescent polymers as active material for dosimeters. The effect of gamma radiation on the optical properties of MEH-PPV, or the poly[2-methoxy-5-(2-ethylhexoxy)-p-phenylenevinylene] is studied. The samples were irradiated at room temperature with different doses from 0 Gy to 152 Gy using a 60 Co gamma ray source. For thin films significant changes in the UV-Visible spectra were only observed at high doses (> 1 kGy). However, in solution, shifts in absorption peaks are observed at low doses (< 10 Gy), linearly dependent on dose. The shifts are explained by conjugation reduction due to photo-oxidation processes. Our results indicate that MEHPPV solution can be used as a dosimeter adequate for medical applications. This work was sponsored by Fapesp and MCT/IMMP from Brazil.

J18.16

Synthesis, Cathodoluminescence and Photoluminescence of ZnO Nanowires. Aurangzeb Khan[1,2] and Martin E. Kordesch[1,2]; [1]Physics and Astronomy, Ohio University, Athens, Ohio; [2]CMSS, Ohio University, Athens, Ohio.

Single crystal ZnO nanowires, nanorods and nanoflakes of size 5-200 nm in diameter are grown by thermal evaporation method in tube furnace having a mixture of ZnO powder and graphite mixture with controlled temperature and gas flow of Argon over Si(100) and Al2O3 with out any metal on its surface. Molybdenum grids were also used for as a substrate in order to use it in TEM. The furnace tube temperature is ramped between 1000-1150 degree C and substrate temperature 400-500 degree C. Photoluminescence of the nanowires reveals that a blue shift occurred in the emission spectrum of ultra small nanowires compared to the bulk ZnO nanowires having diameter of ∼200 nm.

J18.17

Design and Fabrication of Novel Nanotube Electrophysiological Probes. Ludovico M. Dell'Acqua-Bellavitis, Jake D. Ballard, Rena Bizios and Richard W. Siegel; Nanotechnology Center, Rensselaer Polytechnic Institute, Troy, New York.

A device with nanometric resolution in space and millisecond resolution in time, intended for neural electrophysiological imaging and prosthetic applications, was designed, fabricated and tested in vitro. An array of equi-spaced multiple gold electrodes was deposited on an insulating silicon dioxide substrate by means of lift-off lithography followed by subsequent chemical vapour deposition (CVD), oxidation, and CVD nitridation. A second lithography step followed by plasma etching on selected portions of the substrate, was used to expose the tips of the electrodes to designated electric signal recording loci. This process assured electrical insulation of the channels leading to the electrodes. In addition, a composite consisting of multi-walled, carbon nanotubes was designed with conductivity in the range 200-500 [Ω-m]-1 (1,2,3) and was positioned in intimate contact with the multiple electrode array. The nanotubes were grown on silicon dioxide substrates using a different CVD method (4) and, subsequently, infiltrated with in situ polymerized polymethylmethacrylate to achieve electrical insulation between adjacent nanotube bundles. During this process, methyl metacrylate monomers were reacted with azobisisobutyronitrile and decane thiol to achieve in situ polymerization according to published techniques (5). This novel device can be deployed as an interface between mammalian cells and underlying integrated circuits during electrophysiological in vitro studies. Acknowledgement This work was supported by Philip Morris USA and the Nanoscale Science and Engineering Initiative of the National Science Foundation under NSF Award No. DMR-0117702. References 1. A. Cao, G. Meng, P.M. Ajayan (2004) Nanobelt-Templated Growth of Carbon Nanotube Rows. Adv. Mater. 16, 40-44. 2. A. Thess, R. Lee, P. Nikolaev, H. Dai, P. Petit, J. Robert, C. Xu, Y.H. Lee, S.G. Kim, A.G. Rinzler, D.T. Colbert, G. Scuseria, D. Tomanek, J.E. Fischer, R.E. Smalley (1996) Crystalline Ropes of Metallic Carbon Nanotubes. Science 273, 483-487. 3. H. Dai, E.W. Wong, C.M. Lieber (1996) Probing Electrical Transport in Nanomaterials: Conductivity of Individual Carbon Nanotubes. Science 272, 523-527. 4. L.M. Dell Acqua-Bellavitis, J.D. Ballard, P.M. Ajayan, R.W. Siegel (2004) Kinetics for the Synthesis Reaction of Aligned Carbon Nanotubes. A Study Based on In Situ Diffractography, Nano Letters 4, 1613-1620. 5. N.R. Raravikar (2004) Novel approaches towards the development of architectures based on carbon nanotube and polymers. Ph.D. Thesis Rensselaer Polytechnic Institute, Troy, New York - USA.

J18.18

Anomalous Temperature Dependence of Fermi-Edge Singularity in Photoluminescence Spectra of Modulation-Doped AlGaAs/InGaAs/GaAs Heterostructures. K. Gopalakrishna Naik[1], K. S. R. Koteswara Rao[1], T. Srinivasan[2], R. Muralidharan[2] and S. K. Mehta[2]; [1]Indian Institute of Science, Bangalore, India; [2]Solid State Physics Laboratory, Delhi, Delhi, India.

The temperature and power dependence of Fermi-edge singularity in high-density two-dimensional electron gas, specific to pseudomorphic AlxGa1-xAs/InyGa1-yAs/GaAs heterostructures is studied by photoluminescence (PL). In all these structures, there are two prominent transitions E_11 and E_21 considered to be the result of electron-hole recombination from first and second electron sub-bands with that of first heavy-hole sub-band. Along with these transitions week LO-phonon replica is also observed. The major contribution of this work is observation of Fermi-edge singularity (FES) and its behavior with excitation power and temperature. In all the samples, which were divided into two sets, FES is observed approximately 5 -10 meV below the E_21 transition. At 4.2 K, FES appears as a lower energy shoulder to the E_21 transition. The PL intensity of all the three transitions E_11, FES and E_21 grows linearly even with two orders of change in excitation power. However, we observe anomalous behavior of FES with temperature. While PL intensity of E_11 and E_21 decreases with temperature, the FES initially grows, later decreases in intensity as the temperature is increased and disappears around 40K. Though it appears as a distinct peak at about 20 K, it has a maximum around 7 K in one set of samples and at 13 K in another set of samples. In this presentation, we will show experimental observations related to the above parameters and the plausible explanation.

J18.19

Separate Control of InAs Quantum Dot Density and Uniformity on GaAs (001). Zuoming Zhao and Ya-Hong Xie; Materials Science and Engineering, UCLA, Los Angeles, California.

InAs quantum dots were grown on GaAs (001) substrates via molecular beam epitaxy. Quantum dot density and uniformity are controlled separately by two-step growth. In this method, the wetting layer and nucleation are finished at low temperature to get the high density. Dot growth is finished at high temperature to achieve high uniformity. Atomic force microscopy shows both the increase of quantum dot density and the improvement of quantum dot uniformity. The dot density of 7×10^{10} cm^{-2} was achieved with first growth of wetting-layer at 400 ^{o}C and then finishing dot growth at 530^{o}C. Optical properties were characterized by low-temperature photoluminescence (PL). Improvement of PL confirms improvement of dot structure.

J18.20

A Combined Vapor and Electrochemical Deposition Approach to the Controlled Growth of Nanoscale Metal Dendritic Islands, Beaded Wires, and Continuous Wires. Cobey Cross, John C. Hemminger and Reginald M. Penner; Chemistry, University of California Irvine, Irvine, California.

Under conditions of careful control of the experimental parameters of substrate temperature and metal atom flux, conventional vapor deposition can be used to grow a variety of useful metal nanostructures. We use this approach to grow dendritic islands as well as beaded nanowires of gold on graphite substrates. Combining this approach with electrochemical deposition allows us to convert beaded nanowires into continuous nanowires (diameters as small as 20nm) that are many microns in length. Low flux vapor deposition of sub-monolayer amounts of gold on a graphite substrate that is held at or near room temperature generates dendritic islands of gold. The islands are fairly monodispersed in lateral dimensions (∼100nm across). If the graphite substrate is held at higher temperature (≥300°C) "beaded wires" can be grown by decorating the graphite steps. The "beaded wires" are composed of gold "dots" that are 10-20nm diameter. Once again the "beaded wires" consist of gold dots that are highly monodispersed. The "beaded wires" provide excellent nuclei for electrochemical growth of very narrow, long, continuous wires of gold on graphite, where the wires are several microns in length. Each of these classes of structures have potentially interesting uses. The dendritic islands of gold are of interest in studies of the catalytic properties of gold nanostructures. The theoretically expected one dimensional electronic structure and optical properties of linear chains of gold dots that are tens of nanometers in diameter spaced by 10nm are of interest and the long nanometer scale continuous wires of gold are under development for sensor applications.

