Metro Area MEMS/NEMS Workshop

Location: Babbio Center (B122), Stevens Institute of Technology
Date: Monday, July 23, 2007

Micro Electro Mechanical Systems (MEMS) and **Nano Electro Mechanical Systems (NEMS)** are miniature systems integrating electrical, mechanical, optical, chemical and/or biological components that are fabricated via integrated circuit or other related manufacturing techniques. This is a highly multi-disciplinary field. Research in and applications of MEMS/NEMS will shape the basis for the creation of technologies that will impact diverse areas such as information technology, biomedical technology, energy, transportation, robotics, manufacturing, deep space studies, and national security. The goal of the workshop is to facilitate communication and collaboration among MEMS/NEMS researchers in the NYC metro area.

Workshop Coordinators
Frank Fisher, Stevens
Qiao Lin, Columbia
Yen-Wen Lu, Rutgers
EH Yang, Stevens

Abstract Coordinator
Chang-Hwan Choi, Stevens

Poster Session Coordinator
Yong Shi, Stevens

Workshop Advisory Group
Michael Bruno, Dean, School of Engineering, Stevens
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Henry Du, Director, CBME Department, Stevens
Souran Manoochehri, Associate Dean of Research, Stevens
Vijay Modi, Professor, ME Department, Columbia
Kishore Pochiraju, Director, Design and Manufacturing Institute, Stevens

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MECHANICAL ENGINEERING
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PROGRAM SCHEDULE

8:00-8:45 am — **Continental breakfast, poster set-up**

8:45-9:00 am — **Introduction**
George Korfiatis, Provost, Stevens

9:00-10:40 am — **Session I (Chair: Prof. EH Yang)**

- *Keynote: MEMS/MEMS Research & Commercialization,* ***Dr. William Trimmer (Right Force Orthodontics)***
- *CMOS++: Combining nanotechnology and biotechnology with mixed-signal CMOS electronics,* ***Prof. Ken Sheppard (Columbia)***
- *Nano- and Micron-Scale Adhesion in Au MEMS Structures,* ***Prof. Wally Soboyejo (Princeton)***

10:40-11:10am — **Poster Session I & Break**

11:10-12:40 pm — **Session II (Chair: Prof. Vijay Modi)**

- *Pneumatic Manipulators for Biological Study at Microscale,* ***Prof. Yen-Wen Lu (Rutgers)***
- *Integrating MEMS and Microfluidics for Thermal Sensing and Control of Biomolecules,* ***Prof. Qiao Lin (Columbia)***
- *A Closer Look at Microchemical Systems as Platforms for Efficient Chemical Processing: a Discussion of Advantages and Limitations,* ***Prof. Ron Besser (Stevens)***

12:40-2:00 pm — **Lunch**

2:00-3:30 pm — **Session III (Chair: Prof. Wally Soboyejo)**

- *Electric Field Driven Manipulation of Particles in Microfluidics,* ***Prof. Boris Khusid (NJIT)***
- *Functional Nanowires and Their Applications in Sensing and Energy Scavenging,* ***Prof. Yong Shi (Stevens)***
- *MEMS and Shear measurement,* ***Prof. Vijay Modi (Columbia)***

3:30-4:00 pm — **Poster Session II & Break**

4:00-5:30 pm — **Session IV (Chair: Prof. Souran Manoochehri)**

- *Nanophotonic Devices based on Photonic Crystal Membranes,* ***Prof. Stefan Strauf (Stevens)***
- *Microfluidics for Health Diagnostics and Treatment,* ***Prof. Jeffrey Zahn (Rutgers)***
- *Anisotropic Stress State around Pressurized Microchannels,* ***Prof. Yong Gan (Copper Union)***

5:30 pm — **Closing Remarks (Prof. EH Yang)**

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Abstracts for invited talks

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MECHANICAL ENGINEERING
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MEMS/MEMS Research & Commercialization

William Trimmer
Preseident, Right Force Orthodontics

Man has been developing tools and devices on the size scale of hands for millennia. Cooperative efforts have also made substantially larger mechanical systems such as cranes, ships, and even canals and roads possible. Strangely enough until recently small scale structures have not been put to the same good advantage. Recent tools and fabrication techniques are opening a new world. A few of the numerous opportunities include genetic engineering, micro-surgery, drug delivery, the science and engineering of small scale phenomena, micro-metrology, pressure sensors, accelerometers, micro valves and fluid controllers, micro actuators, distributed intelligence, communications and others. This talk is an overview of where the MEMS/NEMS field has been and where it is going and what are the limitations and potential of our field. The relationship between research and commercialization is specially important. Research provides the potential and commercialization provides the profit to support enhanced research.

Bio for Dr. William Trimmer

Dr. William Trimmer is one of the founders of the field of micromechanics. He helped develop the basic fabrication techniques, organized the original conference, was founding editor of two scientific publications, and has operated the micromechanics company Belle Mead Research for fifteen years. At Bell Laboratories, he co-developed the sacrificial-structural techniques now in common usage and called surface micromachining. (The University of California at Berkeley, the Massachusetts Institute of Technology and several other universities also developed sacrificial-structural techniques.) Dr. Trimmer also developed a fiber optic switch for telecommunication and several micro motors.

