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Poster Presentation Abstracts
We fabricate nano-electromechanical systems from single and multilayer graphene sheets by mechanically exfoliating thin sheets from graphite over trenches in SiO2. Vibrations with fundamental resonant frequencies in the MHz range are actuated either optically or electrically and detected optically by laser interferometry. The thinnest resonator consists of a single suspended layer of atoms and represents the ultimate limit of two dimensional nanoelectromechanical systems. The high Young’s modulus (E = 1 TPa), extremely low mass (single layer of atoms), and large surface area make these resonators ideally suited for use as mass, force, and charge sensors. In addition to results on doubly clamped beams and cantilevers, I will show more recent work on resonating drumheads, which consist of graphene sealed nanochambers containing a small volume of trapped gas.


We have developed a hydrogel-based microfluidic device that is capable of generating a steady and long-term linear chemical concentration gradient with no through flow in a microfluidic channel. The device consists of three parallel channels in a hydrogel matrix and the chemical gradient is established in the center channel via diffusion of chemicals from the side channels. By flowing the two side channels with different chemicals one can establish and maintain two independent gradients of different chemicals in the center channel (Fig. 1). Chemotactic responses of E. coli to these “competing concentration gradients” (Fig. 2) provide insights into comparative roles of the receptors in the cells’ chemotactic behavior. Absence of dependence on factors other than the chemical gradients allows for verification of the biased random walk models of E. coli’s response to chemoattractants.
Neurons release neurotransmitters in a process called exocytosis, wherein membrane bound packets of transmitter molecules are released from the cells upon stimulation. The mechanics of this process are poorly understood, but are known to involve three proteins collectively called the SNARE complex. Chromaffin cells of the adrenal gland share this release mechanism, and thus constitute a model system for neuronal release. Quantal release of catecholamine, adrenaline in the case of chromaffin cells, can be measured using the electrochemical technique of amperometry, historically employing a carbon fiber electrode (Wightman, et al 1991 PNAS 88: 10754).

To gain information about the mechanism of transmitter release it is desirable to perform simultaneous fluorescence imaging and electrochemical detection of individual release events. We previously demonstrated that amperometric signals can be measured using opaque platinum electrodes patterned on a glass coverslip (Hafez, et al 2005 PNAS 102: 13879). To minimize diffusional broadening, the electrode needs to be in close contact with the plasma membrane. For simultaneous fluorescence imaging through the electrode transparent electrochemical detector arrays were fabricated on glass using photolithography. Transparent planar microelectrode arrays were fabricated from either indium tin oxide (ITO), or thin (~6 nm) gold. Amperometric spikes from bovine chromaffin cells could be detected with both materials and fluorescence changes monitored through the electrodes at low noise. Amperometric foot signals were detected with both types of electrodes. For arrays with similar geometry mean charge and half width of the amperometric spikes were 0.89±0.44 pC, 34±9 ms (SEM, n= 4 cells) for transparent gold electrodes and 0.38±0.05 pC, 32 ±2 ms (SEM, n=6 cells) for ITO. The difference in quantal size has a p value of 0.18. The results suggest that amperometric detection of catecholamine release with transparent gold electrodes is comparable to that using carbon fibers while ITO may be less efficient.

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Many bacterial plant pathogens exclusively inhabit xylem vessels, the water conducting elements of plant vascular systems. Due to an inability to view the interior of xylem vessels without destructive means, little is known about the in planta biology of these bacteria. To overcome this problem, we developed microfluidic chambers that mimic the interior of xylem vessels and which can be viewed microscopically. Thus, we are able to study xylem-inhabiting bacteria both temporally and spatially.

Our microfluidic chamber consists of two distinct 80 μm wide channels that are parallel to each other. They are spaced so that both channels can be viewed simultaneously with the microscope, allowing for comparisons between different bacterial strains or different environmental conditions. A second microfluidic chamber was developed that utilizes the same channel design, but includes the addition of “pockets” projecting from the channels. These “pockets” provide areas of decreased flow, as may be found naturally in xylem vessels. Construction of the chamber relies on a molded PDMS, containing the structure of the channels, adhered between a cover glass and a microscope slide. Fluid delivery tubing is attached to the device, which can then be autoclaved for an aseptic environment.

*Xanthomonas campestris pv. campestris* is a xylem-inhabiting bacterium which causes black rot disease of cabbage, an economically important crop for upstate New York. The addition of a green fluorescent protein has allowed us to visualize activation and deactivation of gene promoters involved in colonization and virulence (Fig. 1). This promoter activity is being compared to the motile and attached states of the bacterium while in the chambers. Through use of our microfluidic devices, we are gaining new insights into the process of plant infection and colonization by plant pathogenic bacteria.

**Fig. 1.** Fluorescent and brightfield images of the Xcc strain expressing GFP driven by the flagellin promoter.
Xylella fastidiosa is a plant pathogenic bacterium that causes important losses in grapevine, citrus, almond and other high value crops. The bacteria exclusively inhabit the water (sap)-conducting xylem vessels of the plant hosts. It is believed that X. fastidiosa causes disease by developing bacterial aggregates and biofilms that block xylem sap flow. Because temporal and spatial activities of the bacteria can not be observed microscopically within the plant, microfluidic devices have been developed to mimic features of plant xylem (Figure 1). These devices consisted of parallel micro-channels 80μm wide, 50μm deep and 3.7cm long which were supplied with inlets and outlets for culture media and bacterial cells. Using such devices, we discovered that X. fastidiosa migrates upstream via hair-like structures (type IV pili) that are repeatedly extended and retracted from the bacterial cell. Such movement explains, in part, the spread of bacteria in the host plant against the flow of sap. In addition to type IV pili, X. fastidiosa possess shorter type I pili. Using microfluidic devices we measured the adhesion force of both types of pili, and found that the shorter type I pili are primarily responsible for cell attachment to surfaces, therefore having a greater influence on biofilm formation. The presence of the type I pili slow the speed of movement of the bacteria. Currently we are studying the process of autoaggregation, in which individual cells rapidly merge into large cell aggregates (Figure 2). These aggregates may be responsible for the obstruction of water passage in the xylem and the rapid onset of disease symptoms. Using microfluidic devices we are gaining information on the biology and the infection process of X. fastidiosa, which may lead to the development of novel control methods against this pathogen.

Microfluidic Chambers as ‘Artificial’ xylem Vessels Used to Study Movement and Biofilm Formation of the Bacterial Plant Pathogen Xylella Fastidiosa

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Electron beam lithography has represented the most effective way to pattern materials at the nanoscale for almost four decades. The success of e-beam lithography depends on multiple factors such as electron optics, the interaction between the beam of electrons and the pattern material (resist), and the interaction between the developer and the exposed resist. At the Center for Nanoscale Materials at Argonne we use a Raith 150 ebeam tool that operates at 30 KV and a JEOL 9300 ebeam tool that operates at 100KV. We will discuss the spatial resolution achievable with electron beam lithography by cold development [1].

