SYMPOSIUM Y

Materials, Mechanisms, and Systems
for Chemical and Biological Detection and Remediation

April 14 - 15, 2004

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* Invited paper
An essential aspect of scanning force microscopy is a micromechanical cantilever which transduces a force acting on the tip into a deflection or a resonance frequency change. However, not only normal forces acting on the tip lead to a deflection, but also expansive or contractive forces acting on one side of the cantilever surface result in a bending. Frequency changes of the resonating cantilever can also be induced by a change of the mass loading of the cantilever sensor. This behavior together with their very small size (typically 0.5 μm thick, 50 μm wide and 500 μm long) make them very attractive as sensors, to study the interaction of molecules and to detect small amounts of materials. Changes of tensile and compressive surface stress arise when molecules specifically adsorb on one side of the cantilever surface. In this case, a self-assembled monolayer of alkane thiol molecules leads to a compressive surface stress change. It was found that the compressive surface stress change is proportional to the length of the alkyl-chain. This sensor principle can be extended by using a coating of receptor molecules which have specific functionalities such as key-and-lock binding. Molecules in the environment, which have a specific lock, can now bind to the appropriate key-receptor on the cantilever sensor. This binding causes a deflection of the cantilever and the signal can be used as a monitor for environmental control. In particular, the surface stress changes can be measured in liquid, which is a requirement for most biochemistry applications. In the field of biotechnology, DNA hybridization between different functional groups on the effect of surface stress change.

Polymers can be used as a model system to study the influence of functional groups on the effect of surface stress change. Polymer brushes have been synthesized on cantilevers and are exposed to different types of solvents, which induce conformational changes in the polymer chains. A sample - typically a few nanograms - can be attached to the apex of a cantilever. Mass changes of this sample can be determined with picogram resolution by detection of resonance frequency changes of the cantilever sample system. A mass change can result from swelling of a polymer in a solvent. Results of the swelling behavior of Polystyrene spherical particles with am-diameters in toluene are discussed. Tracking the resonance frequency in dependence of temperature allows to study chemical reactions of very small sample sizes. A theory for the relationship of deflection and decomposition reaction of pico- nanometer materials is presented. The small size of the cantilever offers the opportunity to arrange several of these cantilever sensors in an array on a single chip or to use several chips carrying individually coated cantilevers.

Explosive Vapor Detection Using Uncoated Silicon Microcantilevers

Richard Lareaux and Thomas Thundat

Oak Ridge National Lab, Oak Ridge, Tennessee; Department of Homeland Security, Atlantic City, New Jersey.

Fast and sensitive detection of explosive vapors is important for a number of applications ranging from passenger baggage-screening at airports to disarmament of landmines. Such a sensor system based on silicon cantilevers would be additionally desirable due to its compactness and possible low cost. We recently reported a novel detection scheme based on the deflection of explosive material deposited on a piezoresistive microcantilever by heating the piezoceram with a 10 V, 10 ms voltage pulse [1]. In that preliminary work, we used a vapor generator that had a cross sectional area of about 0.07 cm². Since the cross sectional area of the piezoresistive cantilever is only about 10-4 cm², most of the vapor emitted from the vapor generator was "wasted". We have conducted experiments with modified vapor delivery tubings with radii varying from 150 to 500 microns. We will present data taken with these narrow delivery tubes that enabled us to detect smaller vapor concentrations. This work was supported by the Department of Homeland Security. Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for the U. S. Dept. of Energy under contract DE-AC05-00OR22725. 1. L. A. Pinnaduwage, Gutiérrez, L. L. Helden, G. Murahara, T. H. Gweon, T. Sulcuk, L. Manning, B. Rogers, M. Jones, J. D. Adams, "A Microsensor for trinitrotoluene Vapour", Nature 425, 474 (2003).

Cantilever Arrays for Multiplexed Biosensing

Arun Majumdar, Department of Mechanical Engineering, University of California, Berkeley, Berkeley, California.

An accurate, rapid, and quantitative method for analyzing variety of biomolecules, such as DNA and proteins, is necessary in many biomedical applications and could help address several scientific issues in molecular biology. Recent experiments have shown that when specific biological reactions occur on one surface of a microcantilever beam, the resulting changes in surface stress deflect the cantilever beam. To exploit this phenomenon for high-throughput label-free biosensing, we have developed a chip containing a 2-D array of cantilevers with a thin gold coating on one surface. Integration of microfluidic cells on the chip allows for individual functionalization of each cantilever of the array, which is designed to respond specifically to a target analyte. An optical system to readout deflections of multiple cantilevers was also developed. Based on thermomechanical calibration, the reproducibility of the cantilevers and their drift can be characterized. Subsequently, we have used these 2-D cantilever arrays for studying DNA hybridization, antigen-antibody binding, as well as whole bacteria detection. This talk will report the progress in our research towards making such 2-D cantilever arrays universal platform for biological and chemical sensing.

2:00 PM Y2.2 MOSFET Integrated Microcantilevers for Novel Electronic Detection of "On-Chip" Molecular Interactions.

Vasavak P. Devad* and Gojuendo S. Shikohawat, 1 Material Science, Northwestern University, Evanston, Illinois; 2 Institute for Nanotechnology, Northwestern University, Evanston, Illinois.

We have developed a novel bio-chem sensor system based on silicon chip technology for electronic detection of biomolecules. The novel sensing element is an integrated MOSFET transistor, placed at the high stress region of the micro cantilever. The reverse side of the micro cantilever is functionalized with appropriate sensing layer. As selective binding occurs during bio-chip exposure, the well-known bending of the cantilever leads naturally to significant, measurable and reproducible change in the drain current, providing a novel signal transduction mechanism. Such piezo-MOS in the present configuration provide a significant advantage over conventional optical detection such as sensitivity, liquid-gas cell operation, ease of integration, among others. Our initial result indicates clear high sensitivity of MOS detection, down to less than 2 nm cantilever deflection through external actuator. The location of the MOS chip is precisely calculated after numerous modeling and simulation. MOSFET platform not only improves the sensitivity, but also has almost negligible noise figure (large signal to noise ratio), ease of integration with CMOS and RF components. By the use of stress sensitivity MOSFETs as active loads, the size of the transistor is considerably reduced when compared to diffused piezoresistors. The presentation will cover device architecture and proofof-concept sensing examples of biological and gas-chemical analytes.

SESSION V2: Detection Systems I Chairs: Bill Colston and Robert Bätteri Wednesday Afternoon, April 14, 2004 Room 3016 (Moscone West)

1:30 PM *V2.1 Cantilever Based Sensing Devices with Integrated Readout. Anja Boisen, MIC, Technical University of Denmark, Lyngby, Denmark.

