Nanomanufacturing Summit 2009

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Poster Session

May 27 and 28, 5:00-7:00pm
Sheraton Boston Commonwealth Ballroom

P1
Directed Assembly of Polymer Blends on Nano-Scale Patterned Self Assembled Monolayers

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Patterned polymer structures in the area of nanotechnology offer a variety of applications which include the semiconductor industry as well as the biosensor. The majority of research in this particular area has been focused on pure block copolymers with only a few select studies dealt with polymer blends. These polymer blends studies have solely focused on uniform geometry patterns. Recently, block copolymers with the addition of a homopolymer have demonstrated the ability to phase separate into non-uniform geometries. This work investigated the assembly of polymer blends to achieve phase separation on non-uniform geometries. The two polymers chosen for this study will naturally phase separate and will utilize chemically modified surfaces to direct phase separation of the polymer blends. This work demonstrated the ability to form continuous phase separation of polymer blends on complex non-uniform geometry patterned surfaces reliably down to 100 nm.

P2
High Rate Assembly and Transfer of Nanoelements

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Nanoelements such as carbon nanotubes, conducting polymers and carbon black are of great interest in the researcher's community due to their high mechanical, thermal and electrical properties. They are often combined with polymers to enhance their properties; however it is required for some of the specific applications that the particles to be in patterned form over the polymeric surface. In this work we investigate approaches to pattern the carbon nanotubes and conducting polyaniline and transfer this pattern to a polymer substrate using thermoforming, a commercially relevant process. We have used electrophoretic deposition of carbon nanotubes (Single wall (SWCNT) as well as multi wall (MWCNT)) and conducting polyaniline onto the circuits followed by transfer to a polyurethane film by thermoforming. Two circuits designs were used had a copper (Cu) wire with a width of 55 µm and the same 55 µm spacing whereas the other circuit has a gold (Au) wire with a line width of 3µm and the spacing of 9 µm. Nanoelements were deposited onto the Cu and Au wires using the electrophoresis method with direct current (DC) voltage. A novel mold design for the thermoforming process was developed, which has a removable insert to keep the patterned nanoelements circuit inside the mold. The thermoforming process parameters (temperature (heating time), forming time and vacuum) were optimized to obtain transfer of the patterned nanoelements to the polyurethane surface.

P3

Exposure Assessments when Handling and Processing Nanoparticles

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With regard to respiratory exposures to nanoparticles, there continues to be a shortage of published data. To address this lack of information on possible exposure, we have assembled a set of sophisticated air monitoring equipment to assess possible exposures associated with handling nanoparticles both in CHN laboratories and at outside companies and laboratories (using funding supplied by those organizations). Elevated airborne nanoparticles concentrations were detected in several manufacturing facilities and laboratories. To our knowledge, this type of nanoparticles exposure assessment is not occurring at other NSECs. The quantity of data collected to date exceeds any such monitoring reported in the peer-reviewed literature, and has ensured that research work in the CHN and at the outside facilities where we have worked is being undertaken without significant exposures to students and faculty.

There is a similar lack of published information on the effectiveness of various control strategies, such as local ventilation systems, in controlling nanoparticle exposures. We have published the first journal article on the effectiveness of laboratory fume hoods when working with nanoparticles (Tsai and others 2009), and several different fume hoods were studied to evaluate the appropriate handling methods and protocols for working with nanoparticles.

P4

Die Design for Fabrication of Co-extruded Multilayer Films

Madhurima Ogale[1], Ranvir Soni[1], Eji Nakamura[2], Stephen A. Orroth[1], Joey L. Mead[1], and Carol M. F. Barry[1]
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Multilayer materials offer benefits in terms of new materials for packaging and barrier and other applications. The ability to maintain layer stability and uniformity as the material flows into different die designs is important for fabrication of these materials. This work investigates different die designs for use in fabricating multilayer films. Two and three dimensional analyses of different types of manifold designs have been carried out using Polyflow software (Version 3.11.0). Die design optimization (considering material stresses, flow rates, and pressure drop) for monolayer extrusion for polypropylene will be presented. Also effect of die design in multilayer co-extrusion will be discussed using Polypropylene and PMMA as flow materials. Basically for multilayer co extrusion, flow pattern of layers through different die designs would be taken into consideration. The designs would be basically tested for layer stability and uniformity.

Results for mono-layer simulations showed that an elongated tear drop shaped manifold showed better results as compared to a tear drop shaped manifold. An extended tear drop shaped manifold gave rise to lesser shearing of the material which is desirable in multi layer co extrusion. Also a flatter exit velocity profile was observed for elongated tear drop shaped manifold as compared to tear drop shaped manifold. This would help in ensuring that all layers exit at the same velocity. Residence time distribution for tear drop shaped manifold was narrower as compared to the elongated tear drop shaped. But this was a trade-off for uniform exit velocity incase of elongated tear drop manifold.

