SYMPOSIUM O

Advanced Microsystems-Integration with Nanotechnology and Biomaterials

April 13 - 16, 2004

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* Invited paper

SESSION O1/W1: Joint Session: Self-assembled Materials
Chairs: Joanna Aizenberg and Jun Liu
Tuesday Morning, April 13, 2004
Room 3005 (Moscone West)

8:30 AM *O1.1/W1.1

The fabrication of novel biomaterials via molecular self-assembly. Shuguang Zhang, Center for Biomedical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Two complementary strategies can be employed in the fabrication of molecular biomaterials. In the "top-down" approach, biomaterials are generated by stripping down a complex entity into its component parts. This contrasts with the "bottom-up" approach, in which materials are assembled molecule by molecule and in some cases even atom by atom to produce novel supramolecular architectures. The latter approach is likely to become an integral part of nanomaterials manufacture and requires a deep understanding of individual molecular building blocks, their structures, assembling properties and dynamic behaviors. Two key elements in molecular fabrication are chemical complementarity and structural compatibility, both of which confer the weak and noncovalent interactions that bind building blocks together during self-assembly. Significant advances have been achieved at the interface of nanomaterials and biology, including the fabrication of nanofiber materials for three-dimensional cell cultures and tissue engineering, the peptide nanotubes for stabilizing membrane proteins and nanocoating molecular and cell organizations. Molecular fabrications of nanobiomateirals have fostered diverse scientific discoveries and technological innovations.

9:00 AM O1.2/W1.2

The Creation of Novel Hybrid Materials Through the Coupled Self- Assembly of Chaperonin Proteins and Diblock Copolymers. Linda Katherine Molnar[1], Ting Xu[2], Jonathan Trent[3] and Thomas P Russell[2]; [1]Center for Nanotechnology, NASA Ames Research Center, Moffett Field, California; [2]Polymer Science and Engineering, University of Massachusetts, Amherst, Massachusetts; [3]Astrobiology Technology, NASA Ames Research Center, Moffett Field, California.

The combination of polymers and proteins to form hierarchically structured multifunctional materials with the processability of polymers while retaining biological function of the protein is being studied. A unique synergy resulting from the mixing of these two disparate self-assembling systems has been found. The materials utilized were an asymmetric diblock copolymer of polystyrene (PS) and polyethyleneoxide (PEO)denoted P(S-b-EO) and a double ring structure-forming protein from a class of heat shock proteins known as chaperonins. Solvent casting has been shown to be a viable and rapid route by which arrays of nanoscopic PEO domains oriented normal to the surface can be produced in a glassy PS matrix in films with thickness several times the period of the copolymer. Here, we show the chaperonin-driven self-assembly of the P(S-b-EO) diblock copolymer thin film cast from an aqueous solution of chaperonin and polymer. AFM images of the resulting thin films with and without chaperonins show that the chaperonins are interacting with the P(S-b-EO) and enabling the microphase separation of the copolymer. The chaperonins used in these studies, isolated from *Sulfolobusshibatae*, which lives in geothermal hot springs and grows at temperatures of up to 85 degrees Celsius and pH 2.0. Structural data and genetic engineering tools have allowed the creation of chaperonin mutants that bind biomolecules or inorganic nanoparticles. The combination of order from the self-assembling properties of diblock copolymers with the genetic adaptation of proteins opens up new possibilities of producing multifunctional materials and the functional components of devices where both organization and specific biological function are required, e.g., sensors, adaptable materials, medical implants, and biocompatible devices.

9:15 AM O1.3/W1.3

Environmentally Responsive Hydrogels with Tunable Rigidity Constructed Via Peptide Folding and Consequent Self-Assembly. Darrin Pochan[1] and Joel Schneider[2]; [1]Materials Science and Engineering, University of Delaware, Newark, Delaware; [2]Chemistry and Biochemistry, University of Delaware, Newark, Delaware.

By using peptidic molecules in the materials self-assembly design process, one can take advantage of inherent biomolecular attributes, intramolecular folding events and secondary structure, in addition to more traditional self-assembling molecular attributes such as amphiphilicty, to define hierarchical material structure and consequent properties. Importantly, intramolecular folding events impart a molecular-level mechanism for environmental responsiveness at the material level (e.g. infinite change in viscosity of a solution to a gel with changes in pH, ionic strength, temperature). The utility in responsive material design with small, 20 amino acid beta-hairpin peptides will be discussed. The self-assembly construction process is predicated on the peptides first intramolecularly folding into the beta-hairpin conformation from a random coil conformation. The resultant gel scaffold network displays unique nano- and microstructure due to the self-assembly process. Importantly, the scaffold assembly is completely reversible with pH or temperature by reversibly folding and unfolding the constituent peptides that, in turn, assembles or disassembles the scaffold, respectively. In addition, the rigidity of the gel scaffold can be tuned via the magnitude of the environmental stimuli, e.g. gels triggered with temperature form a more rigid network when assembled at higher temperatures due to faster folding and self-assembly kinetics. The molecular design and self-assembly principles, including a model to explain the inherent tunability of the final gel networks that underlie the observed morphological and rheological material, will be discussed.

9:30 AM *O1.4/W1.4

Biomimetic Approaches to the Design of Functional, Self-Assembling Systems. George M. Whitesides, Harvard University, Cambridge, Massachusetts.

Successful solutions to many problems in science and technology have come by extracting design or strategy from biology, and applying it in a non-biological context. The use of biomimetic approaches is particularly well suited when designing self-assembling functional systems, because life - from single cells to complex, multicellular organisms - demonstrates an enormous number of successful, functional designs, and because living systems assemble themselves. There are two reasons for studying self-assembly. First, self-assembly is centrally important for life. Biological systems form and are sustained as a result of self-organization. Understanding life, therefore, requires - among other things - understanding self-assembly. Second, self-assembly can generate ordered 3D aggregates of components ranging in size from the molecular to the macroscopic. These structures often cannot be generated by any other procedure. In the past, self-assembly has been best known as a synthetic strategy in the molecular size regime. New examples of its application to nano- and microscale components are now beginning to emerge. As a consequence, self-assembly is becoming increasingly important as a strategy for the formation of useful, nano- and micro-scale structures. This talk discusses the characteristics of self-assembly in living systems and reviews self-assembled functional systems designed according to biological principles.

10:30 AM O1.5/W1.5

Fabrication of Assembled Virus Nanostructures on Templates of Chemoselective Linkers Formed by Scanning Probe Nanolithography. C L Cheung[1], J A Camarero[1], B W Woods[1], J J De Yoreo[1], T Lin[2] and J E Johnson[2]; [1]Chemistry and Materials Science, Lawrence Livermore National Laboratory, Livermore, California; [2]Dept of Molecular Biology, The Scripps Research Institute, La Jolla, California.

The assembly of genetically engineered viruses and proteins on patterned chemical templates has great potential for directing the formation of ordered protein and virus arrays. Moreover, presentation of certain chemical groups on these macromolecules either through genetic modifications or chemical ligation techniques provides a potential route to hierarchical assembly of organic-inorganic nanostrucures. Here we present a general methodology to create nanoscale ordered protein and virus structures by using nano-grafting and dip-pen nanolithography to create patterns of self-assembling molecules that exhibit chemoselective binding to specific sites on engineered proteins and viruses. Using amino-terminated long-chain alkane thiols as the chemical linker, shorter-chain tri-ethylene glycol terminated alkane thiols as a background "protein resist", and the icosohedral cow peas mosaic virus (CPMV) engineered to present cystene groups at specific sites on its surface, we demonstrate the formation of viral arrays. We find that when the chemical templates have dimensions comparable to the size of the virus, they tend to spontaneously form close-packed structures. Using these templates as platforms for investigating the controls on macromolecular aggregation, we examine the kinetics and morphology of array assembly under difference solution conditions by atomic force microscopy. Preliminary results using these templates to direct the growth of virus crystals and comparisons with bulk virus crystallization experiments is also be discussed. 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.

10:45 AM *O1.6/W1.6

Self-Assembly in Biological Structures. Peter Prevelige, Microbiology, University Alabama Birmingham, Birmingham, Alabama.

In biological systems, dynamic nanometer scale structures self-assemble with sufficient precision that their structures are regular at the level of Angstroms. They do this in a controlled manner, in a noisy environment full of other proteins. To cope with the demands of controlled and precise assembly they have evolved a number of sophisticated control mechanisms. The mechanisms include: well controlled linear assembly pathways, the use of substructure assembly to improve fidelity, controlled conformational switching during assembly, staged assembly, and the use of templates or jigs to assist in form determination. These principles and paradigms are well illustrated in the assembly pathway of the dsDNA bacteriophage. In this talk, a series of vignettes drawn from experimental studies of the assembly of complex biological systems, primarily phage, which serve to illustrate these general principles will be presented

11:15 AM O1.7/W1.7

Surfactant-Assisted self-assembly of water-soluble nanocrystal, ordered arrays, and their integration. Hongyou Fan, Kai Yang, Kevin Malloy, Sigmon Thomas and Jeff Brinker; Sandia National Laboratories, Albuquerque, New Mexico.

Nanocrystals exhibit size-dependent physics and have many important applications in catalysis, biolabeling, and microelectronics and optics. Current monosized nanocrystals are often organic ligands-protected, therefore, dissolve only in organic solvent. Self-assembly and formation of ordered nanocrystal arrays are limited to only organic solvents. Here we report the synthesis of a new ordered nanocrystal (NC) arrays through self-assembly of water-soluble NC-micelles with soluble silica. The ordered arrays comprise gold nanocrystals arranged within a silica matrix in a face-centered-cubic lattice with cell dimensions that are adjustable through control of the nanocrystal diameter and/or the alkane chain lengths of the primary alkanethiol stabilizing ligands or the surrounding secondary surfactants. Under kinetically controlled silica polymerization conditions, evaporation drives self-assembly of NC-micelles into ordered NC/silica thin film mesophases during spin-coating. The intermediate NC-micelles are water-soluble and of interest for bio-labeling. The robust, 3-D NC mesophase solids are of interest for development of collective optical and electronic phenomena, and, importantly, for the integration of nanocrystal arrays into device architectures. Integration of a MOS capacitor using such an ordered gold NC/silica oxide demonstrated charge storage on the gold nanocrystals and discharge behavior dominated by electron transport within the ordered gold nanocrystal array. Temperature dependent device I-V characteristic and electron tunneling behavior have been observed. Sandia National Laboratory is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

11:30 AM O1.8/W1.8

Conjugated Polymer/Silica Nanocomposites with Tunable Mesostructure. Byron McCaughey[1], Chris Costello[2], Donghai Wang[1], J Eric Hampsey[1], Chaojun Li[2], C Jeffrey Brinker[3] and Yunfeng Lu[1]; [1]Chemical Engineering, Tulane University, New Orleans, Louisiana; [2]Chemistry, Tulane University, New Orleans, Louisiana; [3]Sandia National Laboratories, Albuquerque, New Mexico.

Conjugated polymer-ceramic nanocomposites have been extensively researched because they have shown enhanced conductivity, mechanical strength, processability, environmental stability, and other unique properties. Our research focuses on the synthesis of conjugated poly(2,5-thienylene ethynylene) (PTE)/silica nanocomposites with tunable mesostructure. The synthesis approach involves surfactant-induced partitioning, self-assembly and co-organization of 2,5-diiodothiophene monomer and palladium-based catalyst within a poly(silicic acid) matrix. Surfactant choice and self-assembly conditions created hexagonal, lamellar, or cubic silica mesophases. Subsequent polymerization initiated by exposing the monomer/catalyst/silica nanostructures to acetylene gas resulted in the formation of ordered, mesostructured poly(2,5-thienylene ethynylene)/silica nanocomposites as determined by UV-vis, FTIR, XRD, and TEM experiments. PTE formation was verified by a broad UV adsorption between 300 and 600 nm that changed position based on catalyst and monomer concentrations. XRD scans and TEM images demonstrate the formation of hexagonal, cubic or lamellar PTE/silica mesostructure. PTE incorporation within the mesoporous silica was determined by an increase in XRD d-spacing on a series of spin-coated thin films. Also, a robust polymerization mechanism was revealed. Finally, silica removal results in free-standing conjugated polymer particles with mesoporosity and high surface area. This novel approach provides a unique route to synthesize mesostructured conjugated polymers and polymer/inorganic nanocomposites.

11:45 AM O1.9/W1.9

The molecular car and its on-chip infrastructure. Zhigang Suo and Wei Hong; Division of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts.

A molecule adsorbed on a solid surface has an electric dipole moment. It performs random walks when no external field is applied. However, an electrode can direct the motion of the molecule. For example, one can embed an array of individually addressable electrodes near the surface of a dielectric substrate. Charge the electrodes sequentially, and the molecular dipole moves in a desired way: going forward, reversing, and making a turn. Such a molecule, or its monolayer island, is a molecular car. As an illustration, consider a short-chain molecule with three characteristics: its one end adsorbs to a solid surface, its mid-chain has a group with an electric dipole moment normal to the solid surface, and its other end is a passenger receptor. The molecule has a modular structure. The division of labor offers the flexibility to design separate modules, at the molecular level, to fulfill distinct functions. The car captures a specific passenger molecule in one pool, shuttles it, and then releases it in another pool, all on a single chip. This talk describes the mechanics of the molecular car and its on-chip infrastructure, their design requirements, and our numerical simulation. Thermal fluctuation will be an important consideration. One needs to learn to drive the car in perpetual earthquake.

SESSION O2: Interfacial Sciences and Novel Microsystems/Microdevices
Chair: Jun Liu
Tuesday Afternoon, April 13, 2004
Room 3005 (Moscone West)

1:30 PM *O2.1

Programmable Microsystems: A New Paradigm for Nano/Micro-Scale Integration. Terry A. Michalske, Sandia National Laboratories, Albuquerque, New Mexico.

Microfabrication tools and processes are now used to miniaturize complete engineering systems for a wide range of applications including information processing and storage, mechanical sensing and navigation, as well as chemical or biological analysis. Fully integrated microsystems provide significant benefit through increased portability, low power consumption, improved speed of operation, reduced cost, and higher reliability. Increasingly, nanoscale materials and structures to overcome performance limitations associated with microsystem architectures. Examples include nanoscale coatings to modify the surface properties of microscale chemical or biological analysis systems, nanoscale lubricants for micro-electro-mechanical systems (MEMS), or the use of nanoscale magnetic materials to increase information storage density. In this paper I will show how externally tunable properties of nanoscale materials that can be used to develop a new generation of programmable microscale device architectures with improved performance, flexibility, and reliability. Examples include nanoscale electrical elements for Field Programmable Gate Arrays (FPGA), addressable surface adhesion for new MEMS architectures, and tunable control of molecular transport and sorting for chemlab-on-chip applications. The successful development of programmable microsystem architectures will depend on our ability to: 1) address information and energy across the nano-micro length scale, 2) engineer nanoscale materials and devices that can provide a wide range of tunable properties, and 3) physically integrate nanoscale materials within microdevices while preserving their tunable properties. Key to success is a working environment where applications needs, device architecture design, and nano-scale / micro-scale materials and fabrication expertise come together to solve complex problems.

2:00 PM O2.2

Combing of Molecules in Microchannels: A new method for creating micropatterned arrays of stretched and aligned DNA. Cecilia Anna Paulette Petit and Jeffrey D Carbeck; Chemical Engineering, Princeton University, Princeton, New Jersey.

We present a new top-down method for creating microscopic patterns of stretched and oriented single molecules of DNA on a surface. Combing of molecules in micro-channels (COMMIC) - a process by which molecules are deposited and stretched onto a surface by the passage of an air-water interface - creates these patterns. This approach demonstrates that the direction of stretching of the molecules is always perpendicular to the air-water interface; the shape and motion of this interface serve as an effective local field directing the chains dynamically as they are stretched onto the surface. The geometry of the micro-channel directs the placement of the DNA molecules, while the geometry of the air-water interface directs the local orientation and curvature of the molecules. This ability to control both the placement and orientation of chains has implication for the use of COMMIC in genetic analysis and in the bottom-up

approach to nanofabrication.

2:15 PM *O2.3
Microelectromagnets for the Manipulation of Biological Systems. Robert M. Westervelt, Division of Engineering and Applied Sciences and Department of Physics, Harvard University, Cambridge, Maryland.

Microelectromagnet devices were developed for the microscopic control of biological systems. A microelectromagnet matrix has two arrays of straight wires, one array perpendicular to the other, that are separated and topped by insulating layers; the devices are fabricated using lithography. Microelectromagnets can produce strong magnetic fields for the stable manipulation in a fluid of biological systems attached to magnetic beads. By controlling the wire currents, a matrix can move a peak in magnetic field magnitude continuously over the surface of the device, generate multiple peaks simultaneously, and control them independently. These capabilities of a matrix can be used to trap, continuously move, assemble, separate and sort biological samples on a microscopic scale. Supported by the Nanoscale Science and Engineering Center based at Harvard, NSF grant PHY 0117795.

2:45 PM *O2.4
Micro- and nano-devices based on protein molecular motors. dan v nicolau, Industrial Research Institute Swinburne, Swinburne University of Technology, Hawthorn, Victoria, Australia.

