Tuesday Morning, October 30, 2012

MEMS and NEMS
Room: 10 - Session MN-TuM

Optomechanics and Photonic MEMS and NEMS
Moderator: W.K. Hiebert, University of Alberta and The National Institute for Nanotechnology

8:40am **MN-TuM3 Focused Ion Beam Fabrication for Nanophotonics and Microsystems Integration**, ***I.W. Jung***, Argonne National Laboratory **INVITED**

Focused ion beam (FIB) fabrication has become an invaluable tool to pattern nanoscale features on a vast range of materials otherwise not available due to the limitations on selectivity of chemical based reactions for etching. In addition, direct milling to create features allows precision patterning on a variety of surface topology. In this talk, we present work on using the FIB to pattern and integrate nanophotonic elements, e.g. photonic crystals, and microelectromechanical systems for novel device applications. In addition, we explore how the FIB can also be used for applications in integration of microsystems with plasmonic structures to achieve precision control of light-matter interactions at the nanoscale.

9:20am **MN-TuM5 Nanomechanical Resonator Detection using Racetrack Resonator Structures for Use in Mass Sensing**, ***V.T.K. Sauer***, *Z. Diao, M.R. Freeman, W.K. Hiebert*, University of Alberta and The National Institute for Nanotechnology, Canada

Nano-optomechanical systems have been demonstrated as an excellent mechanism for detecting the motion of nanomechanical resonators. They have very high displacement sensitivities and also very large frequency detection bandwidths. These properties make nano-optomechanical systems a promising platform for on-chip inertial mass sensing. By mass loading a resonating mechanical device, the mass of the analyte can be determined by measuring the frequency change this addition of mass causes. The high displacement sensitivities and large operational bandwidth allow for smaller mechanical resonators to be measured which allows for smaller masses to be detectable. Both cantilevers and doubly clamped beams have been detected using the interaction of the evanescent fields from photonic structures such as waveguides, ring/racetrack resonators and torroid structures. Many of these devices incorporate the mechanical resonator directly into the photonic element, but for optimal use in a mass sensing system it is preferable that any added mass not interact directly with the photonic modes. This can cause losses or other uncontrollable effects that negatively impact the operation of the mass sensor. To avoid this, the mechanical element should interact with, but still be external to, the optical cavity structure. Here, cantilever beams 0.5 to 5 µm long and doubly clamped beams 3 to 10 µm long are fabricated 70 to 170 nm from a ring resonator optical cavity. As a beam oscillates in the plane of the wafer, toward and away from a ring resonator, it modulates the ring's effective index. This causes a phase shift in the ring which is detected by a probe laser. The beams are actuated using a power modulated pump laser which uses an optical gradient force to pull the beams toward the optical structure. To increase their mass sensitivity, the devices are implemented into a phase-locked loop and their frequency stabilities are measured.

9:40am **MN-TuM6 Fabrication and Characterization of Ultra-Fast Electrostatically-Actuated Surface Micro-Machined Aluminum Mirrors**, ***J.R. Fox***, *A.D. Mathias, J.P. Cortes, M.S. Allen, S.B. Horowitz*, Ducommun Miltec, *M.G. Temmen, M. Sanghadasa*, U.S. Army Aviation and Missile Research Development and Engineering Center

The design, optimization, fabrication, and characterization of an electrostatically-actuated, surface micro-machined aluminum, torsional-beam micro-mirror is presented. The design was optimized to produce a 5 degree tilt of the 20 x 20 micron mirrors with a settle time of less than 6 microseconds with a 190 V electric potential across a 3 micron gap. The design is repeated in 25 x 25 arrays for high-speed deflection of incident light as an optical shutter. Utilization of the COMSOL Multiphysics finite element analysis environment for parameterization of geometries is described and the resulting optimized micro-mirror design is detailed. Fabrication of micro-mirrors via argon ion-mill patterning of aluminum over sacrificial resists and their subsequent dry release with oxygen plasma will be described. The micro-mirrors were then subjected to scanning electron microscopic examination, and laser-Doppler vibrometry was used to examine micro-mirror actuation performance.