P5

Injection Molding of Micro and Nanoscale Features

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High-aspect ratio micro and nanoscale polymer features are not easily replicated using injection molding, with polymer often adhering to the tooling surface. To improve the replication quality, the tooling should provide both high-resolution and moldability. Therefore, several experimental toolings including silicon, coated silicon, and metal-polymer hybrid type tooling have been suggested as solution for future microtooling. Parts were molded using various polymeric materials and replication quality was determined using optical profiler and scanning electron microscopy. Heat transfer analysis was carried out to compare the performance of the toolings and cooling time optimization.

P6

Preparation of Janus Colloidal Particles for DNA-Directed Assembly

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We present the fabrication process to prepare complex building blocks of Janus biphasic nanocolloids. Micro- and nano-scale anisotropically coated “Janus” particles were successfully prepared using a combination of spin coating and centrifugation processes in conjunction with a metal deposition technique. A monolayer of polystyrene (PS) microspheres was first formed on a glass substrate via a spin coater. The uniformity and continuity of the PS monolayer was characterized and found to be dependent on particle size, the spinning speed, concentration, solvent and, surfactant used. The PS monolayer was coated with gold using a metal evaporator. The amount of gold used dictated the thickness of the gold layer and area of coverage. The coated PS microspheres were separated from the substrate by mild sonication. The Janus particles were separated from the excess gold by centrifugation. These Janus colloidal particles will be further selectively modified with DNA. Self- or directed assembly of the asymmetric micro and nanospheres into 3D colloidal crystal assemblies using the complementarities of DNA-based hybridization is under investigation and expected to be achieved.

P7

Factors that Control the Assembly of Multiphase Polymer Systems on Patterned Substrates

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Polymer blends offer the opportunity to prepare nanoscale flexible structures of non-uniform geometry. These materials can be used for flexible circuits, biosensors, optoelectronic devices, and as templates for the deposition of other elements. Our work investigates the phase separation of polymer blends using chemically modified surfaces to direct phase assembly. Our ability to control phase separation into varying geometry enables us to design systems with feature sizes as small as 100 nm.

P8

Nanoscale Force Measurements for Templating and Transfer Applications

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Lithographically printed alkanethiols on gold surfaces can be used as templates to pattern polymers, biomaterials, and conjugated oligomers. To optimize these processes, it is necessary to understand the interaction of polymers with self-assembled monolayers. In this study, atomic force microscopy (AFM) has been used to measure the forces of adhesion between alkanethiol-modified gold AFM tips and spin-coated polystyrene (PS) and poly (acrylic acid) (PAA) surfaces. AFM tips have been modified with thiols having a variety of functional head groups (CH_3, COOH, NH_2, and OH), and similarly treated gold substrates and polymer films were characterized using contact angle measurements and X-ray photoelectron spectroscopy (XPS). Force measurements have been carried out in dry air of relative humidity less than 1%. In the case of PS, the normalized adhesion forces follow the order: CH_3 > COOH > OH > NH_2. For PAA, the order is: OH > NH_2> COOH > CH_3.

The ability to control the wettability of titanium dioxide surface using UV light could possibly be used to transfer hydrophilic particles from a template to a substrate for nanomanufacturing applications. Feasibility of such a light induced transfer process is explored by measuring the force distance curves between a silicon oxide AFM tip and TiO_2 (110) surface with and without UV exposure. In a dry nitrogen environment, no difference has been observed in adhesive forces measured with and without UV exposure. In a N_2:O_2 (1:1) environment approximately five times higher adhesive forces are observed after UV exposure as compared to when TiO_2 (110) is not exposed to UV light.

P9

Friction Modification from Fundamental Perspective: Tribological Properties of Polyaromatic Thiol Self-Assembled Monolayers

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We have used atomic force microscopy (AFM) in friction mode to study the boundary friction of self-assembled polyaromatic monolayers in adhesive and non-adhesive contacts. The strength of the adhesion between a monolayer-covered flat surface and a monolayer-covered AFM tip was varied by working in a medium of dry N_2 gas or ethanol. Low adhesion (obtained in ethanol) resulted in a linear dependence of the friction force on load; whereas high adhesion (in N_2) gave an apparent area-dependence at low loads. A recent contact mechanics model describing an elastic thin film confined between stiffer substrates was applied to the data obtained in N_2. The same trend was found in the friction coefficient and critical shear stress obtained at low and high adhesion, respectively.