J18.21

Composite Contacts in Microsystems: Fabrication of Metal-Nanostructured Titania Nanocomposites. Zuruzi Abu Samah[1], Marcus S. Ward[1], Ding Chang Song[2] and Noel C. MacDonald[1,2]; [1]Materials Department, University of California, Santa Barbara, California; [2]Mechanical and Environmental Engineering, University of California, Santa Barbara, California.

Micro-Electro-Mechanical Systems (MEMS) switches possess the advantages of both solid-state devices such as being highly miniaturized, light-weight, consume relatively low power, and have short time response as well as those of conventional electromechanical relays, such as low leakage currents. More importantly, since fabrication of MEMS switches utilizes the Si-based CMOS infrastructure already in place, MEMS switches can be integrated into devices and manufactured in large volume thus reducing costs. However, one critical issue associated with MEMS switches is the degradation of contacts due to wear. Ceramic reinforced metal matrix composites (CRMMC) have superior wear properties relative to its metal component alone. Hence it is desirable that CRMMC which are wear resistant and possessing high conductivity be integrated into MEMS switches as contact materials. We have recently developed a technique to form nanostructured titania (NST) into MEMS devices[1]. Here, we demonstrate the integration of patterned metal-NST nanocomposites as contacts in MEMS switches using NST as the ceramic reinforcement. As a first step towards implementing metal-NST nanocomposites contacts, we report a simple route for its integration into MEMS devices. These nanocomposites were developed using a simple process that is compatible with current CMOS process tool and material sets. The process involves formation of patterns of sponge-like NST matrix which is subsequently infiltrated with metal. In this contribution, we shall present results of NST infiltrated with gold. Since gold is detrimental to CMOS device characteristics, its deposition must be selective and occurs only on/in the NST matrices. In the process developed, metal infiltration occurs by an electroless method and hence highly selective deposition of gold was achieved. Selective deposition is confirmed by results obtained using area X-ray Photoelectron Spectroscopy (XPS) as well as X-ray diffraction (XRD). In addition to the above techniques, we have characterized the Metal-NST nanocomposites using Focus Ion Beam machining and high resolution SEM. Finally, we shall demonstrate the formation and integration of NST-metal nanocomposite contacts in a MEMS switch. [1] A. S. Zuruzi and N. C. MacDonald,"Facile Fabrication and Integration of Patterned Nanostructured Titania into Microsystems", Accepted for publication in Advanced Functional Materials.

J18.22

Nanoindentation Mechanical Property Measurements of ZnS Nanobelts. Xiaodong Li[1], Xinnan Wang[1], Qihua Xiong[2] and Peter C. Eklund[2]; [1]Department of Mechanical Engineering, University of South Carolina, Columbia, South Carolina; [2]Department of Physics, The Pennsylvania State University, University Park, Pennsylvania.

ZnS nanobelts are basic building blocks for constructing micro-and nanosystems. The recently developed nanoindenter has the capability of measuring surface morphology at the nanoscale by scanning the sample surface with the same indenter tip, which is analogous to AFM contact mode. Recently, we successfully made nanoindentations directly on individual ZnS nanobelts using the nanoindenter. We used a pyramidal Berkovich nanoindenter tip both to image the ZnS nanobelts of interest and to indent them in-situ. The hardness and elastic modulus were obtained from the nanoindentation load-displacement curves. Posttest in-situ imaging of the indentation impressions together with the load-displacement curves offers a unique opportunity for studying indentation deformation behavior. We also broke individual ZnS nanobelts to assess their fracture toughness. Our preliminary results showed that it is possible to mechanically interrogate the ZnS nanobelts with the nanoindenter.

J18.23

Hydrogen-Mediated Ferromagnetism in ZnCoO. Se-Young Jeong[1,3], Chae-Ryong Cho[2], Chul Hong Park[4] and Hyun-Jun Lee[3]; [1]School of Nanoscience and Technology, Pusan National University, Busan, South Korea; [2]Korea Basic Science Institute, Busan, South Korea; [3]Advanced Materials Research Laboratory, COMTECS Limited, Daegu, South Korea; [4]Research Center for Dielectric and Advanced Matter Physics, Pusan National University, Busan, South Korea.

There is currently great interest in the physical properties of diluted magnetic semiconductors (DMSs) because of their potential use in spintronic devices where both electronic charge and spin degrees of freedom can be exploited. Although many kinds of DMS exhibiting high-temperature ferromagnetism have been identified, the microscopic origin of their magnetic properties is still quite controversial in II-VI as well as III-V-based materials. Generally, ferromagnetism in diluted magnetic systems has been explained by invoking carrier effects and a double exchange interaction. Recently a new mechanism was theoretically proposed for the ferromagnetism in ZnCoO induced by hydrogen[1]. Here, we show that ZnCoO samples have a tendency to become seriously contaminated by hydrogen and that a significantly enhanced ferromagnetism is possible through enrichment of the hydrogen content by exposure to hydrogen gas[2]. We assumed that the hydrogen contamination effect is cause of controversial results experimental reported and experimentally confirmed having reliable results that a strong ferromagnetic spin-spin interaction between Co atoms in a Co-dimer is induced by hydrogen. In this study, we also verified the ferromagnetism originated from intrinsic properties of diluted magnetic semiconductor using a magnetic circular dichrosim. We discussed the relationship between the ferromagnetism and hydrogen contamination in ZnCoO system. [1] C. H. Park et al. Phys. Rev. Lett. (submitted). [2] H. J. Lee et al. Nature materials (submitted).

J18.24

Thermally Stimulated Electron Emission Phenomena from Scratched Metal Surfaces. Keiji Nakayama and Hitoshi Matamura; AIST, Tsukuba, Japan.

Various physical and chemical phenomena have been observed at and near the sliding contact. Typical physical phenomena are the emission of electrons ions and photons from wearing solid surfaces. In insulators and semiconductors, triboplasma is generated by intense electric fields due to tribocharging. Electrons, positive ions and photons produced in the plasma are observed as triboemission particles. Nakayama et al recently discovered the tribomicroplasma [1]. The triboplasma causes tribochemical reactions. On the other hands, for metals, electrons are emitted spontaneously at room temperature by a chemical interaction of the worn fresh surface with the surrounding chemical species. This phenomenon is called chemi-emission of electrons [2]. It has also been reported that thermally stimulated electron emission (TSEE) occurs at much lower temperature than that for thermal electron emission. This suggests that TSEE occurs at and near the sliding contact in addition to the triboemission and chemi-emission by frictional temperature rise. The purpose of the present study is to investigate the TSEE characteristics from scratched metal surfaces. An apparatus to measure TSEE intensity in vacuum was constructed. Using the apparatus, TSEE characteristics were investigated for scratched surface of fourteen kinds of metals of Al, Ti, V, Cr, Fe, Co, Ni, Cu, Mo, W, Pd, Pt, Ag and Au. Their surfaces were scratched by a diamond stylus in an ambient room air atmosphere and set in the vacuum chamber. Then the metal surface was thermally stimulated in a constant heating rate ranged from 1.3 to 4.4 °C/s in a residual gas pressure of 10^{-4} Pa. During the heating, a channeling type secondary electron multiplier detected electrons emitted from the scratched metal surface and I-T curves were obtained, where I is electron emission intensity and T is sample temperature. For all the metals, I-T curve showed that electrons are emitted at temperatures from several tens to hundreds degree C. TSEE disappeared in the second and further heating cycle of the same metal specimen for almost all metals except Cu and Ag. The integrated electron emission intensities for some temperature range depended on metal species. The emission mechanism is discussed from the point of view of chemical process of adsorbed molecules, structure change and the defects in the metals. Acknowledgement This work was supported by Grant-in-Aid through Ministry of Education, Culture, Sports, Science, and Technology.

J18.25

Correlating Thermoelectric Efficiency with Nanowire Diameter for Electrodeposited Bismuth Telluride Nanowire Arrays. Erik Menke and Reg Penner; Chemistry, University of California, Irvine, Irvine, California.