The majority of the cantilever based sensing experiments reported to date have been based on the optical leverage method used in atomic force microscopy. This method is very accurate but for many applications it would be an advantage to have a more compact read-out method. Such a method requires less additional electronic circuitry and a readout integrated on the cantilever would also greatly facilitate operation of arrays of cantilevers and work in liquid. In order to reduce background noise such as thermal drift and turbulence around the cantilever, a reference cantilever is crucial. For monitoring changes in surface stress we have developed various types of micromachined silicon based cantilever devices with integrated piezo-resistive read-out and built-in reference cantilevers. The cantilever dimensions as well as the placement and the doping of the piezoresistors have been optimised for surface stress detection. For plug-in experiments a two-cantilever chip has been developed and applied for gas measurements as well as for detection of biomolecules in liquid (1). Arrays of up to 10 chips have been fabricated in micromachiner offering a method to develop compact biosensors with a simple read-out scheme (2). Recently, we have realised cantilever sensors in the polymer SU-8, which is a negative resist with excellent mechanical, thermal and chemical properties. The use of polymer makes the fabrication process simple, cheap, fast and flexible. Thus, it will be possible to realise a variety of sensor design in a short period of time. Moreover, the polymer technology opens up for new ways of detecting cantilever bending, which might increase the sensitivity. Large arrays of SU-8 cantilevers with varying dimensions have been used to study the mechanical performance of polymer cantilevers (3). The elastic constant of the cantilevers was measured, and their dynamic response was investigated. Characterization of the devices shows that they are suitable for both static and dynamic mechanical measurements in either air or liquid environments. Furthermore, complete devices consisting of polymer microchannels and polymer cantilevers with integrated electrical strain gauges have been realized (4). For mass detection we have developed silicon-based cantilevers with integrated capacitive read-out and electrostatic actuations. Due to problems with high stray capacitances the sensor is monolithically integrated with a CMOS process for on-chip amplification of the signal (5). We investigate the bottom-up approach we are currently pursuing ways of fabricating carbon nanotube based resonators. (1) R. Marie et al, Ultramicroscopy 91, pp 29-36 (2002) (2) J. Thaysen et al, Proceedings of MEMS, pp. 401-404 (Interlaken 2001) (3) M. Calleja et al, Sensor Letters, vol. 1. No.1 pp. 1-5 (2003) (4) M. Calleja et al, Proceedings of μTAS 2003, pp. 207-210 (2003) (5) Z. Davis et al, Sensors and Actuators A, 105 (3), pp. 311-319 (2003)

2:15 PM Y2.3 Cantilever array with integrated readout made in SU-8 and integrated in a micro liquid system. Peter Andreas Rasmussen, Montserrat Calleja, Alicia Johansson, Rodolphe Marie and Anja Boisen; Mikroelektronik Centret (MIC), Technical University of Denmark, Lyngby, Denmark.

We report on a cantilever array integrated in a micro fluidic channel, both of which are made of the photosensitive polymer SU-8. We have previously developed a cantilever platform in silicon[1] and the SU-8 chip represents a new cantilever platform with a much faster fabrication cycle and the possibility to make on-chip fluid channels and encapsulation that will reduce demands on the subsequent packaging of the chip. The readout from the cantilever array is made with gold strain gauges that are encapsulated in the SU-8 cantilevers. The estimated performance of this sensor is at least comparable to that of present cantilever sensors with polysilicon piezoresistors, since the low gauge factor of the metal is compensated by the lower stiffness of the cantilever, and because the noise in the gold resistors is lower than in the polysilicon resistors. The SU-8 device is glued together with SU-8 and packaged in a PDMS/PDMA case tailored by chip bonding, and on the testing of the device in a micro liquid handling setup. [1] J. Thaysen et al, Proceedings of MEMS 2003, Proceedings pp. 207-210, 2003
Photoacoustic spectroscopy is a useful monitoring technique that is well suited for trace gas detection. The technique also possesses favorable detection limits for many species. In this work, we describe improved performance in the micro-system design. The objective of present work is to incorporate two strengths of the Army Research Laboratory (ARL) photoacoustic MEMS device technology, namely, high surface area and biological sensing into a monolithic MEMS photoacoustic trace gas sensor. Examination of a 1/4 scale model of a silicon photothermal wafer shows the possibility of a high-performance photoacoustic resonator structure in a micro-mechanical platform. In order to maintain sensitivity and characterize a typical photoacoustic cell, work has centered on transmission-line modeling of the resonant microstructures. Initial models examined a typical H-style open tube resonance structure including acoustic finger designs. Results from this modeling will be directly incorporated into cell design and will include all pertinent parameters.

MEMS work is centered on improving design and fabrication of a lead zirconate titanate (PZT) sensor-based subsystem to be incorporated into the full photoacoustic device. Second generation microphones have been designed, fabricated and tested. Presently, the piezoelectric microphone performance has revealed the possibility of using a PZT microphone as the passive acoustic detection mechanism of a photoacoustic resonator structure. A typical photoacoustic cell incorporates a photoacoustic resonance structure in a micro-mechanical platform, which provides the ability to select between the acoustic properties of different types of membranes. In order to maintain sensitivity and characteristics of a typical photoacoustic cell, work has centered on transmission-line modeling of the resonant microstructures. Initial models examined a typical H-style open tube resonance structure including acoustic finger designs. Results from this modeling will be directly incorporated into cell design and will include all pertinent parameters.

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apertures and ion target are photodefined and etched from a sheet of kovar plated with nickel. These parts are then inserted into the tube and welded to the tube. The vacuum contact is made by pressing the parts via integral spring structures and then soldering the structures to make them appropriately rigid. Applications requiring tube temperatures above ambient are accommodated by inclusion of an integral heater into the rigid tube structure. Thus, we have produced an IMS tube with the promise of low-cost production for application in the detection of contraband materials important to law enforcement, first-responders, security screening, and many other applications of interest. Sandia is a multi-program 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.

A method is described for generating a variety of chemically diverse, broadly responsive, low power vapor sensors. A key to our ability to fabricate chemically diverse sensing elements is the preparation of processable, and electrically-conducting organic polymers. An array of such sensing elements produces a chemically-reversible, diagnostic pattern of electrical resistance changes upon exposure to different odors. Such conducting polymer elements are simply prepared and are readily modified chemically to respond to a broad range of analytes. In addition, these sensors yield a fairly rapid low-power, dc electrical signal in response to the vapor of interest, and their signals are readily integrated with software or hardware-based neural networks for purposes of analyte identification. Principle component analysis has demonstrated that such sensors can identify and quantify different airborne organic solvents, and can yield information on the components of gas mixtures.

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An ultrasensitive method for detecting protein analytes has been demonstrated. A single filter of report on use of this testbed to examine different solvent systems and have observed different responses for each type of active material. These results indicate that organic devices may have the capacity to be used as in sensor arrays for electronic nose applications. We also reported previously unexplored characteristics of organic TFT sensors including sensor consistency and transient dynamics during prolonged exposure periods. Finally, we also present some work on use of these devices to detect food spoilage.