In 1987, Dr. Trimmer co-organized the original conference in this field. This conference, the MicroElectroMechanical Systems Conference, gave the acronym MEMS to this field. It is now one of the premiere international conferences. Dr. Trimmer organized and was founding Editor of the IEEE/ASME Journal of MicroElectroMechanical Systems ("JMEMS"). This was the first joint IEEE and ASME publication and required substantial negotiation to form a new business structure for joint publication. New journals typically lose money for the first five years. However, the JMEMS Journal made a profit in its second year, and at the end of Dr. Trimmer's six year tenure had over a one year operational budget in the bank. Dr. Trimmer was founding Editor of the Micromechanics Section of the Elsevier publication Sensors and Actuators.

Dr. Trimmer published the IEEE book "Micromechanics and MEMS" which is in its second printing. He has written several chapters in other books and co-authored the NSF booklet "Small Machines, Large Opportunities," that helped define this field. Dr. Trimmer has also written numerous papers, given many invited talks in this field and has 12 patents.

Dr. Trimmer founded Belle Mead Research, BMR, in 1990 and is the President and owner. BMR specializes in developing applications in micromechanics and has helped market micromechanical products, evaluated potential applications, and facilitated other companies profiting from the field of micromechanics. In 1999, Dr. Trimmer was one of the founders and Chief Technical Officer of the Standard MEMS Company, a company that manufactured micromechanical and MEMS devices. When he left Standard MEMS in 2001, the company had grown to over 200 employees. Dr. Trimmer was also one of the founders of the Marcus & Trimmer Company that developed an ultra sharp surgical knife. This company was sold in 1999 to a group specializing in eye surgery.

Dr. Trimmer is presently president of Right Force Orthodontics, a company that is developing a proprietary medical product.

CMOS++: Combining nanotechnology and biotechnology with mixed-signal CMOS electronics

Ken Shepard

Associate Professor of Electrical Engineering
Columbia University

In this talk, I describe on-going research efforts to employ mixed-signal CMOS electronics for non-traditional applications, exploiting co-integration of hybrid technologies with CMOS. Much of this focus has been on active CMOS biochips for affinity-based assays based on both fluorescence and electrochemical detection and incorporating microfluidics for reagent delivery. The fluorescence-based chips are capable of time-resolved measurement and employ both high-speed photodiodes and Geiger-mode avalanche photodiodes for detection. Electrochemical-based detection employs arrays of potentiostats on the chip, capable of both cyclic voltammetry and impedance spectroscopy. In both cases, DNA or protein probes are immobilized directly on the chip surface for detection. Other ongoing projects include designing circuits combining CMOS devices with carbon-based transistors, including both nanotubes and graphene. Preliminary results on “hybrid” circuits will be shown, including biosensing as well as purely electronic applications.

NANO- AND MICRON-SCALE ADHESION IN AU MEMS STRUCTURES

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This paper presents the results of a combined experimental/theoretical/computational study of adhesion in cantilevered Au MEMS structures. Adhesion is studied within a multi-scale framework that ranges from single asperity contact at the nano-scale, to surface asperity contact at the micron-scale. At the nano-scale, atomic force microscopy was used to measure the force-displacement curves associated with single asperity adhesive and elastic interactions. These were then incorporated into adhesion models that were used to extract the surface energies for Au-Au contact and adhesion. At the micron-scale, a novel fracture mechanics approach was used to establish the effective adhesive energies, which were determined by subtracting the crack-tip shielding effects of asperity contact from the energy release rates associated with the crack-like geometries formed by the contact of the Au cantilevered beams on Au contact pads. The effective micron-scale adhesive energies are shown to be comparable to the surface energies obtained the nano-scale. The implications of the results are discussed for the design against adhesion and stiction in MEMS structures.

Pneumatic Manipulators for Biological Study at Microscale

Prof. Yen-Wen Lu
Department of Mechanical and Aerospace Engineering
Rutgers University

An exciting consequence of Nano/Micro-Electro-Mechanical Systems (N/MEMS) is that complicated structures and devices may be implemented and integrated within a tiny compact system. One of the examples is that a complex micromanipulator, such as a bio-mimicking micro-hand, can dexterously handle tiny mechanical parts and biological objects. While many micromanipulators (e.g. grippers, tweezers, needles and pipettes) have previously been developed to demonstrate the feasibility of manipulating tiny objects, they are limited by their motions, operating environment and functions. To have broad capability in diverse and practical situations, a dexterous, flexible and robust micromanipulator is highly desired, such as bio-sample preparation and microsurgery.

The microhand device has been developed to address the above issues. This active microhand will be a major component in many micromanipulator systems. The microhand is composed of the flexible Parylene joints and the robust silicon finger structures and is pneumatically driven to operate in biological liquid environment. Its unique actuation mechanism provides the capability of large force and active grasping that are very useful in microsurgery application. The designs, mechanisms, and fabrications will be explained. The modeling, packaging, characterization and applications of the active microhand will also be presented.

Integrating MEMS and Microfluidics for Thermal Sensing and Control of Biomolecules

Qiao Lin

Department of Mechanical Engineering
Columbia University, New York, NY 10027

Thermal effects are ubiquitous to biological processes. Devices fabricated with microelectromechanical systems (MEMS) technology allow effective and sensitive thermal detection and control, and when integrated within microfluidic systems, can enable interrogation of biomolecules in controlled microscale environments unattainable with conventional technologies. This presentation will highlight our efforts in applying such integration to biomolecular manipulation and characterization.