Physicists have predicted that the thermoelectric figure-of-merit (ZT) for a given material will increase as the material dimension is reduced from 3 to 2 to 1. However, there have been few experimental tests of these predictions because of the difficulties associated with synthesizing the nanowires and in making high quality measurements of ZT. We have devised a method for preparing arrays of very long n- and p-type Bi2Te3 nanowires with diameters ranging from 80 to 250 nm. These nanowires are prepared using electrochemical step edge decoration on graphite and then transferred to the surface of an electrical and thermal insulator. High quality measurements of ZT are possible on these transferred nanowire arrays, and the results of these measurements will be reported in this presentation.

J18.26

Fabrication Methods for Improved Electromechanical Behavior in Micromachined Piezoelectric Membranes. Michelle C. Robinson, Phillip D. Hayenga, Jeong H. Cho, Cecilia D. Richards, Robert F. Richards and David F. Bahr; Materials and Mechanical Engineering, Washington State University, Pullman, Washington.

Piezoelectric materials convert mechanical to electrical energy under stretching and bending conditions. Optimizing the coupling conversion is imperative to the electromechanical behavior of micromachined membrane performance. This paper discusses an analytical model devised to determine the microscale structure that minimizes residual stress and outlines the implementation of fabrication technique variations including three different electrode configurations, trenching around the membrane, and reducing the total composite residual stress of the support structure using compressive silicon oxide. Lead zirconacte titanate (PZT) films between 1 and 3 micron thick with a ratio of Zr to Ti of 40:60 were deposited upon 3 and 4 mm silicon membranes. The total tensile strain energy in the composite structure increases as PZT thickness increases which increases the effective tensile stress with PZT thickness. Effective tensile stresses of 100 MPa are formed for 2 micron thick PZT films on 2 micron thick Si membranes. The support structure consists of both tensile and compressive layers, and thus utilizing the analytical model a structure was determined that minimized the residual stress of the composite and increased the electromechanical coupling 35 times when the effective stress was lowered to 11 MPa. The boundary conditions of the membrane were also found to influence the electromechanical behavior. Changing the geometry of the electrode coverage increased the compliance of the structure by 25%. A simply supported structure releases some of the residual stress as opposed to a strictly clamped structure. Trenching around the membrane released the membrane from the blanket layers of structure which decreased the residual stress further and thus increased the compliance by approximately 10%. A comparison of the electromechanical behavior for each of these structures will be discussed, showing a route towards increasing electromechanical coupling in PZT MEMS.

J18.27

Electron Tunneling at Nano-Cross-Bar Junctions. Nicholas Prokopuk[1] and Kyung-ah Son[2]; [1]Chemistry and Materials Division, Naval Air Warfare Center, China Lake, California; [2]Jet Propulsion Laboratory, Pasadena, California.

Electron tunneling between nano-spaced electrodes is highly sensitive to the intervening medium. Slight changes in the chemical composition and structure of the channel can lead to significant changes in current flow. This current-media dependence can provide a transduction mechanism for identifying chemical analytes. To generate nano-spaced electrodes, cross-bar junctions comprised of 20-200 nm wide gold wires in parallel arrays were fabricated using a top-down nanofabrication approach. The vertical separation between overlapping arrays is determined by a semiconducting germanium layer. The thickness of this germanium layer can be precisely controlled to provide a specific separation of 1-5 nm between the overlapping wires. Subsequent selective removal of the germanium with a hydrogen peroxide etch results in a gold wire cross-bar framework. Dissolution of this germanium layer can be monitored by the changes in the electrical properties of the junctions. Electron-tunneling measurements of the nano-junctions were measured with various organic solvents between the wire arrays.

J18.28

Quantum Sizing of Power Electronics: A Trend Towards Miniaturization of Power Electronic Systems and Equipments. Arindam Chakraborty and Ali Emadi; ECE, Illinois Institute of Technology, Chicago, Illinois.

Human ability to manipulate atoms and molecules on quantum basis has generated a new dimension of physical structures for molecular scale transistors and devices. We will discuss about nanodimensional single electron transistor. This molecular device works as a switching element by controlling the electron tunneling for amplifying the current. The basic structure consists of two tunnel junctions isolated by a common insulator of nanodimensional length. One broader aspect of nano power electronics is that, it has got significant role in nanodimensional device regime as tunneling diodes. They have got inherently fast tunneling rate, which makes them highly suitable for high-speed operation. A special type of tunneling diode is an interband tunneling diode (ITD), which is actually, a p-n diode. . The V-I characteristics of such diodes are dependent upon the tunneling barrier and tunneling process itself. Another special feature of these diodes is their negative-differential-resistance characteristics. This special characteristic of such diodes makes them very useful in switching digital circuits. A special point of notice now in the area of nano power electronics, are the researches on Coulomb blockade circuits based on background charge fluctuations. For making large scale-integration of devices, electrostatic interactions among devices must be overcome, which makes the error tolerance for the Coulomb blockade devices possible. Among the tunneling devices, one very important device is resonant-tunneling device (RTD), which is actually categorized as the premier quantum transport devices. The fabrication technology of such device is scaled upon the level of power consumption, for which minimum current density at low level of voltage is made. Some of the significant uses of such devices are in Giga-Bit/s optoelectronic-switching devices, logic-switching circuits operating at few GHz switching frequencies. There have enough research been made in the area of field effect transistors, especially, MOSFETS at micro and nano dimensions for the fabrication of many high speed switching devices. A very good example of such a FET device may be a double gate MOSFET, which is a great adventure in the area of silicon transistors. Among nanodevices, actuators are very useful for conversion of energy from one form to another. The working principles of such nanodevices are based on the charging principle of carbon nanotubes. The electron-beam lithography can be used; to fabricate nanoscale silicon based power electronic structures of dimension less than 10nm.With technological advancement, as is happening day by day towards miniaturization, many more NEMS and MEMS devices will be developed.

J18.29

In Search of Metallic Nanowires on Si(001). Inder P. Batra and Bikash C. Gupta; Department of Physics, University of Illinois at Chicago, Chicago, Illinois.

The study of metals on semiconductors dates back to the nineteenth century and has seen a vigorous recent revival due to tremendous interest in Nanotechnology. The scanning tunneling microscopy has enabled us to manipulate atoms, place them at will on different surface sites to create exotic artificial atomic scale structures with novel electronic properties [1]. The placement of metal atoms such as Al, Ga and In on Si (001) may lead to the formation of low-dimensional structures, exhibiting significant new electronic and transport properties. Atomic scale structures themselves have technological applications in developing atomic scale devices [2]. In particular, realization of one-dimensional metallic nanowire is of great importance as it may be used as a metallic interconnect in nano-devices. Free standing nanowires have been studied for a large variety of atoms, e.g., K, Al, Cu, Ni, Au and Si [3-4]. In general, free standing nanowires tend to be metallic but these nanowires in practice are to be supported. Silicon is the most widely used substrate for practical applications and the low index surfaces; Si (001) is the surface of choice. With the downward spiral toward nano devices, it is desirable to investigate the electronic properties at the lowest possible coverages. It is in this context that the study of metals like Al, Ga and In at submonolayer coverages on Si (001) take on the added importance. The interaction of metal nanowires with substrate can significantly alter the electronic properties, and not always in the desired direction [5-6]. Electronic structure calculations for the placement of metals like Al, Ga and In are performed for a patterned dihydrogenated Si (001)1x1 in search of nanowires with metallic properties. The di-hydrogeneted Si (001) is patterned by depassivating only one row of Si atoms along the [1 -1 0] direction. Various structures of adsorbed metals and their electronic properties are studied. It is found that Al and Ga nanowire structures with metallic property are rather unstable while the metallic In nanowire shows some promise. It is suggested that metallic In nanowire may be realized at room temperature. The reason behind the lack of stability of metallic nanowires is the struggle against Peierls gap opening transition. References: 1. Advances in Scanning Probe Microscopy, Eds. T. Sakurai and Y. Watanabe (Springer-Verlag, Berlin, 1989). 2. Y. Wada et. al., J. Appl. Phys. 74, 7321 (1993). 3. P. Sen, S. Ciraci, A. Budlum and I. P. Batra, Phys. Rev. B 64, 195420 (2001). 4. I. P. Batra et. al., Technical Proceedings of 2003 Nanotechnology Conference and Trade Show, San Francisco, USA, 2, 206 (2003) and references therein. 5. I. P. Batra, Phys. Rev. Lett. 63 1704 (1989). 6. Bikash C. Gupta and I. P. Batra, Phys. Rev. B 69, 165332 (2004).