Protein molecular motors are ubiquitous natural dynamic nano-devices central to life processes such as cell division, motility at subcellular, cell and multicellular level, and neuro-processes. The invention of motility assays prompted active research on hybrid nano-devices that use protein linear molecular motors, which comprise pairs of motors (e.g. myosin, kinesin) with propelling function and filaments (made of actin or tubuilin) with guiding function. Three possible applications of molecular motors-based nanodevices, i.e. biosensing; power generation and bio-inspired computation are presently envisaged. Bio-sensing is the most obvious application because of the potential of single-molecule detection, but the requirements for a robust biosensor (endurance, no false positives) and the extreme sensitivity of protein motors make this application problematic, from the engineering point of view. The power generation option requires massive parallelism of (many tens of thousands) tracks, if e.g. magnetic beads will be used to generate a useful electric current. Another application, which arose more from the limitations posed by molecular motors rather than their opportunities is parallel computation with agents. Essentially, this type of biocomputation would be based on the exploration (possibly coupled with position-reporting) of micro- or nano-lithographically patterned graphs by agents (e.g. actin filaments). Two possible architectures of a nano-device based on linear molecular motors are possible, namely filaments-moving-on-motors-functionalised-microstructures; and motors-functionalised-beads-moving-on-filaments-functionalised-microstructures. The first architecture is attractive because it offers multiple possibilities for movement control, e.g. either passive means (e.g. motor-selective of filaments-selective patterns combined with confining microfabricated structures) or active means (e.g. fluid flow or electric fields). However, embracing this architecture has several penalties. Firstly, motor proteins are in a sense multiple proteins, i.e. they have very different molecular structures for each stage in the power stroke cycle. It is therefore very difficult to find an engineered surface that would not denaturate the protein in any of its molecular structures. The less-than-optimum surface will then induce a rapid loss of motility. Secondly, it is much more difficult to anchor cargos on filaments than to functionalise them with motors. Thirdly, this architecture does not use the inherent function of the filaments to guide the motion. The second architecture poses very difficult fabrication problems, because one needs to organise the filaments in a meaningful manner at the nano-level. The choice of the nano-device architecture will ultimately depend on the envisaged application. The contribution will review the opportunities and challenges as well as state of the art research on nano-devices based on protein linear molecular motors.

3:30 PM *O2.5
Interfacial Issues in Bio-Integration. Bruce Conrad Bunker[1], George D. Bachand[1], Jospeh M. Bauer[1], Andrew K. Boal[1], Dale L. Huber[1], Ronald P. Manginell[1], Carloyn M Matzke[1], Susan B. Rivera[1], Viola Vogel[2] and Henry Hess[2]; [1]Biomolecular Materials and Interfaces, Sandia National Labs, Albuquerque, New Mexico; [2]Department of Bioengineering, University of Washington, Seattle, Washington.

We are exploring two classes of microfluidic systems involving bioactive materials: 1) systems containing programmable interfaces that can be used to manipulate biomolecules for applications ranging from drug delivery to counter-terrorisn, and 2) systems containing active biomolecules such as motor proteins for providing functions such as active transport. In both types of systems, the interfaces between artificial, man-made materials and biological materials such as proteins must be carefully controlled to preserve, manipulate, and even enhance bio-functionality. This talk will highlight interfacial issues associated with both classes of bio-fluidic systems: 1) Programmable Surfaces for Reversible Protein Trapping. Polymeric interfaces for switching between protein adsorption and desorption, ensuring reversible trapping, and controlling film selectivity will be described. 2) Active Devices Containing Motor Proteins and Microtubules. Interfacial modifications required for using active proteins to manipulate the transport and assembly of nanomaterials in integrated systems will be illustrated. Interfacial modifications involving functionalization of active proteins, use of self-assembled monolayers, and biomineralization of bioactive components will be described.

4:00 PM O2.6
Single-Crystal Cylindrical Nanorings Formed by Epitaxial Self-Coiling of Polar-Nanobelts. Zhonglin Wang, Xiang Yang Kong, Yong Ding and Rusen Yang; School of Materials Science and Engineering, Georgia Institute of Technology, Atlanta, Georgia.

Nanowire and nanobelt based materials have been demonstrated as building blocks for nanocircuits, nanosystems and nano-optoelectronics. Zinc oxide (ZnO) is a versatile smart material that has key applications in catalysts, sensors, piezoelectric transducers, transparent conductor and surface acoustic wave devices. Structurally, the wurtzite structured ZnO crystal is described schematically as a number of alternating planes composed of fourfold coordinated O2- and Zn2+ ions, stacked alternatively along the c-axis. The oppositely charged ions produce positively charged (0001)-Zn and negatively charged (000-1)-O polar surfaces. In this paper, we present freestanding, single-crystal, complete nanorings of ZnO that are formed via a spontaneous self-coiling process during the growth of polar-nanobelts. The nanoring is suggested to be initiated by circularly folding a nanobelt due to long-range electrostatic interaction; co-axial and uni-radius loop-by-loop densely winding of the nanobelt forms a complete ring; and short-range chemical bonding among the loops results in a single-crystal structure. The self-coiling is likely to be driven by minimizing the energy contributed by polar charges, surface area and elastic deformation. The zinc oxide nanoring formed by self-coiling of a nanobelt may be useful for investigating polar-surface induced growth processes, fundamental physics phenomena and nano-scale devices. [1] Pan, Z.W., Dai, Z.R., Wang, Z.L., Science 291, 1947-1949 (2001) [2] Kong, X.Y., Ding, Y., Yang, R.S., Wang, Z.L., Science, to appear in the issue on 02/27/04.

4:15 PM O2.7
The Oriented Immobilization of Proteins onto nanostructured arrays on Self-Assembled Monolayer at Silicon Surface by Electron Beam Lithography. Guo-Jun Zhang[1], Takashi Tanii[2], Takeo Miyake[2] and Iwao Ohdomari[1,2]; [1]Nanotechnology Research Center, Waseda University, Tokyo, Japan; [2]Electronical Engineering and Bioscience, Waseda University, Tokyo, Japan.

Introduction: Proteins immobilized on nanostructured patterns with well-defined feature size and shape are very significant to understand the interactions between cells and surfaces, and have potential applications in proteomics and identification of new drug. This abstract describes patterning of protein nanostructures on octadecyltrimethoxysilane (ODS) self-assembled monolayer (SAM) based on electron beam lithography in combination with biotin and streptavidin system. The resulting protein nanostructures are regular in size and shape with almost no detectable non-specific binding of proteins. Methods and Results: A 10 nm layer of SiO_2 was formed by thermal oxidation on silicon surface. ODS monolayer serving as ultrathin resist film was grown on SiO_2 surface using CVD technique. The nanostructured patterns were then drawn by EB lithography on ODS monolayer. The patterned nano areas were modified with APTES (3-aminopropyltriethoxysilane) to generate amino group after surface activation, and then functionalized with amino-modified biotin via glutaraldehyde. The biotinylated nanostructures were then treated with streptavidin, followed by another incubation with biotinylated GFP. The patterns were characterized by AFM and fluorescence microscopy. The resulting data indicate that the high-affinity molecule recognition leads to the preferential and stepwise immobilization of protein, thereby resulting in homogeneous and parallel protein nanostructures. Conclusion: EB lithography method of fabricating protein nanostructured arrays on SAM at silicon surface is investigated. This approach allows one to precisely control feature size, shape, pitch, and protein attachment on the nanostructured array, which will offer the opportunity to nanofabrication of protein biosensors and biochips.

4:30 PM O2.8
Covalent Immobilization of DNA and Hybridization on Microchips by Microsecond Electric Field Pulses.

Ana Filipa Fixe[1,2], Howard M. Branz[1,4], Duarte M.F. Prazeres[2], Virginia Chu[1] and Joao Pedro Conde[1,3]; [1]INESC-MN, Lisbon, Portugal; [2]CBCE, IST, Lisbon, Portugal; [3]DME, IST, Lisbon, Portugal; [4]NREL, Golden, CO, Colorado.

The widespread application of DNA chips in genetic analysis, pathogen identification and expression analysis requires inexpensive fabrication and simple, reliable diagnostics. The integration of electronics with biology has great potential in both these areas. Previously, we reported the use of single square voltage pulses to enhance by 7 to 9 orders of magnitude the rate of covalent immobilization and hybridization of single stranded DNA probes on a chemically functionalized thin film surface (silicon dioxide). The pulse was applied to integrated metal electrodes (voltage and ground lines) incorporated below the functionalized thin film surface. These metal electrodes were thermally evaporated using a shadow mask and had mm dimensions. In this work, we present a detailed study of the scaling of electric field-assisted immobilization and hybridization using electrodes with dimensions from 2 mm down to 20 μm in width, with electrode separations from 1 mm to 10 μm. Photolithography is used to define the electrode voltage line, ground line, and functionalized thin-film pixel area. At every electrode dimension, the electric field-assisted DNA immobilization occurs in the microsecond time scale, far faster than the 2 hr needed for immobilization without the electric field. The effect of the pulse voltage and pulse duration on the DNA immobilization density will be discussed. The corresponding study for hybridization and an analysis of the spatial selectivity of the electric field-assisted immobilization and hybridization will be presented. We will also describe our new model of the effect of a fast voltage pulse on DNA reactivity in the biochip, based upon field-induced de-stabilization of a pre-adsorbed DNA layer. These results suggest that cleanroom microtechnologies and electronic addressing of pixel elements can be used in both the production of high-density DNA chips (immobilization) and in the analysis of the DNA microarrays data (hybridization).

4:45 PM O2.9
Optoelectronic Detection of DNA Immobilization and Hybridization with an Integrated Thin Film Silicon Photodetector. Ana Filipa Fixe[1], Duarte M.F. Prazeres[2], Virginia Chu[1] and Joao Pedro Conde[1,3]; [1]INESC-MN, Lisbon, Portugal; [2]CBCE, IST, Lisbon, Portugal; [3]DME, IST, Lisbon.

DNA chips have become important platforms for applications in genetic analysis, pathogen identification and in gene expression analysis. The detection of DNA on chips is currently based on the optical acquisition of the emission from the fluorescently-tagged DNA. Although these optical systems show high sensitivity, they require expensive and complex image acquisition systems. The incorporation of a photodetector in each DNA chip pixel is an important stepping stone towards the full electronic detection of hybridization in these devices. In this work, we use an a-Si:H photodetector in a coplanar electrode configuration for optoelectronic detection of immobilized and hybridized single-stranded (ss) DNA. The ssDNA is tagged at the aminated 3$\prime$-end with a fluorescent molecule (PyMPO-SE) that has a large Stoke$\prime$s shift ($\lambda_{excitation}$=400 nm; $\lambda_{emission}$=560 nm). An increase in the response of the photodetector upon excitation with 400 nm wavelength light indicates the presence of tagged DNA. Since the a-Si:H layer has a significant photosensitivity in the UV, both an a-SiC:H UV filter and an interference filter composed by a high-refractive-index quarter wave layer, followed by 15 bilayers of (λ/4) of SiO_x/SiN_x, were incorporated in the device to improve its sensitivity. The length of the aluminum parallel contacts was 30 mm and their separation 5 mm. The present detection limit is 3.7 pmol/cm^2 of DNA. The density of ssDNA covalently immobilized on a functionalized SiO_2 film was estimated to be 32 $\pm$ 2 pmol/cm^2. For DNA hybridization with a complementary DNA strand the density achieved was 4.5$\pm$ 0.7 pmol/cm^2, while with a non-complementary DNA strand the signal of the photodetector was indistinguishable from the initial state. These results indicate that hybridization has occurred and rules out non-specific adsorption as the source of the photodetector signal. An array of the detectors described above can be used for optoelectronic data acquisition in DNA chips.

SESSION O3: Nanoparticle Synthesis and Applications
Chair: James A. Voigt
Wednesday Morning, April 14, 2004
Room 3005 (Moscone West)

8:30 AM *O3.1
Quantum Dots and their Applications in Biomedicine.
A. Paul Alivisatos, Chemistry, University of California at Berkeley, Berkeley, California.

This talk will review basic developments in the preparation of colloidal semiconductor quantum dots, including experiments related to shape control. The quantum dots are resistant to photobleaching and provide many versatile colors for biological labeling. Several strategies have been developed for making the dots biocompatible and for suitable bio-conjugation with oligonucleotides, antibodies, etc.. Application of the colloidal quantum dots to the detection of DNA hybridization in microarrays, as well as to studies of the motility of cells in culture, will be described.

9:00 AM O3.2
Applications of Biofunctional Magnetic Nanoparticles.
Hongwei Gu[1], Chenjie Xu[1], Keming Xu[1], Pak-Leung Ho[2], R. K. Zheng[3], X. X. Zhang[3] and Bing Xu[1]; [1]Dept. of Chem., Hong Kong University of Science & Technology, Hong Kong, NA, Hong Kong; [2]Dept. of Microbiology, University of Hong Kong, Hong Kong, Hong Kong; [3]Dept. of Physics, Hong Kong University of Science & Technology, Hong Kong, Hong Kong.

Magnetic nanoparticles have attracted considerable attentions in the past few years because of their importance in both science and technology. Comparing to magnetic beads (with the sizes of 1 5 mm) conventionally used in biological separation, magnetic nanoparticles promise new phenomena and applications because of their high surface/volume ratio, ease to enter cells, and excellent solubility. Despite of rapid advances in the research of magnetic nanoparticles aimed at microelectronics, applications of magnetic nanoparticles in biomedicine are just emerging. Here we report the applications of biofunctional magnetic nanoparticles for pathogen detection and protein separation. To develop a quick assay for detecting bacteria at ultra-low concentration for environmental monitoring and clinical diagnosis, we designed a system that combines magnetic dipole interaction and specific ligand-receptor interaction. When the ligands covalently bond to the surfaces of the magnetic nanoparticles, the magnetic nanoparticles binds tightly to bacteria. Our designed vancomycin and FePt magnetic nanoparticle conjugates (FePt–Van) exhibited high sensitivity to a broad spectrum of bacteria, and it can capture bacteria, within one hour, at concentration as low as 4 cfu/mL, which is comparable to the assays based on PCR. We will also describe a simple protocol based on α-N,N-Bis(carboxymethyl)-Lysine or biotin modified magnetic nanoparticles for managing proteins and antibodies at low concentrations. We envision that these systems will ultimately lead to useful applications of magnetic nanoparticles in biological research and clinical diagnosis.

9:15 AM O3.3
Nanoparticle Nucleation and Growth in a Continuous Flow Microfluidic Reactor. Thomas Sournart[1], Jessica Bickel[2], David Tallant[1], James A Voigt[1] and Terry Michalske[1]; [1]Sandia National Labs, Albuquerque, New Mexico; [2]Johns Hopkins University, Baltimore, Maryland.

Nanomaterials, including nanoparticles and quantum dots, nanowires, and nanostructured films, are expected to have wide ranging applications such as advanced computing, chemical and biological analysis/detection, drug delivery/discovery, tissue engineering, catalysis, and energy conversion and storage. However, the current ability to manufacture nanomaterials on large scales is still at a state of infancy. Although great progress has been made on the synthesis and property control for simple nanoparticles, there is a general lack of fundamental understanding of the chemical reaction, nucleation and growth processes of complex functional nanomaterials. Traditional batch operations not only involve extreme synthesis conditions with poor control of thermal, chemical, and fluid transport, but also lack in-situ monitoring and feedback mechanisms for obtaining critical information on the reaction pathways. Microfluidic reactor systems afford control over process variables, not accessible to macroscale batch chemistry. Microfluidic technology involves the manipulation of fluids in microfabricated devices with channel length scales on the order of one to hundreds of microns. On these length scales, laminar flow and high heat transfer rates can be exploited to exercise unparalleled control over fluid, mass, and energy transport. In addition to providing better control of reactor conditions, microfluidic systems provide a unique platform for investigation of fundamental reaction processes. We have used a continuous flow microfluidic reactor system to synthesize CdS quantum dots and to characterize their nucleation and growth. Using a two-feed stream system, an aqueous solution containing CdSO4 was continuously fed into one side of a rectangular microchannel while a solution containing Na2S was fed into the other. The laminar flow of the impinging streams allowed for controlled diffusional mixing of the reacting cadmium and sulfide ions at the interface between the two solutions. Using spatially resolved fluorescence imaging and spectroscopy of the solution-solution interface coupled with varying reactant concentrations and flow rates, kinetic data on CdS particle nucleation and growth have been obtained. The large effect different capping agents, such as cysteine and polyphosphate, have on particle nucleation and growth kinetics will be discussed. Results show a red

shift in cysteine mediated CdS luminescence occurring in the first few seconds of reaction, after which no change in the emission spectra is observed. Microreactor models are now being developed to interpret the data and learn how to better control quantum dot size and morphology. 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.

9:30 AM O3.4
Characterization of Alumina and Silica Sol-Gel Encapsulated Fe/Co/Ru Nanocatalysts in Microchannel Microreactors for Fischer-Tropsch Synthesis of Higher Alaknes *.
Debasish Kuila[1], Venkata Satish Nagineni[1], Shihuai Zhao[1], Himabindu Indukuri[1], Yu Liang[1], Avinash Potluri[1], Upali Siriwardane[1], Ji Fang[1] and Seetala Naidu[2]; [1]IfM/Chemistry, Louisiana Tech University, Ruston, Louisiana; [2]Department of Physics, Grambling State University, Grambling, Louisiana.

We have been investigating conversion of syngas (CO:H2) to higher alkanes (Fischer-Tropsch Process) in 5 micron and 25 micron channel microreactors coated with sol-gel encapsulated nanocatalysts. Characterizations of these catalysts, containing Co, Fe, and Ru in alumina and silica sol-gel, have been studied by several techniques. SEM and EDX were used to study the coating uniformity and elemental composition in order to optimize the sol-gel preparation and deposition processes. The magneto-chemical characterization of iron and cobalt has been performed using vibrating sample magnetometer (VSM) to estimate the reduction efficiency (by hydrogenation to pure metal) and the level of poisoning of the catalyst at the end of the catalytic reactions. The results suggest more efficient reduction of the nano-particles of metal oxides in sol-gel matrix compared to that prepared from nitrates. In overall, 85% of the catalyst is poisoned after 17 hrs of catalytic reaction. This is probably due to formation of carbides of Fe and Co. The surface area and the syngas conversion results indicate that silica sol-gel is a better catalyst support since silica has better adhesion to the silicon channel walls than that of alumina. The higher conversion of syn-gas has been achieved using 25 micron channels microreactor as 5 micron channels are too narrow for sol-gel fabrication. We have obtained 73% syngas conversion to higher alkanes by adding Ru as a promoter to the catalyst mixture. * Work supported by NSF-EPSCoR grant.