Our results show improved resolution and contrast for resists that are exposed by polymer chain scission. It does not work for chemically amplified resists. A discussion on why this works for resists like ZEP 520 and PMMA and not for positive chemically amplified resists (such as UV113) is presented. Results for 13 nm structures obtained after metal lift-off using a 30 kV e-beam tool using ZEP 520 resist are shown. These results have impact in the photomask industry and other manufacturers that require squeezing out as much resolution out of their existing tools and materials. It is found that, even with the improvement by cold development, there is a “shot noise” of 2% uncertainty limit that is not surpassed for resists exposed at 100 kV. This explains why high throughput and high resolution electron-beam nanolithography is not possible.

References

Figure 1. Example of cold developed (at -4oC) resist exposed with electron beam lithography. Grating of isolated 60 nm lines in 200 nm thick ZEP20 resist showing less than 5 nm line edge roughness. The open areas were exposed using a 30 KV ebeam tool.

Notes:
Intracellular metal transport systems mediate safe trafficking of metal ions inside cells. These systems are essential in maintaining normal metal metabolism inside cells. The copper chaperone Hah1 mediates copper transport to the P-type ATPase Wilson Disease Protein (WDP) via specific protein-protein interactions. We have used a combination of nanovesicle trapping and single molecule FRET techniques to specifically characterize the protein-protein interactions that mediate copper transfer. Interactions were observed between a single domain construct of WDP, metal binding domain 4 (MBD4) and Hah1. We are able to observe individual interaction events in real time between both proteins. We are also able to observe two different conformational arrangements of the protein complex and their interconversion. The kinetic rates for association to either one conformation as well as their interconversion rates were determined from the residence time of each complex and waiting times between interaction events. Our methodology represents a novel approach to studying weak-pair interaction events at high effective concentration with single molecule resolution.

Physiologists and medical researchers are increasingly using genetically altered mice as models for studying drug effects and disease treatments. Such studies often require measurements of blood flow to various organs, such as the kidney in diabetes studies or the brain in studies of stroke. However, in mice these arteries are quite small (250 to 500 microns in diameter), and existing physiological monitoring tools were too bulky for the diminutive mouse anatomy.

Transonic Systems worked with the Cornell Nanoscale Facility staff and SUNY Albany’s Dr. Bai Xu to develop an SU-8 process that could create biocompatible dual-layer structures exceeding 1200 microns in height. Transonic then used this process to create ultrasonic flow probe bodies, which are precision mechanical fixtures for an ultrasonic transit-time flow measurement system.

Probes were then sent to Dr. Michael Callahan (Wake Forest University), who devised surgical techniques for implanting the probe on a mouse renal artery. This allowed researchers to measure kidney blood flow via a transcutaneous cable as the mouse moved around its cage. This marked the first time that anyone has successfully recorded renal blood flow in a conscious mouse.

Transonic Systems is now commercially selling blood flow measurement probes with bodies manufactured by the Nanofab-developed SU-8 process. These probes are being used in basic research on transgenic mice, as well as by pharmaceutical companies developing new disease treatments.

This work was funded by the National Heart, Lung, and Blood Institute of the National Institutes of Health under SBIR (Small Business Innovative Research) Grant #5 R44 HL 55082-03, “Tools & Techniques for Measuring Flow & Pressure in Mice”. In testimony to Congress, the NIH (National Institutes of Health) cited this project as an NIH SBIR Commercialization Success Story.

Recent Biomedical Research that uses these devices:
Electronic generation of THz signals using GaN is predicted to exhibit high efficiency. Theory shows that electrons can be ballistically accelerated to the Brillouin Zone limit of 2.7 eV [1,2], and above 1.0 eV they will pass beyond the inflection point and have negative effective mass. Finite energy injection at 0.4 eV launches electrons closer to the inflection point to increase the ratio of negative to positive mass electrons. Both $n^+\text{-}i\text{-}n^+$ and AlGaN/GaN (0.4 launching energy) heterostructure devices with cylindrical active regions have been characterized. However, no negative differential conductivity has yet been observed.

A new device geometry is designed to overcome the parasitics and heating issues. In this design, active region is 1μm in diameter whereas the contact area is 25 times greater. Concentrating the current in 1μm diameter will help reduce the spreading resistance which degrades the potential uniformity across ballistic region. On the other hand, 25 times greater area will reduce the I2R heating at the contact which results in catastrophic failure.

We process 15 mm square samples. Epilayers are grown on SiC substrates using our MBE facility at Cornell. The undercut mesa geometry will be implemented using ion milling at an angle of 45 degrees through a lift-off carbon mask. Then, following the ohmic contact evaporation, a standard air bridge process will be used to electrically connect the devices to the contact pads.

References:
We have investigated the high frequency electrical properties of single-walled carbon nanotube field effect transistors by operating the devices as microwave mixers up to terahertz regime. First, by using continuous wave (CW) signal generator, we confirm that there is no loss on the carbon nanotube mixers for frequency up to 40 GHz. Second, terahertz study is carried out by fabricating on-chip terahertz source and using nanotube transistor itself as the detector. We found that nanotube FET can still function as mixer up to terahertz regime, and more importantly, it can measure terahertz pulses as short as 2 pico-second by autocorrelation.

Notes:

One-dimensional semiconducting nanowires have generated intense scientific and technological interest in the past few years. While there are several techniques known in the literature for synthesizing these nanostructures, they are typically grown on a substrate using chemical vapor deposition (CVD) in which a nanowire “film” composed of randomly oriented nanowires is produced. It is also possible to grow aligned nanowire arrays on suitable substrates and under certain growth conditions. One fundamental aspect of such nanowire assemblies that has generally been overlooked both theoretically and experimentally is how light interacts with them. Typical diameters of nanowires, ca. 3-150 nm, are below the wavelength of light used in typical experimental optical measurements (300 nm – 2 μm), whereas their lengths may range from 0.5-20 μm. This “structural” anisotropy, coupled with crystallographic anisotropy, may lead to unique optical properties of such films. Here we examine the impact of silicon nanowire assembly structure, including nanowire diameter, pitch, length, and orientation on optical properties such as reflectance, absorption, and transmission. This is studied via a combination of modeling work, performed using both conventional free-space optical modeling and finite-difference time domain (FDTD) schemes, and the use of total reflectance and transmission measurements. Initial results show that the total reflectance of aligned nanowire arrays (without a catalyst) is lower than control Si wafers over all wavelengths (300-1500 nm) and is also lower than randomly oriented nanowire films between 300 and ~1060 nm. The reflectance of the aligned arrays varies from ~1.5% at 300 nm to ~9% at 1000 nm and the diameter of the nanowires impacts this reflectance, with smaller diameter nanowires providing less reflectance. Furthermore, the total absorption of light in nanowire arrays on glass substrates is higher compared to solid thin films of equivalent thickness. The described effects will be correlated with results of the modeling studies.