P10

Directed Morphology of Polymer Blends using Nanopatterned Templates

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With the rapid advances in nano-science and nano-technology, developing simple and rapid fabrication techniques to create highly ordered functional nanostructures of polymer is required. In our work, chemically heterogeneous patterns were produced by combining electron-beam lithography and self-assembly monolayers (SAMs) of alkanethiols. While solution of polystyrene (PS) / polyacrylic acid (PAA) blends were spin coated onto the nanopatterned templates in only 30 seconds, the bi-continuous morphology of the thin films could be directed by the predesigned patterns. Not only simple lines, but various nonuniform patterns could be replicated by the morphology of polymer blends. Meanwhile, two methods were involved to reduce the pattern size, including increasing spinning speed and reducing solution concentration.

P11

Manufacturing of Femtosecond Laser Induced Self-assembled Nanostructure Arrays

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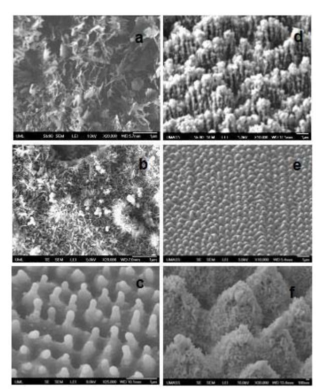

In nano-scale, due to the size of nanoparticles or nanostructures, the surfaces are dramatically increased, which then could greatly improve the properties of the materials in various application areas.

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By using a Ti:sapphire femtosecond laser to irradiate cobalt microparticle powder dispersed in water[1], the surfaces of the cobalt microparticles are transformed into nanometer-scale flakes or grass-like structures (SEM images in Fig. 1a b). In similar way, nanoscale structure arrays with similar size scale can be formed on Si, Fe, Stainless steel, and Pt materials (Fig. 1 c d e f).

A series of experiments are conducted and primarily analyzed, and the results show many positive progresses in applying this group of nanostructures as photosynthesis catalyst, gas sensor, supercapacitor, and Raman enhancement bases.

References

For further information about this project link to mengyan_shen@uml.com

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P12

Nanomanufacturing for Sensing Systems by Soft Nanolithography Method

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The nanospike structures formed with femtosecond laser irradiations have been successfully replicated on the surface of a polyurethane (PU) polymer using a low cost soft nanolithography method. The surface enhanced Raman scattering (SERS) of rhodamine 6G (Rh6G) and dinitrotoluene (DNT) molecules have been measured with silver coated PU nanospiked surfaces. The SnO_2 thin film CO gas sensors on PU nanospikes have also been fabricated and measured at room temperature. Compared to a flat surface, all the sensing signals are significantly enhanced because of the high area/volume ratio and small size of the PU nanospikes. It demonstrates that the highly sensitive, repeatable and low-cost sensing systems can be easily fabricated by using the nanospike structures formed by femtosecond laser irradiation and the soft nanolithography.

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P13

Diameter Selective Growth of Vertically Aligned Single Walled Carbon Nanotubes by Ethanol Flow Control

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Nanotechnologies based on single walled carbon nanotubes (SWNTs) are developing very rapidly because of their outstanding mechanical, electrical, and optical properties. However, large scale synthesis of SWNT with desired structures still have many difficulties. In particular, controlling the diameter and chirality of SWNT is one of the biggest challenges that need to be solved. For the growth of SWNTs, chemical vapor deposition (CVD) process are becoming a strong manufacturing method due to the ability of synthesizing SWNTs in a large-scale and controlling their structure more easily compared to other methods. In this presentation, we introduce the study on role of ethanol flow rate in a CVD process for the diameter selective growth of vertically aligned single walled carbon nanotubes (VA-SWNTs) and simple growth mechanism of SWNTs by computational modeling. In our experiments, three different flow rates of ethanol vapor (50, 100, and 200 sccm) are supplied to grow VA-SWNTs while keeping all other CVD parameters such as growth temperature, thickness of catalyst film, growth time and pressure are the same. Raman RBM mapping technique with an excitation wavelength of 785 nm was performed to evaluate the diameter distribution of VA-SWNTs over the large area. Our experimental results show that as ethanol flow rate increased from 50 sccm to 200 sccm, the total diameter distribution of SWNTs were enlarged. Computation modeling also suggest simple model for SWNTs growth with different flow rates of ethanol. The diameter of nucleation sites on catalyst particles are changed by ethanol flow rates.