9:45 AM O3.5
Reaction and Diffusion Dynamics in a Microfluidic Format.
Rob Lammertink, Dietrich Kohlheyer, Stefan Schlautmann, Geert Besselink and Richard Schasfoort; Science and Technology, University of Twente, Enschede, Netherlands.

A microfluidic device is designed and fabricated, in which multiple laminar flows co-exists in a single a wide flow chamber. Due to low Reynolds numbers, mixing of materials from different flows is purely diffusive. All flows are electroosmotically controlled, so no external pumps are required. Using a simple model the required electrical potentials can be estimated for a given set of flow velocities and positions. Reaction and diffusion kinetics can be studied by positioning laminar streams containing distinct reagents near each other. The stationary state in these geometries can be described by reaction-diffusion equations. Besides that, compounds can be included in additional streams to study more complex competition processes. The operation of the device is further analyzed by results from simulations.

10:30 AM *O3.6
Particle-Based Electrochemical Assays of DNA Hybridzation.
Joseph Wang, Chemistry, New mexico State University, Las Cruces, New Mexico.

The unique properties of nanoparticle-based materials, and the versatility of microspheres, in general, offer excellent prospects for DNA analysis. This presentation will describe new multi-amplification/multi-tag particle-based electrical assays based on variety new DNA-particle nanostructured materials. In particular, combining the catalytic enlargement of the metal-particle tags, with the effective built-in amplification of electrochemical stripping analysis, paved the way to remarkably low (fmol) detection limits. The high sensitivity of the silver-enhanced colloidal gold stripping detection was combined with an efficient magnetic separation. Such use of magnetic beads has been extremely useful for discriminating against unwanted constituents, including a large excess of co-existing mismatched and non-complementary oligomers, chromosomal DNA, RNA and proteins. TEM imaging has indicated that the DNA hybrid links the metal nanoparticles to the magnetic beads. No such aggregates were observed in the presence of noncomplementary or mismatched DNA. The magnetic bead capture was also combined with a label-free detection of DNA hybridization based on highly-sensitive stripping potentiometric measurements of the target guanine. The attractive bioanalytical behavior of the new particle-based electrical assays will be illustrated in connection to the detection of DNA segments related to the breast-cancer BRCA1 gene. Current efforts in our SensoChip Lab are aimed at developing new multi-amplification/multi-tag particle-based bioassays and transforming them to microchip platforms.

11:00 AM O3.7
Biodirected Aqueous Synthesis of Quantum Dots for Cellular Localization.
Saeeda Jaffar[1], Rick Henrikson[1], Christine Flynn[2] and Angela Belcher[2]; [1]Chemical Engineering, MIT, Cambridge, Massachusetts; [2]Bio Engineering, MIT, Cambridge, Massachusetts.

Quantum Dot emission peaks can be finely tuned based on the semi-conductor materials, and the size of the dots. Therefore, they have found several applications in biotechnology, including cellular imaging. We are investigating the aqueous synthesis of biocompatible quantum dots using precursor salts and hydrophilic biological capping agents. In addition to being environmentally friendly, this method does not require additional surface chemistry to make the dots biocompatible. A variety of biological molecules have been used as capping agents, including proteins, peptides and amino acids, in addition to synthetic polymers. All terminators except the peptides associate with the quantum dots via non-specific electrostatic attractions; the peptide was specifically selected to nucleate and bind to CdS. The synthesis were conducted at different temperatures, pH and concentrations, and the product quality was assessed by obtaining absorption / emission spectra and using them to calculate nanocrystal size and distributions. The biocompatibility of the dots was tested by monitoring their fluorescence and cytotoxicity in vitro, over extended periods of time (hours to days). The dots were incubated with cells, and their routes of entry and cellular localization were observed using fluorescence microscopy. Cytotoxicity was determined using Calcein-AM and ethidium homodimer live/dead cell staining. Based on the results obtained thus far, these dots appear to be biocompatible, however their size distribution is not very tightly controlled. In addition, these dots also possess functionalities that may be easily modified for additional bioconjugation, and are potentially useful for building bio-sensors, and serving as an important tool in biolabelling and analysis.

11:15 AM O3.8
Targeting Magnetic Nanoparticles in High Magnetic Fields for Drug Delivery Purposes.
Ramazan Asmatulu, Rick O. Claus and Judy Riffle; FEORC, Virginia Tech, Blacksburg, Virginia.

Recently, several research programs have investigated the use of nanoparticles (in the range of 10 nm to few microns) in cancer therapy. It seems that magnetic nanoparticles have several advantages over other cancer treatment techniques (i.e., surgery, radiation therapy, hormone therapy, biologic therapy and chemotherapy) because they theoretically can be localized in tumors, sparing normal tissues from exposure. This greatly decreases the side effect and increases the efficiency of chemotherapy drugs. In the present studies, methods of developing and guiding magnetic nanoparticles through a rubber tube (used here to simulate part of the arterial system) are investigated by using external magnetic forces. This paper includes discussions of such magnetic nanoparticles for drug delivery, magnetic field properties needed to allow guiding based on these particle characteristics, fluid speed associated with dynamic forces, the uniformity of magnetic fields and gradients, magnet distance effects, solid content and imaging techniques employed to view these particles while in transport. It is determined that these and other factors influenced the type of magnetic guidance system that is needed for an effective drug delivery approach. In addition, an analytical simulation of magnetic forces for controlling test variables and field-particle interactions is also developed to better understand the magnetic particles in the field. Overall, the test results show that the testing variables are important parameters for controlling the positioning of the magnetic nanoparticles using magnetic fields.

11:30 AM O3.9
Photophysical Properties of CdS Nanoparticles in Thin Films for Opto-Chemical Sensing.
Elena A. Guliants[1], Barbara A. Harruff[2], James R. Gord[3] and Christopher E. Bunker[3]; [1]Energy and Environmental Sciences, University of Dayton Research Institute, Dayton, Ohio; [2]Department of Chemistry, Clemson University, Clemson, South Carolina; [3]Propulsion Directorate, Air Force Research Laboratory, Wright-Patterson Air Force Base, Ohio.

In recent years, II-VI compound semiconductor nanoparticles synthesized in a liquid solution have been shown to possess unique optoelectronic properties which are highly attractive for the fabrication of various sensors based on the optical signal readout scheme. The challenge has been to immobilize these nanoparticles into films on solid surfaces, i.e. on a chip, so that they are sufficiently passivated inside the polymeric casting matrix and at the same time

do not suffer any property deterioration as a sensing medium. In the presented work, synthesis of CdS nanoparticles in reverse micelle solution using AOT surfactant as a stabilizer has led to particles with relatively bright photoemission identified as originating from both shallow and deep traps inside the bandgap. Slightly altering the preparation procedure has produced samples with two distinctive crystal structures. Both types of CdS nanoparticles suspended in commonly utilized solvents such as chloroform and hexane were subject to chemical quenching when various organic compounds were introduced into the solution, demonstrating the sensitivity of trap states to their chemical environment. However, the two structures have shown very different optical properties. While post-synthesis treatment had no effect on one type of particle, the other type was able to undergo a photochemical reaction via prolonged UV irradiation, which resulted in an increased luminescence quantum yield FL (12%). The same particle type was also responsive to thermal treatment, showing even higher values of FL (40%). The particles have been cast into thin films by spin-coating on Si chips using various matrix materials. Coating parameters have been investigated in order to achieve optimal control over the film thickness, uniformity, chemical resistance to aggressive environments, temperature tolerance, overall film durability, etc. Photoluminescence data collected for these nanostructured films with exposure to a series of quenching compounds served for identification of the compounds and their concentrations. This paper offers the detailed discussion of photophysical processes in CdS nanoparticle-based thin films with respect to development of novel nanostructured opto-chemical sensors.

11:45 AM O3.10
Decoration of Carbon Nanotubes with Gold Nanoparticles for Catalytic Applications. Xicheng Ma[1,2], Ning Lun[3], Xia Li[3] and Shulin Wen[3]; [1]Department of Material Science and Engineering, Shandong Institute of Architecture and Engineering, Jinan, Shandong, China; [2]School of Chemistry and Chemical Engineering, Shandong University, Jinan, Shandong, China; [3]Characterization and Analysis Center for Materials,School of Material Science and Engineering, Shandong University, Jinan, Shandong, China.

Recently, gold attracted much attention in catalyst research and industrial chemistry since its inertness was disproved by using ultra-fin particles. It has been demonstrated that gold nanoparticles dispersed on metal oxides can exhibit high catalytic activities for various types of reactions, e.g. the selective reduction of NO, selective oxidation of CO, selective oxidation of hydrocarbons, epoxidation of propene and selective hydrogenation, and it is believed that in a number of specific areas, supported Au catalysts will be used in commercial applications, including pollution control. Otherwise, the use of Carbon nanotubes (CNTs) as potential catalyst supports is now attracting the interest of the catalytic community with evidence of unique metal/support interactions resulting in quite distinct catalytic behavior. In the present work, we have tried to couple gold nanoparticles onto the outside surface of CNTs by using a simple electroless plating technique. The purpose of us is to obtain new gold catalysts with improved performance, i.e. high activity and selectivity. There appears to have been no reports to date on the using of eletroless plating technique to deposit Au nanoparticles onto the outside surface of CNTs. However, due to the highly hydrophobic nature and very regular structure of CNTs it may not be an easy exercise; activating their surfaces is an essential prerequisite for linking nanoclusters to them. In our work, activated CNTs were obtained by oxidizing the purified CNTs in a H2SO4-HNO3 blend acid and followed by activating the oxidized CNTs via a single-step activation approach. Both high-resolution transmission electron microscope (HRTEM) and diffusion reflectance infrared fourier transform spectroscope (DRIFT) were used to investigate the surface states of the pretreated CNTs. Both HRTEM and energy-dispersive X-ray spectroscopy microanalysis (EDS) techniques were used to provide information about the composition and microstructure of the samples after electroless plating, the dispersion and the particle size of the supported phase. Experimental results showed that pretreatment with H2SO4-HNO3 can create high-dense active defects and various functional groups such as hydroxyl and carboxyl groups on CNTs, which can act as specific sites for tethering metal ions to the tubes. HRTEM micrographs evidenced the very high-dense and homogeneous dispersion of spherical gold nanoparticles on the outer surface of the carbon nanotubes after electroless plating, with a sharp particle size distribution centered at around 3-4 nm of diameter. The influences of the experimental parameters on the final disposition, i.e. the dispersion and the particle size of the supported phase, were also discussed. The resultant materials presented in this work are expected to have much more improved performances than Au catalysts supported on traditional supports.

SESSION O4: Nanomaterials and Nanofabrications in Microsystems and Microdevices I

Chair: Zhonglin Wang
Wednesday Afternoon, April 14, 2004
Room 3005 (Moscone West)

1:30 PM *O4.1
Controlled Synthesis of Carbon Nanotubes. Shoushan Fan, Department of Physics and Tsinghua-Foxconn Nanotechnology Research Center, Tsinghua University, Beijing, China.

We present a C-13 labeling method for revealing the growth model of carbon nanotubes and monitoring the detailed growth process of a multi-walled carbon nanotube (MWNT) array. C-13 and C-12 ethylene are fed into a chemical vapor deposition (CVD) reactor with pre-designed time sequences to grow MWNT arrays with C-13/C-12 sections, and the isotope compositions of each section in the nanotubes are detected by a micro-Raman after growth. By relating the positions of the isotope compositions to the corresponding feeding times, we can give a detailed picture of the growth model of the carbon nanotubes as well as of the growth process of the nanotube arrays in CVD. We also show a new finding that CNTs can be self-assembled into yarns simply by being pulled out from super-aligned CNT arrays. In this processing, the CNT arrays served as a cocoon. The pure CNT yarn is made of well-aligned CNT segments that are jointed end to end by van der Waals interaction. The CNT based polarizer extending to ultraviolet (UV) region was implemented by parallel aligning a large multitude of yarns. The yarns were also used as the filament of a light bulb, which emitted incandescent light with smaller power consumption. It was found that the strength and the conductivity of the yarns can be considerably enhanced after high temperature treatment. Furthermore, polarized light emission from MWNT filament due to current heating was observed. The spectra of the emitted light fit well with the blackbody radiation distribution and the emitted light is polarized along the axis of MWNT filament.

2:00 PM O4.2
Nanosprings of piezoelectric ZnO nanobelts. Xiang Yang Kong, Yong Ding and Zhonglin Wang; School of Materials Science and Engineering, Georgia Institute of Technology, Atlanta, Georgia.

Nanowire and nanotube based materials have been demonstrated as building blocks for nanocircuits, nanosystems and nano-optoelectronics. Zinc oxide (ZnO) is a versatile smart material that has key applications in catalysts, sensors, piezoelectric transducers, transparent conductor and surface acoustic wave devices. Structurally, the wurtzite structured ZnO crystal is described schematically as a number of alternating planes composed of fourfold coordinated O2- and Zn2+ ions, stacked alternatively along the c-axis. The oppositely charged ions produce positively charged (0001)-Zn and negatively charged (000-1)-O polar surfaces, resulting in a normal dipole moment and spontaneous polarization as well as a divergence in surface energy. To maintain a stable structure, the polar surfaces generally have facets or exhibit massive surface reconstructions, but ZnO (0001) is an exception, which is atomically flat, stable and without reconstruction. In this paper, we report the success of synethsizing freestanding ZnO nanobelts that grow along the a-axis and their large top and bottom surfaces are the polar (0001) facets. Owing to the positive and negative ionic charges on the zinc- and oxygen-terminated +-(0001) surfaces, respectively, a spontaneous polarization is induced across the nanobelt thickness. As a result, helical nanostructures and nanorings are formed by rolling up single-crystal nanobelts; this phenomenon is attributed to a consequence of minimizing the total energy contributed by spontaneous polarization and elasticity. The polar surface dominated ZnO nanobelts are likely to be an ideal system for understanding piezoelectricity and polarization induced ferroelectricity at nano-scale; and they could have applications as one-dimensional nano-scale sensors, transducers and resonators. [1] Pan, Z.W., Dai, Z.R., Wang, Z.L., Nanobelts of semiconducting oxides, Science 291, 1947-1949 (2001) [2] X.Y. Kong and Z.L. Wang, Nano Letters (Dec. 2003) + Cover

2:15 PM O4.3
Carbon Nanotube-Based Permeable Membranes.
Jason Knowles Holt[1], Hyung Gyu Park[2,1], Olgica Bakajin[1], Alexandr Noy[1], Thomas Huser[1] and David Eaglesham[1]; [1]Chemistry and Materials Science, Lawrence Livermore National Laboratory, Livermore, California; [2]Mechanical Engineering, University of California, Berkeley, Berkeley, California.

By virtue of their size (tens of nm diameter or less), multi-walled carbon nanotubes present an ideal medium for molecular separation. This feature also makes them suitable for chemical/biological sensing applications, provided appropriate functionalization can be implemented that does not radically change their electrical properties. To make a robust membrane from this material, however, an appropriate filler material must be chosen, since the as-grown

nanotubes are weakly bound to the catalyst-coated substrate on which they grow. We have found silicon nitride to be suitable in this regard, as it results in conformal deposition around the nanotubes, and results in mechanically stable windows of this composite material of order 10 microns. To remove the excess nitride and open up the nanotubes, a chemical/mechanical polishing or plasma etching step is necessary and both processes have been evaluated. With the resulting nanotube membrane, size-exclusion measurements are being performed using fluorescently labeled polystyrene to verify that there are no large scale (>100 nm) voids that propagate through the material. Isotopic tracer and conductivity measurements will subsequently be performed to look for evidence of molecular/ionic transport through carbon nanotubes – a theoretically predicted, but not experimentally verified phenomenon. The approach we have developed here also provides an ideal platform for producing hydrophilic versions of these membranes, which can be created by combustion of the carbon. Both nanoporous nitride and oxide will be fabricated by this approach and similar transport measurements made.

2:30 PM O4.4
Integrated RF Micro-Coils on Porous Silicon.
Charles Populaire[1], Boudjemaa Remaki[1], Vladimir Lysenko[1], Daniel Barbier[1], Mircea Armenean[2], Emmanuel Perrin[2] and Herve Saint-Jalmes[2]; [1]Laboratoire physique de la matiere, INSA de lyon, Villeurbanne, France; [2]Laboratoire de Resonance magnetique nucleaire, Universite claude bernard, Villeurbanne, France.

We present an improved on-chip integration of rf planar micro-coils using porous silicon (PS). This material exhibits attractive potentialities for electronic and sensor devices. Its low dielectric constant associated with its ability to be micro-machined in thick patterned PS layer, allow the development of powerful integrated inductive components for micro-scale. An original design based on CMOS technology integration compatibility of PS has been developed to include on the same electronic component, a double face planar micro-coil and its associated resonant circuit. Thick patterned PS silicon structures prepared on 0.02 Ω.cm p-type Si substrates using nitride mask were used. The investigation of fundamental electrical parameters and modelization were performed in RF range (1 MHz to 500 MHz). Finally, the quality and the performances of micro-inductors designed on PS for NMR spectroscopy are discussed.