J18.30

Space Charge Limited Current in Porous Silicon with Traces of Nitrogen Dioxide. Stefano Borini, Andrea M. Rossi, Luca Boarino and Giampiero Amato; Nanotechnology and Microsystems, IEN Galileo Ferraris, Torino, Italy.

Apart from the obvious sensor application, the discovery of the steep increase of electrical conductivity in Porous Silicon (PS) samples in contact with traces of Nitrogen Dioxide, NO2, opens the possibility of studying the electrical conduction processes in such a system from a completely new point of view. The system undergoes a change of conductivity of 5 orders of magnitude when exposed to few ppm of NO2, whereas the free charge concentration increases by only one order of magnitude in the same concentration range. The increase of carrier mobility inside the nanowires can be considered as a possible effect occurring thanks to the interaction with NO2. This implies that some trap states are passivated by NO2. The motivation of the present work is then clear. By means of the Space Charge Limited Current technique is possible to study the evolution of defects and trap states consequent to the interaction with NO2. The results clearly indicate that the edges for the Trap Filled Limit shift to higher voltages when NO2 is present. As a consequence, the ohmic region is more extended. From the theory of carrier injection in insulators it is then possible to infer that the charging status of shallow states in PS is modified by the interaction with NO2 molecules. The dramatic reduction of the charging status of shallow defects is then the dominant mechanism at the basis of the observed conductivity variation, more efficient that the simple free charge generation. Other "exotic" effects like the apparent conductivity reduction in thin PS samples exposed to traces of NO2 can be also explained in this framework.In spite of the several intriguing effects and of the topological disorder of the system, the present work shows that the well-known theory of carrier injection in insulators helps us to shade light on the spectacular conductivity effects arising from NO2 interaction.

J18.31

Novel Approach to Fabrication of Atomic-Scale Free-Standing Circular INP Membranes for MEMS Applications.

Oleksa Hulko[1], Brad J. Robinson[1] and Rafael N. Kleiman[1,2]; [1]Centre for Electrophotonic Materials and Devices (CEMD), McMaster University, Hamilton, Ontario, Canada; [2]Department of Engineering Physics, McMaster University, Hamilton, Ontario, Canada.

Free standing diaphragms are an integral part of the vast array of modern micromechanical devices, and their properties and manufacturing methods attract significant attention. One particular area of interest is the fabrication of ultra-thin membrane structures, due to the anticipated increase in sensitivity of the membrane for sensor applications with decreasing membrane thickness. Applications of devices with incorporated membranes include gas pressure or mass loading sensors. Surface and bulk micromachining techniques are often employed to build such structures. Traditionally Silicon is the most common platform for fabrication of MEMS devices and typical processing workflows involve chemical vapor deposition (CVD) of a sacrificial SiO_2 layer followed by a polysilicon layer. An obvious limitation of this technique is the inherent high residual stress in deposited polysilicon films due to high deposition temperatures required in the CVD process. When films are released they often buckle and deform to relieve the stress, causing detrimental effects for the application of such devices. Similarly silicon-on-insulator (SOI) as a technique for ultra-thin membrane fabrication is limited by the minimum thicknesses of Si and SiO_2 layers that can be achieved and their uniformity. Moreover neither SOI nor any other Si based front side fabrication methods are capable of producing fully enclosed membranes and require vias for structure release by wet etching. Wafer bonding and back side etching techniques add another layer of complexity and cost. III-V semiconductors are a viable alternate material system, with superior processing characteristics in many respects. Extreme selectivity to wet chemical etching of various III-V compounds along with precisely controllable high quality heteroepitaxial layers grown by molecular beam epitaxy (MBE) allows far greater flexibility in fabrication of free-standing diaphragm structures than is ever attainable in Si based devices. Yet, surprisingly very few InP-based devices have been reported in the literature. We have developed a novel technique for fabrication of InP free standing circular membrane structures that are just 30 atomic rows thick and 1 to 10 μm in diameter utilizing exclusively front side processing. These are the thinnest (150$\AA$) and among the lightest ($1.27 \mathrm{x} 10^{-16}$ kg) semiconductor membranes manufactured to date. The lateral dimensions of our membranes can readily be further reduced by incorporating e-beam lithography into our process workflow. The combination of light weight and the relatively large surface area of these membrane devices offers the unique advantage of straightforward instrumentation for detection of the small changes in dynamic mechanical properties caused by a sub monolayer coverage of the adsorbate species. We anticipate the fundamental limiting thickness of these devices to be comparable of that of the etch stop layers used in III-V materials, or approximately 50$\AA$.

J18.32

Functional Carbon Nanotube Substrates for Tissue Engineering Applications. Cengiz Sinan Ozkan and Xuan Zhang; Mechanical Engineering, University of California at Riverside, Riverside, California.

A combination of microlithography and chemical vapor deposition is used to engineer patterned vertical multiwalled carbon nanotube substrates. They are used to demonstrate the formation of directed neuronal networks. Multiple substrate geometries and nanotube heights were fabricated to determine the most suitable combination for understanding the cell morphological changes. The interaction between the cell membrane and the nanotube substrate are visually characterized. The viability of the networks on the nanoscale substrates was observed.

J18.33

Low Voltage Electrowetting on Dielectric (EWOD) for Microfluidic Optics Applications. Raj K. Dash, Amir H. Hirsa and Theodorian Borca-Tasciuc; Department of Mechanical, Aerospace, and Nuclear Engineering, Rensselaer Polytechnic Institute, Troy, New York.

Electrowetting on dielectric (EWOD) has recently been implemented in MEMS applications for micro-pumps, liquid transportation, and biomedical devices. This principle has also been used for millimeter scale fluidic lenses although large voltages are necessary for actuation. In this work, we study the implementation of EWOD to micron-scale fluidic optics using MEMS based technology. We investigate the scaling issues associated with two liquid systems (i.e one liquid droplet is immersed in another liquid) and test different polar and non-polar liquid systems. In the current study, the liquid forming the micro-optics is injected through an orifice in the substrate into the second liquid pool. The orifice serves to stabilize the contact line allowing evaluation of wide range of liquid-liquid systems with varies interfacial tension. A change in contact angle and curvature of the micro-droplet is observed when voltage is applied between the liquid pool and an electrode underneath a dielectric layer deposited on top of the substrate. The minimization of the actuation voltage is obtained by optimizing the dielectric layer thickness and materials properties of the dielectric layer.

J18.34

Influence of Growth Parameters and Annealing on the Properties of MBE Grown GaAsSbN SQW. Liangjin Wu, Shanthi Iyer, Kalyan Nunna, Sudhakar Bharatan, Jia Li and Ward J. Collis; Electrical Engineering, North Carolina A&T State University, Greensboro, North Carolina.

GaAsSbN/GaAs single quantum well (SQW) growth and their properties are investigated. These heterostructures were grown on undoped GaAs substrates in an elemental solid source molecular beam epitaxy (MBE) system assisted with a RF plasma nitrogen source. A systematic study has been carried out to determine the influence of various growth conditions such as the source shutter opening sequence, substrate temperature and various nitrogen pressures based on the quality of the layers and optical properties of the structures. GaAsSb/GaAs and GaAsN/GaAs reference QWs were also grown and characterized. The substrate temperature in the range of 450-470°C is found to be optimal. Opening the source shutters simultaneously resulted in sharper QW/barrier layer interface and more incorporation of N. Sb incorporation into the QW layer is strongly influenced by substrate temperature, while source shutter opening sequence also plays a role in N incorporation. The dilute nitrogen was introduced in a range of nitrogen flux (1e-7 to 9e-7 torr) and various characterizations are performed with respect to the nitrogen concentration dependence. The optimum range of N flux based on low PL energy and FWHM was found to be 2e-7 to 7e-7 torr. The Sb composition in the layers was 28-30%. Low 4K PL peak energy of 0.78eV with low FWHM of 28meV was achieved on SQWs for a N concentration of 1.4%. The presence of pendullosung and high frequency fringes due to the cap layer for the entire composition range of N varying up to 2.3% in high-resolution x-ray diffraction (HRXRD) spectra attest to the excellent structural quality of the grown layers and interfaces. For these QWs GaAlAs layers were used as the barrier. The effects of ex-situ in nitrogen ambient and in-situ annealing under As overpressure on the optical properties of the layers have also been investigated. A significant increase in photoluminescence (PL) intensity with reduced FWHM, in conjunction with blue shift in emission energy were observed on annealing the GaAsSbN/GaAs SQWs. In-situ annealing provided better results. Further, the PL line shapes were symmetric and the temperature dependence of PL indicated significant decrease in exciton localization energy as exhibited by less pronounced s-shaped curve, on in-situ annealed samples.