Analysis of the signals produced by a collection of organic polymer-carbon black composite vapor detectors has been performed to assess the ability to estimate various chemical and physical properties of analyte vapors based on information contained in the response patterns of the detector array. A diverse array of composite chemiresistive vapor detectors was exposed to a series of test analytes that had been selected from among five different chemical classes: alcohols, halogenated hydrocarbons, aromatics, unsubstituted hydrocarbons, and esters. The algorithmic task of interest was to use the resulting array of response data to assign one of the five chemical class labels to a test analyte, despite having left that analyte out of the model used to generate these class labels. Algorithms evaluated for this purpose included principal components analysis (PCA) and k-nearest-neighbor (k-NN) analysis employing either Euclidean or Mahalanobis distance calculations. Each data set that was prepared by replicate exposure to an individual analyte was well resolved from all of the other 74 analyte clusters. Furthermore, with the exception of the halide cluster, the analyte response clusters could be robustly grouped into supersets such that each of the five individual chemical classes was well separated from every other class of analytes in principal component space. Accordingly, either of the k-nearest-neighbor algorithms, in excess of 85% of the non-halide test analyte exposures were correctly assigned to their chemical classes, and halides were only minimally confused with some of the other analytes but not with alcohols or hydrocarbons. The detector array response data also was found to contain semi-quantitative information regarding physicochemical properties of the members of the test analyte series, such as the degree of unsaturation of the carbon chain, the dipole moment, the molecular weight, the number of halogen atoms, and type of aromatic ring in the test analytes. The performance in these types of tasks is relevant for applications of a semi-selective array of vapor detectors in situations when no prior knowledge of the analyte identity is available and when there is no assurance that the test analyte will have been contained in the training set database produced by a compiling a library of responses from the detector array.

Small particles of microporous Si are used to detect chemicals by measurement of their optical reflectivity spectrum. Each particle contains in its nanostructure the necessary components to allow self-assembly, spectroscopic identification, and chemical sensing. The particles are generated by electrochemically etching discrete porous one-dimensional dielectric stack (rugate) mirrors into silicon. The complex multilayered structure produces a distinctive reflectivity spectrum that serves as a robust code, allowing positive identification and discrimination of many different types of particles. The identity and wavelength of reflected light is determined by examining the refractive index of the porous nanostructure, which is modified by adsorption of vapors or by specific chemical reactions within the chemically modified porous Si matrix. Sensing is accomplished when liquid or vapor infuses into the porous mirrors, inducing predictable shifts in the optical spectra. Chemically asymmetric particles are also described, which can spontaneously align at an organic liquid/water interface. Thus the micro-sized photonic sensors Si can self-assemble, orient, and sense their local environment. Application of these materials for sensing of pollutants and toxic chemicals will be described.
developed. The system relies on magnetic microparticle probes with antibodies that specifically bind a target of interest [prostate specific antigen (PSA)] and the nanoparticles that are decorated with DNA that is unique to the protein target of interest and antibodies that can sandwich the target captured by the microparticle probes. Magnetic separation of the complexed targets and target follow-up by denaturation of the oligonucleotides on the nanoparticle probe surface allows one to determine the presence of the target protein by identifying the oligonucleotide sequence released from the nanoparticle probe. Because the nanoparticle probe carries with it a large DNA/protein binding event, there is substantial amplification and one can detect PSA at 30 attomolar concentration. Alternatively, one can do polymerase chain reaction on the oligonucleotide barcodes and boost the sensitivity to 3 attomolar. Comparably clinically accepted conventional assays for detecting the same target have sensitivity limits of 3 pM, 6 orders of magnitude less sensitive than what is observed with this method.

11:30 AM Y3.7

Nanoparticles and nanoparticle-based materials are attracting great interest for their unique properties and potential for application in diverse areas. We have developed a new nanostructure containing an enzyme within a hybrid organic/inorganic polymer network with sufficient porosity to allow substrates to diffuse to the active site. The synthetic procedure, entailing enzyme modification and two orthogonal polymerization steps, yields nanoparticles containing a single enzyme that can be observed by transmission electron microscopy. In experiments with chymotrypsin, incorporation into the nanostructure dramatically increased the enzymatic stability. Furthermore, the nanoscale structure around the enzyme is sufficiently thin that it does not impose a significant mass transfer limitation on the substrate. Because these nanoparticles remain soluble or suspended in solutions, they can be processed in a variety of forms. They can be used in solution, cast into thin films, or adsorbed within larger mesoporous structures. Given enzymatic specificity and the great diversity reactions catalyzed by enzymes, coupled with the flexibility in the use of single enzyme nanoparticles, these new nanostructures are very promising for many applications, including biosensors, bioreactors, microfluidic devices, decontamination, remediation, anti-fouling, and protective layers. (1)


11:45 AM Y3.8
Multiplex Biocoupled Using Solution Arrays Based on Encoded Nanowire Particles, George Dougherty1, Frank Chuang2, Satinder Pannu1, Klint Rose1, Michael Sha3 and Sharron Penn1;
1Center for Micro and Nano Technology, Lawrence Livermore National Laboratory, Livermore, California; 2UC Davis Cancer Center, Davis, California; 3Nanoplex Technologies, Inc., Mountain View, California.

We are developing a new platform for performing multiplex biodetection assays with the goal of providing flexibility, user reconfigurability, high sensitivity, low cost, and portability. The platform uses the solution array concept of a suspension of different uniquely identifiable particle types, each type independently functionalized for affinity to a unique biochemical target that may be present in the sample. The particles employed are Nanobarcodes(R), metallic nanowire particles a few microns in length and 50-250 nm in diameter. Synthesized by sequential electrodeposition of different metals within porous anodic alumina templates, these unique particles are encoded with patterns of alternating high and low reflectivity, resulting in stripe patterns similar to those of supermarket barcodes. In contrast to earlier implementations of the solution array concept, such as those using fluorescent beads, the use of these particles allows the assay results to be characterized using standard microscope optics and image processing software, without the need for flow cytometry. In addition, the metallic properties of the particles make it possible to manipulate them within automated fluidic sample processing systems using magnetic and/or other forces. After an overview of the Nanobarcode technology, we present results demonstrating the effective biochemical functionalization of the Nanobarcode particles with self-assembled monolayers for surface property control, and antibodies against several biochemical targets. We demonstrate the use of these novel functionalized particles to carry out the specific detection of biochemical targets within a multiplex solution assay.

SESSION Y4: Detection Systems II
Chairs: Jay Grate and Mike Sepaniac

1:30 PM Y4.1
Chemical Sensing with a MEMS-Based Correlation Radiometer. Michael B Sinclair and Kent B Pfeifer; Sandia National Laboratories, Albuquerque, New Mexico.

We describe a novel MEMS-based correlation radiometer for remote chemical sensing. At the heart of the radiometer is a MEMS programmable diffraction grating called the Polychromator. The radiometer contains an array of 1024 electrostatically actuated reflective beams that are 10 microns wide by 1 cm long and have a vertical travel of approximately 2-4 microns. The deflection profile of the array can be programmed to tune the spectral transfer function of the radiometer. In this manner, the Polychromator serves to replace the reference cell of conventional correlation radiometry. Switching of the radiometer’s spectral transfer function can be accomplished in a matter of seconds. Advantages of this approach to correlation radiometry include the ability to detect multiple chemical species with a compact instrument, the ability to optimize the reference spectra using multivariate techniques to eliminate chemical interferences, and the ability to produce reference spectra for hazardous and transient species. The operation of the radiometer will be discussed and initial results for chemical sensing will be presented. Portions of this work were performed at Sandia National Laboratories. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

2:00 PM Y4.2
High-Index Glass Microspheres as Highly Sensitive Collectors for Remote Sensing Applications. Anthony Esposito, Chad Talley, Christopher Hollars, Thomas Huser and Charles Stevens; Chemistry & Materials Science, Lawrence Livermore National Laboratory, Livermore, California.