P14

Assembly of Functionalized Nanoparticles for Biological Applications

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P15

Electric Field Assisted Directed Assembly of Gold Nanoparticles for Next Generation Vertical Interconnects*

Cihan Yilmaz, Taehoon Kim, Sivasubramanian Somu, Ahmed Busnaina
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P16

Highly Organized Single-Walled Carbon Nanotube Networks for Electrical Devices

Bo Li, Laila Jaber-Ansari, Myung Gwan Hahm, Tae Hoon Kim, Sivasubramanian Somu, Ahmed Busnaina and Yung Joon Jung
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Wafer-scale Liquid-phase manufacturing using directed assembly of highly organized single-walled carbon nanotube (SWNT) networks is demonstrated. The method combines lithographically patterned template guided fluidic self-assembly of SWNTs on a silicon substrate through SWNT solution evaporation with controlled dip coating. Networks in diverse geometries with feature sizes ranging from 150 nm to 9 µm were manufactured. Room temperature electrical I-V characterization of fabricated high coverage SWNT wires shows linear ohmic behavior. This work provides a simple and flexible way of building nanotube-based electronics in a large scale with high-rate.

P17

Polymer Covered Quantum Dots: Synthesis and Properties

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Different synthetic approaches such as, “grafting from” and “grafting to” are employed to functionalize quantum dots with polymers ligands.[1] In addition to dictating the physical properties of quantum dots such as solubility,[1] the ligands provide a measure of control over the photophysical properties of the quantum dots and overall hybrid materials. Electronically active polymers, such as poly(phenylene vinylene) are found to interact with the quantum dots through an energy transfer process.[2]Their presence on the quantum dot surface increases the quantum dot by reducing the frequency of dark states (i.e., blinking). Moreover the ability of the quantum dots to sensitize the polymers is seen in such systems.

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P18

An Atomic Force Microscopy Study on the Actuation Mechanisms of Nanotube Switches

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Current experimental studies on the actuation of carbon nanotube switches have been limited to electronic characterization. The I-V measurements that have been performed on our nanotube switches seem to display characteristics of hysteresis. An experimental setup has been created utilizing an Atomic Force Microscope (AFM) with the aim to provide further information on the mechanical and electrical response to the electrostatic actuation of these switches. A variety of tests may be performed using this setup with the hope that they will provide insight and quantitative information into the mechanisms of switching.

P19

Local Government & Conditions of Uncertainty: Cambridge and the Regulation of Nanomaterials

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Local governments have limited capacity to address potential environmental and public health effects of new technologies, yet such effects are often felt first at the local level. This study looks at the experience of the Cambridge, Massachusetts, Nanomaterials Advisory Committee (NAC) in 2007-08 as it considered rules on nanomaterial research and production within city limits. The NAC's path of action was influenced by the experience of Berkeley, California, which had implemented a nanomaterials reporting ordinance a year earlier, and, more important, by lessons obtained by the Cambridge Environmental Review Board (CERB), which for three decades has overseen what were the first regulations governing biotechnology enacted in the United States

In Cambridge, more than in Berkeley, deliberations involved open discourse among policymakers, industry representatives, academic researchers, legal experts, and local residents. Participants shared their respective expertise to build a common frame of knowledge from which to assess what was known about nanotechnology in general and activities in Cambridge in particular. The outcome – to *not* act– reflected a sober yet watchful understanding that too little was known to promulgate specific rules just yet.

Uncertainties surrounding the health and environmental effects of nanotechnology pose a unique dilemma to local and state governments invested in fueling economic growth through innovation. Understanding the processes by which Cambridge addressed this dilemma may guide other local governments in dealing with uncertainty.

P20

Environmental Assessment of Manufactured Carbon Nanotube Applications

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Nanotechnology shows great potential for a wide range of applications including electronics, materials, energy, and biomedicine. Substantial investment has been afforded to nanotechnology research and development worldwide by governments and corporations. To date, however, there are a very limited number of publications regarding the environmental impacts of nanotechnology processes or products. In particular, there is significant uncertainty over the health effects and handling of carbon nanotubes (CNTs). With unique electrical, mechanical, and thermal properties, CNTs are desirable in industrial applications such as a SWNT switch for nonvolatile memory devices, biosensors, SWNT batteries, and electromagnetic interference (EMI) shielding. The market for these applications is projected to exceed $1.9 billion by 2010. Some studies report that single-walled carbon nanotubes (SWNTs) appear to damage lung tissue in mice, whereas other studies state that there is little detrimental effect. Nanoscale properties of CNTs such as surface area and particle size may also contribute to potential toxicological effects. The U.S. Environmental Protection Agency has recently ruled that CNTs are chemical substances distinct from graphite or other allotropes of carbon listed in the Toxic Substances Control Act (TSCA) Inventory. Thus under TSCA, the many variations of functionalized CNTs may be classified as new chemicals. Given these uncertain risks and unknown outcomes, it is prudent to assess the environmental attributes for nanomanufacturing products and processes while in the developmental phase. Results can inform the development and commercialization of safe, economically competitive, and environmentally responsible nanotechnologies.