J18.35

Current Voltage Characteristics of an Aluminium Gallium Nitride / Gallium Nitride Polarization Barrier. Choudhury Jayant Praharaj, Jeonghyun Hwang and Lester Eastman; Electrical Engineering, Cornell University, Ithaca, New York.

Spontaneous and piezoelectric polarization in group III nitride semiconductors give rise to large sheet charge densities at heterointerfaces. These charges can be used to achieve desired device characteristics by engineering the band profile. A polarization barrier consisting of a 50 angstroms thick undoped Aluminium Gallium Nitride layer between two undoped Gallium Nitride layers was fabricated using Molecular Beam Epitaxial growth and standard lithographic techniques. The undoped layer thicknesses are 300 nanometers and 20 nanometers. Highly doped n-type Gallium Nitride layers are used as terminating layers and for making ohmic contacts. Equal and opposite charges at the two interfaces of the barrier layer result in a voltage drop of about 1.5 volts across it. This facilitates tunneling of electrons with high enough energy due to a large electric field of 3.2 MV per cm over a triangular barrier width of 18 angstroms. The current voltage characteristics of the barrier show rectifying behavior due to the large leverage ratio for barrier lowering in the forward and reverse directions. The device turns on at around 1 volt of forward bias and the forward current is limited by space-charge limited current flow at large forward bias. The device undergoes impact ionization breakdown just above 25 volts of reverse bias. The ideality factors of these barriers are around 2 or higher due to dislocation conduction paths associated with dislocations in these materials.. This barrier can be placed in the channel layer of an Aluminium Gallium Nitride/ Gallium Nitride High Electron Mobility Transistor to block current flow paths far away from the interface between the barrier layer and the channel layer.

J18.36

Explosive Porous Silicon - A New Microsystem and its Potential Applications. Dominik Clement, Joachim Diener and Dmitri Kovalev; Physics Department, TU Munich, Garching, Germany.

We present a highly explosive nanosilicon based composite material. This self-confined and mechanically stable micro-system is based on solid oxidizer filled porous silicon (PSi) layers or micrograins. We demonstrate that due to the production method, a commonly used electrochemical or chemical etching process, any planar configuration of microexplosive layers can be achieved by ordinary photolithographic methods and selective etching. The production is completely compatible with the established standard silicon technology and full bulk silicon wafers can be processed to achieve the required geometrical configuration of the explosive material. Its explosive potential on a micrometer scale reveals a variety of new possible applications in different industrial fields, e.g. as novel, very fast micro-actuators. The chemical and physical parameters of the reaction and the material itself are determined and are presented. We discuss the specifics of morphology of this composite explosive material and its long-term stabilization. The preparation of a nanoscaled mixture of fuel and oxidizer via filling of the nanopores is shown. Furthermore, the explosive efficiency of various PSi/oxidizer systems and the influence of interfaces on the explosive power are discussed. The reaction time was found to be faster than 10^{-6} s and the energy yield for a stoichiometric ratio of Si to oxidizer is at least 9.2 kJ/g. This yield is higher than that of other high explosives. The system can be ignited in different ways, thermally, optically and electrically. The electrical ignition fulfils the standard automotive requirements for air-bag initiation. Finally, we demonstrate a construction and behaviour of the first industrial prototype of air-bag initiator, based on this nanocomposite system, and suggest further possible applications, particularly in orientation/propulsion systems and medicine.

J18.37
Abstract Withdrawn

J18.38
Two Dimensional Biphasic Nanocables from a C_{60} Based Acceptor-Bridge-Donor Dyad.
S. Shankara Gayathri and Archita Patnaik; Chemistry, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India.

Self assembly at different length scales offers rich possibility to construct nano-structured materials. Fullerene C_{60} amphiphilic derivatives self-assemble at the nanometer scale leading to fullerene based optical and electronic devices. Thus, a fair understanding of molecular structure, design, intermolecular interactions, and thermodynamic conditions is necessary for successful self-assembly of such amphiphilic molecules. On basis of the above, a fullerene derivative with Acceptor-Bridge-Donor structure has been designed and synthesized. The redox active chromophore in the adduct showed increased absorption relative to pristine C_{60} and the HOMO-LUMO gap was experimentally found to be 1.6 eV as against a theoretical gap maximum of 2.39 eV, obtained using LCAO approach with DFT/B3LYP(3-21G). The transmission electron microscopic images of the 2-D surface structure of the spread monolayers revealed the formation of uniform diameter ($\sim$ 200 nm) biphasic nanocables with distinct ridges comprising of fullerene molecules. Each subunit of the cable has a C_{60} peripheral amorphous layer of $\sim$ 36 nm in diameter, connecting these molecules through van der Waals interaction. The C_{60} sandwiched region is indicative of hydrophobic alkyl chain network with distinct crystallinity which further self-organizes into a vesicular nanowire assembly. Such materials with directed structure in constricted dimensions are ideal materials for directional electron transport.

SESSION J19: Applied Micro- and Nanotechnology
Chair: Joseph Michael
Friday Morning, April 1, 2005
Room 2003 (Moscone West)

8:30 AM J19.1
A New Approach for Roughness Gradient Fabrication.
Tobias P. Kuenzler, Tanja K. Drobek and Nicholas D. Spencer; Surface Science, Federal Institute of Technology (ETH), Zuerich, Switzerland.

Studies in medicine, biology and materials science can often benefit from experimental techniques that are capable of performing as many tests as possible within a minimum time. Gradient surfaces allow systematic studies to be performed with a continuously varying surface parameter within a single experiment. One such parameter is the surface chemistry, and a number of methods have recently appeared for the fabrication of surface-chemical gradients [1-3]. Another parameter that can also influence biological or materials science phenomena is the surface morphology. However, there are only very few reports of the fabrication of gradients in surface morphology [4]. We propose a new approach for the reproducible production of well-defined surface morphology gradients on a centimeter scale with topographical features in the micrometer and sub-micrometer range. To obtain such a gradient we first sand blasted a piece of aluminum sheet with ceramic beads with a diameter range of 125-250 microns or 0-63 microns to create a homogeneous stochastic roughness. In a subsequent chemical-polishing process the sample was immersed into a hot acidic solution and then continuously withdrawn by means of a linear-motion drive. The polishing solution, depending on the residence time of the specific surface location, preferentially removed features with a small radius of curvature and thus led to the smoothing out of the surface topography. The gradients were characterized by means of scanning electron microscopy (SEM), laser profilometry and atomic force microscopy (AFM). Calculations of the standardized Ra and RMS integral roughness values from data obtained with laser profilometry showed values of 2.3 and 3.4 microns, respectively for the rough end and 0.3 and 0.4 microns, respectively for the smooth end of the gradient. Following the gradient axis from rough to smooth, the Ra and RMS values were found to decrease monotonically. The surfaces were further investigated by applying fast Fourier transformation (FFT) wavelength-dependent roughness analysis approaches [5]. [1] Elwing, H., et al., Journal of Colloid and Interface Science, 1987. 119(1): p. 203-210. [2] Liedberg, B., et al., Langmuir, 1995. 11: p. 3821-3827. [3] Morgenthaler, S., et al., Langmuir, 2003. 19(25): p. 10459-10462. [4] Karlsson, L.M., et al., Journal of The Electrochemical Society, 2002. 149(12): p. C648-C652. [5] Wieland, M., et al., Wear, 1998. 237: p. 231-251.

8:45 AM J19.2
Small Particle Manipulation Using the Stick-Slip Effect.
Michael Eglin[1], Robert W. Carpick[1] and Mark A. Eriksson[2]; [1]Engineering-Physics, University of Wisconsin - Madison, Madison WI, Wisconsin; [2]Physics, University of Wisconsin - Madison, Madison, Wisconsin.

Recently there has been an increasing demand for methods enabling the manipulation (transport, positioning, separation, or removal) of micro- and nanoparticles. Examples of such techniques include particle transport and separation in microfluidic channels or by electrophoresis and particle manipulation using optical trapping, micromanipulators, or atomic force microprobes. Most of these techniques either manipulate particles one at a time or rely on the use of a carrier medium to transport or suspend the particles. In contrast, we present a simple method to transport a large number of micrometer sized particles in parallel without the need of a carrier medium. Piezoelectric shear plates are used to excite asymmetric shear waves which are coupled into a substrate. At the surface of the substrate, linear motion of particles is induced due to inertial forces on the particles and the stick-slip effect. This method is very versatile. We have successfully applied it to a range of particle sizes and materials as well as different substrate materials. The transport mechanism is size-selective and the particle velocity can be controlled by the waveform, amplitude, and frequency of the electronic drive signal used to excite the shear waves. A modification of this technique was used to investigate the tribological behavior of particles on surfaces. In this case, a symmetric waveform is applied to the piezo in order to detach the particles, which allows the probing of the static friction force between the particle and substrate. The frictional behavior of particles was investigated for a range of chemically functionalized surfaces.