Sensitive remote chemical detection is of significant interest for national security purposes. We have investigated the use of high-refractive-index glass microspheres as collection elements for such remote sensing applications. Optical characterization of these microspheres indicates that their light focusing and gathering properties are comparable to those of high numerical aperture microscope objectives, but are more applicable to use in the field due to their intrinsic omnidirectional scattering properties. We have obtained fluorescence spectra from dilute dye solutions (10^-10 to 10^-11 M), and show single-molecule sensitivity when the microspheres are employed as the light focusing and collecting elements. Chemical functionalization of the microsphere surface with fluorescent labels or metal nanoparticles for surface-enhanced Raman spectroscopy should enhance the collected signal, and comparison of the Raman signal to a spectral database will allow for identification of specific compounds in the collection volume of the microsphere.

* 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 number W-7405-Eng-48.

2:15 PM Y4.3
Multi-Wavelength Excitation and Fluorescence From Single Biological Particles. Alan E. Houston, Vassiliki Simvagkas, Jay Eversole and Cathy Scott; Optical Sciences Division, Naval Research Laboratory, Washington, District of Columbia.

A new, fluorescence-based biosensor sensor technique is described that uses 266 nm and 355 nm laser pulses from diode-pumped Nd:YAG lasers to sequentially excite single, micron-sized aerosol particles. A number of biosensor detection systems have been developed that utilize 266 nm UV excitation to provide an indication of whether an aerosol particle contains biological material or not. This determination is based on the observation of laser-induced fluorescence in the 340 nm range from aromatic amino acids that are present in all biological organisms. The problem with this approach is that there are a number of non-biological interferents that also fluoresce when excited at 266 nm. As a result, the false alarm rates are too high for practical implementation. Systems have also been described that utilize 355 nm UV excitation to excite bioluminescence. In this case, the bio-fluorescence is due to chemicals such as NADH and flavinoid compounds that are metabolic products of living cells. The system that we have developed utilizes a continuous wave 800 nm diode laser to detect the presence of an aerosol particle in an optical/aerosol chamber. The scattered light amplitude is used as a measure of the size of the particle as well as to trigger the firing of two Nd:YAG lasers. The first laser is used to generate a 355 nm laser pulse that excites the detected aerosol particle. Fluorescence generated by the 355 nm pulse is detected in two broad wavelength bands centered at 450 nm and 550 nm. A second laser is used to generate a pulse at 266 nm. This pulse is delayed by 1 microsecond...
with respect to the 355 nm pulse and excites the same aerosol particle. The fluorescence excited by the 266 nm pulse is detected in a broad band centered at 350 nm and in the 460 nm and 500 nm bands that were used to detect the 355 nm excited fluorescence. The photomultiplier tube that is used to detect the 350 nm band is gated to respond only to the fluorescence generated by the 266 nm pulse, otherwise the broad band light from this tube would damage the detector. Six distinct pieces of information are acquired for every aerosol particle that enters the chamber, including particle size and five fluorescence signals. The light scatttering and fluorescence signals of several aerosol particle standards, proteins, bacterial and fungal species were investigated and analyzed using the technique of Principle Component Analysis (PCA). The PCA results obtained to date indicate promise in helping to classify different particles. In addition, PCA signal separations in submicron fungal spores, bacteria and proteins are clustered into distinct regions in the PCA plots. Further work is continuing to determine the degree of discrimination that may be possible using the two-wavelength fluorescence excitation approach.

2:30 PM *Y4.4* Carbon nanotube interface to molecular-scale processes in viable cells, Michael L Simpson1,2,3, Timothy E McKnight1,2 and Anatoli V Melnikov1,2,3, 1Molecular-Scale Engineering, Oak Ridge National Lab, Oak Ridge, Tennessee; 2Materials Science and Engineering, University of Tennessee, Knoxville, Tennessee; 3Center for Environmental Biotechnology, University of Tennessee, Knoxville, Tennessee.

One of the key challenges for advanced bio-detection strategies and post-genomic biology in general is the ability to coherently describe and characterize the molecular-scale components and their interactions that produce complex cell functionality. As they reside at the same scale as the biomolecular machines of cells, engineered nanoscale devices are poised to provide the means for real-time monitoring and manipulating cellular processes. Other investigators have highlighted this interface of nanotechnology and biotechnology such as the use of non-bleaching fluorescent nanocrystals in place of dyes, but usually as a means of monitoring rather than controlling cellular processes. Pulled glass capillaries with nanoscale tips have been implemented for cellular and subcellular electrophysiological monitoring and for microinjection of membrane-impermeable molecules (e.g. proteins, DNA), but these devices require manipulating cells one at a time using individual elements observed under a microscope, and thus provide only a serial interface to cells. Parallel embodiments of these devices have been fabricated using silicon microfabrication methods, but as with all micromachining techniques there are limitations to the ultimate size scale and density of features (tip radii and spacing of the silicon needles) and a limited choice of substrate materials (i.e. not easily fabricated on transparent substrates convenient for cell culture). In contrast, carbon nanotubes (CNTs) and related nanostructures avoid these limitations and provide the means to construct addressable functional nanoscale devices including chemically specific AFM probes, electrochemical probes, and electromechanical manipulators. Within this family of structures, carbon nanotubes are uniquely suited for the construction of intracellular devices because of the ability to exquisitely control their synthesis. Deterministic arrays of closely-spaced (pitch = 1 pm) vertically aligned carbon nanofibers (VACNF) may be grown on a wide variety of substrates (including quartz and glass slides) with wide bases that provide mechanical strength while still generating a small diameter tip (< 5 nm tip radius) appropriate for insertion directly into cells. We present a critical enabling step toward the hardware tools needed for the coupling of molecular-scale cell function theory and modeling with experiment by demonstrating the controlled synthesis, directed assembly, and then functional integration of VACNF elements within viable cells. The viability of the cells after VACNF insertion is demonstrated by the long-term expression of a constitutively-expressed green fluorescent protein (GFP) gene carried on nanotube-based plasmid molecules.

3:30 PM *Y4.5* The Autonomous Pathogen Detection System. John Dzenitis1, Ray May2,3,4, Jay W Grate1, Marvin Warner1, Norman C Anheier2, Michael L Simpson1,2,3, and James D Marks4. 1Chemical Sciences Division, Pacific Northwest National Laboratory, Richland, Washington; 2Electronic Systems Group, Pacific Northwest National Laboratory, Richland, Washington; 3Biological Sciences Division, Pacific Northwest National Laboratory, Richland, Washington; 4UCSF, San Francisco, California.