We will discuss the integration of MEMS thermodynamic sensing with microfluidics, focusing on a miniaturized differential scanning calorimeter. The device consists of a pair of freestanding microfluidic chambers integrated with MEMS thermal elements. Minute differential heat between the sample and buffer contained in the chambers is measured to assess the biochemical reaction, potentially with orders-of-magnitude smaller sample volumes when compared with conventional instruments. We will also present an investigation of microfluidic platforms for manipulating biomolecules using synthetic and bio-polymers that undergo strong temperature-induced, reversible conformational changes. For example, aptamers, or oligonucleotides with sequence-dependent shape to bind specifically to other molecules, can potentially enable efficient miniature extraction systems. This is demonstrated by capture of small-molecule analytes by aptamer-functionalized microbeads in a microfluidic chamber, and analyte release and device regeneration by exploiting thermally induced, reversible breakage of analyte-aptamer binding.

A Closer Look at Microchemical Systems as Platforms for Efficient Chemical Processing: a Discussion of Advantages and Limitations

Professor Ron Besser
Stevens Institute of Technology

Miniaturization has revolutionalized many technological areas in the past decades and has given us a multitude of productivity- and lifestyle-enhancing products and services that we now consider routine. At a slower pace has been the development of miniature systems for *chemical processing*. Although analytical applications in biomedicine, such as lab-on-a-chip, have been well publicized, less well known are microchemical systems for the *production* of chemicals. Because of microscale geometry these systems can possess extraordinarily high rates of heat and mass transport, enabling unprecedented levels of processing efficiency as measured by such figures of merit as conversion, selectivity, space-time yield, etc. on a per volume basis. Our group has been involved in understanding the crucial issues and fundamental limitations of such systems in a variety of applications. The presentation will highlight a few examples of these applications, especially in the areas of hydrogen generation for portable fuel-cell powered systems where system compactness and light weight are paramount, and in the synthesis of pharmaceutical intermediates where improved manufacturing efficiency can result in purer products, simpler processes, and lower costs.

ELECTRIC FIELD DRIVEN MANIPULATION OF PARTICLES IN MICROFLUIDICS

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Micro-analytical systems are widely used in a variety of applications ranging from biological warfare agent detection to the healthcare industry. The first step in the operation of a micro-system consists of concentrating and separating the analytes of interest followed by positioning them into the selected locations for subsequent analysis. Compared to other available techniques, dielectrophoretic methods have been demonstrated to be particularly well-suited for the manipulation of minute particles in microfluidics. Although numerous papers published within the last decade have contributed to our knowledge about the fabrication of electro-microfluidics, very little has been achieved in mastering the phenomena that underlie the behavior of a suspension subject to a high-gradient strong electric field. In particular, the concepts currently favored for the design and operation of dielectrophoretic devices ignores the effect of the interparticle hydrodynamic and electric interactions on the suspension behavior.

Surprisingly, we have recently demonstrated experimentally [1-6] that the presence of the interparticle interactions can drastically affect the suspension behavior. A distinct front, separating regions enriched with and depleted of particles, was observed in suspensions subjected to high-gradient ac electric fields and a theoretical model equations for the motion of interacting particles, containing no fitting parameters, was developed. This phenomenon suggests a new method for the field-driven particle manipulation and building large-scale microparticle structures. Analytical theory indicates two limiting mechanisms of the concentration front formation: thermodynamic and hydrodynamic. The former corresponds to the thermodynamic equilibrium when dielectrophoresis is accompanied by a field-induced phase transition. The latter operates in transient regimes through the balance of the dielectrophoretic and hydrodynamic forces caused by the rapid local growth of the suspension viscosity due to the field-driven particle accumulation in certain areas of the domain.

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Functional Nanowires and Their Applications in Sensing and Energy Scavenging

Yong Shi
Department of Mechanical Engineering
Stevens Institute of Technology

One dimensional nano structures such as nano-tubes, nano-wires and nano-fibers have great potential as either building blocks for micro/nano devices or as functional materials for micro-scale sensing and actuation applications. They provide more design flexibility and performance which may not be achievable before. Functional nanowires such as PZT or ITO are two very good examples which were used in bulk or thin film forms usually. In this talk, the fabrication and characterization of nano piezoelectric (PZT) fibers and ITO nanofiebrs will be discussed. We demonstrated that PZT nanofibers can be used to harvest energy from dynamic loading and mechanical vibration. PZT nanofibers were fabricated by electrospinning process. SEM image of PZT nanofibers has shown that the average diameter of these fibers is about 150nm. Titanium substrate with ZrO_2 layer was used to collect the PZT nanofibers for the demonstration of energy harvesting from dynamic loading. The largest output voltage is 170mV under 0.5% strain, which suggest that PZT nanofibers have great potentials for energy harvesting from environments. Gas sensors based on ITO nanofibers were prepared on Si substrate. The morphology and crystal structure of ITO nanofibers were studied by SEM and XRD, respectively. The sensitivity of ITO nanofiber sensor increased to a peak of 9.8 at 160°C for 50 ppm NO_2, which is very significant under such a relatively lower temperature.

MEMS and shear measurement

Jiang Zhe,Vijay Modi

Columbia University

The measurement of shear is of great interest since shear is the primary means of interaction between a flow and the solid surface. It is the genesis of drag and the controlling factor in the removal/deposition of particles, heat and chemical species at a wall. The initial motivation for this particular study arose from the need to characterize flows for electrochemical processing through polymeric photoresist masks for microfabrication of high-density patterned structures. A silicon-based, micromachined, floating-element sensor for low-magnitude wall shear-stress measurement has been developed. Sensors over a range of element sizes and sensitivities have been fabricated by thin wafer bonding and deep reactive ion etching techniques. The design objective is to measure the shear stress distribution at levels of O(0.10Pa) with a spatial resolution of approximately O(100μm). It is assumed that the flow direction is known, permitting one to align the sensor appropriately so that a single component shear measurement is a good estimate of the prevalent shear. Using a differential capacitance detection scheme these goals have been achieved. We tested the sensor at shear levels ranging from 0 to 0.20 Pa and found that the lowest detectable shear stress level that the sensor can measure is 0.04 Pa with a 8% uncertainty on a 200 μm×500 μm floating element plate.