Environmental assessment for the manufacture of two developmental CNT applications was carried out using life cycle assessment (LCA) tools: a CNT switch and a CNT-polymer mesh. Process parameters and life cycle inventory data are collected for all of the inputs (raw materials, energy and equipment used) and outputs (emissions to land, water and air) by observation of laboratory scale processes and discussions with researchers. for the manufacture of each device are collected on the laboratory-scale at CHN. These data are input into SimaPro™, a LCA software program, using the Eco-Indicator 1999 method, for the environmental impact assessment. By using Eco-Indicator 1999 methods, emissions are categorized into impact areas such as climate change, acidification, eutrophication, land use, mineral depletion, ecotoxicity, ozone layer depletion, and carcinogens.

Results indicate that significant, measurable impacts are found to fossil fuels, airborne inorganics, and climate change for the manufacture of both applications. The impact on fossil fuels is dominated by processes that require energy-intensive equipment. In terms of airborne inorganics, the process steps that have the greatest environmental impact include pre-diffusion cleaning and piranha etch & rinse cleaning. These larger impacts are due to the quantity of sulfuric acid used in these process steps. Effect on climate change is primarily due to the release of carbon dioxide from energy use. These results highlight process drivers associated with the environmental burdens of manufacturing both CNT applications.

P21

MEMS Devices for Reliability Testing of Nanoelements

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This project is to design Microelectromechanical system (MEMS) devices to characterize the reliability of nanoelements such as nano thin films, nanowires, carbon nanotubes (CNTs). Nanowires and thin films are essential components in virtually all prospective nanodevices. Their characterization has been recognized as an important area for the development and successful implementation of nanotechnology. Thus, the determination of their electrical, thermal, magnetic, and mechanical properties has been the subject of numerous recent investigations. However, the behavior of films and nanowires under rapid thermal cycling has not been studied. This type of testing is important for understanding the key parameters for reliability analysis of systems experiencing thermal cycling. In this work, a MEMS microhotplate for the characterization of electrical resistance of thin films and nanowires under rapid temperature cycling is reported. Besides nanowires and thin films, CNTs are also found promising candidates for novel nanoelectronic devices with their unique mechanical and electrical properties. Among all kinds of research on CNTs, the study of the physics of adhesion force between carbon nanotubes (CNTs) and different material substrates is of great interest for the development of nanoelectronics and also has been conducted by several authors. However, few directly controllable measuring systems have been built until now. So it has a great significance to develop an easy and stable testing system to precisely study and better understand the adhesion mechanism of CNTs. Here MEMS device design for adhesion force measurement between CNTs and substrate is presented.

P22

3-D Perpendicular Assembly of SWNTs for CMOS Interconnects

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We present a room temperature and pressure green methodology for fabricating nanoscale interconnects between different layers in an integrated circuit in a time period less than a few minutes over very large areas. The electric field assisted directed assembly method is employed to assemble SWNTs aligned perpendicular to the substrate in the vias. The electric field is applied between the electrode at the bottom of the vias and a reference electrode placed far away from vias. A typical SEM micrograph of final substrate with assembled SWNTS shows that vertical assembly of SWNTs in via holes is effectively achieved.

P23

Highly Flexible and Biocompatible SWNTs-Parylene Thin film Transistor for Wearable and Implant devices

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Bistable Nanoswitch - SWNT memory device

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We propose a new design for a non-volatile bi stable nano electro-mechanical switch employing single wall carbon nanotubes as the actuation element. In this new design the actuation of states are achieved at the same voltage when compared to several other SWNT electromechanical devices.

P26

Single-Walled Carbon Nanotube based pH Sensor

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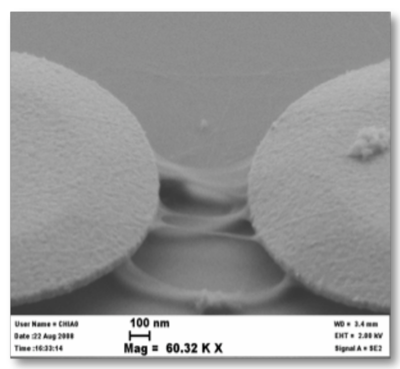

Single-Walled Carbon nanotubes, due to their large surface area to volume ratio, high aspect ratio and miniature size are excellent candidates for nanoscale sensors. Several applications of SWNTs based sensors are demonstrated which include biological and optical sensors. The measurement of pH in solution is one of the most common tasks in environmental analysis, process control and clinical analysis. Theoretical studies have shown significant changes in the electronic properties of SWNTs because of the hydroxide (OH^-) in pH solution. Due to the attachment of the OH^- group on the wall of the SWNTs in the buffer solutions, the changes of conductivity from the SWNTs shows that it can be a promising candidate as pH sensors. In this work, we have designed and fabricated a SWNTs based pH sensor utilizing low temperature Dielectrophoresis (DEP) assembly process. In order to improve the electrical contact between SWNTs and metal electrodes, an electroless zincation process was performed after assembling of SNWTs. The resistivity of the SWNTs was measured by using HP34401A multimeter with LabVIEW program at room temperature. To describe the pH response of the SWNTs, 0.1µL of pH buffer solution is placed on top of the SWNTs. The experimental results show that the resistance of SWNTs decrease corresponding to an increase in pH value of the buffer solution. In summary, a SWNTs based pH sensor has been demonstrated and its integration with CMOS circuitry has been demonstrated which paves the way for future integrated low cost high performance nanotube based sensor systems.