Rapid detection of botulinum toxin was demonstrated using a renewable surface immunoassay, which included on-column detection of a fluorescein-labeled secondary antibody in a sandwich immunoassay. Yeast display and directed molecular evolution were used to create a high affinity antibody to the botulinum toxin heavy chain receptor binding domain, ARlo. This antibody was modified with biotin and coupled to streptavidin-coated Sepharose 4B beads. A secondary antibody that binds to the botulinum heavy chain 3D12 was labeled with a fluorescent dye, Alexa 633. A rotating rod renewable surface microarray was used to immobilize antibodies and nanofiber-borne plasmid molecules. The sensor was monitored in-line, and thus provided a direct measurement of antigen concentration levels using the same reagents. These experiments demonstrate how a combination of high affinity reagents and a sensor configuration enabling rapid mass transport can be combined for rapid, sensitive biodetection.

4:15 PM *Y4.7* Micro electrical impedance spectroscopy of healthy and cancerous cells. Luis Jose Cruz-Rivera1, Kumar Ravelu2 and A. Bruno Frazier1. 1ECE, Georgia Institute of Technology, Atlanta, Georgia; 2Department of Biomedical Engineering, University of California Los Angeles, Los Angeles, California.

Empirical data has shown that dielectric properties of cells depend on the cell type and physiological status. The specific impedance of mammalian cells, describe their complexities and membrane barrier functions. While these have been shown to respond to cell pathologic and physiologic changes, of particular interest is the frequency response and characteristic dispersions measured by micro-electrical impedance spectroscopy (µEIS) and the differentiation of the electrical properties between normal and cancerous cells. This report describes the fabrication and characterization of a µEIS microsystem and its use to characterize the cellular impedance differences in a mammalian system that may be related to the cancerous state. Microelectrical impedance spectroscopy (µEIS) and the characterization of the peptide differences between normal and cancerous cells. This report describes the fabrication and characterization of a µEIS microsystem and its use to characterize the cellular impedance differences in a mammalian system that may be related to the cancerous state. The confirmatory test is polymerase chain reaction (PCR, DNA-based) using a real-time TaqMan assay. The system can operate continuously autonomously monitoring and manipulating cells one at a time using individual elements observed under a microscope, and thus provide only a serial interface to cells. The system performs continuous aerosol collection, particle sample preparation, and multiplexed biological tests of two types: The primary screen is a multiplexed immunoassay (protein-based) using a LuminoFlow cytometry platform. More than ten agents are assayed at once. The confirmatory test is polymerase chain reaction (PCR, DNA-based) using a real-time TaqMan assay. The system can operate continuously autonomously monitoring and manipulating cells. The APDS detected releases of live plague and anthrax in a chamber test at Dugway Proving Grounds, and has been field-tested in a public nucleus and subway. Results obtained to date indicate promise in helping to classify different particles. In addition, PCA signal separations in submicron fungal spores, bacteria and proteins are clustered into distinct regions in the PCA plots. Further work is continuing to determine the degree of discrimination that may be possible using the two-wavelength fluorescence excitation approach.


Chemical and biological sensors based on organic thin film transistors (OTFTs) have begun to attract significant interest. Such devices can be easily and inexpensively fabricated on a variety of substrates, and the organic semiconducting molecules can be chemically synthesized or modified for specific applications. We have previously shown that pentacene OTFTs can be used to make sensitive humidity sensors. In the current work, we demonstrate the applicability of OTFTs for...
detecting biological species in aqueous environments. Pentacene OTFTs were fabricated on Si substrates with SiO$_2$ as the gate dielectric, and polystyrene sulfonate (PEDMS) microfluidic channels were used to expose the active regions of the transistors to aqueous solutions with a range of ionic strengths and pH as well as buffer solutions containing rat basophilic leukemia (RBL) cells. We will also discuss unusual field-effect transistors based on the dopant conducting polymer poly(ethylene dioxy-thiophene)-poly(styrenesulfonate) (PEDOT:PSS) and the application of these transistors to DNA and glucose sensors.

4:45 PM Y4.6
Ultrasonic Nanowire Sensors for Drug Discovery and Medical Diagnostics, Wayne Uei Wang,$^1$ Yi Cui,$^1$ Gengfeng Zheng,$^1$ Kengo-Liu Lin,$^1$ Charles M. Lieber,$^1$ $^1$Dept. of Chemistry and Chemical Biology, Harvard University, Cambridge, Massachusetts; $^2$Biophysics, Harvard University, Cambridge, Massachusetts.

Semiconductor nanowires represent an important class of nanostructured materials with the potential to impact applications from nanoscale electronics to biotechnology. For example, silicon nanowires can be configured as field-effect transistors (FETs) with characteristics exceeding that of conventional planar devices. These electronic properties make silicon nanowire FETs ideal transducers for electrically addressable, real-time and label-free sensing. Here we describe modification of nanowire surfaces with biological receptors to create nanoscale biosensors for both protein and drug molecule concentrations as low as 0.025 pg/ml, and moreover, the generality of detecting biological species in aqueous environments. Pentacene dielectric, and poly(dimethyl siloxane) (PDMS) microfluidic channels were used to expose the active regions of the transistors to aqueous solutions. We report a novel method to excite resonating cantilevers for MEMS. We present a cantilever with piezoresistive readout developed for AFM and tensile testing. The maximum actuating frequency depends on the devices' cooling rate, hence the power input/output of the different designs were measured at 100 deg. C in water by using incrementing DC current and the onset of boiling (bubbles) as a set temperature point. The results showed the optimal actuator configuration and surmounted the maximum actuating frequency of 1 MHz in 10 MHz in water (for the given actuator size). The optimal device was tested dynamically with a 160x2 urn cantilever- resonance was observed at 54 kHz and the Q factor was determined to 21. Resonant frequency of a cantilever is linearly proportional to its size. Hence, both the resonant frequency and the maximum actuating frequency increase linearly as size goes down, and the actuation principle is fully scalable.

Y5.3

Hybridization of DNA was detected with silicon microcantilever array sensors that were coated on one side with a thin layer of gold. By increasing the temperature of the array higher than the melting temperature of the double-stranded DNA (dsDNA) hybrid, the consequent surface stress change causes the cantilever array elements to bend. This bending is due to the denaturation of the dsDNA hybrid. The melting temperature of double-stranded DNA depends on the number of A-T base pairs and G-C base pairs. The more G-C base pairs, the higher the melting temperature. The denaturation of the dsDNA hybrid occurs when the DNA is immobilized on either the gold-coated side or the silicon side of the cantilevers.

Y5.4
Optimising the design of a cantilever biosensor with single crystalline silicon piezoresistors, Peter Andreas Rasmussen and Anja Boisen; Mikroelektronik Centret (MIC), Technical University of Denmark, Lyngby, Denmark.