Nanophotonic devices based on photonic crystal membranes

Stefan Strauf

Assistant Professor
Physics and Engineering Physics
Stevens Institute of Technology

Photonic crystals are attractive systems for fundamental studies of light-matter interaction and hold great promise for novel nanophotonic device applications in both, classical and quantum information science. Photonic crystal membrane (PCM) structures are of particular interest due to their unprecedented ability to control, bend, trap, switch, slow, and extract light and to sense the environment at the nanoscale. Ultimately, this research is aiming for the creation of photonic circuits with superior bandwidth and yet unforeseen functionalities.

In this talk I will show recent results for two devices based on PCM nanocavities, which have been processed into GaAs wafers with embedded InAs quantum dots (QDs) as active emitters: Biofunctionalyzed sensing devices can be created by attaching self-assembled monolayers of polypeptide molecules to the GaAs surface and utilizing coupling to the evanescent optical field [1].

PCM nanolasers are realized by engineering cavities providing a large overlap between the optical mode and the active QD gain medium. Measurements demonstrate that our wavelength tunable nanolasers have extremely high coupling efficiency leading to operation at world-record low lasing thresholds [2, 3].

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Microfluidics for Health Diagnostics and Treatment

Jeffrey D. Zahn

Assistant Professor Dept. of Biomedical Engineering Rutgers University

Batch fabricated microfluidic platforms that can mimic conventional sample preparation techniques performed in laboratories hold great potential to enable both research and healthcare advances. Such miniaturized diagnostic devices have been termed micro total analysis systems (μTAS) or biochips and combine sensing mechanisms (physical, optical, electrical or chemical) with microfluidics. While microfluidics promises to have an impact in many research fields, one of the more attractive applications has been towards biomedical and life science diagnostics. There is a growing market for point of care diagnostic devices for both bedside and outpatient monitoring. This seminar will provide an overview of research projects currently underway in the Zahn laboratory which utilize microfluidic technologies for the clinical diagnosis and treatment of disease. First, research on miniaturized hypodermic injection needles and an on-chip microdialysis system for continuous glucose monitoring for diabetes treatment will be discussed. Next, approaches towards developing devices which can separate blood plasma from whole blood and measure the concentration of clinically relevant proteins in a continuous, real time fashion will be discussed. This is especially important for monitoring inflammatory responses in patients undergoing cardiac surgery when cardiopulmonary bypass (CPB) is used. Finally, an approach for improving DNA purification from cells using a two phase liquid extraction with electrohydrodynamic (EHD) instability micromixing is discussed.

Anisotropic Stress State around Pressurized Microchannels

Prof. Yong Gan

Department of Mechanical Engineering
The Cooper Union, 51 Astor Place, New York, NY 10003

Internal pressure induced stresses around square-shaped microchannels are derived. In this talk, some background materials of microchannels in micro/nanosystems are provided to show the significance of investigating the stress and deformation states around the channels. In the second part, a simplified model is developed to characterize the plastic flow and/or motion of dislocations within crystalline materials containing the microchannels. Based on the model, slip bands around the channels in the materials under plane strain deformation conditions are identified. The third part deals with the derivations for obtaining the solutions to the stress states around the microchannels. Closed form solutions in the zones both containing the inner boundary and away from the inner boundary of the channels were obtained. The stress solutions were presented in graphic forms in both physical space and stress space. The results predict nonuniform deformation states around the channels. The yield conditions associated with the plastic flow along different slip bands were also revealed. Finally, case studies on the stress states of microneedles containing square shaped microchannels for applications such as fluid injection, nanofiber growth and cell registration were presented.

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Abstracts for poster sessions

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Design and Fabrication of Silicon-Pyrex Micromixers for Mixing Enhancement Study

John T. Adeosun (PhD candidate in CBME Dept.) and Adeniyi Lawal (Professor and Director of Chemical Engineering Program in CBME Dept.)

Affiliations: (1) Chemical, Biomedical, & Materials Engineering, Stevens Institute of Technology and (2) New Jersey Center for MicroChemical Systems (NJCMCS)

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The ineffective mixing in microchannel mixers/reactors, primarily due to the inherently diffusion-dominated laminar flow that characterizes such small-volume environment, has become an issue of significant interest to many investigators working in the field of microreaction engineering. The goal of our research study is to investigate mixing enhancement in microchannel mixers, through a theoretical as well as an experimental mixing study of currently utilized as well as proposed micromixing configurations. The design of our proposed micromixers for mixing enhancement is based on the mechanisms of fluid multilamination and elongational flow. In the mixing configurations designed, mixing is enhanced by placing static or passive mixing structures on the mixer channel floor to reduce the fluid diffusion path while at the same increasing significantly the fluid contact areas via creation of folding as well as local and global re-orientation of fluid interfaces. The outcome of our prior numerical study using Computational Fluid Dynamics (CFD) approach shows that the proposed mixing configurations exhibit remarkably better mixing performance when compared with the standard T-junction micromixer. However, for our experimental mixing study, we select the standard T-junction micromixer (TjM) and one of the proposed mixing configurations that we refer to as multilaminated/elongational flow micromixer-4 (MEFM-4) based on the set criteria of minimum pressure drop and high mixing performance.