9:00 AM J19.3
Critical Process Issues in the Fabrication of A Lateral, Self-Cleaning, MEMS Switch.
Yong Shi[1] and Sang-Gook Kim[2]; [1]Mechanical Engineering, Stevens Institute of Technology, Hoboken, New Jersey; [2]Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

A lateral contact MEMS switch was developed to address the needs for long life cycle, low contact resistance and low cost. The switch is unique in the periodic self-cleaning of particles at the contact, self-alignment of contact surfaces and the mechanical anchoring of the contact metal into the polymer switch structures. This paper will discuss the critical issues related to the fabrication of the switch and its near vertical metal sidewalls. The major issue for the lateral contact device fabrication is the creation of the vertical Au sidewall. Existing physical or chemical vapor deposition methods are found not suitable since the deposited metal is neither dense nor robust in the narrow gap of the contact. The final device fabrication requires 5 masks including process steps, such as: bottom electrode lift-off, Su-8 mold formation, electroplating, switch structure formation and device release. Lateral contacts are made by molding electroplated Au into a pair of parallel vertical trenches of polymer mold, and subsequently removing the spacer between the two molded metal plates. The device is released with XeF2. Both positive photoresist and Su8 are investigated as mold materials for the electroplating. The pulsed electroplating method is used with parameters such as frequency, temperature, current density carefully controlled. Bottom electrode cleanness is one of the key parameters to deposit high quality metal on the electrode, especially into the sharp bottom corners of the 10 micro meter thick Su-8 beam structure. It has been observed that electroplating temperature control prevents mold de-bonding and under-plating. SEM pictures show that the undulated surfaces are created successfully and the surface of the electroplated Au is much smoother and denser than that by e-beam evaporation. The long lifecycle test shows that the contact resistance has been maintained below 0.1 ohm over 10 billion cycles and is expected to maintain the resistance far beyond that. The fabricated switch shows that the self-cleaning works well and opens the possibility of direct contact MEMS switch for high power and low cost RF applications.

9:15 AM J19.4
Self Organized InAs Quantum Dot Arrays on Patterned GaAs Substrates. Matthias Schramboeck, W. Schrenk, M. A. Andrews, T. Roch, M. Austerer, W. Brezna, A. Lugstein and G. Strasser; Institut fuer Festkoerperelektronik, TU Wien, Wien, Austria.

Self-assembled semiconductor nanostructures such as quantum dots (QDs) have been under intense investigation during the last years due to their appealing electronic and optical properties. Unique physical properties have been observed in QD structures and device applications using QDs, such as lasers, detectors and memories have been explored. However, for novel QD devices, like single photon sources or transistor structures, it is desirable to control the lateral position of the QDs. To achieve this, nanoscale grid patterns can be used to laterally align the QDs. In this work, the self organization of InAs quantum dots grown with molecular beam epitaxy (MBE) on pre-patterned GaAs substrates, using different methodologies and growth parameters was investigated. The investigated techniques for substrate pre-patterning include lithographic and non-lithographic methods. Among the lithographic methods holographic lithography was studied because it provides an easy and efficient way to create nanosized patterns over large areas. For holographic lithography a He-Cd laser at a wavelength of 325nm was used as an ultraviolet (UV) light source. After coating the GaAs substrate with photoresist it was then exposed in a holographic apparatus twice, with the sample rotated 90° after the first exposure. The nanoscale grid patterns were then transferred onto the GaAs using wet chemical etching or reactive ion etching (RIE). Also a non-lithographic method - Focused Ion Beam (FIB) processing - was studied for its applicability to transfer nanosized patterns into the substrate for subsequent QD growth. FIB processing has the advantage that it offers the possibility to directly etch the patterns without the need of lithography. After preparing the substrates they were cleaned and inserted into the MBE-chamber and prepared for the growth. Different GaAs-based buffer layers were grown on the substrates, consequently covered with self assembled QDs. These dots are either embedded into GaAs or serve as surface dots for further investigations. Various thicknesses and sequences of buffer layers are used and covered with InAs QDs or stacks of QDs. The influence of the pattern size and height, the pattern definition, the etching technique, the preparation and the buffer sequence on dot quality and density are investigated. Furthermore the influence of different dot growth conditions on dot quality and density is examined. The dot density, lateral and size distribution of covered as well as surface dots is measured using surface and cross sectional atomic force microscopy (AFM). Photoluminescence (PL) measurements performed on the samples with and without patterns give further information on dot size and size distribution.

9:30 AM J19.5
Exploiting Nanoscale Structure to Tune Electrical Characteristics of Macroscopic Films. Al-Amin Dhirani, Paul-Emile Trudeau and Yoshinori Suganuma; University of Toronto, Toronto, Ontario, Canada.

Electrical measurements of nanostructures represent a frontier in chemistry and physics. One of the driving forces in this field is the idea that control over local conductivities within a material offers a possibility to design rationally its averaged electrical properties. Using nanoparticle/molecular linkers as building blocks, we can generate composite films (or "artificial solids") with a very wide range of properties. In particular, by varying film parameters, we can drive a rapid percolation transition and an insulator-metal transition. The results point to a significant potential to generate materials with designer properties.

9:45 AM J19.6
Advanced Applications of Anodised Aluminium Oxide Templates for Nanotechnology. Darren J. LeClere, Materials Science Centre, University of Manchester, Manchester, United Kingdom.

Anodised aluminium oxide films have been applied to the construction of varies nanometre sized structures. The production of such structures requires either a "Two-Step" method or a minimal amount of embossing, with optical gratings or micro-machined Si templates, which allows for accurate control over the inter-pore distances. For other structures precise manipulation of the pore sizes throughout the entire anodising procedure must be maintained to modify the shapes that can be obtained. After removing the excess aluminium the barrier layer is partially or fully etched away, depending on the desired outcome. The oxide films are then used in conjunction with evaporation and sputtering techniques, electro-chemical deposition or replication with polymers to produce arrays of structures with applications to various areas of nanotechnology at greatly reduced costs.

SESSION J20: Self-Assembled Structures
Chair: Somuri Prasad
Friday Morning, April 1, 2005
Room 2003 (Moscone West)

10:30 AM J20.1
Responsive Supramolecular Assemblies from Homopolymeric and Small Organic Molecular Building Blocks. Huisheng Peng and Yunfeng Lu; Chemical and Biomolecular Engineering, Tulane University, New Orleans, Louisiana.

Nanometer- and micrometer-sized polymeric objects are of great interest for applications in biology, medicine, photonic, electronic and other areas. The current synthesis methods often involve the micellization of block or graft copolymers in selective solvents. Such a spontaneous assembly process can form aggregates with different morphologies through balancing the stretching force from the core-forming molecular blocks, interfacial tension between the core and the solvent, and the intercorona repulsion. However, their lengthy, complicated synthesis procedures may limit their large-scale applications. Herein, we demonstrate a novel route to produce micrometer-sized polymeric aggregates with controlled morphologies through cooperative assembly of low-cost homopolymers and diacetylenic acids (DA) in their common solvent. As-synthesized supramolecular assemblies not only exhibit tunable macroscopic morphologies but also show structural hierarchy at mesoscale (hexagonal for hollow spheres, lamellar for solid spheres and rods). The self-organization of the DA molecules allows the diacetylenic units to arrange into ordered arrangement. Topo-polymerization of the aggregates under X-ray or ultraviolet irradiation results in blue polydiacetylene, which further changes to red color after heating. These responsive hierarchical polymeric aggregates are of interest for functional hierarchical aggregate design, smart carriers, controlled delivery and other applications.

10:45 AM J20.2
Eutectic Al2O3-GdAlO3 Composite Consolidated by Combined Rapid Quenching and Spark Plasma Sintering Technique. Kazuyuki Kakegawa[1], Masayuki Nagata[1], Naofumi Uekawa[1], Takashi Kojima[1] and Young-Hwan Han[2]; [1]Faculty of Engineering, Chiba University, Chiba-shi, Chiba, Japan; [2]Department of Chemical Engineering and Materials Science, University of California, Davis, Davis, California.