We present a cantilever with piezoresistive readout optimised for the task of measuring isotropic surface stesses found for example when biological species immobilise on the surface of the cantilever[1]. The cantilever sensor is based on an SOI substrate. The optimisation takes into account the different stress distributions along the [110] directions for the AFM case the forces acting on the apex of the cantilever will create a dominantly longitudinal stress, since only a fraction will be converted to transversal stress through the Poisson contraction. This will give a high frequency response. However, the stress created on the surface of a cantilever when measuring the immobilisation of biological species will be isotropic in nature, and on long slender beams, where the effect of the clamping is small, the effective gauge factor will be the sum of the longitudinal and transversal gauge factors. For the above mentioned...
p-type resistor (on (100) silicon) the sensitivity will be very low, as the longitudinal gauge factor and the transverse gauge factor are of almost opposite sign. The subthreshold effect for the gauge factor found at low doping levels[2] the effective gauge factor will be almost an order of magnitude higher with a n-type resistor than with a p-type resistor. For short resistors, where the stress development is restricted by the clamping, i.e. the cantilever should be treated as a plate, the situation becomes more complex, and the sensitivity will depend on the ratio of the longitudinal to the transverse part of the resistance, and hence be very design specific. [1] R. K. Bird, L. R. Kavanagh, H. Butt, and P. Skodá, Micromechanical cantilever-based biosensors, Sensors and Actuators B: Chemical, 79(2-3):115-129, 2001. [2] C.S. Smith, Piezoresistance effect in germanium and silicon, Phys. Rev., 84(42), 1953.

Y5.6 High Resolution Visualization of Pathogen Signatures and Function by In Situ Atomic Force Microscopy.

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We will present high-resolution in situ atomic force microscopy (AFM) studies of pathogenic and non-pathogenic viruses, bacteria and bacterial spores. Several virus families, which span the size range from 17 nm diameters for satellite plant viruses to nearly half a micron for vaccinia, were characterized (1-3). In the case of the cowpea stunt virus, 28 nm diameter, it was demonstrated that not only protein capsomers on the virion surfaces could be clearly resolved, but also different T=3 virus families could be discriminated on the basis of capsid structure(1). The lateral resolution of a few nanometers was achieved on virions in situ. Further dissection of viral particles with detergents and enzymes, as was demonstrated(2) with Herpes Simplex Virus (HSV-1) revealed in addition to the intact, enveloped viruses: (a) the underlying capsids with associated protein complexes and membranes, (b) the capsomers composing the HSV-1 capsid, and their surface arrangement, and (c) the encapsidated viral DNA. The work on individual virus particles, in situ, culminated in the study of vaccinia virus (VAV). Vaccinia, as well as smallpox vaccine, is a laboratory model for what many consider to be one of the most significant bioterrorist threats. It is one of the largest and most complex viruses in human transcriptome. Intact vaccinia viruses were visualized under physiological conditions. The vaccinia virions were subsequently treated individually, or with a series of chemicals and/or enzymes intended to denude the particles from the outside to the inside, and ultimately to reveal the internal structure of the virus. Consecutive subviral structures including core envelopes, viral cores, nucleoprotein filaments, as well as viral DNA were visualized. A novel structural model of vaccinia virion based on the hierarchy of observed subviral structures was constructed(3). In the case of bacteria Chlamydia trachomatis, we were able to identify surface exposed proteins versus proteins embedded in the outer membrane. Differences in morphological signatures and high-resolution structural attributes of various bacterial species were demonstrated. Further investigation revealed dissection of spores revealed strain-specific nanometer scale features of internal structures. Dynamic morphological changes of dormant bacterial spores in response to the environment were visualized. These results demonstrate that AFM could be incorporated into the array of early detection techniques for identifying infectious and pathogenic organisms and agents. 1. A.J. Malkin, M. Lomp and A. McPherson, Appl. Biochem. Biotechnol. 457 (2004). In: DNA Viruses: Methods and Protocols. (Ed. P.M. Lieberman). Methods in Molecular Biology Series. The Humana Press Inc., in press. 2. M. Lomp, M.K. Rice, E.K. Wagner, A. McPherson and A.J. Malkin (2002). American J. of Pathology. 160, 1959-1966. 3. A.J. Malkin, A. McPherson and P.D. Gerashov (2009) J. Virology, 77, 632-6340.

Y5.7 Optimization for High-Specificity Sensor Coating.

Lee-Deok Oh 1, Karolyn M Hansen 2 and Thomas G Thundat 3.

1Electrical & Computer Engineering, University of Tennessee, Knoxville, Tennessee; 2Life Science Division, Oak Ridge National Lab., Oak Ridge, Tennessee; 3Chemistry Department, University of California, Berkeley, Berkeley, California.

MEMS/NEMS-based sensors can be made into multiple arrays to detect specific chemical and biological agents. The sensing mechanisms and response to molecular or biological agents can be highly versatile; the location, size and geometry of the array can be tailored to the target agent. By using arrays of similar microcantilevers and a novel tuning technique, the location, size and geometry of the surface may be tailored. The MEMS sensor is shown to function favourably both inside and outside of pressurized pipelines and may be implemented with complementary leak detection systems to provide a full suite of leak protection.

Y5.8 Abstract Withdrown

Y5.9 Cationic inorganic materials for remediation of anionic pollutants, Scott R. J. Oliver, Tolulope O Salami and Dat T Tran.

Department of Chemistry, SUNY-Binghamton, Binghamton, New York.

The EPA has listed many anionic species, such as chromate, selenite and arsenate, as priority pollutants. Current anion-getters have limited thermal and pH stability, which forbids their use in the harsh conditions of many waste solvents. We are interested in developing a new class of thermo-chemically stable cationic open-framework metal oxide hosts with anionic guests. These microporous materials have potential application in anion-exchange, anion-trapping and base catalysis. The properties are opposed to those of zeolites, which are primarily anionic hosts, and therefore limited to cation-based properties. Our efforts towards the solvothermal synthesis and potential application of cationic extended materials will be discussed. We have discovered a cationic inorganic material that expels nitrate and sorbs a variety of anions, such as dichromate and benzoate, in high capacity. Anion-exchange of pertechnetate analogs, for the potential application of pretreatment of high-level radioactive waste (HLW), has also been successful. Our materials could also be used to remove chromates from these wastes, which are known to decompose the glass matrix and trap the HLW. Certainly, anion remediation is a high priority and our cationic materials have the potential to address some of these problems.

Y5.10 A Label-Free Colloidal Assay for Membrane Binding Affinity.

Eather M. Winter 1, Michael M Baksh 2 and Jay T Groves 3.

1Chemical Engineering, University of California, Berkeley, Berkeley, California; 2Biophysics, University of California, Berkeley, Berkeley, California; 3Chemistry, University of California, Berkeley, California.
Two-dimensional dispersions of silica microbeads, coated with fluid liquid layer membranes, exhibit transitions between dispersed and condensed phases. The collective phase behavior of this novel colloidal system is governed by membrane-membrane interactions and serves as a readily detectable amplifier for subtle molecular events occurring at the membrane surface. This study explores the efficacy of colloidal phase transitions as a label-free and power-free assay of membrane surface binding affinity. Equilibrium dissociation constants for the interactions between ligands and membrane-associated receptors are measured by optical read-out assay and label-based solid phase read-out techniques. The membrane-derivated colloid assay is compatible with high-throughput screening technologies.