Silicon MEMS technology was used to successfully fabricate the proposed multichannel micromixer and the standard T-junction micromixer for mixing enhancement study. Packaging via anodic bonding of the structured silicon substrates with Pyrex was performed to facilitate optical and fluidic access to the channels of the micromixers. This packaging produces the desired triple-stacked (Pyrex/silicon/Pyrex) multi-channel micromixer and double-stacked (Pyrex/silicon) single-channel T-junction micromixer. Our present work focuses on the testing and characterization of these fabricated devices for the ultimate purpose of designing efficient micro-channel mixers for microchemical systems' applications. In essence, our plan is to validate experimentally our numerical study on mixing enhancement using these fabricated devices.

Dynamics of a gas-liquid meniscus in complex micro-geometries, and potential actuation applications

Jie Xu and Daniel Attinger

Columbia University

This poster describes the design and manufacturing of a microfluidic chip, allowing for the actuation of a gas-liquid interface and of the neighboring fluid. A first way to control the interface motion is to apply a pressure difference across it. In this case, the efficiency of three different micro-geometries at anchoring the interface is compared. Also, the critical pressures needed to move the interface are measured and compared to theoretical result. A second way to control the interface motion is by ultrasonic excitation. When the excitation is weak, the interface exhibits traveling waves, which follow a dispersion equation. At stronger ultrasonic levels, standing waves appear on the interface, with frequencies that are half integer multiple of the excitation frequency. Also, a microstreaming flow field observed in the vicinity of the interface is characterized. The meniscus and associated streaming flow have the potential to transport particles and mix reagents.

A WIDE FREQUENCY RANGE TUNABLE VIBRATION ENERGY HARVESTING DEVICE USING MAGNETICALLY INDUCED STIFFNESS

Vinod R Challa, Dr. Frank Fisher, Dr. Yong Shi, Dr. M.G. Prasad

Department of Mechanical Engineering
Stevens Institute of Technology, Hoboken, NJ 07030

Wireless sensors are of increasing interest in recent years because of their wide applications, but they lag in one major requirement, i.e. having a self-sustainable energy source. Vibration energy proves to have the potential to power these devices using ambient and mechanical vibrations that exist in environment. However one major requirement in vibration energy harvesting is that the energy harvesting device operate in resonance. Most of the energy harvesting devices developed to date are typically designed for a single resonance frequency. Since such devices can only efficiently harvest energy at the specific frequency for which they are designed, their commercial application would be limited. The ability to tune the natural frequency of the device to match the source frequency will allow us to efficiently harvest energy over a wide range of frequencies. While the obvious manner to alter the resonance frequency of the device is to change the geometrical parameters that determine the natural frequency, such an approach may be impractical in a number of applications. We have thus designed and developed a resonance frequency tunable energy harvesting device based on using external magnetic forces to provide variable system stiffness. Through this mechanism, the stiffness of the beam can be increased and decreased to tune the resonance frequency of the device to match the source frequency. As a proof-of-concept, a piezoelectric cantilever-based energy harvesting device with a natural frequency of 26 Hz was fabricated whose resonance frequency was successfully tuned over a frequency range of 22 Hz to 32 Hz, enabling a continuous power output of 240 to 280 μW over the entire frequency range. Using this technique, we are thus able to obtain a device operational frequency range of 40% without sacrificing the energy output efficiency.

Keywords: Energy harvesting, Frequency tunable, Vibration energy, Piezoelectric

Optimizing Rhodopsin Using Ab Initio Methods Within Gaussian03W

Brittany Corn, Svetlana Malinovskaya

Department of Physics and Engineering Physics, Stevens Institute of Technology

Rhodopsin, a photosensitive pigment generated within the rod cells of the retina, is responsible for the first events in the perception of light in higher organisms. Specifically, we have focused in on the cis-trans isomerization of its chromophoric component, retinal ($C_{20}H_{28}O$). Using the program Gaussview, we have modeled the configuration of 11-cis retinal and iteratively optimized the structure using ab initio methods within the Gaussian03W program. When adding polarization functions to the basis set for all atoms, and diffuse functions to only heavier atoms, we witnessed a significant change in the charge distribution of the molecule. After optimizing both the 11-cis and all-trans retinal using this polarized and diffusive basis set, we found the all-trans molecule to have a lower energy by a difference of 0.2663668eV, and therefore must be in a more favorable configuration. After closely studying the charge distribution of the cis and trans molecules, we were able to see a transfer of charge in the region where the torsional motion occurs. It is possible that this transfer of charge contributes to the isomerization of 11-cis retinal.

Micro / Nano Scale Resonators for RF Filter Applications

Richard Galos[1] and Yong Shi[2]

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500 Hills Drive, Bedminster NJ 07921

[2]Department of Mechanical Engineering
Stevens Institute of Technology

Microwave Filters are key components constraining the performance of Satellite and Wireless Communication Systems. Typical tunable filters are somewhat lossy and bulky. RF MEMS / NEMS technology introduces low loss and high linearity elements to outperform and miniaturize today's technology.

The goal of this project is to fabricate and characterize nano-wire resonators employing piezoelectric materials. The RF stimulus interacts with the piezoelectric beam element, exciting a resonance / anti-resonance at its natural frequencies. The frequency response is useful for filter applications.