A mixture of Al2O3 and GdAlO3 was melted and rapid quenched to produce an amorphous film. Dense eutectic composites were consolidated from ground amorphous powder using both conventional and spark plasma sintering (SPS). Conventional sintering at temperatures above 1600C for 24 h was required for complete sintering. However, using SPS complete sintering could be obtained at temperatures between 1300 and 1500C with no soaking. The SPS technique could consolidate ultrafine eutectic structure from rapid quenched amorphous material, while conventional sintering was not successful owing to grain growth. A combination of rapid quenching and SPS resulted in an ultrafine eutectic Al2O3?GdAlO3 structure.

11:00 AM J20.3
Colloid Crystal Wires from Directed Assembly. Feng Li[1], Xavier Badel[2], Jan Linnros[2] and John B. Wiley[1]; [1]Department of Chemistry, University of New Orleans, New Orleans, Louisiana; [2]Department of Microelectronics and Information Technology, KTH Royal Institute of Technology, SE-164 40 Kista, Sweden.

Methods are reported for the fabrication of colloidal crystal wires with tubular packings. Both free and silica-encased wires have been prepared. Porous silicon membranes are infiltrated with silica spheres, treated with various amounts of silane, and annealed. After removal of the silicon template, low silane concentrations are found to result in colloidal crystal wires with varied packing geometries, while the higher silane concentrations produce a thin translucent silica membrane around the wires. Packing in the wires varies with the channel diameter of the Si membrane. The channels used in this study typically produce wires with six sphere strands, though wires with 4 to 7 strands have been observed. Both chiral and a chiral packings are also possible.

11:15 AM J20.4

The Performance of the Gate Electrode using Co Thin Films Selectively Deposited on SAMs Patterns for a-Si TFT.

Heejung Yang[1], Taewook Kwon[1], Jeonggil Lee[1], Myungmo Sung[2], Hyunjung Shin[1], Jiyoung Kim[1] and Jaegab Lee[1]; [1]School of Advanced Materials Engineering, Kookmin University, Seoul, South Korea; [2]Department of Chemistry, Kookmin University, Seoul, South Korea.

We have successfully developed selective deposition of Co thin films using MOCVD coupled with Octadecyltrichlorosilane (OTS) micro-contact printing(μCP), which was used as gate electrodes in a-Si TFT. The developed process of Co gate electrodes selectively formed on SAMs patterns can replace the conventional TFT one, by eliminating the photolithography and etching steps. MOCVD Co shows excellent selectivity over OTS at the low temperature regime, in which the growth of Co films is surface limited with an activation energy of 0.8 eV. In addition, the as-deposited Co films reveal smooth surface (rms =2 nm), and low resistivity of 12 $\mu\Omega$-cm for 60 nm-thick Co. The process pressure is identified to be a critical factor to achieve selective deposition of Co films on OTS patterns. Finally, the TFT has been fabricated using the Co thin films selectively formed using MOCVD and micro-contact printing as gate electrode, and electrically characterized. The subthreshold slope and on/off current ratio are 0.88 V/decade and 6x106, respectively. The electron field-effect mobility at saturation is 0.35 cm2/Vs for Vd = 9V. It can be concluded that the newly developed process is suitable for a-Si TFT fabrication, and thus replacing the conventional one.

11:30 AM J20.5

Ink Dependence of Poly(dimethylsiloxane) Contamination in Microcontact Printing.

Ruben Sharpe[1], Dirk Burdinski[2], Jurriaan Huskens[1], Harold J. W. Zandvliet[1], David N. Reinhoudt[1] and Bene Poelsema[1]; [1]MESA+ Institute for Nanotechnology and department of Science and Technology, University of Twente, Enschede, Overijssel, Netherlands; [2]Molecular and Biomolecular Engineering, Philips Research, Eindhoven, N. Brabant, Netherlands.

Self-assembled monolayers (SAMs), being well ordered molecular assemblies of extremely low thickness, allow the tuning of surface chemistry without affecting the bulk properties of a substrate. SAMs, therefore, find application in a host of areas where (local) control of interfacial properties is desired. Microcontact printing is a well-established, highly versatile technique for patterning SAMs, in which suitable molecules (ink) are transferred to a substrate upon intimate contact with a polymeric relief structure (stamp). Usually, due to its versatility, chemical inertness and mechanical properties, poly(dimethylsiloxane) (PDMS) is the polymer of choice. An inherent drawback of it, however, is its inclination to contaminate printed substrates with low molecular weight PDMS fragments. In this study it is shown, by a combination of lateral force microscopy (LFM), Fourier transform infrared spectroscopy (FT-IR) and X-ray induced Photoelectron Spectroscopy (XPS), that the severity of the PDMS induced contamination is highly dependent on the nature of the ink. Contrary to intuition, the contamination was found to be worst for the transfer of hydrophilic inks, when using hydrophobic PDMS as the ink transfer medium. Hydrophobic alkanethiols, on the other hand, were found to shield the substrate to a large extent from contamination. A possible mechanism and its implication on other ink/stamp/substrate systems is discussed.

SESSION J21: Nanomaterials Synthesis and Applications

Chair: Mark McNie
Friday Afternoon, April 1, 2005
Room 2003 (Moscone West)

1:30 PM J21.1

Surface Electronic States and Electrostatic Attractive Forces between Metals or Semiconductor and Tribocharged Polymers.

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Attractive force between the sheets of silicon and metals and polymer surfaces was measured and its relationship to the electronic nature of the silicon and metal surfaces has been investigated to clarify the interaction force involved. The attractive force was measured by an electronic balance as a function of the distance between the sheets of silicon wafer and metals and polymers. The electronic nature of the silicon and metal surfaces was characterized by temperature programmed photoelectron emission (TPPE) technique developed by the authors [1]. The TPPE was measured as a function of incident light with wavelength from 300 to 170 nm. The TPPE characteristics are the amount of emitted photoelectrons (PE total count) and the photoelectric threshold value. commercial silicon wafer and rolled nickel and titanium sheets were used. The silicon wafer used was as received, and the metal surfaces were prepared by three surface treatments: successive abrasion with three emery papers of 80, 20 and 5micron grain size (T1), ultrasonic cleaning in acetone (T2) and heating oxidation in air at 873K for 1 h (T3). Polymers such as polystyrene foam (PS), polytetrafluoroethylene (PTFE), and polyimide (PI) were used. Prior to use the polymer surfaces were rubbed with a cellulose paper, and negatively charged. The attractive force increased progressively with decreasing distance. With silicon wafer the attractive force depended on the polymers, resulting in the decreasing order: PS > PTFE > PI. With the metals for PS the attractive force for nickel was much greater than that for titanium. With both metals the attractive force for T1 was much greater than that for T2 and T3. The TPPE characteristics also depended strongly on the metals and the surface treatments. For all the treatments the PE total count for nickel was greater than that for titanium, while the threshold value for nickel was smaller than that for titanium. With both metals the PE total count for T1 was greater than that for T2 and T3, and the threshold value for T1 was smaller than that for T2 and T3, resulting in that the PE total count decreased linearly with increasing threshold value. This means that the abraded metal sample has high ability to emit electrons from the surface compared with the metal samples cleaned in acetone and oxidized in air. Thus it is concluded that the attractive force between the metal and the polymer surfaces was well correlated with the electronic nature evaluated by the ability of the metal samples to emit electrons.

Acknowledgement This work was supported by Grant-in-Aid through Ministry of Education, Culture, Sports, Science, and Technology.

References [1] Y. Momose, M. Honma and T. Kamosawa, "Temperature-programmed photoelectron emission technique for metal surface analysis", Surf. Interface Anal., 30 (2000), 364-367.

1:45 PM J21.2

Chirality Characterization of Dispersed Single Wall Carbon Nanotubes.