Y5.11 The Role of Film Thickness in Organic Thin Film Transistor Gas Sensors. Christopher Chen, Frank Liao and Vivek Subramanian; Electrical Engineering and Computer Sciences, University of California, Berkeley, Berkeley, California.

Organic thin film transistors (TFTs) have shown much promise for use in a variety of gas sensing applications. When exposed to an analyte, gas molecules interact with the organic active layer of these devices and influence transistor behavior in a variety of ways, including shifts in on-current, current density, mobility, and threshold voltage. Furthermore, because several organic semiconducting materials are soluble in common solvents, TFTs can be easily fabricated by spin-casting or inkjetting the active layer. In this study, we analyze the relationship between film thickness, analyte exposure time, and the response of organic TFTs. We report on transient adsorption and desorption cycles for sensors with different film thicknesses exposed to a variety of analyte compounds. Experimental results indicate that film thickness greatly influences certain sensor characteristics, while other parameters are thickness-independent. We report on a strong correlation between film thickness, exposure time, and change in on-current. Our analysis indicates distinct relationships between sensor film thickness and shifts in transconductance, threshold voltage, and mobility. Finally, we demonstrate the existence of an optimal active layer thickness for each parameter examined.

Y5.12 Directed Assembly of Nanomaterials for Miniaturized Chemical Sensors. Ming Su and Vinayak Dravid; Department of Materials Science and Engineering, Northwestern University, Evanston, Illinois.

The abundant knowledge about synthesis of nanomaterials has paved the way for the controlled construction of miniaturized sensors and sensor arrays. However, self-assembly methods lack precise position control, the ability to pattern multiple species and overall reproducibility, among other considerations. In view of these challenges, directed assembly of nanobuilding blocks by various site-specific patterning approaches is desired. We have reported dip-pen nanolithography (DPN) to pattern diverse nanomaterials (semiconducting metal oxides, conducting polymers, and hybrid/organic materials) as various building blocks which assemble into final functional form. The site-specific and multiple-ink patterning capabilities of DPN are put to use in fabrication of miniaturized chemical sensor arrays with either solvent-based inks which yield gas sensitive semiconducting metal oxides, or "monomer" inks which polymerize to form conducting polymer structures. The miniaturized sensors constructed in this manner show ultrapfast response and rapid recovery, and can be further integrated to form sensor array that have excellent gas recognition capabilities. We have recently extended this approach to "electronic nano-nose", whereby multiple sensor elements are integrated in an array for multiplexed gas sensing.

Y5.13 Detection and Classification of Volatile Organic Amines and Carboxylic Acids Using Arrays of Carbon Black-Dendrimer Composite Vapor Detectors. Ting Gao and Nathan S Lewis; Chemistry and Chemical Engineering, California Institute of Technology, Pasadena, California.

Carbon black-polymer composite chemiresistive vapor detectors have been prepared using dendrimers as the polymeric constituent of the composite. Amino-terminated dendrimer-carbon black composites exhibited an ultrahigh sensitivity of 104 in detection of volatile carboxylic acids as compared to non-dendrimeric insulating polymer-carbon black composites. Similarly, protonated carboxylate terminated and protonated amino-terminated dendrimer-carbon black composites showed an 103-104 increase in sensitivity for detection of volatile amines relative to the response of non-dendrimeric insulating polymer-carbon black composites. The protonated amino-terminated dendrimer carbon black composite detectors exhibited a signal-to-noise ratio (S/N) of 22.4 ± 0.9 upon exposure to 2.7 ppb of butylamine in air, whereas poly (ethylene oxide)-carbon black composites exhibited a S/N of 3.5 ± 1.2 at 54 ppb of butylamine. The protonated amino-terminated dendrimer-carbon black detectors additionally exhibited relatively small responses to water vapor. Compositional diversity in an array of protonated amino-terminated dendrimer vapor detectors was obtained by varying the type and generation of the dendrimer, and the type and concentration the acid dopant. 15 analytes chosen from primary amines, branched amines, aminals and non-amine organic analyte vapors were all robustly discriminated from each other by their different response to corresponding vapor detectors. The signals produced by these 15 analytes additionally clustered into groups based on the chemical class of the analyte.

Y5.14 Synthesis of nanostructured electrodes for biosensor applications. Maria P. Gil, Donghai Wang and Yunfeng Lu; Chemical and biomolecular engineering, Tulane University, New Orleans, Louisiana.

One of the current driving forces in the research field of glucose biosensors for food, biological and medical applications is the miniaturization of the sensors for in vivo applications and reduction in the size of portable monitoring devices. We are proposing a new type of material for the transducer of the sensor. The two main characteristics of nano-scale materials are their small size and dramatically high surface area. An electrode with high surface area would allow the immobilization of a high amount of enzyme, and in consequence, the sensor would display a high sensitivity while reducing the cost of detection. Nano-scale materials for application electrodes for amperometric glucose biosensors were synthesized by the following step: 1) construction of a nanostructured mesoporous thin film template by self-assembly of surfactant and silicate species, 2) electrodeposition of platinum within the pores of the silica template, 3) removal of the silica template, and 4) immobilization of the enzymes on the platinum electrode. X-ray diffraction (XRD), transmission electron microscopy (TEM) and cyclic voltammetry were used to characterize the synthesized materials, and the glucose sensitivity was determined amperometrically. Two types of platinum nanostructured materials (2D nanowires or 3D nanonem structures) were synthesized depending on the surfactant used to prepare the silica template. The sensors prepared with these platinum electrodes show a sensitivity to glucose ranging form 0.6 uA-cm²/mM to 1.4 uA-cm²/mM) and retain this sensitivity for about a month. In comparison, an electrode prepared by chemical vapor deposition showed a sensitivity of 0.15 uA-cm²/mM and retained this sensitivity for about 3 days, after which it began decreasing.

Y5.15 Nanotechnology for Explosive Detection: The use of fluorescent nanoparticles for sensing NO2 containing organics. Sorelis Nieto1, Lewis Mortimer Gomez1, Alberto Santana1, Samuel P Hernandez2, R. Thomas Chamberlain2, Richard Lareu3 and Miguel E. Castro1; 1Chemical Imaging Center and Center for Chemical Sensor Development Department of Chemistry, The University of Puerto Rico at Mayaguez, Mayaguez, USA, Puerto Rico; 2Chemistry, University of Puerto Rico at Mayaguez, Mayaguez, USA, Puerto Rico; 3Federal Aviation Administration, William Hughes Technical Center, Atlantic City.

Homeland security is an important area that requires input from a myriad of science and engineering areas. Nanotechnology is expected to play a central role in contributing to improvements in homeland security issues. Small and lightweight and field deployable systems that can be used for explosive detection systems can be developed with new and emerging nanotechnologies. In this presentation, we will present recent results on the use of fluorescent nanoparticles for the detection of trace amounts of TNT, a powerful explosive. Quantum dots, excited with a femtosecond laser pulse, exhibit a decrease in fluorescence signal intensity and small shift in emission wavelengths upon addition of solutions containing traces of TNT. The direction of the shift depends on the particle size. The chemistry that takes place on the nanoparticle surface is interrogated with a battery of surface analytical techniques that includes X-ray photoemission spectroscopy, near field optical microscopy, atomic force microscopy and Fourier transform infrared and Raman microscopy.