Nano-wires can be most easily fabricated in a clamped-clamped beam configuration. Although this is not the most optimum for minimizing support energy dissipation, it will serve for easier electrical excitation. The available resonator materials are either PZT 5H or Indium Tin Oxide (ITO). Preliminary calculations show that using a 500 nm thick wire with a length of 4 microns will produce a resonator with a first mode natural frequency of 100 MHz with a Q of 300. In this case, the support Q is the dominant factor. We are in the process of estimating the impedance.

The challenges that we anticipate include overcoming transduction inefficiencies when combining filter elements to shape the overall response. Additionally, measuring the insertion loss of high impedance devices without overpowering them will be explored.

Alternative Usages: Nano-wire resonators can also be used as very sensitive Bio-chemical detectors in various environments. A chemical reaction on the beam's surface can alter its natural frequency via mass load, temperature or surface stress changes. Detection of the frequency change provides information regarding the absence or presence of a particular substance.

Processing and Electrochemical Properties of Nanostructured Materials for Green Energy Applications

Jenny He and Yong X. Gan*

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Electrocatalytic reactions of nanoporous materials in biodegradable fluids have been studied. In order to obtain high efficiency catalysts, electrochemical etching was conducted to selectively extract metallic elements from alloys to form porous structures. Electrocatalytic properties of the porous materials were characterized. Comparative studies on the electrochemical activities of the nanoporous metallic electrodes with bulk metallic catalysts were performed. It is found that nanoporous structures with high electroactive surface areas can be obtained through controlled electrochemical etching in diluted acids. The current density at the nanoporous electrode is higher than that of the bulk electrode with the same chemical compositions. The electrochemical catalytic properties of different nanoporous materials in biodegradable fluids are different. It is also shown that fermentation enhances the electrochemical catalytic oxidation of biodegradable fluids on the nanoporous electrodes.

Electric-Field-Assisted Plane Wave Transmission through a Magnetized Quantum Point Contact

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We analyze the role of an electric field in the scattering/tunneling of an incident plane electron wave through a quantum point contact in a magnetic field. In this, the point contact is modeled as a saddle potential. We employ the Bogoliubov transformation and guiding center coordinates following the techniques of H. A. Fertig and B. I. Halperin (Phys. Rev. B **36**, 7969 (1987)), but we expand the analysis to include the effects of the applied electric field here and examine the temporal development of the incident plane electron wave rather than that of a bath eigenfunction.

Studies on MEMS Acoustic Energy Harvesting

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There has been increasing interest in energy harvesting using MEMS based devices. Although several studies on vibration based energy harvesting are published, acoustics based energy harvesting is also reported to be promising. This work presents the initial stages of development of a MEMS acoustical energy harvester (AEH). This micro-scale harvester is a Helmholtz resonator (HR) with a piezoelectric circular membrane for electro-acoustic transduction serving as one of its walls. The HR consists of a narrow neck appended to a cavity of much larger volume which amplifies incident acoustic waves by resonating with the frequency of the waves. However, ambient acoustical noise consists of a spectrum and a fixed volume HR can be designed for only discrete frequencies. The proposed solution is modifying the HR by adding a piston to the back wall of the cavity. The piezoelectric membrane will be part of the piston wall. Such a piston will continuously change volume in the cavity, and thus the resonant frequency of the device to match that of the incident waves. The studies will include modeling, analysis, and experimental work. Future research includes variations in HR shape and design and analysis of the piezoelectric membrane to capture the acoustic energy and convert it to useful energy.

Surface Nanostructuring via Redox Switching of Doped Polypyrrole for Biomedical Applications

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We present preliminary data on the redox-induced transformation in surface roughness of doped polypyrrole. By varying the electric potential of as-deposited doped polypyrrole in aqueous sodium dodecylbenzene sulfonate (0.1M) from -0.6 to +1.5V, doped polypyrrole transforms from being a hydrophilic film (60° contact angle) to a hydrophobic film (101° contact angle). AFM measurements confirm that the surface morphologies of doped polypyrrole, when subject to applied potentials from -0.6V to +1.5V, change from smooth (average roughness of 3.1 nm) to rough (average roughness of 31.1 nm), representing a 10-fold increase in surface roughness. Based on these evidence, we postulate that the application of positive external potentials produce an oxidation-induced surface roughening effect.

Effect of process variables on Structural Formation in Poly (Butylene Terephthalate) and PBT Nanocomposites

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Poly (butylene terephthalate) (PBT) is a semi-crystalline thermoplastic polyester, which is often processed in fiber and film forms. The deformation of PBT depends upon the processing conditions, which affect the crystallization behavior and resulting crystal morphology developed within the processed sample. The polymer crystallization kinetics and morphology is also affected by addition of nanoparticles. To further understand the effect of various process variables such as shear, and annealing on polymer crystallization behavior and resulting crystal morphology, pure PBT was melt mixed with different amounts of multi-walled carbon nanotubes (MWNTs). Differential scanning calorimetry (DSC) results indicate an increase in crystallinity in sheared and annealed PBT and nanocomposite samples, which was confirmed with XRD analysis of the samples. The goal of this work is to establish a relationship between the process variables, morphology and mechanical properties of PBT nanocomposites. Another aim is to use a crystallization technique and crystallinity to make high strength micropatterns of PBT and nanocomposites.

Schrödinger Green's Function Matching For Three Regions of Adjoining Semiconductor Layers Having Different Effective Masses and Potentials

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We apply the method of Green's function matching to the determination of the global Schrödinger Green's function for all space subject to joining conditions at two planar interfaces separating space into 3 distinct semiconductors having different effective masses and potentials. The object of this technique is to determine the full space global Schrödinger Green's function in terms of the individual Green's functions of the constituent parts taken as if they were themselves extended to all space. This analytical method has had successful applications in the theory of surface states[1,2,3], and remains of interest for nanostructures.