Notes:
The Center for Nanoscale Materials (CNM; Figure 1) is a DOE funded user facility located at Argonne National Laboratory. Our research interests cover nanophotonics, nano-bio interfaces, nanofabrication, x-ray microscopy, electronic and magnetic nanomaterials, and theory and simulation (Figure 2). We will present a brief overview highlighting recent results at our facility, such as directed hierarchical self-assembly of hybrid nanocomposites, magnetic vortex dynamics, novel phenomena in sub-wavelength photonic materials, cold development, nanofluidic devices, and flexible ribbon electronic materials. More information about the CNM is available on the web at http://nano.anl.gov.

Facile Route for Assembly of Metal Nanoparticles onto Electrospun Nylon 6 Nanofibers

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A facile approach for assembly of metal nanoparticles (Ag and Au) onto the surface of electrospun nylon 6 nanofibers by immersing the nanofiber mat into pH-adjusted solutions of metal nanoparticles has been demonstrated. Metal nanoparticles in aqueous media were synthesized using citrate as a stabilizer. The key factor determining assembly phenomena was identified as the modulation of hydrogen-bonding interaction between amide in nylon backbone and carboxylic acid groups capped on surfaces of metal nanoparticles. The assembly is strongly dependent on the pH of the media. The pH value, which affects protonation of the carboxylic ions on metal nanoparticles and therefore H-bonding interaction, is highly related to the quantity of metal particles assembled on the surface of nylon 6 nanofibers. Metal nanoparticles with a large quantity were bound on the surface of nylon 6 nanofibers in the pH intervals from 3 to 6, whereas only very few metal nanoparticles were found on the nylon 6 nanofibers when pH ≥ 7. These hybrid materials have been characterized using TEM, FESEM and UV-Vis spectroscopy.

Notes:
In contrast to thermal ink jetting that uses heat to generate fluid drop ejection, MEMS-constructed piezoelectric ink jet printheads use a thin PZT slab bonded to a silicon diaphragm to generate acoustic energy that drives drop formation. This novel, non-contact, and nondestructive printing process immobilizes a variety of functional materials while retaining their activity. By formulating an ink and determining jetting parameters, drop-on-demand immobilization of a variety of functional materials can be employed for one-sided deposition. We have formulated a variety of inks for the printing of DNA, peptides, proteins, dendrimers and carbon nanotubes using both direct inking and scaffold carriers for the immobilization of nucleic acids and antibodies. After printing is completed, these molecular recognition elements remain functional and bind their complimentary oligonucleotides or their cognizant protein, respectively, from complex samples indicating that their biological activity is retained during processing. Moreover, after dendrimeric printing, patterned silicon dioxide thin films are grown on the material measuring less than 170 nm. We have demonstrated the strength and utility of this technique to print components, and further directions will be to integrate these processes in device fabrication.

Notes:

For more than a decade the idea of using supercritical fluids in semiconductor processing has been actively explored by many researchers. With its low critical temperature, zero surface tension, and non-polar inert character, supercritical CO₂ (scCO₂) shows great potential for its ability to process sensitive materials with patterned features on a very small length scale. However, barring excessive fluorination, most materials traditionally used by industry show poor solubility in this solvent. This is where molecular glass resists show their unique nature. Because of their small size, molecular glasses have the potential for scCO₂ solubility while still showing equal performance to polymer photoresists. Also, because of their small, discrete structures, these materials also can show lower line-edge roughness compared to traditional polymer resists. We will demonstrate some recent successes in developing photoresist features in the sub-65 nm range with only scCO₂ as the developer solvent. Additionally, we evaluate the effect of molecular structure on photoresist dissolution rate and show the consequences of protecting groups and pi-pi stacking on dissolution.

Notes:
The unique self-assembling properties of block copolymers have much to contribute to the field of high resolution nanolithography. Our group has been working on a unique block copolymer, poly(α-methylstyrene)-block-poly(4-hydroxystyrene), PαMS-PHOST, which self-assembles upon spin coating to form cylindrical PαMS nanodomains in a matrix of PHOST. When small amounts of a photoacid generator (PAG) and crosslinker are added, the PHOST block behaves as a negative tone photoresist, and the PαMS block may be subsequently thermally removed due to its low ceiling temperature. Therefore, photolithography can be used to crosslink the PHOST matrix on select areas of the wafer, and then PαMS nanopores can be removed to create sub-lithographic features within these patterned areas.

Recently, we have found that solvent vapor annealing and formation of the film within lithographically patterned trenches dramatically improves the arrangement of these cylindrical nanodomains into hexagonally close packed, well ordered structures. The orientation of the cylinders relative to the substrate – either parallel or perpendicular – can be controlled by the choice of solvent (Figure 1). These films may be used as nanoporous masks to create periodic nanoscale features within these patterned areas.

Additionally, we have shown through cross-sectional transmission electron microscopy (TEM) that polar PAG particles tend to sequester into the polar phase PHOST domain. Poly(styrene-block-hydroxystyrene) (PS-b-PHOST) was synthesized anionically as a model amphiphilic block copolymer to test its compatibility with ionic triphenylsulfonium hexafluoroantimonate PAG. The high atomic number of the Antimony within these PAG molecules enables optical contrast between the microphase separated domains (Figure 2). Being able to control the location of the PAG molecules through directed self-assembly means that we are able to effectively concentrate the PAG molecules where they are needed for crosslinking in the PαMS-PHOST system, and it provides an additional handle to control the photochemistry in other photoresist systems.
This work describes the development of an electroactive microwell based chemical/drug delivery system and its pupa stage implantation within Manduca Sexta moths, forming one of the critical components in our development of “Insect Cyborg Sentinels”. The goal of this system is to provide “on-command” chemically induced immobilization and subsequent reanimation.

The microdevice platform is partially implanted (inset, Figure 1b) within the insect at the dorsal thorax of the pupae. To find the optimal location (which minimizes its physiological footprint, maximizes survivability, and favorably disperse the toxin), both the platform size and implantation location were varied. Figure 1a shows the results of a successful emergence of an insect. Besides, a number of injection experiments have been conducted to determine the dosage effects on the degree and length of insect paralysis, and for example of 5 μL of L-Aspartate acid which comprises one of the major components of spider venom, into the thorax, the insect was immobilized for approximately 12hrs, after which the insect regained its pre-injection activity level.