10:40am **MN-TuM9 A Comparison of Different Releasing Methods in Fabricating Nano-Optomechanical Devices**, ***Z. Diao***, National Institute for Nanotechnology, NRC Canada and University of Alberta, Canada, *V.T.K. Sauer, J.E. Losby, M.R. Kan, M.R. Freeman*, University of Alberta and The National Institute for Nanotechnology, Canada, *W.K. Hiebert*, National Institute for Nanotechnology, NRC Canada and University of Alberta, Canada

Nano-optomechanical systems (NOMS), in which guided light is utilized to actuate and transduce the motion of nanomechanical resonators, have received intense attention in recent years [1, 2]. This actuation and transduction scheme offers unprecedented displacement sensitivity and ultrahigh bandwidth, which is also able to be fully integrated with state-of-the-art opto-electronic and semiconductor technology. It can be envisioned that NOMS will see a large variety of applications in mass sensing, gradiometry, and high precision frequency counting.

Strong optical forces and large evanescent field gradient, both critical factors in defining the actuation efficiency and the motion transduction sensitivity in a nano-optomechanical system, only exist in a distance smaller than the wavelength of light from the nanophotonic waveguide. This requires the nanomechanical resonator in NOMS to be brought in close proximity to adjacent nanophotonic structures (normally in the range of 100 – 300 nm). A well known device failure mechanism in this case is stiction of released structures due to attractive forces with adjacent surfaces. A critical point drying process is so far conventionally utilized in NOMS fabrication to remedy this issue [1, 2].

In this work we report on our attempt in utilizing alternative device releasing protocols in fabricating NOMS structures. The test structure selected is a several tens of micrometers long doubly clamped beam embedded in a race-track nanophotonic resonator. The entire device was fabricated on a silicon-on-insulator substrate with deep-UV lithography. The race-track resonator possesses an optical quality factor of a few tens of thousands and a finesse of ~ 20. The large finesse of the optical resonator allows sensitive motion transduction in which thermomechanical noise of a ~ 10 µm long device was able to be detected. Device releasing methods tested include sublimation drying with dichlorobenzene and cyclohexane, and hard masked hydrofluoric acid vapour etching. Finally, we also discuss the influence of different device releasing methods on the photonic properties of the system and the undercut profile.

[1] M. Li et al., Nature Photon. **3**, 464 (2009).

[2] J. Roels et al., Nature Nanotech. **4**, 510 (2009).

11:00am **MN-TuM10 Optomechanical Experiments with Large Area Graphene Membranes**, ***V.P. Adiga***, *R.A. Barton, I.R. Storch, B.R. Ilic, C.B. Wallin, P.L. McEuen, J.M. Parpia, H.G. Craighead*, Cornell University

Large area, ultra-thin membranes are useful as mechanical resonators whose mechanical degree of freedom can be easily controlled using light due to low spring constants and resonator mass. In this regard, there are advantages associated with using two dimensional materials like graphene and ultrathin silicon nitride. However, achieving large area suspended devices with high mechanical quality (Q) factors in these high surface-to-volume-ratio resonators has been a challenge. Recently it has been observed that the Q of these membranes can be significantly improved by a combination of tensile stress, resonator geometry and optimized fabrication techniques. Here we fabricate CVD grown, electrostatically tunable graphene drums of diameter up to 100 mm and measure high quality factors (up to 4000) at room temperature. We then use lasers to control the amplitude of mechanical vibrations using the back action provided by the photothermal effect. We can effectively cool (increase the effective damping) or heat (decrease the effective damping leading to self oscillation) the graphene membrane in a Fabry-Perot cavity formed by the membrane suspended over prefabricated trench, with cavity detuning provided by a highly reflective movable mirror. The strong optomechanical coupling1 observed in these membranes is due to the low mass and relatively strong absorption in the atomic monolayer.

1) *Cavity Optomechanics with Graphene Resonators,* R. A. Barton et al, Submitted.

11:20am **MN-TuM11 Optomechanics of Graphene Resonators**, ***R.A. Barton****, I.R. Storch, V.P. Adiga, R. Sakakibara, B.R. Cipriany, B.R. Ilic, S. Wang, P. Ong, P.L. McEuen, J.M. Parpia, H.G. Craighead*, Cornell University

By virtue of their low mass and stiffness, atomically thin mechanical resonators are attractive candidates for use in optomechanics. Graphene, in particular, is an ideal material to investigate as it possesses excellent electrical and mechanical properties as well as a strong interaction with light over the entire visible range. Here, we demonstrate photothermal back-action in a graphene mechanical resonator comprising one end of a Fabry-Perot cavity. As a demonstration of the utility of this effect, we show that a continuous wave laser can be used to cool a graphene vibrational mode or to power a graphene-based tunable-frequency oscillator. In addition to enabling studies of fundamental physics, the remarkable sensitivity of graphene optomechanical resonators and their ability to operate over a broad range of wavelengths and mechanical frequencies makes them attractive for applications.

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