2:45 PM O4.5
Patterning and Alignment of Crystalline Nanostructures Using Modified Surfaces. Z. Ryan Tian, Julia W.P. Hsu, James A. Voigt, Jun Liu, Carolyn M Matzke and Bonnie B. Mckenzie; Sandia National Lab, Albuquerque, New Mexico.

Integration of top-down lithographic-based micropatterning with bottom-up self-assembly of nanostructures is a powerful methodology for producing subassemblies for use in advanced microsystems. Here we describe the use of solution synthesis routes for the nanostructured growth of crystalline assemblies (e.g. SiO2, ZnO, etc.) on a variety of micropatterned substrates. Mesophase silicates were synthesized in the form of octahedral crystalliites through the self-assembly of surfactant-mediated micelles. X-ray diffraction (XRD) and transmission electron microscopy (TEM) work indicate that the silicate octahedra are cubic in structure. Through controlling growth conditions, a wide variety of crystallite morphologies of varying hierarchical structure were prepared. These crystallite structures, in turn, were patterned through the use of patterned self-assembled monolayers of organic thiols on Au. The hydrophobic compatibility between the (-CH2CH2-) group in the silicate precursor and the hydrocarbon chain of the surfactant is believed responsible for the registration of the octahedra on the micropatterns. The shape and size of the micropatterns control the morphology and spatial organization of these patterned silicate crystallites. For surfactant-free systems in which nucleation and growth occur by assembly of simple ions from solution, patterning is accomplished through use of self-assembled monolayers possessing hydrophilic tails. We will describe the controlled patterned growth of arrays of ZnO nanorods using this type of SAM system. 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.

3:30 PM *O4.6
Filling Carbon Nanotubes with Biological Molecules: Simulation, Theory and Experiment. Yong Kong[1], Daxiang Cui[1], Cengiz Ozkan[2] and Huajian Gao[1]; [1]Max Planck Institute for Metals Research, Stuttgart, Germany; [2]Department of Mechanical Enginneering, University of California, Riverside, California.

The interaction between materials science and biology has emerged as a new area of research in which theoretical and experimental studies of structure, function and behaviors of DNA, RNA and protein together with nanostructured materials have become a focus. Bio-nano-materials, which combine the unique properties of nano-materials with biological recognition capabilities, could lead to novel nanoscale devices for applications in bioengineering, clinical medicine and other fields. A central issue for bio-nano-systems is the functionalization of nanostructures and understanding the interfaces and interactions between nanomaterials and biomolecules. We have demonstrated by molecular dynamics simulations, theory and experiment that DNA oligonucleotides and polypeptides could be encapsulated inside of a carbon nanotube in an aqueous environment due to van der Waals and hydrophobic interactions between nanotube and biological molecules. With an external electrical field, DNA molecules could be actively or selectively translocated through nanotubes. This study has general implications on filling nano-porous materials with water solutes of molecular cluster or nano-particles. The encapsulated carbon nanotube-oligonucleotide or other carbon nanotube based bio-nano-complex will be further exploited for applications such as molecular electronics, sensors, electronic gene sequencing, and nano-technology of gene/drug delivery systems.

4:00 PM O4.7
Control of Doping and Electronic Transport in Nanowires for Nanowire-based Microsystems. Jianxin Zhong, Computer Science and Mathematics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Recent breakthrough in successful growth of semiconductor nanowires [1-4] offers great opportunities to revolutionize technologies in electronics, opto-electronics, and spintronics. We believe that the key toward such potential applications is a clear understanding of the fundamental mechanism of doping in nanowires for manipulating carrier transport and signal processing. Traditional theory of electronic disorder predicts that doping in one-dimensional systems leads to electron localization, limiting practical applications of nanowires because of poor electron mobility. In this paper, we study electron dynamics in nanowires of electronic disorder induced by doping, using the quantum diffusion approach [5]. We show that electron transport in a doped nanowire strongly depends on the positional distribution of dopant atoms because of the nanometer size of transverse section of the nanowire. When doping a nanowire only in its wall region, we find that the electron localization length in the nanowire undergoes a transition as dopant density increases. It decreases first but increases after the strength of the electronic disorder exceeds a critical value, indicating that electron mobility can be enhanced under heavy doping. This novel concept different from the traditional view may find many important applications in future nanowire-based electronic, optical, and magnetic microsystems.
[1] A.M. Morales, and C.M. Lieber, Science 279, 208 (1998). [2] L.J. Lauhon, M.S. Gudlksen, D. Wang, and C.M. Lieber, Nature 420, 57 (2002). [3] Y.Y. Wu, R. Fan, and P.D. Yang, Nano Lett. 2, 83 (2002) [4] M.T. Bjork et al., Nano Lett. 2, 87 (2002). [5] J.X. Zhong et al., Phys. Rev. Lett. 86, 2485 (2001). * Supported by the Material Sciences and Engineering Division Program of the DOE Office of Science under contract DE-AC05-00OR22725 with UT-Battelle, LLC.

4:15 PM O4.8
Synthesis and Device Applications of Hierarchical Continuous Metallic and Semiconductor Nanowire Thin Films.
Donghai Wang, Maria P Gil, Rong Kou, David T Johnson, Byron F McCaughey, J Eric Hampsey and Yunfeng Lu; Chemical and Biomolecular Engineering, Tulane University, New Orleans, Louisiana.

Nanoscale materials often show unique and superior physical, chemical, and tribological properties. The promise of nanotechnology is fulfilled when these unique properties are translated into dimensions that human beings can touch or see. A significant step towards this goal is the assembly of nanoscale materials into three-dimensional hierarchical structures with large length scales. In this talk, we will demonstrate a novel synthesis of hierarchical continuous metal and semiconductor (Pd, Pt, CdS, CdSe) nanowire/mesh films, and apply them to sensor and photovoltaic applications. These nanowire/mesh thin films were synthesized by electrodepositing metal, semiconductor, or alloys into mesoporous silica thin films. Removal of the templates leads to the formation of continuous nanowire/mesh thin films with hierarchical structure controls (e.g., mesostructure, nanowire diameter, crystalline structure). The structure of the nanowire thin films has been studied using TEM, SEM, XRD, and other techniques. Electrochemical active area of Pt nanostructured film was measured by hydrogen adsorption in cyclic voltammogram. Electrochemical active areas larger than 27 m2/g were achieved. We have immobilized emzymes like glucose oxidase on Pt nanowire films and fabricate glucose sensors with excellent stability and better sensitivity. We are able to tune the optical properties of the semiconductor nanowire thin films through tuning diameter of the nanowires. We have also demonstrated the fabrication of high-efficiency photovoltaic devices by infiltrating hole-conducting polymers within the continuous CdSe nanowires film. This research provides a new approach to synthesize

nanostructured films for device fabrications.

4:30 PM O4.9
Integrating Carbon Nanotubes for Advanced Nanodevice and Nanosensor Applications. Qi Laura Ye, Alan Cassell, Jie Han and Meyya Meyyappan; Center For Nanotechnology, Eloret Corporation, NASA Ames Research Center, Mountain View, California.

Carbon nanotube (CNT) related nanostructures possess remarkable electrical, mechanical, and thermal properties. To produce these nanostructures for real world applications, a large-scale controlled growth of carbon nanostructures is crucial. We have taken the approach of combining nanopatterning and nanomaterials synthesis with current silicon microfabrication technologies. In this paper, we report our recent work on plasma enhanced chemical vapor deposition (PECVD) method for controlled wafer-scale carbon nanotube growth. This development has made it possible to integrate nanomaterials on micron-scale devices and sensors at large quantities. This integration requires a catalyst or nanomaterial protection scheme. We will discuss various approaches that we have studied. We have used these technologies successfully to produce carbon nanotube AFM cantilever probes on whole wafers. We will address the design and fabrication considerations in detail, and present the preliminary scanning probe test results. This work may serve as an example of rational design, fabrication, and integration of nanomaterials for advanced nanodevice and nanosensor applications.

4:45 PM O4.10
Polyaniline Nanowires: Promising Materials for Chemical Microsensors. Bruce H. Weiller[1], Shabnam Virji[2,1], Jiaxing Huang[2] and Richard B Kaner[1]; [1]Space Materials Laboratory, The Aerospace Corporation, Los Angeles, California; [2]Department of Chemistry & Biochemistry, University of California, Los Angeles, Los Angeles, California.

Polyaniline is a conjugated polymer whose conductivity varies over many orders of magnitude upon doping or dedoping by acids or bases. These characteristics are greatly enhanced when polyaniline is produced with nanoscale features and this is the basis for promising new chemical microsensors. A simple, template-free chemical synthesis is described that produces polyaniline nanowires with narrow distributions of diameters in the range of 25 to 150 nm. This interfacial polymerization is selective for nanowires can be readily scaled to make large quantities and the conditions can be controlled to produce nanowires with the desired diameters. The integration of polyaniline nanowires with microfabricated chemical sensors results in improved time response and sensitivity to many analytes over conventional polyaniline thin films. These include acids, bases, organic solvents, alcohols and hydrazine. Furthermore, the nanowires show essentially no thickness dependence in their sensitivity or time response. Unlike conventional thin films, the sensitivity and time response appears to be controlled by the diameter of the nanowires and not the overall thickness of the film. The small diameters allow rapid and more complete diffusion of analytes into the nanowires, which results in a faster and larger change in electrical response over conventional thin films. These unique properties of polyaniline nanowires make them promising materials for new chemical microsensors.

SESSION O5/W9: Joint Session: Tissue Engineering
Chair: Jeffrey T. Borenstein
Thursday Morning, April 15, 2004
Room 3005 (Moscone West)

8:30 AM *O5.1/W9.1
Microdefining Cellular Habitats for Cardiovascular Tissue Engineering. Tejal Ashwin Desai, Biomedical Engineering, Boston University, Boston, Massachusetts.

Cells in viable tissues respond to mechanical stimuli under both physiological and pathophysiological conditions by changing their metabolism, mass, internal structure, and resorption or production of proteins and extracellular structures, thereby altering their interactions with adjacent cells. In order to begin to understand these complex interactions, cells must be exposed to an appropriate in vivo-like environment. Thus, an important challenge in tissue engineering is to control the 3-D organization of cells in their microenvironments. A key determination in the engineering of these tissues is how, and to what extent, this environment can be controlled in vitro to recreate in vivo-like architecture. Currently, the most common approach to developing a tissue-engineered construct for the restoration, repair, replacement, or regeneration of functional tissues is to allow cells to randomly distribute in an extracellular matrix or polymer scaffold to create a 3-D cell culture environment. However, controlling the cellular microenvironment is essential for the creation of functional tissue engineered constructs. Nonetheless, little work has been carried out in controlling the spatial arrangement of multiple cell populations in 3-D culture. We have utilized micro and nanopatterning and microfluidic delivery techniques to create more physiologic-like tissue engineered constructs. Microtextured substrates have been used to create more physiologic cardiac cell cultures. Microfluidic channels with microtopography, created in polydimethylsiloxane (PMDS) elastomers, will be micropatterned with vascular cell populations (Human Umbilical Vascular Endothelial Cells (HUVEC) and Smooth Muscle Cells (SMC)). The extent to which microarchitecture can influence cellular behavior will be described. Such information will have important implications for implantable tissue engineering constructs and the reduction of immunogenicity in cell -seeded synthetic grafts. This presentation will describe novel tissue engineering approaches for microdefining cell populations, furthering our knowledge of the effects of spatial organization and mechanical stimulation on cell behavior and tissue formation. The proposed technologies and techniques may also offer a more flexible method for the design of tissue engineering constructs. By culturing cells under conditions that are closer to those found in vivo, the relationship between cell function and microenvironment can be more easily studied. In vitro methods for growing cells in tissue-like environments not only has direct application in organ regeneration, but may also be applied to cell-based biosensors, biochips, and high throughput cell-based pharmaceutical screening.

9:00 AM O5.2/W9.2
Fabrication and Evaluation of Uniformly Sized Nanoporous Alumina for Human Osteoblast Cell Culture. Erin Leary Swan, Ketul Popat and Tejal A Desai; Biomedical Engineering, Boston University, Boston, Massachusetts.

Bone tissue engineering requires the ability to regulate cell behavior through precise control over substrate topography and surface chemistry. Aluminum oxide, or alumina, has been extensively employed as a substrate for bone cell seeding in dental and orthopedic implant applications. However, the current techniques do not allow precise surface topography and orientation of the porous material. A new method of producing alumina has been developed to improve osteoblast adhesion and proliferation. A two-step anodization process has been optimized for fabrication of hexagonally arrayed nanoporous alumina membranes. The method allows for the creation of uniformly sized pores in the range of 30 to 80 nm diameter determined by anodization voltage. The membranes display uniform pore density and pore size, which is suggested by scanning electron microscopy (SEM). From this process, a pure, uniform alumina membrane with through holes and specific control of nanostructure was produced. In order to test the compatibility of this porous alumina with osteoblasts, adhesion, proliferation, morphology, and matrix production were tracked for various pore sizes and compared to amorphous aluminum oxide. Growth and adhesion results were evaluated by cell counting and microscopic imaging, while matrix production was quantified by enzymatic assays. Also, alumina surfaces were modified by cell adhesion peptides, and osteoblast growth was compared to the unmodified membranes. Nanoporous alumina can be produced with highly defined pores of constant size and density and provides a stable platform for osteoblast culture that is easily tailored to optimize growth and function. The alumina membranes show promise for employment as a substrate for dental or orthopaedic implants.

9:15 AM O5.3/W9.3
Use of Soft Lithography for Multi-layer MicroMolding (MMM) of 3-D PCL Scaffolds for Tissue Engineering. Yang Sun, Nicholas Ferrell and Derek Hansford; Biomedical Engineering Center, The Ohio State University, Columbus, Ohio.

It is desirable that 3-D scaffolds for tissue engineering have precisely controlled geometries due to their improvement of cellular adhesion and functionality. Surface features smaller (1-10μm) than typical cell dimensions have been shown to have significant effects on cell behavior and cell-surface interactions. In this paper, a soft lithography technique was used to fabricate polydimethylsiloxane (PDMS) stamps of repetitive groove and grid patterns with feature sizes of 5μm width, 5μm depth, and 45μm wide spaces. Several methods were compared for the fabrication of 3-D multi-layer polycaprolactone (PCL) scaffolds with the precise patterns. First, spin coating and oxygen plasma were combined to build 3-D scaffolds with PDMS stamps of the groove pattern. The resultant scaffolds had good alignment and connection between layers; however the upper layer collapsed due to the poor mechanical rigidity. Second, the micromolding in capillaries (MIMIC) technique was used to deliver the polymer into the small grooves by capillarity; however the resultant lines were discontinuous and not able to form layers. Finally, a new multi-layer micromolding (MMM) method was developed and successfully applied in a grid pattern to fabricate 3-D scaffolds. Proper heating and stamping parameters were identified that allowed the successful demonstration of the process on the thermoplastic PCL polymer. Scanning electron

microscopy (SEM) characterization showed that the multi-layered scaffolds had high porosity and precisely controlled 3-D structures. Initial cell seeding experiments showed that the micropatterned scaffolds enhanced cellular attachment and proliferation, and encouraged cellular growth into the scaffold structure.

9:30 AM O5.4/W9.4

Design and Fabrication of a Constant Shear Microfluidic Network for Tissue Engineering. Jeffrey T Borenstein[1], Mohammad Kaazempur-Mofrad[2], Brian K. Orrick[1], Eli J. Weinberg[1,2] and Joseph P. Vacanti[3,4]; [1]Biomedical Engineering Center, Draper Laboratory, Cambridge, Massachusetts; [2]Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; [3]Department of Pediatric Surgery, Massachusetts General Hospital, Boston, Massachusetts; [4]Department of Surgery, Harvard Medical School, Boston, Massachusetts.

Recent progress in microfabrication of biodegradable materials has resulted in the development of a three-dimensional construct suitable for use as a scaffold for engineering blood vessel networks. These networks are designed to replicate the critical fluid dynamic properties of physiological systems such as the microcirculation within a vital organ. Ultimately, these 3D microvascular constructs will serve as a framework for population with organ-specific cells for applications in organ assist and organ replacement. This approach for tissue engineering utilizes highly engineered designs and microfabrication technology to assemble cells in three-dimensional constructs that have physiological values for properties such as mechanical strength, oxygen, nutrient and waste transport, and fluidic parameters such as flow volume and pressure. Three-dimensional networks with appropriate values for blood flow velocity, pressure drop and hematocrit distribution have been designed and fabricated using replica molding techniques, and populated with endothelial cells for long-term microfluidic cell culture. One critical aspect of the fluid dynamics of these systems is the shear stress exerted by blood flow on the endothelial cells lining the walls of the vessel; a key parameter that is known to initiate a cascade of mechanotransduction phenomena whereby mechanical shear forces yield biological responses that govern the cellular function. In this work, we report the design and construction of three-dimensional microfluidic constructs for tissue engineering that have uniform wall shear stress throughout the network. This type of control over the shear stress offers several advantages over earlier approaches, including more uniform seeding, more rapid achievement of confluent coatings, and better control over endothelial cell behavior for in vitro and in vivo studies.

10:15 AM *O5.5/W9.5

NanoLiterBioReactor: Monitoring Long-Term Mammalian Cell Physiology at Nanofabricated Scale. Ales Prokop[1,2], Zdenka Prokop[1], David Keith Schaffer[3], Eugene Kozlov[2], John P Wikswo[4], David E Cliffel[5] and Franz J Baudenbacher[6]; [1]NanoDelivery, Inc., Nashville, Tennessee; [2]Chemical engineering, Vanderbilt University, Nashville, Tennessee; [3]Mechanical Engineering, Vanderbilt University, Nashville, Tennessee; [4]Physics and Biomedical Engineering, Vanderbilt University, Nashville, Tennessee; [5]Chemistry, Vanderbilt University, Nashville, Tennessee; [6]Biomedical Engineering, Vanderbilt University, Nashville, Tennessee.