The electroactive microwell drug delivery system developed here is based on the fusion of previous implantable drug delivery technologies [1] with our recently developed electrokinetically active microwells [2]. Briefly, the drug is stored within a well, etched into a silicon substrate which is sealed from the exterior using a thin gold membrane. When a dosage command is issued, a voltage is applied to electrochemically dissolve the gold membrane [3], exposing the toxin. Unlike previous approaches, which rely on diffusive transport of the drug, we incorporate an electrokinetic injector whereby a potential field is applied between the top and bottom of the well and the drug is electroosmotically rejected from the well. As will be demonstrated this approach reduces the drug injection time from approximately 30 minutes for diffusive transport to less than 1mS.
The idea of using small molecules instead of polymers for next generation lithography has enabled improved resolution and line edge roughness (LER). Rather than using polymeric materials we are focusing on a new class of materials known as molecular glasses. These are low molecular weight organic materials that demonstrate high glass transition temperatures despite their modest size. Unlike polymeric resists, these molecules have the added advantages of distinct size and uniformity. We have synthesized a series of molecular resists containing rigid aromatic backbones and phenolic moieties. An increase in glass transition temperature is observed with increasing size and rigidity. Glass transition temperatures (Tg) between 80-130°C have been observed for resists with molecular weights within the range of 500-900g/mol.

These phenolic based resists also show the high sensitivity and sub-100nm contrast required of candidates for next generation lithography. Sub 50nm features were demonstrated through EUV (13.4nm) exposure.

The recent interest in the development of nucleic acid biosensors and high-throughput screening techniques has been in part driven by the need to rapidly diagnose emerging viral threats. Currently the key challenges are to develop label free biosensors with low mass sensitivity and high specificity without sacrificing the extreme parallelism of the microarray format. In this talk we will present our work towards the development of Nanoscale Optofluidic Sensor Arrays (NOSA), which represents a potential solution to this problem. Two variants of the NOSA will be presented here. The first one consists of a single silicon-on-insulator (SOI) waveguide coupled with multiple ring resonators of different sizes along the length, each of which is functionalized with a different oligonucleotide probe. Each resonator contributes a sharp resonant peak to the output spectrum of the device. Occurrence of a binding event at a particular resonator site induces a measurable shift in its corresponding resonant peak which is related to the presence or absence of a nucleic acid target in the solution. The second approach utilizes a 1D resonant cavity on a 1D waveguide with a unique differential size functionalization approach. This approach allows binding events at one or at a combination of the many sensing sites which causes a unique shift in the output resonator spectrum. The advantage of the former approach is that it can very easily be multiplexed to perform massively parallel detections while the latter potentially allows for sub-femtogram level detections. Our current goal is to demonstrate the multiplexed detection of four separate homologues to the Dengue virus RNA. 
The ability to perform controlled trapping and concentration of nanoscale objects is becoming an important part of the development of high sensitivity, low limit of detection nano-sensor devices. Essential to the development of integrated microfluidic devices incorporating such functionality is the ability to fuse active target handling components with electrical and/or optical sensor elements. Traditional optical trapping mechanisms allow for a great deal of control in two dimensions, but exhibit a fundamental limitation. It is well known that electromagnetic forces applied to a particle are proportional to the intensity of the incident light. This intensity is equal to optical power divided by the cross sectional area (spot size) of the trapping laser. To achieve the necessary intensity for trapping smaller particles, smaller spot sizes obtained using high numerical aperture lenses are needed. This necessarily results in a decrease in the interaction length between the optical force field and the transported particle, limiting the distance over which is can travel.

Waveguide structures confine light within microscale structures through total internal reflection over extremely long distances. While the majority of the optical energy is confined within the solid core of a waveguide, there exists a near-field non-propagating component called the evanescent field. This field extends from the waveguide surface and exponentially decays into the surrounding medium over a distance of a few hundred nanometers. This rapid decay in optical intensity results in a strong trapping field. Such confinement also enables radiation pressure propulsion of particles along the length of a waveguide.

In this poster, we will present our recent analytical, numerical and experimental work on determining the conditions necessary for propulsion and trapping stability within microfluidic environments (Figure 1). We also present our experimental results using waveguides fabricated from SU-8 cross-linked polymer integrated with PDMS microfluidics demonstrating the dynamic trapping of flowing particles and subsequent radiation pressure propulsion (Figure 2). We establish an empirical relationship for the electromagnetic and hydrodynamic forces acting on a particle as a function of experimentally relevant parameters. These devices have the potential to develop into sophisticated optical train tracks, allowing for a new paradigm in particle manipulation.

In this work, we have been investigating the properties of non-linear ballistic transport. This is part of an effort to develop a novel switching device we have termed the Ballistic Deflection Transistor. The device consists of a gated nanostructure that steers electrons to an engineered scattering object. This gated nanostructure operates without creating any depletion regions, enabling ultra high speeds. This novel design which does not rely on a thermionic barrier, is intended to operate at THz frequencies and beyond with very low power requirements. Its differential design will result in more compact circuits with reduced device counts over current CMOS designs. Device structures demonstrating all of the physical effects required to make an operable Ballistic Deflection Transistor have been fabricated. Efforts now are focused toward achieving an operational device with high gain. The current transistor design is fabricated using electron beam lithography and utilizes features less than 50 nm.

Figure 1: Model system and optical mode profile. (Top) Diagram of model system with relevant forces outlined. (Bottom) Cross-section plot of system with optical mode.

Figure 2: Trapping and propulsion of a particle on a curved, optically excited 2µm SU-8 waveguide.

Figure 1: SEM image of a Ballistic Deflection Transistor Structure.

Figure 2: Graph demonstrating the observed steering effect. Left gate voltage, shown on the bottom from 1 to 2 Volts, right gate voltage transitions from 2 volts down to 1 at the same time. Output response is purely from steering as depletion effects occur near -1 Volt.
Magnetic resonance force microscopy (MRFM) is an emerging technique for acquiring magnetic resonance images of a single molecule; to date we have demonstrated a sensitivity of ~$10^5$ proton spins. In MRFM the force exerted on the cantilever, per spin, is proportional to the field gradient from the cantilever’s magnetic tip. To increase the force requires reducing the magnet size. Achieving the attonewton force sensitivity necessary to image single spins requires mitigating surface induced dissipation. We choose to meet both of these conditions by creating nanoscale tip magnets the leading edge of silicon cantilevers. As proof of concept, we will present a 50-nm wide overhanging cobalt magnet fabricated by a process involving electron beam lithography and anisotropic KOH etching, as well as cantilevers with 50-600 nm wide, non-overhanging magnets. Our current goal is to integrate these fabrication processes. With our designed cantilever, we expect a sensitivity of better than $10^3$ protons.

Notes:
Patterned polymer brushes have attracted much interest due to their possible applications in microelectronics, biosensing, and microfluidics. Typically, polymer brush patterning is done by first patterning an initiator monolayer and carrying out the surface polymerization afterwards. However, direct patterning of polymer brushes would be more favorable as this would eliminate many steps and reduce the possibility of contamination. Poly(methyl methacrylate) and poly(2-hydroxyethyl methacrylate) brushes were prepared using atom transfer radical polymerization (ATRP) and electron beam lithography was carried out on the brushes to produce nano-patterned surfaces. We are in the process of studying the relationship between the polymer brush thickness and the necessary dose to pattern the brushes, and investigating the smallest features attainable by direct patterning of the brushes via e-beam lithography.