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"SMART" MICROFLUIDIC PRECONCENTRATION OF SPECIFIC BIOMOLECULES

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Preconcentration (PC) is a valuable tool that can be used to enhance the sensitivity of microfluidic devices. Existing PC systems incorporate hydrophobic and ion-exchange phases that tend to extract compounds with similar physical or chemical interaction properties indiscriminately and hence, lack acute selectivity. This poses problems especially in systems of multiple analytes where similar detection signals from non-specific molecules may confuse resulting analyses. Here we report a microfluidic preconcentrator using an aptamer affinity phase featuring high specificity to thiazole orange adenosine monophosphate (TO-AMP) and programmable regeneration. Selective preconcentration as well as release was demonstrated.

Affinity interaction/binding involves the selective reaction between ligands and specific target molecules. Our study used biotinylated adenosine triphosphate aptamer (ATP-aptamer) immobilized on streptavidin coated polystyrene beads. TO-AMP binds specifically to ATP-aptamer to be intelligently released either by competitive binding or thermal energy.

Fabrication included standard polydimethylsiloxane (PDMS) processing. A mold was produced on a Si wafer by lithography of SU-8. Microfluidic channels were realized after PDMS was released from the mold following a pour/curing step. Fluorescence intensity measurements were obtained in a straight line direction (A-A') across each micrograph (similar for subsequent analyses).

The approximate binding time of TO-AMP to ATP-aptamer was determined by detecting fluorescence signals in discrete time intervals immediately following a 400 nM sample injection. No appreciable increase in fluorescence intensity occurred after 10 min of incubation time. This was considered when determining binding time between TO-AMP and ATP-aptamer. Preliminary findings show TO-AMP concentrated at least 10 times from an original sample solution (200 & 500 nM). A nearly linear trend in concentration increase suggested the analyte had yet to saturate the beads, posing a strong potential for attaining higher concentration factors.

An attractive attribute for bio-analytical devices is the ability to intelligently capture and release target molecules. We performed release of TO-AMP (10 μM) by competitive ATP displacement and thermal energy revealing thermal release as more effective. After 2 gradient injections, competitive release could not attain the base fluorescence signal which was achieved by temperature release in 1 step. It was found that the transition temperature required to release TO-AMP from ATP-aptamer existed between a narrow range (32-40 ^{o}C). This microfluidic device realized repeatable regeneration by thermal energy, which proved significantly efficient, thus showing a strong ability to intelligently capture and release small molecules. Our device demonstrated the benefits to microfluidic preconcentration using highly specific affinity interaction. With integration of MEMS components such as on-chip heaters and sensors, this device provides a suitable platform for a micro total analysis system.

High Flow Rate, Low Power Consumption Microvalve

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In this research a novel design for a low power consumption, high flow rate and normally closed microvalve is presented. In order to reduce the needed static power consumption, several remedies are investigated through which, the actuation force reduction is developed. Hence a two-stage actuation mechanism is designed. To avoid extreme pressure drop, clog possibility and large-stroke, magnetic actuation mechanism is utilized.

Effects of coupling between the vibrational modes on the CARS signal

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CARS is well suited spectroscopy method for imaging specific molecules, e.g.., proteins and live cells, diagnosis of cancerous cells,duetrated compounds etc.CARS imaging techniques avoid problems associated with photo bleaching and photo induced toxicity. The CARS signal is accompanied by strong non resonant background which may overshadow the weak signal of interest. Two methods, using femtosecond chirped laser pulses and providing the Rabi oscillation and adiabatic passage type of control, allow one to achieve sensitivity with high resolution and are known to efficiently suppress background . It has been previously shown, that coupling between vibrational modes affects the sensitivity of the Raman signal selective excitation of the vibrational modes. In this paper we will discuss simulation results on vibrational coupling between modes and its impact into control mechanisms of the CARS signal.We will separately demonstrate the coherence and selectivity for different vibrational modes in weak and strong fields.

Novel High-Performance Inertial Sensors

Dr. Catherine Rice, VP, Technology

MET Tech, Inc., Jersey City, NJ, www.mettechnology.com

MET Tech, Inc. has developed a radically new category of inertial sensors (linear and angular accelerometers, gyroscopes, inclinometers and seismometers) based on its proprietary inertial sensing technology, called Molecular Electronic Transducers (MET).

Unlike other inertial sensing technologies, MET sensors use a liquid electrolyte as their inertial (proof) mass. They do not contain any precision mechanical (micromechanical) parts or springs, and are relatively simple and inexpensive to manufacture.

MET Tech's device performance and fabrication activities will be discussed at the workshop.

Microfluidics Device Thermal Design Optimization Methodology for Oscillating Flow Polymerase Chain Reaction (PCR)

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Polymerase chain reaction (PCR) is used to amplify the amount of DNA (deoxyribonucleic acid) fragments prior to DNA analysis. PCR is essential for DNA analysis used in chemical, biological, medical, environmental, and other fields. Compared to existing PCR technology, microfluidics PCR utilizing MEMS technology requires less sample, less reagent, and shorter processing time. Using microfluidics technology, various PCR device designs have been proposed. Among these designs, oscillating flow PCR microfluidics has been selected for this study because of its advantages including faster analysis time than cavity PCR microfluidics, and smaller contact area between the sample and polymer channel wall compared to flow-through PCR microfluidics, which reduces DNA adsorption and enhances DNA detection accuracy. Because the oscillating flow PCR requires only one set of three temperature zones, it needs much less chip area compared to flow-through PCR.