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Two surfactants in aqueous solutions are used in order to disperse a batch of HIPCO single wall carbon nanotubes (SWNTs). The surfactants used are sodium dodecylbenzene sulfonate (NaDDBS) and sodium dodecyl sulfate (SDS); these surfactants, as well as a range of organic solvents, are utilized for their efficacy in dispersing SWNTs in solution. Raman scattering and optical absorption spectroscopy are used for the chirality characterization of the SWNTs. Three resonant breathing mode (RBM) peaks are identified by directly comparing the Raman spectra with the Kataura plot. The SWNT diameters are calculated from these resonant peak positions. Next, a list of (n, m) pairs, yielding the SWNT diameters within a few percent of that obtained from each resonant peak position, is established. Finally, the interband transition energies are calculated based on the tight binding energy expression for each list of the (n, m) pairs, and the pairs yielding the closest values to the corresponding optical absorption peak are selected. The results reveal (2, 10), (6, 7) and (2, 12) as the most probable chiralities of this particular batch of SWNTs. Directly relating the Raman scattering and optical absorption spectra, the present method is considered the simplest technique currently available.

2:00 PM J21.3

Energetic Neutral Atom Beam Lithography/Epitaxy for Nanoscale Device Fabrication.

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Energetic neutral atom beam lithography/epitaxy (ENABLE), recently developed at LANL, is a versatile technique that permits both patterning of nanoscale features into polymer substrates and the low temperature growth of nitride and oxide thin films into the patterned features. ENABLE achieves the direct activation of surface chemical reactions by exposing substrates to a beam of atoms with energies between 0.5 and 5.0 eV. Polymers that form volatile oxidation products may be anisotropically etched using a neutral beam of oxygen atoms, thereby avoiding problems inherent to other etching techniques related to charged species and diffraction effects. Directed low temperature growth of high quality thin films may then be achieved by exposing the patterned substrate to a concurrent flux of evaporated metal (Al, Ga, In etc.) that reacts with the energetic O- or N-atoms impinging upon the sample to form oxide or nitride films. Since the reaction is being activated by the kinetic energies of the impinging atoms and not high substrate temperatures, film deposition at temperatures as low as ambient becomes feasible. As a result, nitride and oxide thin films are grown on previously etched polymeric templates that would otherwise decompose at high temperatures. Furthermore, the chemical stability of the deposited thin films allows protection and passivation of underlying surfaces and/or materials. Taking advantage of these properties we have used ENABLE to encapsulate active layers of nanocrystals into operational LEDs with extended lifetimes. The application of the ENABLE for producing photonic, MEMS and NEMS, microfluidic, and novel electronic devices will be discussed along with the latest results on nanoscale etching and device integration.

2:15 PM J21.4

TiN/GaN Metal/Semiconductor Multilayer Nanocomposites Grown by Reactive Pulsed Laser Deposition. Vijay Rawat[1] and Timothy Sands[1,2,3]; [1]School of Materials Engineering, Purdue University, West Lafayette, Indiana; [2]Electrical and Computer Engineering, Purdue University, West Lafayette, Indiana; [3]Birck Nanotechnology Center, Purdue University, West Lafayette, Indiana.

Metal/semiconductor multilayers with nanoscale periods and tailored barrier heights are expected to exhibit novel thermal and electronic cross-plane transport properties. Theory suggests that metal/semiconductor multilayers with controlled interface roughness have the potential to yield solid-state thermionic energy conversion efficiencies that are substantially greater than those of conventional thermoelectric materials [1]. Potential applications include conversion of waste heat to electrical power in automobiles and direct thermal-to-electrical generators for naval vessels. In this study, TiN/GaN metal/semiconductor multilayers have been chosen for initial investigations of metal/semiconductor multilayer growth mechanisms. Nitrides have high melting points and excellent corrosion resistance. Furthermore, the properties (e.g., barrier height and thermal conductivity) of metallic and semiconducting nitrides and their interfaces can be tuned by alloying. TiN/GaN multilayers with periods ranging from 5 nm to 10 nm were grown by reactive pulsed laser deposition (PLD) using elemental metal targets at an ammonia pressure of 20mtorr onto Si(100), MgO(100) and sapphire(0001) substrates. For growth on Si and MgO substrates, an epitaxial 40 nm thick TiN buffer layer was deposited prior to deposition of the multilayers. An epitaxial 40 nm GaN buffer layer was grown on sapphire substrates. For all substrates, layer thicknesses and periods investigated, high-resolution x-ray diffraction and cross-sectional transmission electron microscopy revealed {0001} texture for the GaN, and {111} texture for the TiN in the multilayers. Both TiN layers and GaN layers thicker than $\sim$ 2nm appear to be continuous, with no evidence of agglomeration. Both phases are crystalline, with lateral grain sizes comparable to the layer thickness. These results suggest that epitaxy will not be necessary to fabricate pinhole free metal/semiconductor multilayers in the nitride system. Cross-plane electrical and thermal properties of these first metal/semiconductor multilayers will be reported. [1] "Improved Thermoelectric Power Factor in Metal-Based Superlattices", D. Vashaee and A. Shakouri, Phys. Rev. Lett. 92, 106103(2004). This work was sponsored by ONR (MURI thermionic energy conversion center).

2:30 PM J21.5

Improved Magneto-Rheological Elastomers: Preparation, Characterization, Actuation and Application. R. Lloyd Carroll, Daniel B. Blum, Brandon R. Lunk and Rich Superfine; Physics and Astronomy, University of North Carolina - Chapel Hill, Chapel Hill, North Carolina.

Composite nanomaterials combine the properties of the individual components in a synergistic manner, resulting in functionally new materials that fill or create the need for new applications. Currently, magnetically responsive elastomeric materials (or magneto-rheological elastomers, MREs) are used largely in industrial applications and have not been explored for potential applications in nanoscience. Commercially available MREs are unsuitable for precision applications, largely due to the size and variation of the magnetic component. We have prepared improved magnetic elastomers through the homogeneous distribution of stabilized iron or iron oxide nanoparticles within a siloxane rubber base. These MREs are suitable for submicron scale templating applications, and exhibit strong magnetic response sufficient to allow actuation of templated structures by the application of oscillating magnetic fields. We will describe the preparation and characterization of the materials and the devices. In addition, we have measured the mechanical properties of the MREs. The magnetic properties of the material vary depending on the loading fraction of the magnetic nanoparticles. We will describe further applications of these materials in device fabrication.

2:45 PM J21.6

Zinc Powder Evaporation: an Efficient Way of Synthesizing a Wide Range of High Quality ZnO Nanostructures at Lower Temperature. Yue Zhang[1,2], Jian He[1], Yunhua Huang[1], Yousong Gu[1], Zhen Ji[1] and Cheng Zhou[1]; [1]Department of Materials Physics, University of Science and Technology Beijing, Beijing, China; [2]State Key Laboratory for Advanced Metals and Materials, University of Science and Technology Beijing, Beijing, China.

ZnO, recognized as one of the most promising oxide semiconductor materials because of its good optical, electrical, and piezoelectric properties, is probably the richest family of nanostructures among all materials. Among all the fabrication methods reported for ZnO, simple ZnO thermal evaporation is considered as the most efficient way in achieving a large range of ZnO nanostructures in spite of the demand of a high temperature more than 1300 degrees centigrade. To seek a lower temperature in achieving this we applied ourselves to study synthesis of ZnO nanostructures by zinc powder evaporation. The experiments were carried out in a quartz tube (diameter 30 mm, length 90 cm) of a tubular furnace. The source materials were put in an alumina ceramics boat and a silicon substrate was placed above it. After the alumina ceramics boat was inserted into the center of the quartz tube, the processes of deposition were conducted under the desired temperature (550-700 degrees centigrade), evaporation time and flow rate of Ar/O2 gas mixture. Accordingly, a wide range of structures such as, tetrapod-like nanorods, nanobelts, toothed nanobelts, nanoneedles, nanocables, a diverse group of nanonails and a diverse group of nanocombs have been fabricated successfully through this method. Meanwhile, XRD, SEM, TEM, HRTEM and EDS investigations were also performed on the products and revealed the products in bulk quantities have wurtzite crystalline structure, clean surface and uniform nanoscale morphology respectively, which demonstrate that a wide range of high-quality ZnO nanostructures can also be achieved at lower temperature by our method. Except nanocables, these nanostructures were synthesized without a catalyst. The growth of these quasi one dimensional nanostructures was induced by the three types fastest growth directions–<0 0 0 1>, <0 1 -1 0> and <2 -1 -1 0> and VS (vapor-solid) mechanism. Interestingly, the nanocables, i.e. ZnO nanowires coated with amorphous silicon oxide layer, grow along a unique direction of [2 0 -2 1], which was first reported by us to our knowledge. The growth of nanocables was probably based on the eutectic alloy of Au-Si system, where Au served as a catalyst. To sum up, the way of zinc powder evaporation is efficient enough and promising to synthesize a large family of high-quality ZnO nanostructures in lower temperature.