Microminiaturized cell-culture environments, i.e., NanoLiterBioReactors (NBRs) for growing and maintaining populations of few cultured mammalian cells in volumes three orders of magnitude smaller than in standard environments would lead to major advances in a number of areas. The small NBR volume would reduce the time required for diffusive mixing and thermal equilibrium; allow accurate cell counting; minimize volumes of expensive compounds used for testing; and provide many culture chambers on a single instrumented chip. Such devices would enable development of a new class of miniature, automated cell-based arrays for massively parallel monitoring of the environment of multiple cell lines. Closed-loop adjustments of the environment, e.g., pH and ionic concentrations, could be added to maintain homeostasis. For a nonspecific monitoring of metabolic activity of cells, the biosensor elements might include planar pH, dissolved oxygen, glucose, lactate and redox potential sensors, or even an isothermal picocalorimeter to measure heat response. Given such sensors, one could perform short and long-term cultivations of several mammalian cell lines in a perfused system and monitor their response to test substances/toxins, enabling automated, parallel, and multiphasic monitoring of multiple cell lines for drug and toxicology screening. An added bonus is the possibility of studying cell populations with low cell counts, detached from typical tissue densities, or in controlled physical and chemical gradients. We have fabricated prototype NBRs using glass culture substrates, and connected PDMS microfluidic channels that can be molded using soft-lithography. Input/outlet ports enabled cell seeding and the supply/withdrawal of culture medium into/from 10-120 nL chambers via injectors. The NBRs were sterilized by UV exposure. This system allowed in situ optical/fluorescence microscopy to monitor culture progress. CO2/air supplywas provided by the high oxygen permeability of the PDMS material. Tests were conducted using fibroblast, CHO and Hep2G hepatocyte cell lines. Biocompatibility was determined for different substrates and coatings of extracellular matrix components. A fluorescent PicoGreen DNA assay was used to evaluate the viability and proliferation over 1-5 day period as compared to a plain glass substrate. Glass was found suitable for cell culturing within the NBR environment. For all three lines, viabilities >90% were achieved. The effect of cell seeding density on cell viability and survival was studied in plating experiments using standard well-plate dishes coated with different substrates. A minimum density was noted for some cell lines to achieve a commencement of cell growth. An instrumented NanoBioRector represents a dramatic departure from the standard mammalian culture environment and opens a new paradigm of cell biology, so far largely neglected in literature.

10:45 AM O5.6/W9.6

Increased Function of Bladder Smooth Muscle Cells on Nano-Structured, Three-Dimensional Polymer Constructs. Megan A Pattison, Thomas J Webster and Karen M Haberstroh; Biomedical Engineering, Purdue University, West Lafayette, Indiana.

Many treatments for bladder diseases or disorders, such as bladder cancer and bladder outlet obstruction, require resection of the bladder wall. When this is necessary, biomaterials are needed as bladder wall replacement materials. For these reasons, the objective of the present in vitro research was to construct a three-dimensional synthetic polymer scaffold that has nano-dimensional surface features similar to what cells experience in the bladder. Three-dimensional polyurethane (PU) and poly(lactic-co-glycolic acid) (PLGA) scaffolds were constructed using solvent casting and salt leaching processes. These scaffolds were then manipulated to possess nano-dimensional surface features by soaking in nitric acid and sodium hydroxide respectively at select concentrations for various periods of time. Human bladder smooth muscle cells were seeded into the scaffolds at a density of 25,000 cells per scaffold to perform cytocompatibility studies. Adhesion and proliferation experiments were performed for 4 hours, and 1, 3, and 5 days respectively. In all cases, control cells were placed in an incubator and subjected to normal atmospheric pressure, while experimental cells were placed in a pressure chamber and subjected to a sustained pressure of 10 cm H2O. This pressure was chosen because of its physiological significance, as the bladder experiences between 0 and 10 cm H2O pressure during most of its normal cycle. Additionally, intracellular and extracellular amounts of collagen an elastin were quantified as a measure cellular attraction to the surface. Results of this study provide evidence that porous, nano-dimensional polymer scaffolds can be constructed using these methods. Additionally, cell counts, quantity of elastin (both intracellular and extracellular), and amount of collagen (both intracellular and extracellular) were increased on substrates having smaller surface features for both types of scaffolds. Exposure to pressure did not alter cellular adhesion or proliferation on materials, and cells experiencing sustained pressure contained the same amount of extracellular elastin, intracellular collagen, and extracellular collagen as control cells. Cells experiencing sustained pressure, however, contained less intracellular elastin than control cells. These results indicate that the 3D, nano-dimensional synthetic scaffolds created and studied in this research may be suitable bladder wall replacement materials.

11:00 AM *O5.7/W9.7

Challenges Involving Biologically-Inspired Hydrogel ECMs for Tissue Engineering. Kevin E. Healy, Materials Science & Engineering, Bioengineering, Univ. California at Berkeley, Berkeley, California.

A critical problem limiting the field of tissue engineering is the lack of engineering design rules to guide the synthesis and fabrication of artificial extracellular matrices (ECMs) or scaffolds. To address this issue, we have created artificial ECMs that are environmentally responsive and tunable with respect to mechanical properties (e.g. G*), biological ligands, tissue adhesion, and protease degradation. Our current approach is to create modular hydrogel ECMs where different properties of the matrix can be manipulated independently, thus creating a system where parametric analysis of the effect of hydrogel properties on cell proliferation and differentiation is possible. For example, we have synthesized and characterized the physical properties of semi-interpenetrating polymer networks (sIPNs) consisting of linear polyacrylic acid (pAAc) chains within a thermo-responsive N-isopropylacrylamide-co-acrylic acid network [p(NIPAAm-co-AAc)]. To impart biomimetic character into the hydrogels, the AAc groups on the linear chains have been functionalized with peptides containing the RGD and other sequences. The system allows for easy synthesis of admixtures of peptide sequences while maintaining the mechanical properties of the matrix. Therefore, studies addressing the effect of ligand type and density, in

the context of matrices with various mechanical properties, can be easily performed. These peptide-modified p(NIPAAm-co-AAc) hydrogels with protease degradable crosslinks serve as useful tools for studying cell-material interactions within three dimensional structures and have the potential to be used as injectable scaffolds for tissue engineering applications. In addition, the synthetic strategy we have employed allows for easy control of mechanical and chemical properties of the matrix allowing parametric analysis of the effect of these properties on tissue development both in vitro and in vivo.

11:30 AM O5.8/W9.8
A Novel System for Self-Assembly of Muscle-MEMS Devices. Jianzhong (Jeff) Xi, Jacob Schmidt and Carlo Montemagno; Bioengineering, UCLA, Los Angeles, California.

As microcomponents in engineered systems, biological muscles have unique advantages such as large force transduction, utilization of biochemical fuel, and self-assembly from single cells, over other inorganic actuators for biomedical engineering applications. Successful integration of muscles with inorganic fabricated structures and electronics promises the capability of precisely characterizing muscles' mechanical properties and fabricating self-assembled controllable autonomous structures powered by ubiquitous glucose. However, the use of extracted muscle tissue from animals on these devices is impractical and inefficient, as the tissues must be dissected and incorporated into each device by hand with crude interfaces between the biological tissue and inorganic materials. Integration of muscle with fabricated structures would be optimally achieved through self-assembling muscle cells on MEMS. The construction of self-assembled muscle-powered MEMS structures is complicated by the stringent requirement to spatially direct the cell growth, control the tight connection of these differentiated structures with MEMS structures, and enable the cells and the integrated hybrid to be free to move. Conventional and soft photolithography techniques have been extensively employed to pattern the growth of a variety of cell types and investigate their interaction with substrate in the micrometer level. However, these techniques are only suitable for patterning static cells on a surface, so a novel system of spatially patterning the contractible cells must be developed to enable the cells and the integrated hybrid devices to be free to move. Here we present a novel system of self-assembling myocytes on MEMS devices. This system has shown its capability of spatially and selectively directed growth and differentiation of myocytes into single muscle bundles in situ, attachment of these functional bundles to MEMS structures, and the controlled partial release of the resultant hybrid devices. A novel force transducer capable of in situ characterization of the mechanical properties of muscle at both tissue and single-cell levels has been fabricated using this system. The mechanical properties of the neonatal ventricular myocytes 1-3-day-old Sprague-Dawley rats (NRVMs), such as substrate-induced stress (2-2.5 kPa) and Young's modulus (40 kPa), have been measured using this force transducer. This force transducer has also allowed us to perform dynamic studies of myocytes. Mechanical and dynamic characterization of healthy muscle cells will contribute to better understanding of cardio tissue physiology and further engineering of functional cardiac tissue constructs. Our force transducer has shown the ability to achieve this goal. Furthermore, using this system, we have also created the first self-assembled muscle-powered microrobots. The studies of the characteristics of these microrobots will be also reported.

11:45 AM O5.9/W9.9
Biomimetic Processing of a Biodegradable, Segmented-Polyurethane for Use in Tissue Engineering Devices. Danielle N Rockwood[1], Jean S Stephens[1], John F Rabolt[1], Kimberly Woodhouse[2] and Joanna Fromstein[2]; [1]Materials Science and Engineering, University of Delaware, Newark, Delaware; [2]Chemical Engineering and Applied Chemistry, University of Toronto, Toronto, Ontario, Canada.

A segmented-polyurethane has been synthesized using an amino acid-derived diisocyanate and a phenyalanine-based chain extender. Contrary to many polyurethanes used for tissue engineering applications, this polymer is biodegradable and should prove to be biocompatible. In addition, the segmented nature of the polyurethane allows for elastomeric behavior thus providing the mechanical properties required to respond to physiological stresses. Combined with these advantageous physical properties, the chemical architecture of this polymer unites the necessary functional components (e.g., hydrolyzable groups to promote in vivo degradation) to satisfy the many of the desirable requirements for a tissue engineering construct. The goal of many tissue engineering devices is to closely mimic natural systems. In the case of tissue constructs, the extracellular matrix (ECM) contains protein fibers that range in diameter from a few microns to nanometer scale. In order to mimic the ECM architecture, electrospinning has been used to create membranes of nanometer scale polyurethane fibers. The nature of the electrospinning process is such that a range of fiber diameters and surface morphologies can be produced depending on the choice of processing protocols1. In addition, Raman spectroscopy has been used to ensure the conformational integrity of the polymer before and after processing. Our overall goal is to seed cardiomyocyte cells on these electrospun membranes with the hope that these cells will eventually synthesize their own proteins. Over time, the polyurethane construct will be bioresorbed and the cells will create their own ECM. 1 S. Megelski, J. Stephens, D. B. Chase and J. F. Rabolt, Macromolecules 35, 8456 (2002)

SESSION O6: Nanomaterials and Nanofabrications in Microsystems and Microdevices II
Chair: Zhonglin Wang
Thursday Afternoon, April 15, 2004
Room 3005 (Moscone West)

1:30 PM *O6.1
Nanoimprint Lithography: An Enabling Platform Engine for Nanomanufacturing and Nanosciences. Stephen Y. Chou, Dept of Electrical Engineering, Princeton University, Princeton, New Jersey.

Abstract Not Available

2:00 PM O6.2
Novel Chemistry Approach to Achieve Advanced Soft Lithography by Developing New Materials for Nano-Resolution Plastic Electronics and Microfluidic Devices. Kyung M. Choi[1] and John A Rogers[2]; [1]Bell Labs, Lucent Technologies, Murray Hill, New Jersey; [2]Materials Science and Engineering, University of Illinois at UC, Urbana, Illinois.

Recent developments in advanced microfabrication techniques have brought us useful devices with high performance. Soft lithography has attracted much attention in high resolution pattern transfer by making stamps, molding, and contact-printing with low cost and easy processability, for use particularly in plastic electronics and microfluidic device fabrication. However, the resolution of soft lithography techniques, which rely on elastomeric elements, PDMS stamp materials, often result in collapse and mergence due to their low mechanical strength, especially in the nano-scale regime using commercially available PDMS stamps. New advances in high performance pattern transfer are essential to extend this technology to new areas. These limitations have motivated this work, which demonstrates a chemistry approach to develop useful materials for achieving novel devices with desirable functions. We developed a new stiff, photocured PDMS stamp material. The molecular modification of PDMS structure results in an excellent stamping capability compared to commercial PDMS materials using a master with the most challenging tall and narrow nano-features. Microfluidic droplet reactor is also fabricated using the new PDMS material for submicroscale synthesis of nanoparticules. We also employed molecularly imprinted polymers (MIP) as either chemically functionalized photopatternable material or microfluidic droplet to fabricate novel patterns with specific functionalities such as molecular recognition for bio-device applications.

2:15 PM O6.3
Applications for Polymer Brushes in (Opto)electronic Devices. Gregory L Whiting[1], Henry J Snaith[2], Jason C Pinto[2], Wilhelm T S Huck[1], Richard H Friend[2] and Henning Sirringhaus[2]; [1]Chemistry, Cambridge University, Cambridge, United Kingdom; [2]Physics, Cambridge University, Cambridge, United Kingdom.

The formation of polymer brushes via surface-initiated polymerizations has seen an enormous rise in popularity over the last 5 years. We have previously reported applications of polymer brushes in areas such as switchable surfaces, however the use of this material in organic (opto)electronic devices has not yet been explored. We believe that the properties of polymer brushes, such as enhanced polymer chain alignment, substrate connectivity, and the ability to achieve nano-scale control of the synthesis, make polymer brushes ideal for applications as both active and passive elements in electronic devices. The polymerization techniques that we employ are tolerant of a wide variety of monomers, and as brushes can be synthesized from various substrates, we have been able to show that this flexible system can be exploited for use in polymeric electronic devices. Specifically, the use of polymer brushes for both photovoltaic devices and transistors has been examined. Through our research we have developed the synthesis of a hole-transporting polymer brush from an ITO surface. By fabricating a photovoltaic device using this material as an active component, we have observed a substantial increase in efficiency as compared to a device generated from a standard spin-coating method. We have also been able to use polymer brushes for the generation of thin, dense dielectric layers for use in organic transistors. By taking advantage of the bottom-up nature of the

fabrication of polymer brushes, thin dielectic layers can be formed, which will allow for lower operating voltages in these devices.

2:30 PM O6.4
Fabrication of Poly Acrylic Acid nano-domes with controlled surface distribution for biological applications. Andrea Valsesia, Pascal Colpo, Giacomo Ceccone, Douglas Gilliland and Francois Rossi; EU-JRC-IHCP, Ispra, Italy.

A. Valsesia, P. Colpo, D. Gilliland, G. Ceccone and F. Rossi Institute for Health and Consumer Protection, Joint Research Center, 21020 Ispra (Va) Italy The interaction between material surfaces with specific chemical functionalities and bio-molecules has been widely investigated in order to modulate the performances of bio-sensors and medical devices. Moreover, the tailoring of the geometrical distribution of the active functionalities at the micro- and nano-scale introduces new physical modes of interactions such as the lateral confinement of the interacting bio-molecules. The objective of this work is to develop a reliable technique to produce chemical contrast at sub-micrometric level in creating nano-island of Poly Acrylic acid (PAA), a polymer rich of carboxylic functionalities on a substrate having different properties. First, a thin layer of PAA is deposited on the substrate by PE-CVD. Then, a layer of polystyrene colloidal nano-particles is deposited by spin coating. The nano-particles are then totally removed by oxygen plasma etching of the surface. Whereas unmasked PAA film is completely etched, some nano-domes of PAA (located under the etched nano-mask) are created evenly on the surface. The 2-D geometry of the resulting PAA nano-domes (lateral distribution, surface density) is controlled by the deposition technique of the nano-particles, in particular by the physico-chemical properties of the plasma deposited PAA surface and the dynamic parameters of the spin-coating process. The resulting nano-structured surfaces have been studied using AFM, SEM, SPM and SIMS in imaging mode. Protein adsorption tests are reported.

2:45 PM O6.5
Synthesis and Properties of Polythiophene Confined Within Ordered Nanoscale Inorganic Channels. Xuan Li[1], Xiangling Ji[1], Jiebin Pang[1], Byron McCaughey[1], Donghai Wang[1], Sarah Tolbert[2] and Yunfeng Lu[1]; [1]Department of Chemical and Biomolecular Engineering, Tulane University, New Orleans, Louisiana; [2]Department of Chemistry and Biochemistry, UCLA, Los Angeles, California.

Conjugated Polymers have attracted much attention in the last two decades and these novel materials have many potential applications in optoelectronic devices,such as organic light-emitting diodes, photovoltaic, field-effect transistors, and biosensors. Polythiophene (PTH) has been the subject of extensive work because of the stable conductivity, redox, and the tunable optical and electrical properties. In this research, PTH has been suceessfully electrodeposited into mesoporous silica thin films with variuos pore geometries(e.g. hexagonal, cubic, and largely disodered) and pore diameters (2-10nm), forming a mesostructured PTH/silica nanocomposite thin films. Compared with the bulk PTH, UV-vis spectra and fluorescence spectra of the PTH/silica nanocomposite thin films show significant blue shifts. Such blue shifts also are due to the quantum confinement effects and charges of the conjugation length. After removal of the silica templates, the energy transfer is much quicker, and the template-free PTH thin films exhibit red shifts. This work provides a basic understanding of the confined electrodeposition process of PTH within nanoscale channels and a further insight og the quantum confinement of conjugated polymers embedded in the channels of mesoporous silica.