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Nanobiotechnology is by its nature very interdisciplinary and requires a diversity of equipment and capabilities not easily accessible or affordable on an individual research group level. Thus, access to high performance instrumentation and labs in an integrated setting, is of key importance in order to conduct world class research in this field. One of the Nanobiotechnology Center (NBTC) goals is to provide a multidisciplinary environment that allow users to perform a wide range of research experiments as well as carry out biotechnology related NEMS/MEMS fabrication & characterization. Conveniently located in Duffield Hall on the Cornell central campus the NBTC user facilities provide this environment through suitable clean-room and laboratory space, equipped with state-of-the-art tools for nanobiotechnology research. Also, in collaboration with users, methods, processes and instrumentation are adapted and modified to suit special applications. Here we present a general overview of the capabilities available in the NBTC shared facilities.

Notes:
The application of nanotechnology to medical and life science research is providing significant new insights into biomedical research, advanced diagnostics and more effective therapeutics. The Nanobiotechnology Center promotes and supports interdisciplinary research projects in these areas through a competitive review process of proposals submitted by faculty at our six partner institutions, including the Weill Cornell Medical College.

Nanofabricated devices are capable of detecting individual bacteria and virus particles, microfluidic systems are improving diagnostics through higher sensitivity and selectivity. Such systems are also advancing drug discovery efforts through cell culture analogs which model living systems and reduce the need for early stage animal testing. These and other efforts are enhancing our understanding of complex biological systems at the nanoscale and will likely have a significant impact on biomedical research.

Notes:

The NBTC is committed to fostering science education in our community and nationwide through numerous outreach programs. Our programs involve teachers, students, and the community as a whole.

For teachers, we offer an annual two-day Elementary Teacher Science Workshop and an annual week-long Nanobiotechnology Institute for Teachers. NBTC staff members also present at various teacher professional development workshops and conferences throughout the year. The NBTC has created over 40 science kits which make up our Lending Library: a free science resource for teachers nationwide. Teachers from around the country can borrow these kits to use in their classrooms, and, in the library’s second full-year of existence, the kits have reached more than 3000 different students.

Through our outreach directly to students, we are able to educate students of all ages. Elementary school students at a local elementary school and at Onondaga Nation School participate in bi-monthly science clubs, where they engage in hands-on science experiments and learn different science techniques. High School students from around the country have the opportunity to spend four weeks at the Cornell campus, learning the basics of nanobiotechnology, participating in the scientific process, and working with Cornell students, staff, and faculty. Undergraduates from universities nation-wide are selected from a highly competitive applicant pool to come to the Cornell campus for 10 weeks in the summer, as part of the NBTC’s Research Experience for Undergraduates (REU) program. These REU students work alongside Cornell faculty members, postdocs, and graduate students in labs around campus, and they present on their research at the end of the summer.

As community outreach, we present at science fairs and other events throughout the area. One of our largest events is the New York State Fair, where we make polymers with more than 8,000 people per year. The NBTC also created a 3,000 sq. ft. hands-on interactive museum exhibition. It’s a Nano World. This traveling exhibition introduces children and their families to a world that is too small to see with just their eyes and has been showcased in science museums nationwide, including Epcot Center in Walt Disney World.

Notes:
Two Traveling Museum Exhibitions on Nanotechnology

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A traveling 5,000 sq. ft. hands-on interactive museum exhibition focusing on how we see and make things that are too small to see. Nanoscale science and engineering is the process through which materials are manipulated on the molecular scale to generate very, very small structures and devices.

Target Audience: Designed for 8-13 year olds and their families.
www.toosmalltosee.org
Partners: Cornell University and Painted Universe Inc., funded by NSF

The NanoScale Informal Science Education Network

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Nanoscale Informal Science Education Network

The NISE Network is a $20 million project funded by the National Science Foundation to engage the public about nanoscale science, engineering, and technology.

The project will create a nationwide network of museums working with research scientists to provide the following:

• Interactive Exhibits and Programs in 100 museums by 2010
• Visualization Lab to experiment with the best ways to help visitors visualize the nano landscape
• Public Forums to encourage open discussion and debate about issues related to nanotechnology
• Media Productions that will bring current developments in nanoscale research to a broad audience
• Public Website that will provide a gateway to nano resources for the general public
• Professional Development efforts that will foster collaborations between nanoscience researchers and educators
• Professional Resource Center that will provide resources to help informal science professionals present nanoscale science to the public.

Notes:
We have used optical drive and detection to study dissipation in silicon nitride beam resonators whose frequency and quality factor can be dynamically tuned several hundred percent by macroscopic bending of the substrate. Quality factors in vacuum and at room temperature approaching half a million have been attained at megahertz frequencies. We have studied losses resulting from clamping and surface related effects for the highest quality factor devices operated in vacuum, with hopes of maximizing quality factor for use of these devices as force sensors as well as frequency elements in signal processing applications. We have also tracked the dissipation in these devices over a large pressure range, from high vacuum to atmospheric pressure, in order to determine the nature of the gas damping for mechanical resonant devices with cross-sectional dimensions on the order of tens of nanometers. A thorough understanding of this gas damping should prove useful for sensing and signal processing applications at ambient conditions.

In a magnetic multilayer, a spin-polarized current generated by one magnetic layer can deposit spin angular momentum into a thinner magnetic layer and generate a steady-state precessional excitation of the thinner layer [1]. This effect is of technological interest because it may allow the production of high-quality nanoscale frequency-tunable microwave sources and resonators.

Our devices consist of two magnetic layers [typically permalloy (Py), Co, or CoFe] separated by a Cu spacer. One of the magnetic layers, called the free layer, is very thin (about 5 nm), thereby making it susceptible to the spin-transfer torque. The other magnetic layer, called the fixed layer, remains stationary. This is accomplished by either a) making it very thick (40 nm), or by b) exchange-biasing it with an antiferromagnet, such as IrMn (8 nm). The devices have an elliptical cross-section, with an aspect ratio of 2:1 or 3:1 and a minor axis of 50-70 nm.

In our measurements, we vary the angle between the applied magnetic field and the energetically-favored magnetically easy axis of the free layer. We use a spectrum analyzer to measure the resistance oscillations arising from spin-transfer-driven magnetic precession. We find that the field direction studied most commonly, in-plane along the magnetic easy axis of the ellipse, generally gives the largest linewidths, corresponding to the least coherent precession. As the field is rotated away from the easy axis, the linewidths can change dramatically, decreasing by a factor of 50 in some devices. We have observed the largest angular dependence in exchange-biased devices, and we are currently exploring several possible mechanisms to try to understand these dramatic variations.

