MEMS and NEMS
Room: 211A - Session MN+AM-WeM

Emerging Materials & Fabrication Technologies toward Scalable & Additive Nanomanufacturing I
Moderator: Philip Feng, Case Western Reserve University, Roya Maboudian, University of California at Berkeley

8:00am **MN+AM-WeM1 The Why, the What and the How of Nanomanufacturing**, ***Khershed Cooper***, National Science Foundation (NSF) **INVITED**

In 2010, at the conclusion of the review of the NNI, PCAST recommended greater emphasis on commercialization by doubling investment of the Federal Government in nanomanufacturing R&D. Federal agencies responded in various ways. The NNI Signature Initiative: Sustainable Nanomanufacturing was announced, OSD's MURI topic call included nanomanufacturing as a high-priority theme, and NSF announced the Scalable Nanomanufacturing solicitation. The private sector also responded to the need for nanotechnology commercialization through interest groups such as the NanoBusiness Alliance and, as the Institutes for Manufacturing Innovation multiply, nanoscience and nanotechnology appear to play an increasing important role. This is the 'why' of nanomanufacturing. Nanomanufacturing is the fabrication of nano-scale building-blocks, their assembly into higher-order structures and the integration of these into larger scale systems such that both heterogeneity and complexity are achievable with manipulation and control at the nano-scale. R&D activities address the nanomanufacturing value chain and manufacturability challenges such as scale-up and cost. This is the 'what' of nanomanufacturing. This talk will discuss these aspects of nanomanufacturing and 'how' the nanomanufacturing programs (NM, SNM, NSEC, NERC, SBIR) at NSF are meeting these challenges through support of basic and applied research involving novel ideas. Proposed ideas encompass a wide range of materials, processes and applications and are usually based on strong fundamental foundations. Research outputs are nanomanufacturing fundamentals that will help overcome barriers to large-scale, high quality production of nano-enabled products for the benefit of society.

8:40am **MN+AM-WeM3 Large-Area Nanoimprinting and Nanoplasmonics for Energy Harvesting, LEDs & Biosensing**, ***Stephen Y. Chou***, Princeton University **INVITED**

This talk will present (1) the technology advances and applications of nanoimprinting, a revolutionary nanofabrication method that not only allows the fabrication of nanostructures that could not be fabricated before, but also offers a viable way to mass manufacturing of nanostructures and hence commercialization; and (2) new nanoplasmonic structures for high efficiency solar cells and LEDs and ultrasensitive biosensing that have unprecedented properties and performances.

In nanoimprint, the presentation will address the advances in (a) planar as well as roll-to-roll nanoimprinting, (b) methods of making large nanostructure nanoimprint molds without using direct-write (e.g. electron-beam lithography), (c) self-perfection technologies, and applications in electronics, optics, optoelectronics, magnetics, biotechnologies, displays, and energy harvesting.

In nanoplasmonics, the presentation will discuss the advances in design large-area, high performance nanoplasmonics used for solar cell, LEDs and biosensing, in particular, two new nanoplasmonic structures: disk-coupled dots-on-pillar antenna-array (D2PA) and plasmonic cavity with subwavelength hole-arrays (PlaCSH). Significant enhances in energy efficiency and detection sensitivity have been achieved using D2PA and PlaCSH.

9:20am **MN+AM-WeM5 Scalable Nanomanufacturing of Plasmonic and Metasurfaces**, ***Regina Ragan***, *F. Capolino*, University of California Irvine **INVITED**

Nanodisks and nanoparticles serve as meta-molecule building blocks to tune plasmonic and metamaterial properties when arranged in planar and three-dimensional geometries. For example, the ability to control nanomaterial interfaces via colloidal synthesis allows for tuning of the plasmon resonance as well as mitigating losses affecting extinction spectra. In addition, colloidal assembly is beneficial as a high-throughput, wafer scale deposition method. We have achieved robust surface enhanced Raman scattering (SERS) sensors approaching single molecule detection limits *reproducibly* over large areas using colloidal assembly. Transmission electron microscopy data shows that by varying driving forces for assembly, diffusion versus electrophoresis, nanoparticle clusters with gaps between nanoparticles of 4 nm down to 1 nm, respectively, are obtained. Corresponding orders of magnitude decreases in detection limit allow for identification of fermentation products present in the parts per billion range in cystic fibrosis patients.