3:00 PM O6.6
Liquid Phase Deposition of Poly(ethelyne terephthalate) Films. Robert M. Bryce[1], H T Nguyen[2], R R Tykwinski[3], R G DeCorby[4,2], M R Freeman[1] and Y Y Tsui[4]; [1]Department of Physics, University of Alberta, Edmonton, Alberta, Canada; [2]TRLabs, Edmonton, Alberta, Canada; [3]Department of Chemistry, University of Alberta, Edmonton, Alberta, Canada; [4]Electrical & Computer Engineering Research Facility, University of Alberta, Edmonton, Alberta, Canada.

Poly(ethelyne terephthalate), or PET, has been widely used in materials studies due to its well characterized properties and its availability in sheets as thin as 1.5 μm. Its resistance to chemical attack makes PET a good choice as an inert substrate, but also makes it challenging to deposit thin films from liquid phase solutions. Further, attempts to deposit films from the vapor phase has had limited success [1]. A PET thin film technology is desirable, since PET is transparent, hydrophobic, inert, amenable to micropatterning (plasma etching, laser ablation, nanopen lithography), has good thermal, electric, and mechanical properties, and is well characterized. As such, PET films are highly suited for microsystem fabrication of devices for photonic, biomedical and microelectronic applications. We report a simple method allowing liquid phase deposition of thin PET films up to 10 μm thick, and characterize the film structure using atomic force microscopy and Fourier transform infrared spectroscopy. References: [1] V. Shrinet, U.K. Chaturvedi, S.K. Agrawal, and A.K. Nigam, "Deposition of thin Mylar films by a vacuum thermal evaporation technique", J. Vac. Sci. Technol., 21 (4), 1982, 1040-1042.

SESSION O7: Integrated Microanalysis
Chair: Piotr Grodzinski
Thursday Afternoon, April 15, 2004
Room 3005 (Moscone West)

3:30 PM *O7.1
Dielectrophoretic Methods for Sample Preparation and Molecular Analysis. Peter R.C. Gascoyne, Molecular Pathology, The University of Texas M.D. Anderson Cancer Center, Houston, Texas.

Automated micro total analysis systems offer tremendous potential for achieving medical diagnosis at the patient's bedside, at home, at the corner drugstore, and in environments lacking sophisticated medical infrastructure including undeveloped and developing countries. They also promise to enable the development of compact sensors that can detect multiple pathogens and bioagents. Achieving these potentials demands that all steps from sample preparation through molecular detection be accomplished seamlessly and without human intervention in an integrated device. Our lab focuses on a comprehensive view of this problem by attempting to develop mechanically simple technologies for solving all of these requirements. Unexpectedly, the central problem that emerges is the manipulation, sorting and isolation of target biological cells and the molecules within them that are the indicators of disease. In contrast, molecular detection is comparatively well developed. To accomplish comprehensive sample preparation we exploit the phenomenon of dielectrophoresis, the motion of particles caused by induced electrical polarization in non-uniform AC electrical fields, in several forms to address all aspects of cellular and molecular manipulation. This talk will present the current status of our dielectrophoretic sample preparation work, including technologies for: • the identification and isolation of target cells • cell electrobursting to release target molecules • dielectrically-engineered carrier beads able to isolate multiple molecular species in parallel • a programmable fluidic processor, based on discrete droplet chemistries, for multiple end-stage molecular analyses The results will show that dielectrophoresis can allow all steps from sample preparation through molecular analysis to be accommodated in a single, reusable chip having structural and mechanical simplicity and adaptability to many different types of bioanalysis including disease and bioagent detection.

4:00 PM O7.2
Ion Channel Sensor on a Silicon Support. Michael Goryll[1], Seth Wilk[1], Gerard M Laws[1], Trevor J Thornton[1], Stephen M Goodnick[1], Marco Saraniti[2], John Tang[3] and Robert S Eisenberg[3]; [1]Departement of Electrical Engineering, Arizona State University, Tempe, Arizona; [2]Department of Electrical and Computer Engineering, Illinois Institute of Technology, Chicago, Illinois; [3]Department of Molecular Biophysics and Physiology, Rush Medical College, Chicago, Illinois.

Research on biosensors has attracted considerable interest during recent years. One of the challenges in this field is to combine highly sensitive biochemical detection mechanisms with conventional silicon-based readout electronics. Among the various approaches towards biochemical detection, gated ion channels provide a promising way of achieving high sensitivity with excellent selectivity among several reagents. Ion channels inserted in a host lipid bilayer membrane have already shown the desired properties and work reliably. However, these measurements still require a sophisticated laboratory setup. Our approach tries to provide a more rugged design of the measurement setup. Using silicon as the supporting substrate material allows the use of well-established microfabrication tools, thus enabling a downscaling of the bilayer area as well as integrating multiple sensing elements and even electronics on the same chip. In this paper we present a process flow involving conventional optical lithography and deep Si reactive ion etching to create micromachined apertures in a silicon wafer that act as a support for a lipid bilayer membrane. In contrast to other approaches using a silicon nitride layer as a support, our process only involves silicon that is thermally oxidized after the aperture is fabricated to provide the necessary electrical isolation. In order to provide surface properties for lipid bilayer attachment that are similar to those of the PTFE films that are currently used, we coated the silicon surface with a fluoropolymer using plasma CVD. When compared with the surface treatment methods using fluorocarbon chemicals, this novel approach towards modifying the wettability of a SiO_2 surface provides an easy and fast method for subsequent lipid bilayer attachment. An additional 50 μm thick SU-8 epoxy resist layer is applied to one side of the sample to

decrease the capacitance of the sample in the measurement setup. Samples were prepared using 4 inch Si (001) substrates with 520 μm thickness. To create a geometry similar to that in existing PTFE systems, with a hole of 150 μm diameter and an aspect ratio of 1, certain areas of the substrate were thinned down to 175 μm thickness. The holes that were etched all the way through the wafer in these thinned down areas exhibit excellent uniformity and smooth sidewalls. The plasma deposited PTFE film facilitates lipid bilayer formation. Measurements of the sealing resistance of a lipid bilayer attached to such a 150 μm wide silicon aperture show that a gigaohm sealing resistance could be achieved. Subsequently an OmpF channel protein could be inserted into this membrane. I-V measurements are obtained which demonstrate the voltage dependent gating expected from a porin ion channel.

4:15 PM O7.3
Thin film technology based Micro Spectrometers and Spectrometer Arrays. Dietmar Knipp[1], Kyung Hoon Jun[2] and Helmut Stiebig[2]; [1]Department of Science and Engineering, International University Bremen, Bremen, Germany; [2]Institute of Photovoltaic, Forschungszentrum Juelich, Juelich, Germany.

A novel optical micro system using partially transparent sensors will be presented. The sensor concept based on the sampling of a standing wave. The standing wave is created in front of a tunable mirror and sampled by the partially transparent sensor. The spectral information of the incoming light can be analyzed by a Fourier transformation of the transient photocurrent spectra. The working principle of the sensors facilitates the realization of a new class of micro Fourier spectrometers. Due to the simple setup of the system the realization of 1D and 2D micro spectrometer arrays is feasible. The micro system is of interest for applications like adaptive sensing and spectral recognition of objects. The performance of the micro system is limited by the design of the sensor taking the interaction of the standing wave with the multi-layer stack into account. On the other hand the device performance is limited by the material properties. In order to sample a standing wave the active region of the sensor has be distinctly thinner than the wavelength of the incident light. We investigated amorphous silicon and amorphous silicon carbon based pin diodes, which a transmissivity of 60% to 80% in the visible part of the spectrum. Despite extremely thin absorption layers (40nm) the diodes (thickness of the diode <100nm) exhibit excellent diode characteristic with reverse currents as low as 1 nA/cm^{2}up to -0.5V. The measured photocurrents using laser with different wavelengths were compared with simulations using an optical model of the micro system. The model was applied to investigate the optical generation within the thin film detector, the modulation of the photocurrent and the spectral sensitivity of the partly transparent sensor as a function of the position of the mirror.

4:30 PM *O7.4
Microchips Containing Engineered Materials for Biochemical Analysis. Anup K. Sigh, Sanida National Laboratories, Livermore, California.

With the completion of human genome sequencing, the next revolution lies in developing techniques for separation and analysis of thousands of proteins and peptides present in cells. Microfabricated systems are attracting significant attention in the area of proteomics because of their portability, speed of analysis, potential for multiplexing and high throughput, and ability to analyze minute sample volumes. Chromatography (e.g., HPLC) and Gel Electrophoresis, because of their outstanding separation power and versatility, are the most common analysis methods for proteins and peptides and their miniaturization holds substantial promise for rapid analysis of complex biological samples. We have developed microchips for performing chromatography and gel electrophoresis using a photopolymerization technique to controllably and reproducibly place microporous polymer matrices in the channels of a chip. These polymers can be cast in situ in less than 10 minutes, are robust and reproducible with respect to separation characteristics. Microchip containing photopatterned acrylate was used for chromatography of peptides and amino acids and yielded separations that were fast (6 peptides in 45 sec), efficient (up to 600,000 plates/m) and reproducible (run-to-run variability <3%). SDS-PAGE-in-a-chip was developed by photopolymerizing crosslinked polyacrylamide in the microchannels. We were able to separate 6 proteins of molecular weight from 20 to 200 kD in less than 30 seconds using a 1 mm-long channel. The use of solid crosslinked polyacrylamide gel instead of liquid sieving matrix in SDS-PAGE offers a number of advantages including higher peak capacity, higher resolution, and easier integration with other separation channels. We have also developed a miniaturized concentrator for proteins based on a novel phenomenon of "electrokinetic trapping" enabled at the nanoscale. In electrokinetic trapping, charged macromolecules are reversibly trapped in a microchannel packed with nanoporous silica particles under an applied electric field. It is reversible and trapped proteins can be recovered quantitatively by removal of the electric field. A model protein, ovalbumin, could be concentrated by over two orders of magnitude using electrokinetic trapping.

SESSION O8: Poster Session
Chair: Piotr Grodzinski
Thursday Evening, April 15, 2004
8:00 PM
Salons 8-9 (Marriott)

O8.1
Abstract Withdrawn

O8.2
Rapid Prototyping of Glass Microfluidic Devices using Femtosecond Laser Pulses. Myung-Il Park[1], Jun Rye Choi[2], Mira Park[3], Dae Sik Choi[2], Sae Chae Jeoung[2] and Chong-Ook Park[1]; [1]Department of Materials Science & Engineering, Korea Advanced Institute of Science & Technology, Daejon, South Korea; [2]Laser Metrology Laboratory, Korea Research Institute of Standards & Science, Daejon, South Korea; [3]National Creative Research Initiatives Center for Ultrafast Optical Characteristics Control & Department of Chemistry, Yonsei University, Seoul, South Korea.

Laser micromachining technology with 150 femtosecond pulses is developed to fabricate glass microfluidic devices. A short theoretical analysis of femtosecond laser ablation is reported to characterize the femtosecond laser micromaching. The ablated crater diameter is measured as a function of the number of laser pulses as well as laser fluence. Two different ablation regimes are observed and the transition between the regimes is dependent on both the laser fluence and the number of laser shots. Based on the ablation phenomena described, microfluidic devices are fabricated with commercially available soda lime glasses (76 mm × 26 mm × 1 mm, Knittel Glaser, Germany). In addition to a microchannel for microfluidics, the capillary as well as optical fiber for detecting is integrated on the same substrate. The substrate is successively packaged with a lid slide glass by a thermal direct bonding. The presented developments are suitable for fast turn-around design cycle and inexpensive procedure, which provide rapid prototyping of MEMS devices.

O8.3
Optimization of mechanical properties of thin free-standing metal films for RF-MEMS. Jaap M.J. den Toonder and Auke R. van Dijken; Philips Research, Eindhoven, Netherlands.

Within Philips Research we are developing microelectromechanical systems (MEMS) for RF functions in wireless applications. Examples of particular functions that are being developed are tunable capacitors and switches. There are several advantages of RF-MEMS with respect to the conventional passives and switches: for example, they provide critical reductions in power consumption and signal loss thereby extending battery life or reducing weight, and they can be integrated on-chip which enhances miniaturization. The main feature of an RF-MEMS is a thin free-standing metal film made by surface micromachining techniques, which can be actuated electrostatically. The film thickness is about 1 micron, whereas its lateral dimensions are typically 100 microns. The mechanical properties of thin film materials used in RF MEMS are crucial for the reliabiliy and proper functioning of the devices. What is required, in particular, are a sufficiently large yield strength and a low sensitivity to creep to avoid permanent deformation of the films both during processing and use. In this paper a large number of aluminium alloys are studied as possible thin film materials for RF-MEMS. Much is known about the influence of alloying elements in aluminium for bulk materials. However, the effect in thin films (with a thickness of the order of 1 micron) may be quite different, in particular due to the dominance of the free surface and/or the interface with other materials on the behavior. Special techniques were used to determine the yield strength, creep behavior, microstructure, composition, and specific resistivity. Nano-indentation was used to measure the yield strength and the creep properties of the films. Bulge testing was used to study the general stress-strain behavior of the freestanding metal films. Several conclusions could be drawn and interesting materials were identified. The influence of the alloying elements depends on the particular composition. An AlCu(4wt%) alloy exhibited a significant increase in yield strength compared to pure aluminium (a factor of more than 3.5), and clearly less creep. The increase in yield strength of an AlCu(1wt%) alloy, on the other hand, was not that dramatic (only 40 percent), however the creep was substantially less. Several other alloys containing two or more alloying elements exhibited favorable mechanical properties, namely AlMnMg, AlMgCuSi, AlTiB, AlMgCu, AlCuMgMn, and AlSiMgCuNi. All these alloys showed and increase in yield strength with more than a factor of 3 and substantially less creep than pure aluminium. The trends observed in the properties of the alloys could

be explained by the microstructure, in particular the formation of precipitates and the grain structure. The overall conclusion is that the mechanical properties of thin aluminium films can be improved substantially by using alloying elements. Of the alloys studied in this paper, AlCuMgMn and AlMnMg show the best overall performance.

O8.4

Membrane processes studied by a biomimetic lipid/polydiacetylene Langmuir Films. Roman Volinsky[1,2], Amir Berman[1,3] and Raz Jelinek[1,2]; [1]Ilse Katz Center for Nano- and Mesoscience and Technology, Ben-Gurion University of the Negev, Beer-Sheva, Israel; [2]Chemistry, Ben-Gurion University of Negev, Beer-Sheva, Israel; [3]Biotechnology Engineering, Ben-Gurion University of the Negev, Beer-Sheva, Israel.

Molecular assemblies containing phospholipids and conjugated polydiacetylene lipids exhibit unique biochromatic properties and have attracted increasing interest in recent years as potential bio- and chemosensors. We present a detailed study of the thermodynamic and morphological properties of binary films of phospholipids and diacetylene lipids deposited at the air-water interface. Surface pressure-area isotherms analysis, Brewster angle microscopy (BAM), atomic force microscopy (AFM) and fluorescence microscopy have been applied to investigate the formation, organization, and structure of the film domains. BAM data acquired at different temperatures, film compositions, and surface pressures reveal the appearance of distinct patterns of the diacetylenic moieties. In particular, the exceptionally high-quality BAM images point to dendritic and fractal-like appearance of the diacetylene domains; these phenomena are discussed in a framework of diffusion-limited aggregation processes. The results of the microscopy analysis further indicate that the two molecular components already segregate at low compression pressures and that the combined effects of film composition and temperature influence the occurrence of transitions between different phases within the films. This study sheds light on the molecular and cooperative features of mixed lipid/diacetylene films and further helps to understand the unique biosensing properties of these assemblies.

O8.5

Chemical Synthesis and Surface Modification of Core-Shell Nanoparticles for Biological Applications. Hongwei Gu[1], Rongkun Zheng[2], Xixiang Zhang[2] and Bing Xu[1]; [1]Dept. of Chem., Hong Kong University of Science & Technology, Hong Kong, NA, Hong Kong; [2]Dept. of Physics, Hong Kong University of Science & Technology, Hong Kong, Hong Kong.

Here we report a simple procedure to synthesis uniform core-shell magnetic nanoparticles-Co_5Sm@Fe and Co_5Sm@Fe_2O_3 (diameter of 8nm), which are capped with biomolecules via Fe-O bond. This type of magnetic nanoparticles monodisperses in a aqueous solution, and can serve as a useful tool for biological applications, for example, to capture bacteria or viruses at ultra-low concentrations and to enrich biomolecules under magnetic field.

O8.6

Using Biofunctional Magnetic Nanoparticles (BMNP) to Detect Proteins at Ultra-Low Concentration. Hongwei Gu, Fan Yuan and Bing Xu; Dept. of Chem., Hong Kong University of Science & Technology, Hong Kong, NA, Hong Kong.

Here we report a simple and highly efficient method to capture proteins at ultra-low concentrations. Covalently decorated with biotins, FePt magnetic nanoparticles (4 nm) bind to streptavidin. Under magnetic field, the biofunctional magnetic nanoparticles, whose surfaces are adsorbed with proteins, can be controlled by a small magnet when the magnetic nanoparticles aggregate. This process offers experimental advantages-highly efficient for enriching proteins and allowing protein to be moved to any place by a magnetic force.

O8.7

Microstructural Design and Evaluation of Porcelain/ Mullite/Alumina Layered Structure for Dental Application. Dong-Ho Park[1], Hyung-Jun Jang[1], Yeon-Gil Jung[1], Hee-Soo Lee[2] and Brian R. Lawn[3]; [1]Dept.of Ceramic Science and Engineering, Changwon National University, Changwon, Kyungnam, South Korea; [2]Material testing, Machinery and Material Center, Korea Testing Laboratory, Seoul, South Korea; [3]Materials Science and Engineering Laboratory, National Institute of Standards and Technology, Gaithersburg, Maryland.