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P27

Robust Design and Fault Diagnosis Methods for Nanoscale Products, Processes and Systems

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The National Nanotechnology Initiative (NNI) Grand challenges and the NSF have reported that one of the fundamental technical barriers to realizing nanomanufacturing is "How can we test the long-term reliability of nanocomponents, and detect, remove, or prevent defects and contaminations?" We believe that *now* – when the nano research is at the R & D stage – is the most opportune time for the nano community to examine issues that would impact the quality and reliability of nano process and products down the road at the commercial production stage. Instead of taking recourse to the production stage problem-solving to the quality of nano products, one should address the quality and reliability issues at the R & D stage of the nanomanufacturing to reap high dividends at the commercial production stage.
We examine the quality issues of nanomanufacturing, both for product design and process design, in Taguchi's framework of off-line and on-line quality control. Off-line quality control focuses on quality issues at as early as process and product design, while the on-line quality control targets the quality improvement at the production stage. Our off-line quality control research includes the following topics: Selecting nano product configuration and features, including starting materials, components, and subassemblies; determining optimal parameter setting for nano product features; specifying appropriate tolerances about the nominal values established in the parameter design; selecting the most appropriate nanoprocesses; determining optimal settings for nanoprocess parameters and variables; and determining the allowable variation in process parameters and variables from the target.

Our on-line quality control research focuses on the following objectives: identify the key barriers and issues in monitoring and diagnostics of nanoscale engineered systems; investigate the monitoring and diagnostics methods that are effective for nanoscale systems; and demonstrate the proposed approaches on the nanomanufacturing process.

Current we are working on the quality and repeatability of MgO thin films grown on a 6H-SiC substrate using Molecular Beam Epitaxy process.

P28

Direct-Write Deposition of Functional Nanostructures Using Thin-Film Nanoparticle Electron Beam Resists

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Deposition of different materials with nanoscale features is crucial for the semiconductor and data storage industry. This presentation describes a new "direct-write" process to fabricate patterned nanostructures with fewer process steps than conventional photolithography and electron-beam lithography. Solutions of nanoparticles in organic solvents were prepared to be used as a direct-write resist. These particles can be synthesized in different sizes and from a variety of different materials including metallic, magnetic and semiconducting nanoparticles. We report a three-step process--spin coating, electron-beam exposure and solvent rinse-- to fabricate patterned nanostructures with arbitrary lateral shape with dimensions down to 20 nm. We discuss the properties of thin nanoparticle films to determine how the exposure process changes the bonding between particles and consequent properties. These nanostructures may be used for a variety of new applications, including nanoscale rapid-prototyping, nanoimprint master fabrication and hierarchical nanomanufacturing.

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Menisci Formed by Capillary Force Lithography

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Surface tension generally tends to flatten out any curved interfaces rather than enhance them, but in the size scale of micrometer or nanometer that is not the case. Specifically, in a capillary filled with water one will expect to see a meniscus, which is one interesting example of surface tension inducing curvature. The smaller the size scale, the smaller the capillary number and the bond number, meaning that menisci will be formed faster and be more pronounced. What is even more interesting is when the cross-section of the capillary is not circular, which is what my research focus. Menisci with various shapes formed inside cavities with different cross-section geometries have been observed, e.g., a triangular cross-sectioned capillary will help to form a meniscus with elevated corners, while two parallel walls made of connecting cylinders will yield a pair of wavelike walls. We obtain those menisci by doing Capillary Force Lithography and satisfying two conditions: a) the molten polymer substrate wets the PDMS mold relatively well and b) the cavities in the mold are only partially filled. In the practice we also noticed that the quality (including resolution and structural strength) of the PDMS mold is critical in our experiments, which is also the main obstacle we have to overcome. In the near future, we will be looking into the possibility of integrating Capillary Force Lithography technique into a roll-to-roll process. That, we believe, can significantly increase product yield, and thus improve accessibility as well as efficiency of nanofabrication.