Ultrananocrystalline diamond (UNCD) is a fine-grained (3.5nm),
smooth, biocompatible diamond material. Here we give an overview of various properties that make this material particularly suited as a platform for biosensors and MEMS devices: mechanical (high hardness and fracture strength), electrical (highly conductive with significant mobilities), chemical (surface modification), and tribological (low friction and stiction). We will discuss the microwave plasma-enhanced chemical vapor deposition (CVD) growth process that is used to produce UNCD films, the various seeding processes employed, the effects of alternate plasma chemistries, and doping. We show how the nanostructure of the films is affected by these processes, and discuss this in the context of UNCD as a platform sensor/MEMS material. In particular, we will discuss conductive UNCD as a basis for electrically active FET and MEMS devices, and address device integration issues critical to the development of real-world MEMS structures, such as the fabrication of diamond-to-metal contacts and the growth of oxides on UNCD films by both sputter deposition and atomic layer deposition.


Biological researchers need to simultaneously record electrical signals from multiple locations in order to fully understand a neuronal system. An ideal electrode array would conform to the physical layout of the neurons, and it would also be optically transparent and biocompatible. Polydimethylsiloxane (PDMS) is a material that fits these requirements. An additional benefit of PDMS is that the biological tissue can be pinned directly onto the PDMS. In this work, we present a new fabrication method to create small features in thick (1mm) PDMS. First, we developed recipes to deposit PDMS uniformly onto a substrate. By adjusting the spin speed and ramp-up time, we were able to spin on PDMS coatings with a uniform thickness between 500μm and 1mm. Then, using the ESI-4440 laser system, we successfully developed methods to "cut-out" shapes and drill holes in 1mm-thick PDMS, without damaging the underlying substrate. The average diameter for a 1mm-deep hole was 43μm. For cutouts, we made partial cuts through the PDMS, then either pulled or punched out the inside material using sharp tweezers. We successfully punched out 100μm square pixels using this method. The initial results indicated that the feature depth can be controlled to within 8μm, and the typical edge roughness of holes was 8μm. We characterized the feature depth in relation to the number of laser pulses, and the two values were related through a linear curve. We then used this curve to successfully predict the feature depth of subsequent holes and shapes. By spin-coating PDMS onto a hydrophobic surface, the patterned PDMS was easily peeled off and placed onto a glass substrate patterned with gold. This eliminated any damage to the gold electrodes by the laser micromachining process. We have also developed methods to create channels in PDMS, which help with the placement of neuronal axons. Using laser micromachining, we have taken the first step to developing an improved electrode array to record extracellular neuronal signals. The fabrication process is both simple and flexible. A hole diameter of 1mm allows biological researchers to use existing methods to physically fix the neuronal tissue.

Y5.18 Lithographically Patterned Microcoils for High Sensitivity NMR Chemical and Biological Detection, Julie Lynn Herberg1,2, Sarah C Chinn1, Robert Maxwell1, Anthony F Bernhardt2 and Vincent Malha2; 1Chemistry and Material Science, Lawrence Livermore National Laboratory, Livermore, California; 2Electronics Engineering Technologies Division, Lawrence Livermore National Laboratory, Livermore, California.

It is well known that nuclear magnetic resonance (NMR) offers a non-destructive, powerful, structure-specific analytical method for the identification of suspect analytes and biological systems. NMR, however, is hampered by relatively poor sensitivity. Lithographically patterned NMR microcoils offer a path to increasing the sensitivity of a conventional NMR system while retaining the high information content data streams NMR provides. Recent advances in micro-receiver technology, for example, have demonstrated a >70-fold increase in mass sensitivity, but are typically limited to solution coil forms. Lithographic production methods, however, possess a level of flexibility that goes beyond other production methods enabling the fabrication of a diverse range of coil forms. Here, detailed electrical characterization of microcoils produced by a unique three dimensional laser lithography system that can pattern on curved surfaces will be discussed, along with integration of these microcoils into a conventional and portable NMR systems. Initial NMR results obtained with both 1 mm and 360 μm. O.D. receivers will be presented along with ongoing methods of resolution enhancement and the future integration of a Capillary Liquid Chromatography separation-detection system. Current and future applications of lab-based microcoil NMR techniques will be discussed.

Y5.19 Surface Wave Properties of AlN Epitaxial Layers, Jianzeng Xu, Qianghua Wang, Hao Ying and Gregory Auner; Electrical & Computer Engineering, Wayne State University, Detroit, Michigan.

Hexagonal AlN, known for its high acoustic velocity, is a promising candidate for highly sensitive chemical or biological detection. A lot of study has been done regarding Rayleigh wave propagating on AlN for microwave devices. However, these devices are not suitable for biological detection due to the acoustic energy dissipation in liquid. We hereby report the study on excitation of Rayleigh wave and transverse mode wave on AlN epitaxial layer. AlN thin film has been deposited on C-plane, R-plane, and A-plane Sapphire by plasma enhanced molecular beam epitaxy method (PSMBE). XRD shows the highly epitaxial growth of (0001) AIN//(0001) Al2O3, and (11 0) AIN//(1 0 2). Al2O3, and (10 0) AIN//(1 1 0) Al2O3. The velocity dispersion with respect to kh is presented, where k is the wave number and h is the film thickness. The effect on the transverse mode excitation due to the misalignment between wave propagation direction and crystal axis has been studied. Linear temperature coefficient is derived on these AlN acoustic wave devices. Device mass sensitivity of is also determined experimentally. The study would help to clarify the excitation mechanism for transverse mode on AlN and provide practical guidance for developing AlN based biological sensors.

Y5.20 Investigation on AlN/AIN/AI Structure for Ultrasound Biological Transducers, Qianghua Wang, Jianzeng Xu, Ratna Naik and Gregory W Auner; 1Department of Electrical and Computer Engineering, Wayne State University, Detroit, Michigan; 2Department of Physics and Astronomy, Wayne State University, Detroit, Michigan.

Here we report the progress on developing AlN based piezoelectric transducers for ultrasonic imaging applications. Aluminum nitride (AIN) thin films was sandwiched by two metal layers deposited on silicon substrate. In order to avoid thermal damage to silicon device and integrated circuit, the deposition temperatures was chosen at 450°C, lower than 650°C for epitaxy AIN films grown by plasma source molecular beam epitaxy (PSMBE) technology. X-ray diffraction (XRD) shows the films exhibit a c-axis texture. Oxygen component is about 1% from X-ray photoelectron spectroscopy (XPS) analysis. The roughness of film surface determined by AFM decreased with increasing target-substrate distance and increasing nitrogen concentration. Electrical properties of AlN/Al/AI sandwich structure have been measured as a function of the frequency in 1kHz - 10MHz region. Optimizing the processing conditions is important to utilize AlN thin films for various devices.