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

Emerging Materials & Fabrication Technologies toward Scalable & Additive Nanomanufacturing II
Moderator: Susan Burkett, The University of Alabama, Philip Feng, Case Western Reserve University

2:20pm **MN+AM-WeA1 Scalable Laser-Assisted Three Dimensional Printing of Nanomaterials**, ***Costas Grigoropoulos***, University of California at Berkeley **INVITED**

Nanomaterials and nanotechnology offer unique opportunities for fabricating devices of novel architecture and enhanced performance and can overcome system integration issues challenging current nanomanufacturing methods that are suited to planar geometries and are confined to top-down architectures. The central motivation of our work is to develop a new manufacturing method that offers scalability and flexibility enabling nanoscale device fabrication and integration in truly three-dimensional architectures over large areas and with arbitrary densities.

The core research strategy takes advantage of ultrafast laser beam processing for generating the scaffold multi-scale structures with 100 nm feature resolution. Two-photon polymerization is used to fabricate structures of tunable properties that are sensitive to pressure, light, heat and electrical stimulation. This technique, together with ultrafast laser micro/nanomachining will be adapted to multiple beam configurations in order to increase the processing throughput. Once the template is constructed, the directed self-assembly of block copolymers will be used to produce three-dimensional materials with tailored functionality where pattern amplification will be used to push the length scale to finer dimensions.

3:00pm **MN+AM-WeA3 Material Requirements and Challenges for NEM Logic Relays**, ***Tsu-Jae Liu***, University of California at Berkeley **INVITED**

The proliferation of mobile electronic devices and the emergence of applications such as wireless sensor networks and the Internet of Things have brought energy efficiency to the fore of challenges for future information-processing devices. The energy efficiency of a digital logic integrated circuit is fundamentally limited by non-zero transistor off-state leakage current. Mechanical switches have zero leakage current and potentially can overcome this fundamental limit. Contact adhesive force sets a lower limit for the switching energy of a mechanical switch, however, and also directly impacts its performance.

Stable operation with high endurance is a key requirement of switches for digital logic applications, and generally is a challenge for mechanical devices. The reliability of a miniature relay is limited not by structural fatigue or dielectric charging, but by contact oxidation or stiction.

This invited talk will begin with a review of recent progress toward the development of a reliable nano-electro-mechanical (NEM) relay technology for digital logic applications. It will then discuss the influence of contacting electrode material properties on relay performance and reliability. Opportunities for ultra-low-power computing with relays will be described.

4:20pm **MN+AM-WeA7 Microplasma-based Direct-write Patterning Processes for Additive Microfabrication**, ***Christian Zorman***, Case Western Reserve University **INVITED**

Metals comprise the most versatile and widely used class of materials in micro- and nanosystems, serving as electrical contacts, interconnects, electrodes, and even mechanical components. The most commonly used method to fabricate metallic structures involves physical vapor deposition combined with photolithography. This subtractive approach is effective in producing device structures with high pattern fidelity; however, such processes are limited by modest throughput, use of aggressive chemicals and high material wastage. Reliance on vacuum-based deposition processes limits process scalability and can hinder adoption in cost-sensitive applications. The emergence of flexible electronics has stimulated the development of additive approaches such as ink-jet printing for depositing patterned metal structures. Printing is attractive for such applications because it is performed under ambient conditions and can be integrated into large-scale roll-to-roll systems. However, the inks can be expensive and the variety of materials that are available as inks is limited. In addition, the organic capping agents that are used to stabilize nanoparticle-based inks are difficult to remove, which can compromise conductivity and mechanical integrity. Removal of the organics requires post-deposition processes that can limit the usage of certain polymer substrates. Adhesion of the printed structures to the substrates can also be a significant issue, especially in flexible applications.

This paper describes two novel microplasma-based processes under development at Case Western Reserve University to fabricate patterned metallic structures with micro- to nanoscale dimensions on rigid and flexible substrates. Our principal process utilizes electrons extracted from an atmospheric pressure microplasma to electrochemically reduce metal ions within a polymer substrate, selectively forming continuous metallic structures within that polymer. Recently, we have developed a microsputtering process that uses ions generated by an atmospheric-pressure microplasma. This process capitalizes on a physical vapor that is generated within a small capillary by Ar ion bombardment of small diameter metal wires. Forced Ar flow aids in the ejection of the resulting physical vapor through the orifice, which is positioned in close proximity to the substrate. Both processes are performed under ambient conditions thereby offering the same advantages as ink-jet printing, including potential scale-up to roll-to-roll processing. This presentation will detail the two processes and summarize most recent results in creating and characterizing micropatterned metal structures on a variety of substrates.

5:00pm **MN+AM-WeA9 Ni-induced Graphitization for Enhanced Long-term Stability of Ohmic Contact to Polycrystalline 3C-SiC**, *S. Chen*, *L.E. Luna*, University of California at Berkeley, *Z. You*, Tsinghua University, *C. Carraro*, ***Roya Maboudian***, University of California at Berkeley

Micro- and nano-electromechanical systems (M/NEMS) technology enables a diverse range of physical and chemical sensing under conditions close to ambient. However, there is a growing interest in sensors that can operate under harsh environments, including high temperature, high pressure, extreme radiation and corrosive. Sensing within these environments necessitates a robust semiconductor platform, different from those employed in traditional Si-based M/NEMS. A robust material, such as silicon carbide (SiC) provides compelling advantages not achievable with Si-based devices. SiC is a wide bandgap semiconductor with excellent mechanical, chemical and electrical stability, and thus is well suited for designing devices capable of operation in many harsh environments. Yet, harsh-environment stable metallization remains one of the key challenges with SiC technology. Here, we present a novel metallization scheme, utilizing solid-state graphitization of SiC, to improve the long-term reliability of Pt/Ti contacts to polycrystalline n-type SiC at high temperature. The metallization scheme includes an alumina protection layer and exhibits low stable contact resistivity even after long-term (500 hr) testing in air at 450 ºc. This study provides a feasible fabrication method and discusses the role of induced graphitic layer on contact stability.

5:20pm **MN+AM-WeA10 Fabrication of High Aspect Ratio Millimeter-Tall Free Standing Post Arrays using Carbon-Nanotube-Templated Microfabrication with a Sacrificial Hedge**, ***Guohai Chen***, *R. Vanfleet*, *R.C. Davis*, Brigham Young University

Carbon-nanotube-templated microfabrication (CNT-M) has shown precise high aspect ratio features in interconnected geometries.[1] However, the feature of isolated posts remains challenging.[2] Here we developed a process which involves fabrication of CNT posts connected by supporting hedges using CNT-M followed by oxygen plasma etching to remove the sacrificial hedges. We have explored the fabrication of posts with diameters from 10-40 um and heights up to 1.3 mm using sacrificial hedges of 1-5 um in width. With the CNT template, isolated free standing posts from a variety of materials can be made. For example, silicon or silicon nitride posts can be fabricated by infiltrated with silicon or silicon nitride. The creation of hybrid carbon/metal (copper, nickel) posts can also be realized through pulse electroplating.

1. J. Song, et al. Carbon-Nanotube-Templated Microfabrication of Porous Silicon-Carbon Materials with Application to Chemical Separations. Adv. Funct. Mater., 2011, 21, 1132.

2. K. Moulton, et al. Effect of iron catalyst thickness on vertically aligned carbon nanotube forest straightness for CNT-MEMS. J. Micromech. Microeng., 2012, 22, 055004.

Authors Index

Bold page numbers indicate the presenter