P30

Low-Index Photonic Crystal Cavities

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In this work, we are pursuing design, fabrication and experimental validation of low-index photonic crystal (PhC) nanobeam cavities for quantum information processing applications. In order to improve efficiency of quantum-emitters, it is important to enhance the photon production rate as well as the collection efficiency of emitted photons. This can be achieved by embedding quantum emitters within optical cavities. These cavities were designed to operate for emitters in the visible particularly near 637nm in order to strongly enhance the zero-phonon-line (ZPL) emission of nitrogen-vacancy (NV) color center in a diamond nanocrystals (NC)s while suppressing emission into the phonon side-band. In spite of the low-index of silicon nitride (SiNx) and titanium oxide (TiOx), we were able to design optical cavities with quality (Q) factors of $1.4x10^6$ and $1.6x10^6$, mode volumes of $0.78(\lambda/n)^3$ and $0.44(\lambda/n)^3$, respectively. Simulation studies show $Q > 1x10^6$ for diamond NC embedded inside or on top of the cavity. Preliminary characterization show Q's as high as 14000 in SiNx without any diamond NC or other emitters like quantum dots inside or near the cavity. The presented work is an important step towards the realization of diamond based single-photon sources, including switches.

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Arrays of Nanotraps for Studying Single Molecules

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Arrays of three-dimensional nanoscale physical traps were developed for study of single fluorescently labeled biomolecules. These traps reversibly seal off volumes of solution small enough to contain at most one molecule. Electron-beam lithography followed by reactive ion etching was used to fabricate an array of cubic and orthorhombic nanowells on a fused silica substrate. The width and the depth varied from 40 nm to 200 nm. The top surface of the traps was covered by a removable lid made of polydimethylsiloxane (PDMS). We present progress on proof-of-principle experiments with a dilute solution of fluorescently labeled proteins and/or nucleotides applied to the nanotrap device. The existence of single molecules inside the traps is verified by fluorescence imaging. This device provides isolated and confined environments to biological molecules, eliminates Brownian diffusion out of the field of view, and thereby enables us to track fluorescence signals from many single molecules simultaneously.

P32

Carbon Nanotube Dispersed Liquid Crystal: A Nano-electromechanical System and Non-Volatile Memory Effect

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The self-organizing properties of nematic liquid crystals (LC) can be used to template carbon nanotubes (CNTs) on a macroscopic dimension. The nematic director field, coupled to the dispersed CNT long-axis, enables controlled director reorientation using well-established methods of LC alignment techniques, such as patterned-electrode-surface, electric fields, and magnetic fields. Electric field induced director rotation of a nematic LC+CNT system is of potential interests due to its possible applications as a nano electromechanical system. The relaxation mechanism for a LC+CNT composite, on the removal of the applied field, reveals the intrinsic dynamics of this anisotropic system. Dielectric hysteresis and temperature dependence of the dielectric constant coherently shows the ferroelectric-type behavior of the LC+CNT system in the nematic phase. The strong surface anchoring of LC molecules on CNT walls results in forming local isolated *pseudo-nematic* domains in the isotropic phase. These domains, being anisotropic, respond to external fields, but, do not relax back to the original state on switching of the field off, showing non-volatile memory effect.

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Multi Bit Clusters and Patterned Media Enabled by Novel Nanofabrication Techniques

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Copolymer self-assembly has been investigated intensively for patterned media applications as the technology has been proved to be able to push the magnetic storage density over 1T/in2 for the bit media devices. When the bit-per-area density is substantially high, the interaction between the neighboring bits can cause collective switching during the writing process – this is one of the many challenges to be addressed for the real application. This research presents a method to favorably use the interaction between nanomagnetic bits as we turn a cluster of few bits into the basic cell of the storage media. The interacting multi-bit cluster has several discrete magnetostatic states which can be used to represent multi level information. Experimental efforts will be discussed with two approaches, high resolution EBL on suspended SiN for proof-of-concept, and patterned media assisted by block copolymer self assembly patterned by EBL.

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Nanofabrication of Metal Array Hybrid Structures Using High Resolution E-beam Lithography for Fluorescence Enhancement by Exciton-Plasmon Interactions

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A number of advanced optical applications require highly ordered fine metallic nanostructures for plasmonic effects. By using suspended 100 nm silicon nitride window as a substrate, structures with sub-30 nm feature sizes were produced using e-beam lithography (EBL) with only 20kV acceleration voltage. This technique enables the fabrication of arrays of gold or silver nanostructures that exhibit both localized and extended surface Plasmon polaritons. Using time, angle, and polarization resolved photoluminescence (PL) spectroscopy, tuning dispersive plasmon modes of metal disc arrays into resonance with emission of adjacent semiconductor nanocrystals, we show that near-field interactions between anisotropic metal nanostructures and dipole emitters result in emission with directionally enhanced radiative decay rates, and achieve ten fold enhancement of radiative transition rates so far. This plasmon-enhanced florescence can be used in advanced biomedical molecule detection, sensors and other related applications.