References:
Spin-polarized currents can transfer spin angular momentum to a ferromagnet, generating a torque that can efficiently reorient its magnetization. Achieving quantitative measurements of the spin-transfer-torque vector in magnetic tunnel junctions (MTJs) is important for understanding fundamental mechanisms affecting spin-dependent tunneling, and for developing magnetic memories and nanoscale microwave oscillators. Here we present direct measurements of both the magnitude and direction of the spin torque in Co$_{60}$Fe$_{20}$B$_{20}$/MgO/Co$_{60}$Fe$_{20}$B$_{20}$ MTJs. At low bias $V$, the differential torque $\frac{d\tau}{dV}$ lies in the plane defined by the electrode magnetizations, and its magnitude is in excellent agreement with a prediction for highly-spin-polarized tunneling. With increasing bias, the in-plane component $\frac{d\tau_{||}}{dV}$ remains large, in striking contrast to the decreasing magnetoresistance ratio. The differential torque vector also rotates out of the plane under bias; we measure a perpendicular component, $\tau_{\perp}$, with bias dependence $\propto V^2$, for low $V$, that becomes as large as 30% of the in-plane torque.

Quantitative Measurements of Spin-Transfer Torque in Magnetic Tunnel Junctions

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We report the first-ever investigation in situ and in real-time of the structural evolution of organic small molecule thin films of pentacene during deposition by grazing incidence wide-angle X-ray scattering. Small molecule films were deposited in a custom-built vacuum sublimation chamber, which was fitted on the D1 beam line. These measurements have provided both in-plane and out-of-plane structural information about the growing polycrystalline films from the moment the growth begins. We report a number of interesting features in these measurements and find that the structure of pentacene films is essentially unaffected by the choice of the dielectric substrate. We also show morphological data from ex situ atomic force microscopy measurements and we measure transistor characteristics for these films.

In Situ Real-Time GIWAXS Study of the Growth of Small Molecule Organic Thin Films of Pentacene

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Colloidal suspensions are thermal systems consisting of solid, traditionally spherical particles suspended in a liquid solvent. The colloidal particles can be large - on the scale of one micron - making them big and slow enough to observe with an optical microscope. As such, colloids offer a truly unique opportunity to actually watch the time evolution of a thermodynamic system, particle by particle. Studies of colloidal suspensions have revealed phase transitions which occur as the particle volume fraction (or area fraction, in 2-D) is varied. Results obtained from experiments on colloidal systems have been used to probe unanswered questions in analogous molecular systems whose constituents are made inaccessible by both size and speed.

While the spherical particle is a reasonable choice for representing an "atomic unit", recent advances in particle synthesis techniques have enabled the production of many new, exotic anisotropic particles. In terms of "molecular unit" representation, the simplest nonspherical candidate is a peanut-shaped particle consisting of two connected spherical lobes. This particle shape crudely approximates a dimer molecule. Such peanut particles can fit into the same random close-packed crystals that are formed by free spheres, with their lobes occupying the crystal lattice positions. This similarity to free spheres implies that the study of colloidal peanuts may constitute a simple but fundamental extension to the vast body of knowledge on colloidal spheres.

Inspired by such implications, we have explored phases formed by fluorescent silica peanut shells (Figure 1). These hollow colloidal peanuts are made up of two tangential spherical lobes of diameter 1 micron. The particles are suspended in water and confined in 2-D microfabricated devices (Figure 2) which restrict them to lie in the plane. The peanuts are slightly density mismatched in the water, a fact which is exploited to tune the particle area fraction. The particles are then observed using a confocal microscope.

Light-emitting devices based on electrospun nanofibers as small as 300 nm in diameter have been fabricated and their electroluminescence characterized. Light-emitting devices were prepared by electrospinning arrays of these fibers onto gold interdigitated electrodes with interelectrode spacings of 0.5 and 5 micrometers. For the smaller interelectrode spacing, we observed light emission at low operating voltages (2.5-4V), with turn-on voltages approaching the bandgap limit of the organic semiconductor. Devices with a 5 micrometer interelectrode spacing revealed that the light emission from these nanofibers is highly localized. Emission in the radial dimension was confined by the thickness of the fiber, and, due to the operational mechanism, emission along the axial dimension was limited to a 500 nm or smaller region. Furthermore, the location of this emission region was tunable by changing the applied voltage. The spatial confinement of the emission zone of these fibers is an attractive feature for nanometer-scale sensing and spectroscopy applications, where extremely localized light emission is necessary.

Notes:
Electrospinning is a technique for depositing micron- and submicron-sized fibers from a wide range of materials using an electrically forced fluid jet. Under the influence of a strong electric field, a polymer solution will form a cone from which a fluid jet is expelled towards a grounded surface. As the fluid is accelerated, the jet thins and solidifies due to solvent evaporation, producing small fibers. We have used particle image velocimetry to measure velocity profiles in the jet, which will determine the mechanical properties of the deposited fibers. Using a high speed intensified camera, we take video of fluorescent particles traveling in the jet and measure the velocity as a function of position, from which the strain rate and Deborah number profiles are determined. We have also directly measured mechanical properties of individual suspended electrospun fibers using an atomic force microscope and show that their Young’s modulus is larger than that of the bulk. Finally, in order to control the deposition of electrospun fibers, we have used time-varying electric fields transverse to the charged jet to steer the electrospinning jet. By applying appropriate high voltage waveforms to the steering electrodes, single patterns can be drawn.
The Cornell Center for Materials Research (CCMR) was established in 1960 to foster interdisciplinary materials research and education of the highest quality, while addressing fundamental problems in science and engineering that are important to society. CCMR contributes to materials research through its interdisciplinary research groups; by educating and training the next generation of scientists, engineers, and educators; and by fostering the development of new experimental techniques. At the center of these contributions are the CCMR Shared Experimental Facilities, offering sophisticated instruments maintained and enhanced by expert staff, who assist and train researchers. CCMR facilities users have the rare opportunity to receive personal, expert training in experimental techniques, from routine to complex.

Our facilities support researchers nationwide across a variety of disciplines, including physical and biological science, engineering, agriculture, and medicine. The CCMR user community spans academic institutions, government laboratories, and commercial enterprises.

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Although great strides have been achieved in ability to pattern organics, the photolithography technique used in the mature and entrenched industry of silicon processing have made little impact in this field. This is primarily due to incompatibilities between chemicals used in photolithography and the vast majority of organics. Overcoming these incompatibilities promises a breakthrough in the manufacturing of organic electronics.