Arrays of tightly coupled metal and metal- dielectric nanoparticles also support narrow band resonances, Fano resonances, based on "dark" electric and/or magnetic resonances. We will discuss how material interfaces can be used to mitigate losses that eliminate Fano resonant features. For example, the extinction and absorption efficiencies resulting from an array of linear trimers of Au nanoshells in homogeneous environment show that efficiency is affected by changing dye concentration in nanoshells. The use of dyes as gain media induces sharpened Fano resonance features (attributed to the meta-molecule nature of the linear trimers) and increased maximum absorption efficiency at 422 THz. Using similar methods, circular nanoclusters (CNC) of metal nanoparticles can support a magnetic Fano resonance at 472 THzvia dipole moments forming a current loop underoblique TE-polarized plane wave incidence. In particular, array-induced resonances are narrower than single-CNC-induced ones and also provide even larger field enhancements, in particular generating a magnetic field enhancement of about 10-folds and an electric field enhancement of about 40-folds for a representative metasurface.Natural magnetism fades away at infrared and optical frequencies and artificial magnetism is cumbersome to achieve in these regimes, as conventional split ring resonators are difficult to scale down to optical wavelengths. Nanoparticles assembled from colloids are a scalable approach to engineer materials' electromagnetic properties.

11:00am **MN+AM-WeM10 Roll to Roll Processes at the University of Michigan: Continuous Patterning, Flexible OPVs, and Growth of Carbon Nanomaterials**, ***Jay Guo***, University of Michigan, Ann Arbor **INVITED**

Roll to roll fabrication is regarded as a high-throughput and cost-effective method for future manufacturing of flexible electronics, large area photonic elements and functional surfaces for a variety of applications. This talk will discuss a few examples of roll to roll processes developed at the University of Michigan. First, roll-based patterning processes will be introduced. These include roll to roll nanoimprint lithography (R2RNIL) based on mechanical deformation of polymers and capable of tens of nm resolution, photo-roller-lithography (PRL) by using flexible photomasks to pattern sub-micron and larger features continuously on a moving web. These techniques can be used in many applications, such as metal wire grid based transparent conductors. Next, fabrication of organic optoelectronics OLED and OPV by roll to roll coating processes such as blade coating, blade-slit coating will be discussed. The coating process should be selected properly by considering the thickness requirement for each active layers in the devices. Finally I will report some progress made by the UM team in the Scalable NanoManufacturing program in the roll based continuous growth of carbon nanotubes and graphene.

11:40am **MN+AM-WeM12 Nanotube Templated Manufacturing of Hierarchically Structured High Throughput Fluid Filters**, ***Andrew Davis****, R.C. Davis, R. Vanfleet,* Brigham Young University, *N. Morrill*, Precision Membranes

High throughput microfilters for use in water purification have been developed to address filtration challenges by dramatically decreasing flow resistance and filter size while improving filter strength, longevity, and affordability. The microfilters were fabricated out of a high strength carbon-nanotube composite material using a process for precise hierarchical patterning on both the micro and nano scales.

12:00pm **MN+AM-WeM13 Improved Vacuum Deposition of Small Patterned Features Using Precision Shadow Masks and a Novel Low Pressure Sputtering Source**, ***Rob Belan***, Kurt J. Lesker Company, *V. Heydemann*, Advantech U.S. Inc, *S. Armstrong*, Kurt J. Lesker Company, *T. Fisher, B. Brocato*, Advantech U.S. Inc

A novel, low pressure sputter source has been used in conjunction with a precision shadow mask to deposit crisp features on glass substrates. The low pressure sputter source (LPSS) exhibits high-rate omnidirectional deposition and can form crisp lined features that are typically 5 µm to 50 µm in size when combined with precision mask technology. These feature sizes are a factor of 5x smaller compared to traditional magnetron sputtering at typical sputtering pressures (~1 Pa). The LPSS operates at pressures lower than 0.1 Pa which increases the mean free path of the sputtered atoms and reduces the spread of the deposited pattern through a shadow mask that is often associated with magnetron sputtering at normal pressures.

The LPSS sputters at rates (up to 3 Å/s) with precise rate control in the range of 1 Å/s to 3 Å/s for target/substrate distances from 76 mm to 101 mm. The first generation LPSS utilized a 137 mm x 5.4 mm aluminum cathode. The second generation LPSS employed a 826 mm x 32.5 mm high purity (10 ppm) aluminum cathode demonstrating the scalability of this novel deposition source.

Patterned thin films with thicknesses between 300 Å to 2,000 Å were deposited using the first and second generation low pressure sputter sources. The impact of ambient pressure, power and source/substrate distance on the resulting thin film was investigated. The deposition runs were conducted under static conditions, with stationary source and substrate, as well as with a scanning source.

Patterned features were deposited on display-grade borosilicate glass substrates by placing custom manufactured nickel shadow masks with apertures in the 20 µm to 50 µm size range between the low pressure sputter source and the substrates. The shadow masks are manufactured by an electroforming process that allows precise control of the mask thickness. Typical shadow mask materials are nickel and invar (FeNi36). As well as studying the sputtering process parameters of the LPSS the quality of the deposited patterned features were investigated using a variety of mask thicknesses and aperture dimensions.

The low pressure operation of the LPSS source enables thin film deposition of precision nanostructured patterns via shadow masks and sputtering, an area traditionally kept to evaporation methods. Results and conclusions of this work will be presented for this emerging fabrication technology.

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