New concept features proposed in this study include: (1) the oscillating flow PCR microfluidics device design is improved by adding a thermo-pneumatic micropump to realize a total lab-on-chip system. PDMS (polydimethylsiloxane) and glass are selected as the chip material for realizing a disposable chip, (2) water impingement cooling is applied to effectively isolate the temperature zones, and (3) a copper layer is attached outside of the chip to enhance uniform temperature distribution within the temperature zones. The channel dimensions are determined by considering the trade-off between thermal response time and sample contact area with PDMS channel wall. The resulting thermal response of the sample in the temperature zone is comparable to an existing study which uses silicon as the chip material. Transient FEM heat transfer analysis for the PCR temperature zone is performed to enhance the thermal design. Using the thermal analysis results for the PCR temperature zones and micropump, optimal component location on the microfluidics chip is determined.

A MEMS DSC DEVICE FOR BIOMOLECULAR CHARACTERIZATION

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We present a miniaturized differential scanning calorimeter with integrated microfluidics for measuring structural transitions of biomolecules in solution. The device is polymer-based and fabricated with microelectromechanical systems (MEMS) technology. The device, fabricated on a 1 cm × 1 cm chip, features two identical thermally-isolated polymeric freestanding membranes, which are integrated with a bimetallic thermopile differential temperature sensor. Integrated with polymer (PDMS) microfluidic channels and chambers, the sensor allows efficient handling and differential measurement of small volumes (~1 □) of biomolecular solutions.

The device was applied to measure thermally induced protein unfolding. First, two chambers were filled with buffer, and the baseline of the instrument over the entire temperature range of interest was obtained by recording the thermopile output voltage. After filling the chamber with the sample, the chamber temperature was scanned at a certain rate and the thermopile output voltage was recorded. Figures 1 and 2 present the thermopile output, and the accordingly calculated molar enthalpy change, for the unfolding of the protein ribonuclease A (RNase A; concentration: 18 mg/ml). The melting temperature and enthalpy change of RNase A thus determined are respectively 61.9°C and 444.0 kJ/mol, which are in agreement with values (61.2°C and 452 kJ/mol) reported in the literature.

These preliminary results show that MEMS DSC devices have the potential to enable integrated and high-throughput measurements of biomolecular transitions and interactions with minimized consumption of biological material.

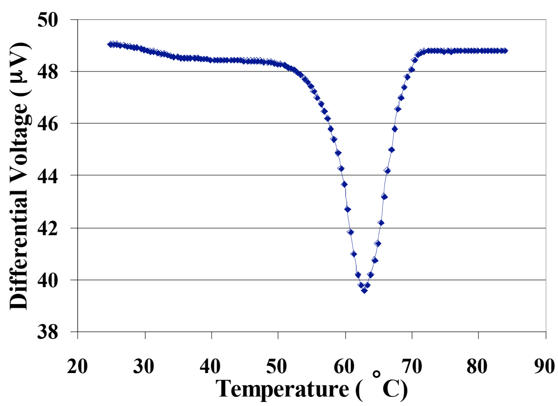

Fig. 1. Unfolding of RNase A (concentration: 18mg/ml; temperature scanning rate: 5 °C/min).

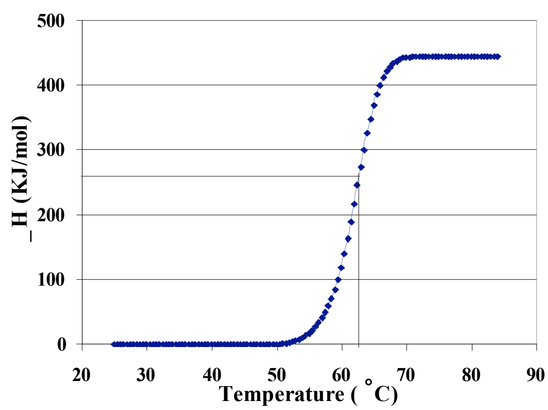

Fig. 2. Molar enthalpy change of RNase A calculated from experimental data of Fig. 1.

Energy Harvesting From PZT Nanofibers

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There are lots of great achievements in the development of nanodevices in the past few years, which requires self-powering or wireless applications. The current power sources are limited for operating these devices because they are relatively large for nanosystem and they need to be replaced or recharged regularly. 1-D nano piezoelectric materials have great potential to provide a solution to these problems. For example, ZnO nanowires have been used to covert mechanical energy to electrical energy [1, 2].

In this paper, we demonstrated that Lead Zirconate Titanate (PZT) nanofibers can be used to harvest energy from dynamic loading and mechanical vibration. PZT nanofibers were fabricated by electrospinning process. SEM image of PZT nanofibers has shown that the average diameter of these fibers is about 150nm, which can be tuned from 50nm to 200 nm by varying the composition and viscosity of the precursor for electrospining. Titanium substrate with ZrO_2 layer was used to collect the PZT nanofibers for the demonstration of energy harvesting from dynamic loading. The largest output voltage is 170mV under 0.5% strain; the frequency of the output voltage is the same as that of the input loading. Silicon substrate with trenches was used to collect the nanofibers for energy harvesting from vibration. The output voltage generated from 150Hz sinusoid vibration source has peak voltage of 64.9mV and -95.9mV, which is also sinusoid with the same frequency. These experimental results suggest that PZT nanofibers have great potentials for energy harvesting from environments and using as nanogenerators. Further study is under the way to optimize the design and improve the efficiency.

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