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Self-Assembled Templates for High Volume Applications

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Biological Oxidative Damage as a Predictor of Nanomaterials Toxicity: Implications for Responsible Nanomanufacturing

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Novel engineered nanomaterials (ENMs) are being introduced into the market at a fast pace with little understanding of their potential toxicity. This reality has posed a pressing need to develop fast and predictive screening techniques for these novel ENMs. Biological oxidative damage (BOD) has been shown to be a useful biomarker to evaluate the toxicity of ENMs. A 'Ferric Reducing Ability of Serum (FRAS) assay, optimized by our group, was used to quantitate the degree of BOD induced by 19 commercially important NMs, including several types of carbon black, fullerenes, carbon nanotubes, nano silver, titanium dioxides, nano and alumina. The relationship between BOD and various physicochemical parameters of ENMs was investigated. Furthermore, we investigated the ability of FRAS to predict toxicity by comparing it to multiple toxicological endpoints on similar classes of ENMs from the literature reports across multiple testing platforms. Comparing the FRAS results to cytotoxicity or pathological effects presented by other researches, BODs induced by EMNs revealed an association to several physicochemical parameters and displayed a good consistency to other complex in vitro or in vivo systems. The evidence strongly indicates that the simple and robust FRAS approach can be applied as a screening method to exam the hazard effects of ENMs. Future work includes; to further investigate and understand the relationship of FRAS-measured BOD and physicochemical parameters of ENMs, to compare FRAS-measured BOD and cytotoxicity and adverse health effects of ENMs, and to provide the research results to assist ENM manufactures in producing greener products (ie. by altering physicochemical characteristics that reduce BOD).

P37

Bandwidth and Phase Effects of Ultrafast Surface Plasmon Pulses

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We report on the detailed analysis of femtosecond surface plasmon polariton (SPP) pulse generation under resonant excitation. Using prism coupling technique we excite femtosecond SPP pulses at a gold/air interface with ultrafast laser pulses. We show that the photon-SPP coupling is a resonant process with a finite spectral bandwidth that causes a spectral phase shift and a narrowing of the SPP pulse spectrum. Both effects result in a temporal pulse broadening and, therefore, set a lower limit on the duration of ultrafast SPP pulses with consequences for ultrafast SPP applications.

SPP building blocks are considered to be attractive components for photonic circuits to achieve high packing densities and strong non-linearities. For time resolved SPP sensors and high-speed SPP circuits, it is important to understand excitation and propagation of ultrafast SPPs. Here, we will show details of the ultrafast SPP pulse generation process under resonant excitation. In our experiment a 50nm thick gold film was illuminated through a glass prism with sub-20 fs laser pulses of a Ti:sapphire oscillator. Under resonant energy and momentum condition we excited ultrafast SPPs. The excitation process was then analyzed by characterizing the reflected laser and the scattered SPP pulses. We found that even under resonant photon-SPP condition the SPP coupling was incomplete, because of the finite spectral bandwidth of the coupling process that does not support the spectral width of the femtosecond excitation pulses. As a consequence, the spectrum of the scattered SPP pulses was determined to be narrower than the incident excitation pulse spectrum by 22%. Theoretical considerations illustrate that the spectral width of the SPP prism coupling is ~40 meV setting a lower limit for the SPP pulse duration of ~11 fs, independent of the pulse duration of the excitation pulse.

In addition, since ultrafast SPP pulse generation is a resonant process, we measured a spectral phase shift around the resonance frequency. We employed spectral interferometry to measure the phase of the reflected pulse that provides a good fingerprint of the SPP pulse. Around the SPP excitation photon energy we find a significant phase shift of ~□/2 within 50 meV. The spectral phase shift is characteristic of a resonant process and matches very well the calculated phase of the reflected electric field.

Both spectral narrowing and phase shift effects lead to temporal broadening of ultrafast SPP pulses and are direct consequences of the conventionally used prism coupling technique to excite SPPs. It is noteworthy that our discussion here is not restricted to the prism coupling technique, but is common to any SPP excitation process that uses resonant coupling between photons and surface plasmons.

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Fabrication of Co-extruded Multi-layer Films

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Multi layered products are used in a number of applications where the explicit properties of two or more different materials are required. This is currently done by using multiple extruders and multi-manifold dies.

A novel method to do this is to use layer multiplying elements (LMEs). Once the flow pattern is obtained the layers can be multiplied by the addition of LME's. The use of a multi manifold die which are very expensive can be avoided. Also, by using this approach, two extruders can be used to create a multilayer film that would have required several extruders using conventional techniques.

Current work is directed at achieving the maximum number of layers with no or minimum amount of break-up and layer mix-up. A multi-layered film with stable and uniform layers if commercialized will find applications in various fields.