We present new photolithography approach for organic patterning. In this approach a random copolymer, composed of 1H,1H,2H,2H– Perfluoro decyl Methacrylate (FDMA) and tert-Butyl Methacrylate (TBMA) were prepared as negative type photoresist for patterning of organic material utilizing supercritical carbon dioxide. We have successfully demonstrated the proof of the concept by making patterned organic light emission devices with 10 micron smallest features size.
Tuning the Kondo Effect With a Mechanically Controllable Break Junction

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We have fabricated C_{60} single-molecule transistors with the ability to mechanically adjust the spacing between two electrodes. We use this device geometry to study the Kondo effect, a many-body phenomenon in which conduction electrons in the vicinity of a localized spin screen the spin to form a correlated state reflected in transport as a zero-bias conductance anomaly.

By varying the electrode spacing, we show that both the Kondo temperature $T_K$ and the magnitude of the zero-bias conductance signal associated with the Kondo resonance are modified. These changes allow a determination of how the motion affects the relative coupling of the molecule to the two electrodes. The normalized linear conductance exhibits scaling behavior as expected within the theory of the Anderson Model. The same devices can also exhibit finite-bias inelastic Kondo features at an energy that corresponds to the lowest-energy intracage vibrational mode of C_{60}. Changes in electrode spacing can tune the energy and amplitude of these signals.

Two-photon lithography has gained tremendous importance over the last decade because of its ease in fabricating extremely complex three-dimensional structures. The two-photon absorption process is confined at the focal point to a volume of approximately the cube of laser wavelength used, meaning that high spatial resolution three-dimensional structures can be fabricated with this technique. We have used this method in two separate research problems.

Firstly, we have microfabricated 2-hydroxyethyl methacrylate hydrogels in various shapes and sizes on neural prosthetic devices. Neural prosthetic devices are being used for recording and stimulating specific targets in the central nervous system. Unfortunately, the long-term performance of these devices is compromised by cellular encapsulation and changes in tissue impedance, neuron numbers and distribution. By selectively microfabricating hydrogels near electrodes on the device using two-photon lithography, growth factors can be released from them to stimulate neurons and make highly efficient neural connection with electrodes to make longer-lasting neural prosthetic devices.

Secondly, we have used two-photon lithography to make controlled defects inside an inverse-opal C-dot photonic crystal. C-dots are bright and stable core-shell fluorescent silica nanoparticles. The photonic crystal template is made from these fluorescent nanoparticles stacking in the inverse opal form. Holes of the inverse opaline C-dot structure were filled with a resin, and then the resin was polymerized inside the inverse opal using two-photon lithography to make controlled three-dimensional defects.

Both these research activities show potential application of two-photon lithography in diverse areas of science.

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While magnetic damping is understood to play a fundamental role in spin-torque phenomena, little experimental work has been done to study the effect of varying the damping parameter $\alpha$ in nanoscale magnetic devices. Recently, light terbium (Tb) doping in thin films of permalloy (Py) has been shown to increase $\alpha$ by several orders of magnitude [1]. To directly study the effect of increased $\alpha$ on spin-transfer systems, we have fabricated 0.004 $\mu$m$^2$ Py/Cu/Py nanopillar spin valves with Tb-doping of 0 and 2% in the free layer. We find that the critical currents for reversibly switching the free layer, generally expected to be proportional to $\alpha$, are several times larger on average in the 2% Tb samples than in pure Py samples. This substantial increase is still considerably less than the increase in $\alpha$ observed in the bulk film measurements of similar composition samples, suggesting that processes other than intrinsic spin-orbital coupling can dominate $\alpha$ in spin-transfer nanopillars, in agreement with simulation and pulsed measurements on similar undoped Py nanopillar devices [2]. As the enhanced damping effect increases strongly at lower temperatures in the bulk films, we have measured critical currents across a range of temperatures from 4.2 K to 295 K. We find the critical currents increase with decreasing temperature, reaching several times their room temperature value. These results suggest one approach for controllably reducing the negative impact of spin-torque effects on nanoscale spin valve and tunnel junction read head sensors, and achieving a deeper understanding of these spin-torque devices.

References

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We report on a novel design of an organic thin-film transistor (OTFT) that is used as a sensor device. This electrochemical transistor is based on a conducting electroactive polymer, called PEDOT:PSS, and operates at low voltages. The sensor response is measured as the drain-source current of the channel while a potential is applied on the gate. The behavior of the transistor can be understood in terms of an electrochemical mechanism which is proven to depend on the ionic concentration of the electrolyte.

The possible applications of these devices in sensing, e.g. sensing of harmful chemical and biological agents, are explored as the advantages are many. Organic materials offer facile processing, e.g. roll to roll printing, which can result into low cost fabrication onto flexible substrates and therefore disposable sensors. Chemical synthesis can be used to tune their electronic properties and provide selectivity and specificity through their integration with biological systems. Low end performance which limits the range of applications of organic transistors is not an issue in sensors as they provide fast enough responses. Furthermore, lifetime and fouling issues are avoided in disposable sensors. Results from different type of biological sensing applications utilizing epithelial cells for the detection of harmful enteric pathogens, e.g. bacteria, viruses, toxins, etc. will be presented. Use of different recognition elements in these devices can result in sensors for different applications. Work in progress includes the development of arrays of sensors so that many different agents can be detected at the same time.

Photolithography has been a mainstay of the semiconductor industry for decades due to its high through-put, superior feature size and resolution, as well as it robustness as a patterning technique. The emerging area of organic electronics, in which crystalline semiconductor materials are replaced with polymers or small molecules with similar properties, has shied away from these techniques, in part because the chemicals used aren’t generally compatible with the organic films. Here I demonstrate a couple of different methods of getting around this incompatibility. The first method uses the CVD deposited polymer parylene to create a chemically resistant stencil mask. By using standard lithography and etch techniques, patterns as small as 1μm can be transferred from photoresist to parylene and then to the organic film by mechanically peeling the parylene from the substrate. Using this technique, small channel organic transistors have been realized. A variation on this technique has enabled the placement of a solution deposited light emitting small molecule between electrodes in a planar configuration without leaving any material on top of the electrodes. This enables electric force probing of the ion motion in the organic film which enables its operation. The second method for patterning organic materials with photolithography involves the use of photoresist that is developed in super-critical carbon dioxide instead of the normal alkaline developer. This developer has little effect on most organic films and thus renders the process safe. Demonstrated here is progress towards fabrication of organic transistors of various types using this process.
The dielectric properties of poly(etherimide) (PEI), dissolved in binary solutions of dimethylacetamide (DMAC) with tetrahydrofuran (THF), were used to predict the solutions’ ability to form nanofibers using the electrospinning process. While viscosity and conductivity have been amply used to predict spinnability of polymer solutions, dielectric analysis has not received as much attention. Because electrospinning involves application of an electric field to the polymer solution, we believe dielectric spectroscopy to be advantageous for understanding polymer dynamics during the electrospinning. Dielectric permittivity, $\varepsilon'$, can be related to the polymer chain conformation, and reorientation of dipoles, along with the elasticity of the solution, providing new insight to the fundamentals of electrospinning. PEI solutions ranging from 100 to 220 mg/mL in varying solvent ratios were studied using a full-factorial experimental design. Maps of $\tan(\delta)$ as a function of composition of the polymer solution as well as comparisons of the dielectric and rheology data were used to determine the optimum conditions to produce PEI nanofibers approximately 10 times smaller than previously reported data. Potential uses of these fibers include fire resistance for textile nonwoven materials and high temperature filtration medium.