All ceramic crowns are superior to traditional prcelain-fused-to-metal crowns in aesthetics, wear resistance, and chemical inertness. Quantitative data on clinical performance have not been extensively documented, but some existing studies indicate a tendency for all ceramic crowns to fail after a few years in the mouth. Molar crowns are subject to a demanding environment-typical histories involve $>10^7$ biting cycles at loads up to and even above 200 N over contacts between opposing cusps of characteristic radii 2 to 4mm, in aqueous solution. Herein, we describe the microstructural design and contact damage of porcelain/mullite/alumina layered structure for dental application. The substrate of layered structure was fabricated by using gel-casting process. The infiltration depth of aluminosilicate sols for mullite precursors was dependent on the calcinated temperature of the green substrate (alumina; Al_2O_3), which was calcinated at 900°C and 1100°C, respectively. Three kinds of mullite compositions, such as silica-rich ($Al_2O_3 \cdot 2SiO_2$), stoichiometric ($3Al_2O_3 \cdot 2SiO_2$), and alumina-rich ($7.5Al_2O_3 \cdot 2SiO_2$) mullite precursor sols, were used as the buffer layer (intermediate layer). Porcelain was coated on the alumina/mullite bilayered material. After sintering the layered material, the delamination and/or cracks were not observed at the interface and substrate. Also, continuous microstructure and composition were indicated. Hertzian contact tests were used to investigate the evolution of crack propagation and damage modes, as functions of contact load and coating thickness, in porcelain/mullite/alumina layered structure conceived to simulate the crown structure of a tooth.

O8.8

Low coherence interferometric metrology ultra-thin MEMs structures. Wojciech Walecki, Frank Wei, Phuc Van, Kevin Lai, Tim Lee, SH Lau and Ann Koo; FSM, San Jose, California.

The low coherence optical interferometry has been proven to be an effective tool for characterization of thin and ultra-thin semiconductor Si wafers [1]. In this paper we explain extension of this method to characterization of ultra-thin MEMs structures such as membranes in micromachined devices (MEMs). The usually commonly employed tools for wafer thickness metrology are based on capacitance and air pressure methods. The first of these two competing technologies has been proven to be extremely powerful tool for measurement of thickness, bow, warp and related parameters in relatively thick and well conducting materials. Capacitance method however is not suitable for measuring thickness of semi-insulating and fails to measure insulating materials, and very thin wafers (thinner than 100 mm). Furthermore it has relatively low spatial resolution limited by physical size of probes, and may not be suitable for direct measurement of wafers mounted on insulating carriers or MEMs structures. Air pressure based metrologies are able to measure insulating materials however they also cannot be directly applied to wafers mounted on carriers. Both these competing techniques require access from both sides of the wafer. In this paper we present alternative technique, which does not suffer from above discussed limitations, and discuss it applications for metrology of ultra-thin membranes. Let us consider ultra-thin membrane defined in 300 mm thick (111) oriented wafer by means of anisotropic etch. Nominal thickness of membrane is 20 mm. Structure illuminated by low coherence beam. The low coherence beam is impinging top surface of the membrane and is partially reflected. The remaining transmitted portion of the beam is reflected from the bottom surface of the membrane. The reflected radiation is analysed by low coherence Michelson interferometer similar to this discussed in [1]. The interferogram reveals several features corresponding to various reflections from membrane structure. The optical delay between observed features is directly proportional to thickness of the measured membrane. The measured thickness of membrane was 17 um. Typical reproducibility of the measurement is better than 0.4 mm (1 sigma) measurement takes about 0.3 sec. Better reproducibility can be achieved by averaging results of many measurements. The accuracy is function of accuracy of refractive index used for calculation of the optical delay between features R1 and R2, and typically is of the order 0.1% of measured thickness or better. [1] W.J. Walecki, R. Lu, J. Lee, M. Watman, S.H. Lau, A. Koo, Novel non-contact wafer mapping and stress metrologies for thin and ultrathin chip manufacturing applications, 3 rd International Workshop on Thin Semiconductor Devices Manufacturing and Applications November 25, 2002, Munich, Germany

O8.9

Tuning the Mechanical Properties of Poly-Silicon Film by Surface Modification Using Plasma Treatment. Wang Shen Su[1], Weileun Fang[2] and Ming Shih Tsai[3]; [1]Institute of MicroElectroMechanical System, Institute of MicroElectroMechanical System, National Tsing Hua University, Hsinchu, Taiwan; [2]Institute of MicroElectroMechanical System, Institute of MicroElectroMechanical System, National Tsing Hua University, Hsinchu, Taiwan; [3]National Nano Device Laboratories, Hsinchu, Taiwan.

The mechanical properties of thin film are very critical for the performance of MEMS devices. Since Poly-silicon film is of great use in MEMS, this study investigates the surface modification by various plasma treatments to finely tune the chemical and mechanical properties of poly-silicon film. The changes of chemical bonding and mechanical properties of poly-silicon after plasma treatment were characterized by X-ray photoelectron spectroscopy (XPS), Fourier

transform infrared spectroscopy (FTIR), secondary ion mass spectrometer (SIMS), atomic force microscopy (AFM) and Nano-Indenter. Various plasma treatments, including H2, O2, and NH3, were implemented to modify the original Si-Si film bonding, Young/s modulus, and hardness of poly-silicon film. These were significant Si-O, Si-OH/Si-H and Si-O-NH2/Si-N bonds formed after O2, H2 and NH3 plasma treatment, respectively. According to the SIMS depth profile of N, O and H analysis, the thickness of surface modified layer would be ranged from 50 to 120 nm. The surface roughness of the poly-silicon film before plasma treatment was 1.96 nm. After treated with O2 or NH3 plasma the surface formed the dense oxide or nitride passivation layer, so that the surface roughness had no significant change. However, the surface roughness became 14.85 nm after H2 plasma treatment. Since there is no oxide or nitride surface passivation, the Si-Si networking bonds would be destroyed during the H2 plasma treatment. The Si-H terminal bonding is formed after plasma treatment, so as to weaken the mechanical strength of poly-silicon film. The Young/s modulus and hardness of the poly-silicon film before plasma treatment was 169.9/10.5 GPa. After treated with O2 or NH3 plasma, the surface formed the oxide or nitride passivation layer so that the hardness was increased about 21%. However, the Young/s modulus had no significant change. After treated with H2 plasma, the Young/s modulus and hardness had significant change and became 115.0/3.4 GPa. This was mainly due to the formation of Si-H terminal bonding, thus, the mechanical strength of poly-silicon film was decreased. If this sample was further vacuum annealed at 600°C, the Young/s modulus and hardness even became 70/1.59 GPa. In summary, the surface modification with H2 plasma can reduce the elastic modulus of poly-silicon film for about 32%; moreover, the following vacuum annealing will further reduce the elastic modulus for about 60%. Therefore, surface modification with an adequate plasma treatment would be an effective method to change the chemical and mechanical properties of poly-silicon film.

O8.10

SAM-Ceramic Bilayer Coatings for MEMS Devices.

Scott R. J. Oliver[1], Tolulope O Salami[1], Quan Yang[2], Kaustubh Chitre[2] and Junghyun Cho[2]; [1]Department of Chemistry, SUNY-Binghamton, Binghamton, New York; [2]Department of Mechanical Engineering, SUNY-Binghamton, Binghamton, New York.

A wide range of substrates, such as those in MEMS structures or optoelectronics, often require surface protection from severe environmental conditions. Ceramic coatings as protective films have reliability concerns due to their inherent brittleness, defects formed during deposition and thermal expansion mismatch with the substrate. Organic coatings themselves cannot be used in such applications either, because of their poor mechanical and thermal properties. We are developing a new type of protective bilayer, consisting of both a hard inorganic coating and a complaint underlying organic buffer layer. We thereby utilize the advantage of each layer, combining them into a synergistic coating. The nanoscale self-assembled monolayer (SAM) coatings are chemically tuned or modified as to promote subsequent growth of the hard ceramic coating. The synthetic techniques and characterization of our resultant bilayers will be discussed, as well as efforts into using self-assembled multilayers as the organic coating.

O8.11

Fabrication and Characterization of Platinum-Iridium Electrodes with Micro-Structured Surfaces for Neural Stimulation Applications.

Sachin Suresh Thanawala[1,2], Daniel G Georgiev[2], Afzal Khan[2], Ronald J Baird[2] and Gregory Auner[2,1]; [1]Dept. of Biomedical Engineering, Wayne State University, Detroit, Michigan; [2]Dept. of Electrical and Computer Engineering, Wayne State University, Detroit, Michigan.

Controlled structuring of electrode surfaces on a microscopic scale is expected to decrease the impedance and improve the current injection capabilities of neural stimulation electrodes. We have identified conditions for the fabrication of micro-bumps on platinum-iridium alloy surfaces by means of KrF excimer laser (λ=248nm) irridiation under ambient conditions. A regular array of closely spaced micro-bumps with diameter of about 5μm and heights of about 3 μm was generated on the polished face of a Pt-20%Iridium wire with a diameter of 75μm. A projection system with demagnification factor of 8.9 was used to image a mask with a pattern of circular-holes on the polished face of the wire. Several thousand pulses at a repetition rate of 10Hz and a fluence of 3J/cm^2 were applied to produce the micro-bumps. The modified electrode surfaces were studied by optical microscopy and scanning electron microscopy, and the results show the formation of micro-bumps of reproducible shape. Simple two-electrode AC impedance measurements in the physiological saline in the frequency range of interest to neural stimulation applications (20Hz-20kHz) show a 3-fold reduction of the impedance of micro-structured electrodes with respect to the impedance of a polished electrode.

O8.12

Electroactive Polymer and Composite Microactuators Integrated with Thin-Film Photoconductive High-Voltage Switches for BioMEMS Applications.

Cheng Huang, T.-B. Xu and Q.M. Zhang; Materials Research Institute and Electrical Engineering Department, The Pennsylvania State University, University Park, Pennsylvania.

Polymer or plastic based micro-total-analysis-systems (μ-TAS), BioMEMS and microfludic devices have attracted much interest due to their low cost, lightweight, flexibility, ease of mass production and biocompatibility of the polymer materials. For such a polymer-based μ-TAS system, it is describe to have integrated polymer-based microactuators, micropumps, and microvalves. However, in spite of more than a decade of effort, it is still a challenge to realize microactuators capable of operating over a broad frequency range with high force level and large displacement output. The fundamental reason behind this is the lack of active materials or actuation mechanisms that possess high elastic energy density with high strain capability over a broad frequency range. Electroactive polymers (EAP) with high electromechanical performance are needed in order to meet the demands in applications such as artificial muscles, smart skins for drag reduction, actuators for active noise and vibration controls, and microfluidic systems for drug release and delivery and micro-reactors. Recently a series of poly(vinylidene fluoroethylene-trifluoroethylene) P(VDF-TrFE) based high performance electroactive polymers have been developed using high-energy electron irradiation, or terpolymer approach, which show high electrostrictive strain (7%) and high elastic energy density (1 J/cm3). However, to achieve high-efficiency systems, these EAPs need to work under high voltages. The introduction of all-organic composites with high dielectric constant effectively reduced the driven electric field (13V/μm). Micromachined EAP actuators have been fabricated on the silicon or polymer substrate based on the electrostrictive P(VDF-TrFE) polymers. The performance of the devices demonstrated indicates that this type of electrostrictive P(VDF-TrFE) based MEMS devices is very attractive for micropumps, microvalves, and ultrasonic microtransducer applications. Compared with the ionic-type EAPs, such as conductive polymer and hydrogel actuators, these field-type polymeric actuating materials have great potential applications in BioMEMS, all-platic μ-TAS systems or microfludic pumps and devices biomedical analysis. Furthermore a new smart microsystem was designed and developed using electric EAP microactuators integrated with thin film photoconductive high voltage switches fabricated on the same substrate. The microactuator is P(VDF-TrFE) electrostrictive polymer that moves under electric stimulation. The microactuators is conneted to the high voltage power supply through a photoconductive switch. The amorphous silicon switches are made here. The swithces were tested and the microactuators were successfully working. The integration of electric EAP microactuators with thin film electronic micro-switches shows the path to making novel micro-optoelectromechanical systems (MOEMS) for BioMEMS applications.

O8.13

A Fabrication Technology for Micro Fluidic Systems for Cell Analysis.

Eileen D. Moss, Arum Han and A Bruno Frazier; Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, Georgia.

The development of generic flexible polyimide-based micro fluidic systems with integrated electrical functionality has been realized through the combination of laser ablation, micro stenciling, and heat staking. Utilization of these techniques provides the systems with micro channels, thru and embedded vias, and metallic electrodes and contact pads which lend the systems to cellular assays. Multiple layers of Kapton®, a commercially available, flexible, and translucent polyimide sheet, are bonded together to form the device. Thru holes less than 4 um in diameter, with aspect ratios of over 12:1 have been obtained using laser ablation. The electrical components are deposited on the Kapton® using a micro stenciling technique. The reusable stencil is a silicon wafer patterned with the ICP BOSCH process. The use of the stencil eliminates the multiple steps involved in photolithographic processing. The patterned layers were bonded together without distortion or de-lamination using high levels of heat and pressure (350°C, 1.65 MPa). The current cellular analysis system consists of an array of 16 cell cavities, with two to four electrodes per cavity. The cell cavities are connected to a micro fluidic network. Small thru holes separate the cavities from both the fluid channel and additional electrodes located at the bottom of the channel. Characterization of the micro analysis system will include various electrophysiological analyses of single cells. Patch-clamping studies will be performed, utilizing the electrodes beneath the cell cavities. Impedance spectroscopy and impedance tomography measurements will also be taken which uses the electrodes that are in direct contact

with the cells in the cavities.

O8.14
A simple soft lithographic approach to pattern within microfluidic channels: Fabrication of arrays of cells or proteins within microfluidic channels. Ali Khademhosseini[1], Kahp Yang Suh[2], Sang Yong Jon[2], Guan-Jong Chen[2], George Eng[2], Judy Yeh[2] and Robert Langer[1,2]; [1]Biological Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; [2]Chemical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

The control of surface properties and spatial presentation of functional molecules within a microfluidic channel is important for the development of diagnostic assays and microreactors. Here, we present a simple technique, applicable to all soft lithographic methods, to create robust microchannels with precise control over the spatial properties of the substrate. In this approach, the patterned regions were protected from oxygen plasma by controlling the dimensions of the PDMS mold as well as the sequence of steps during the fabrication process. The approach was used to pattern a polyethylene glycol (PEG)-based copolymer or hyaluronic acid (HA) within microfluidic channels. These non-biofouling patterns were then used to fabricate protein arrays of fibronectin (FN) and bovine serum albumin (BSA) as well as mammalian cells. In addition, precise control over the deposition of multiple proteins onto multiple or individual patterns could be achieved using laminar flow. Also, cells that were patterned within patterned channels remained viable and capable of performing intracellular reactions on the patterned regions and could be potentially lysed for analysis.

O8.15
Fabrication of the cantilever for nanotweezer and nano-hall probe. Seong Choi[1], Jong Suk Moon[2], J.H. Boo[2], K.S. Kim[3], D.W. Kim[1] and Y.H. Lee[3]; [1]Physics, SunMoon University, Ahsan, Chungnam, Chungnam, South Korea; [2]Chemistry, Sungkyunkwan University, Suwon, Kyung Gi Do, South Korea; [3]Physics and Nanoscience, Sungkyunkwan University, Suwon, Kyung Gi Do, South Korea.

Recently there have been considerable interests about nano-manipulation techniques in addition to the characterization of the nano-structure. The simple approach is to exploit the van der Waals force to break off and lift a single nanostructure, the other approach is to use the opposing forces applied by the form of tweezers, where the actuation was carried out by applying an electrostatic potential between the nanotubes. The third one is to use the carbon-based tip using electron beam induced deposition, rather than attachment of CNT. The deflection of the MWNT will be dependent upon the applied voltage, The separation of the nanotweezer will depend upon the applied potential. The two types of the cantilever, rectangular and triangular-type, were fabricated. The length of the fabricated cantilever will range from 50- 100 micrometer; on the other hand, the width of the cantilever will be ranging from 5 micrometer to 20 micrometers. The width of the Ti metallic line will be 200 nm, and the line pitch will be ranging from 200 nm to 1.3 micrometer. The final processing for the nanotweezer will be carried out soon. The microfabricated nanostructure on the cantilever can be utilized either nanotweezer or nano-hall probe.

O8.16
Synthesis and Characterization of Ag, Ag-TiO_2 Nanoparticles and Ag-TiO_2-chitosan Complex and Their Application to Antibiosis and Deodorization. Young Hwan Kim and Youngsoo Kang; Department of Chemistry, Pukyong National University, Pusan, South Korea.

Ag nanoparticles have been prepared by thermal decomposition Ag-oleate complex using electric furnace called autoclave at 300 °C for about 4 hrs. TEM images of the particles showed 2-dimensional assembly of particles with diameter of 8.0±1.3 nm, demonstrating the uniformity of these nanoparticles. Ag-TiO_2 nanoparticles were synthesized by sol-gel process and they had core-shell structure. Results showed the formation of the silver core and the coating with titanium oxide. In this study, we will investigate processes and results of Ag and Ag-TiO_2 nanoparticles and Ag-TiO_2-chitosan complex applied to antibiosis, deodorization and so on. These products were analyzed with thermogravimetric analysis (TGA), X-ray diffraction (XRD), Energy dispersive X-ray (EDX), UV-vis spectrophotometer and TEM images.