**Comparing Dielectric Spectroscopy and Rheological Analysis for the Electrospinning of Poly(etherimide) Nanofibers**

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Figure 1. Electrospun PEI from a solution of 220mg/mL PEI in 2:1 (v:v) DMAc/THF.
Are Nanoparticles Really “nano” in the Environment? Monitoring the Aggregation of Titanium Dioxide Nanoparticles in Dilute Electrolytic Aqueous Solutions

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The United States Environmental Protection Agency has called for basic science research on the environmental impact of nanomaterials including how aggregation affects the transport and transformation of nanomaterials in the environment. The use of titanium dioxide nanoparticles (nano-TiO₂) in many consumer products, such as sunscreens, increases the probability that they will be introduced into the environment on a significant scale. While current surface science theory predicts that individual nanoparticles will be highly unstable in aqueous solutions, there have been few systematic investigations of nanoparticle aggregation in dilute electrolytic solutions at a moderately acid to circumneutral pH range typical of environmental soil and surface-water conditions. The current study looks at the morphology and rate of formation of nano-TiO₂ aggregates as a function of ionic strength, cation type, and pH. Dynamic light scattering shows that 5 ± 0.5 nm titanium dioxide particles (Fig. 1) form stable aggregates with an average diameter of 50 to 60 nm at pH ~ 4.5 in a NaCl solution adjusted to an ionic strength of 0.0055 M. Increasing the ionic strength to 0.0205 M with NaCl leads to the formation of micrometer aggregates within 15 minutes at the same pH. At all other pH values tested (5.8-8.2) the particles form micron-sized aggregates in less than 5 min, even in low ionic strength solutions adjusted to 0.0105 M with NaCl. Using CaCl₂ to adjust the ionic strength to 0.0165 M resulted in micron-sized aggregation within 15 minutes at pH 4.5, indicating that the presence of divalent cations may enhance aggregation of nano-TiO₂ in soils and surface waters. In situ optical micrographs showed branching aggregates in sizes ranging from the 1 μm optical limit of the microscope to tens of micrometers in diameter (Fig2).
A portable, fully-automated PCR-based detection system has been developed in our lab for the rapid detection of bacterial pathogens[1]. To further broaden the utility of this system, we have developed a microfluidic sample preparation module, which removes cells of interest from a raw sample by mixing with antibody-coated magnetic beads. Fabrication of the microfluidic mixers employs a two-step SU-8 process to generate the polydimethylsiloxane (PDMS) mold. The PDMS-on-PDMS mixer chip consists of serpentine channels (200μm width, 50μm height) with herringbone structures (50μm width, 50μm spacing, 10μm height) for passive mixing [2, 3]. Using an external magnetic field, bacterial cells have been selectively isolated from both pure bacteria culture samples and contaminated raw chicken samples and lysed to release DNA. Bead leakage at various flow rates were studied in conjunction with different methods of magnetic field application. Subsequent microfluidic steps used silica-coated microstructures to selectively bind, wash, and elute nucleic acids for subsequent real-time PCR.

The automated detection platform, with integrated microprocessor, pumps, valves, thermocycler and fluorescence detection modules, is used in conjunction with microfluidic chips to isolate and lyse bacterial cells, purify bacterial DNA, and detect bacterial DNA by real-time PCR amplification. Experiments with different methods of PDMS passivation were conducted, and it was found that incubation with 5% BSA was most effective. Between 100 and 1000 S. typhi cells could be detected using this system with an average turnaround time of 120 minutes.

References
The National Nanotechnology Infrastructure Network (NNIN) is an integrated networked partnership of user facilities, supported by the National Science Foundation, serving the needs of nanoscale science, engineering and technology.

The mission of National Nanotechnology Infrastructure Network (NNIN) is to enable rapid advancements in science, engineering and technology at the nano-scale by efficient access to nanotechnology infrastructure. We provide shared open, geographically distributed laboratories, each with specific areas of technical excellence, and provide fabrication, synthesis, characterization, and integration resources to build structures, devices, and systems from atomic to complex large-scales. Our users belong to diverse areas: astronomy, plant pathology, materials science, physics, chemistry, life-sciences, various branches of engineering, etc., and come from academe, national laboratories, and industry. Users can perform research on-site using facility equipment, training and staff support. For many tasks, remote usage is also feasible. External users typically spend a week or two, or commute, to complete their work although longer visits are possible. We help users succeed by providing strong pre-visit technical interaction, mechanisms that let users protect their intellectual property, and strong training and knowledge support.

NNIN Laboratories are located at:
- Cornell University
- Stanford University
- Georgia Tech
- University of Michigan
- University of Washington
- Penn State University
- UC Santa Barbara
- University of Texas Austin
- University of Minnesota
- University of New Mexico
- Howard University
- Harvard University
- North Carolina State University / TNLC

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The National Nanotechnology Infrastructure Network conducts a multifaceted, education program spanning levels from. Education and outreach components of the NNIN include network-wide programs to address needs at the national scale and more specific efforts for communities that are local to network sites. The NNIN has established the following goals for its network-based educational outreach and training:

- Expose young people to advanced and exciting research in nanotechnology and motivate them to educate themselves for careers in the sciences or engineering;
- Train teachers and guidance counselors about the discipline of experimental sciences, provide additional teaching tools, and enhance their enthusiasm for having students pursue careers in science;
- Create and distribute educational materials for children, college students, technical professionals, teachers and the general population, as well as improve the understanding and involvement with science, technology, engineering and mathematics;
- Focus these efforts on population segments having disproportionately low employment and education in sciences, including women, disadvantaged minorities, and the economically disadvantaged.

Specific activities which address these goals will be described including the NNIN REU program and the NNIN RET program.

Notes:
The National Nanotechnology Infrastructure Network’s computational drive (NNIN/C) is a multi-university initiative, funded by the National Science Foundation (NSF) as part of NNIN, to establish a national computing resource for nanotechnology. This network is open to the academic and industrial research community and provides hardware resources and simulation tools dedicated to nanoscience research. Strong technical and scientific support is provided by staff experts so that the tools and resources can benefit interdisciplinary research. The software tools include commercial software packages for design, characterization and analysis of nanometer scale devices as well as some of the latest academic advances in nanoscale modeling and simulation software.

Primary computation resources are located at Cornell University and Harvard University.

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