O8.17
a study of growth curves of bacteria e. coli and c. xerosis in a medium that contain nanometric particles of cobalt ferrite. David Quispitupa[1], Nicole Villalba[2], Omayra Rivera[3], Morjorie Flores[4], Javier A. Avalos[5] and Oscar Perales[6]; [1]Ciencias, Tegnologia y Salud, Universidad Metropolitana, San Juan, Puerto Rico; [2]Universidad Metropolitana, San Juan, P.R, Puerto Rico; [3]Universidad Metropolitana, San Juan, P.R, Puerto Rico; [4]Universidad Metropolitana, San Juan, P.R, Puerto Rico; [5]Ciencias, Tegnologia y Salud, Universidad Metropolitana, San Juan, P.R, Puerto Rico; [6]Science and Material Engineering Program, Puerto Rico University, Mayaguez, P.R, Puerto Rico.

Previous publications shown the sensibility of Bacteria E. coli and C. xerosis, when these were reproduced in mediums that contain nanoparticles of luminescent silicium. This sensibility was reflected in the differences of the patterns of the population's bacterial growth with the time, in comparison with the observed in absences of the nanoparticles. The mentioned effect will be taken in the development of a bacteriological sensor. In this same direction of the investigation, the present work is centered in the study of the curves of growth of the bacteria mentioned, but now in presence of nanometric particles of Cobalt Ferrite (CoFe2O4) were produced by the co-precipitation method in watery phase. These nanoparticles present the ferromagnetism characteristics (coercivity in ambient temperature among 600-5000 Oe for a size among 15-40nm). The experimental results evidence that the stage of adaptation of the bacteria in contact with a stable suspension of nanoparticles of ferrite shows a curve of growth above the one obtained in absence of the nanoparticles (standard curve). The probable interaction of the magnetic field generated by the nanoparticles of cobalt ferrite with the bacteria and the electric polarity that these possess, should be involved with the observed phenomena. The procedure and the mechanisms involved in the synthesis of the nanoparticles of cobalt ferrite, as well as a study of the changes found in the curves of growth of the bacteria in evaluation will be presented and discussed in our presentation.

O8.18
Adhesion, friction and wear on the microscale of nanostructured fluorocarbon films. Giuseppe Bregliozzi[1], E. Sardella[2], Imad Ahmed[1], Pietro Favia[2], Riccardo D'Agostino[2] and Henry H aefke[1]; [1]CSEM Swiss Center for Electronics and Microtechnology, Inc., Neuchatel, Switzerland; [2]Department of Chemistry and IMIP-CNR., University of Bari, Bari, Italy.

The strong influence of surface forces is a cause of concern in Microelectromechanical Systems (MEMS). Due to the significant technological potential of MEMS, there have been many efforts to find viable solutions. The use of hydrophobic surfaces like self assembled monolayers or Langmuir-Blodgett films have shown promising results. Nanostructured fluorinated films, which combine chemical and structural hydrophobicity, may also have an important role to play. Yet, their microtribological properties are not known and still need to be thoroughly examined. We report on experimental results obtained from thin fluorocarbon (CFx) films on silicon deposited in plasma deposition processes fed with C2F4 and run in different regimes. Under continuous deposition conditions it is possible to deposit amorphous films characterized by a F/C ratio as high as 1.4, water contact angle value of 110° at most, and with very low roughness values. By additionally modulating the discharge (100-300 ms of period; 2-20% of duty cycles) it is possible to deposit, in a certain window of experimental conditions, highly fluorinated, partially crystalline films with a ribbon-like nanostructure randomly distributed all over the surface. When the surface density of such structures is very high, the film becomes extremely hydrophobic, exhibiting water contact angle values greater than 150°. The microtribological properties of three different films were examined: flat, scarcely and highly-dense ribbon-like nanostructured films. A precision reciprocating microtribometer was used to study adhesion and friction on the microscale. Results show that while the adhesion of the highly nanostructured films is the lowest, they show higher friction than the flat films. Also, wear studies indicate higher wear of the dense ribbon-like nanostructures. This is attributed to the adhesion between the ribbon-like nanostructures and the silicon surface. Correlations between the structure of the films and the wetting and microtribological behavior under various environmental conditions will be presented.

O8.19
Phase Field Modeling of Moving Elastic Solids with Interface-Induced Stresses. Adam Clayton Powell, Materials Science and Engineering, MIT, Cambridge, Massachusetts.

The phase field methodology uses a diffuse interface representation to model multiphase phenomena based on thermodynamic statements of free energy. Elastic strain can be used as a tensor field along with order parameter and velocity fields in order to model elastic behavior in solids which are moving and rotating as they are carried by a liquid. This strain field can also store information about the local state of a material, such as orientation in polymers. At small scales, interfaces and elastic stresses interact in the solids, leading to interesting dynamics when small particles coalesce or break apart.

This presentation will focus on the physical completeness and accuracy of phase field representation of such phenomena.

SESSION O9: Nano and Bio Microsystems and Devices
Friday Morning, April 16, 2004
Room 2003 (Moscone West)

8:30 AM *O9.1
Nanofluidic systems and biomolecular analysis.
Harold Craighead, Cornell University, Ithaca, New York.

We have been exploring nanomechanical and nanofluidic systems for isolating and analyzing small amounts of biomaterial. With the appropriate nanostructures one can transduce the activity of a single active biomolecule and detect individual molecular binding events. This talk will discuss devices and results for combining small-scale fluid systems with optics for single molecule analysis. We have also been exploring resonant mechanical systems as sensors, detecting binding of material with masses on the order of attograms. New approaches to fabrication are required for this class of bio devices, combining high resolution processing with organic materials processing. This talk will address some of these methods as well.

9:00 AM *O9.2
Cell Based Biosensors. Cengiz Sinan Ozkan, Mechanical Engineering, University of California at Riverside, Riverside, California.

Cell based biosensors offer the capability for quickly detecting chemical and biological agents with high sensitivity in a wide spectrum. Membrane excitability in cells plays a key role in modulating the electrical activity due to chemical agents. However, the complexity of these signals makes the interpretation of the cellular response to a chemical agent rather difficult. It is possible to determine a frequency spectrum also known as the signature pattern vector (SPV) for a given chemical agent through analysis of the power spectrum of the cell signal. I will describe a system for the measurement of extracellular potentials from primary rat osteoblast cells isolated onto micromachined planar microelectrode arrays. Fast Fourier and Wavelet Transformation techniques are used to extract information related to the frequency of firing and response times from the extracellular potential. Quantitative dose response curves and response times are obtained using local time domain characterization techniques. In order to determine the real time sensing capability of single cell based sensors, cascaded sensing is conducted and the performance of the sensor is evaluated. Cell based sensing technology could change the paradigm of chemical and biological warfare detection from detect-to-treat to detect-to-warn, since it has the capability to directly access the physiological changes and the resulting human performance decrements.

9:30 AM O9.3
Using a Biological Laser Printer to Deposit Lyophilized E. Coli Onto an Optical Biosensor Platform. Peter K. Wu[3], Jason Barron[1], Joanne Jones-Meehan[1], Rachael Rosen[2], Barry Spargo[1], Shimshon Belkin[2] and Bradley Richard Ringeisen[1]; [1]Chemistry, Naval Research Lab, Washington, Virginia; [2]Environmental Sciences, Hebrew University of Jerusalem, Jerusalem, Israel; [3]Department of Physics, Southern Oregon University, Ashland, Oregon.

We have developed a biological laser printer that rapidly deposits patterns of active biomolecules and living cells onto various substrates including biosensor platforms, layers of tissue scaffolding, and micro-devices. Unlike ink jet or manual spotting techniques, our process delivers small volume (nL to fLs) aliquots of biomaterials without using an orifice, thus eliminating potential clogging issues and enabling diverse classes of biomaterials to be deposited. Here we will present studies using this technique to add lyophilized E. coli, as the active element, to an optical biosensor platform. By using lyophilized cells, this sensor has a potential shelf life of several years compared to several days for sensors based on active cell cultures. In addition to demonstrating computer-controlled (automated) deposition of dried cells directly into the desired micron-scale feature of the biosensor platform, we will also present characterization experiments that verify the viability of laser printed cells and their retained ability to respond to chemical stimulants. Specifically, after being deposited into the device, the lyophilized cells were refreshed to enable nalidixic acid detection through fluorescent protein gene reporting.

9:45 AM O9.4
Integrating Biomaterials into Microsystems: Formation and Characterization of Nanostructured Titania.
Zuruzi Abu Samah[1], Blaine C. Butler[2], Emily R. Parker[1], Ayesha Ahmed[2], Heather M. Evans[2], Cyrus R. Safinya[2] and Noel C. MacDonald[1]; [1]Materials Department, and Mechanical and Environmental Engineering Department, University of California, Santa Barbara, California; [2]Materials Department, Physics Department, and Biomolecular Science and Engineering Program, University of California, Santa Barbara, California.

Nanostructured titania is a versatile material with diverse applications from solar cells to gene therapy. However, significant challenges of crack formation and incompatibility of current synthesis methods with microelectronics fabrication procedures hinder its use in Si-based nano—micro-electro-mechanical systems (N—MEMS) devices. Here we propose a technique, compatible with microelectronics manufacturing practices, for fabricating crack-free nanostructured crystalline titania layers by reaction with aqueous hydrogen peroxide. Cracks were observed in titania layers formed on blanket Ti films but absent on arrays of patterned Ti pads below a threshold dimension. High resolution scanning electron microscopy (SEM) reveals that nanostructured titania layers consist of nanofibers as well as a sponge-like nanoporous morphology. Chemical and structural properties of titania layers were characterized by X-ray photoelectron spectroscopy, X-ray diffraction and focus ion beam machining. We have investigated the use of these layers as an inorganic cell-scaffold on N—MEMS devices by performing cell culture studies. Mouse fibroblast cells remain viable after up to 3 days. Optical, confocal and SEM microscopy show excellent attachment between cells and nanostructured titania layers. These observations demonstrate the feasibility of the present technique for integrating nanostructured titania into N—MEMS devices for biological applications. It is also envisaged that this method can be used to integrate nanostructured titania which will render functionalities of gas sensing, catalysis and macromolecular separation in future N—MEMS devices.

10:15 AM *O9.5
Microsystems for cellular analysis. Joel Voldman, Massachusetts Institute of Technology, Cambridge, Massachusetts.

As bioscience drives toward the study of whole cellular subsystems, there has been an increasing need for new methods to study and manipulate individual cells and cell assemblies. These methods allow the acquisition of new kinds of biological information, leading to new insights into how cells work. This talk will describe our research in transforming both the culture and assay of cellular systems. Specifically, I will present results on our use of dielectrophoresis and microfluidics to manipulate the cellular microenvironment as well as for downstream assay.

10:45 AM O9.6
Investigation of Controlled Release of Ligand Immobilized Drug Molecules from Polymeric Scaffolds: A Predictive Model. Srinivas Chollangi and Andrew Thomas Metters; Chemical Engineering, Clemson University, Clemson, South Carolina.

A novel approach to immobilize the drug molecules in degradable/non-degradable hydrogel networks by incorporating the reversible protein-ligand interaction into the system is under study. Experimentally, the drug-encapsulating matrix can be readily formed from multi-functional poly (ethylene glycol) (PEG) molecules crosslinked through chain or step-wise polymerization mechanisms. Ligands possessing some degree of affinity for the drug of interest are covalently bound to the PEG network. Incorporating the ligands into hydrogel network brings in two new controlling parameters Keq (between the drug and ligand) and Ligand-Drug concentration ratio, in addition to the already known control parameters, degradation rate constant of the hydrogel, mesh size of the network, volume fraction of the polymer in the gel. These new parameters can be varied to effectively tailor the release profiles in desired manner. A numerical model was developed to predict the release behavior of various small molecule and protein therapeutics from this system. Structural and kinetic information has been incorporated into the numerical model to account for time-dependent diffusion rates as well as to describe the reversible binding occurring between the drug and tethered ligand species. Degradation of the overall network is also accounted for by the theoretical model and provides prediction of diffusion or degradation-controlled release profiles. Simulations predicted that the drug release can be delayed by increasing Keq. And for a given drug-Ligand system (fixed Keq) the reslease can further be delayed by increasing the Ligand/Drug ratio. In an attempt to attain the zero order release, various patterns of Drug and Ligand distribution within the polymer matrix have been simulated and interesting results were observed. Experimental verification of this system is under progress.

11:00 AM O9.7
Impedance-based Biosensors. David W Greve[1], Xiaoqiu Huang[1], Duc Nguyen[2] and Michael Domach[2]; [1]Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania; [2]Department of Chemical Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania.

Impedance measurements on arrays of microelectrodes can provide

information about the growth, motility, and physiology of cells growing on the electrodes. In this talk, we report recent results obtained for the growth of 3T3 mouse fibroblasts and HCT116 human cancer cells on gold electrodes approximately 0.4 mm2 in area. Cells produce a characteristic peak in the impedance change plotted as a function of frequency. With the aid of electrical modeling of the cell-electrode system, the details of the changes in the measured impedance can be correlated to the cell size, fractional electrode coverage, and cell-electrode gap. In particular, comparison of impedance measurements of these two cell types show clear differences in the growth rate and the ratio of the cell-electrode gap to the cell size. In addition to presenting these experimental results illustrating the utility of electrode impedance measurements, we will outline the issues encountered when electrodes are scaled to cell size and incorporated into a matrix-addressed array.

11:15 AM *O9.8
From an Integrated Biochip Detection System to a Defensive Weapon Against the SARS-CoV Virus: OBMorph.
Chih-kung Lee[1], Shiming Lin[2], Adam Shih-Yuan Lee[3], Chii-Wan Lin[4], Jiun-Yan Wu[1], Shu-Sheng Lee[1], Wen-Hsin Hsiao[5] and Shih-Jui Chen[1]; [1]Institute of Applied Mechanics, National Taiwan University, Taipei, Taiwan; [2]Center for Optoelectronic Biomedicine, National Taiwan University, Taipei, Taiwan; [3]Department of Chemistry, Tamkang University, Tamshui, Taiwan; [4]Institute of BioMedical Engineering, National Taiwan University, Taipei, Taiwan; [5]AdvanceWave Technologies Inc., Taipei, Taiwan.

An integrated multifunction Biochip Detection System called "OBMorph" which integrates almost all optoelectronic based biological diagnostic tools and which includes in the system an ellipsometer, a laser Doppler vibrometer/ interferometer, a SPR (surface plasmon resonance) analyzer for amplitude and phase detection, an interference microscope, a photon tunneling microscope, an optical coherence tomography and a confocal scanning microscope, will be presented. This integrated system which can be used from the beginnings of sensor chip fabrication, through signal detecting and monitoring, and then to the final biological analysis, is a powerful diagnostic studying tool. In this presentation, the constitution and preliminary experimental results of the multifunctional biochip detection system OBMorph will also be presented. An innovative SARS (Severe Acute Respiratory Syndrome) virus denaturing material that was derived based on the study of biolinker fabrication in biochips with the OBMorph system will also be discussed. Some of the testing strategy developed by integrating biochip technology and utilizing an atomic force microscope to prove the validity of this denaturing agent will also be examined. The fundamental working mechanism of the SARS-CoV, which was determined to be based on principles of Nano/Bio-mechanics, can be adapted to disinfect other viruses and even bacteria will be described. Some design strategies and innovative working mechanisms derived from this SARS virus-denaturing agent will also be discussed.

11:45 AM O9.9
Development of Ferroelectric Nanomechanical Resonators for RF Bandpass Filters.
Kyung-ah Son[1], Thomas George[1], Robert W. Fathauer[2], srinivasan Bhaskar[2], Wei Cao[2], Sandwip K. Dey[2], Lifeng Wang[2], Stephen M. Phillips[2], Brian Houston[4], James E. Butler[4], Bruce Lambert[3], Daniel P. Weitekamp[3], Jinwei Yang[5], Grigory S. Simin[5] and M. Asif Khan[5]; [1]Jet Propulsion Lab., Pasadena, California; [2]Arizona State University, Tempe, Arizona; [3]California Institute of Technology, Pasadena, California; [4]Naval Research Laboratory, Washington, District of Columbia; [5]University of South Carolina, Columbia, South Carolina.

Due to their ultra-small volumes, high sensitivity, and high operating frequencies, micro/nano-mechanical resonators have numerous applications, including the detection of chemical or biological molecules and RF communications. In our work, we are developing nanometer-scale ferroelectric mechanical resonators for high-Q, low-power, compact RF bandpass filters. For the excitation of mechanical resonance, we have functionalized these nanomechanical torsional resonators with blocks of ferroelectric material, i.e. lead zirconate titanate (PZT). An RF signal couples to the permanent dipole moment of the ferroelectric block, providing a driving torque resulting in an angular amplitude that scales with the RF signal strength at the resonance frequency. We detect the resonator motion optically via light scattering from Au nano-particles fabricated on top of the ferroelectric blocks, or electrically by the current induced by the motion of the ferroelectric moment. We are examining torsional resonators in Si, GaN and nanocrystalline diamond that promise high-Q performance through a combination of superior bulk and surface properties and optimized geometry. Resonators are fabricated using optical and electron beam lithography followed by various reactive ion etching (RIE) methods specially developed for each material. For resonance frequencies in the range of 0.1 - 1.0 GHz, we are examining structures with beam cross sections of 200 nm x 200 nm. Evaluation of resonator designs is carried out experimentally using scanning Laser Doppler Vibrometry (LDV), and compared to the numerical simulations of resonator performance developed using finite element-based structural dynamics codes. Ferroelectric blocks on resonators are nanofabricated with PZT films grown by the sol-gel methods or by chemical vapor deposition. Au nanoparticles are created using electron-beam lithography and the shapes are optimized for best optical scattering efficiency.