MEMS and NEMS
Room 102B - Session MN+NS-WeA

Optomechanics, Photonics, and Quantum Nanosystems

Moderators: Leonidas Ocola, Argonne National Laboratory, Robert Ilic, National Institute of Standards and Technology, Center for Nanoscale Science and Technology

2:20pm **MN+NS-WeA1 Transducing between Microwaves and Light using Mechanics*, Andrew Cleland,*** University of Chicago **INVITED**

In this talk, I will describe my group's progress in developing technology that would serve as a fundamental component of a quantum repeater, a hypothetical device that will be a central component for practical long-range quantum communication. The devices we have developed to date rely on the parametric conversion of signals between microwave and optical frequencies, via a strong optomechanical interaction in a suspended one dimensional photonic/phononic crystal. The device is coupled to a fiber optic line for transmission of classical (ultimately quantum) optical information, and its microwave frequency (few GHz) mechanical mode is strongly coupled to a piezoelectric transducer. This device would ultimately be coupled to a microwave frequency quantum bit, either based on superconducting or semiconducting quantum technology, which would serve to purify and/or entangle quantum information. I will include a brief description of our approach and a description of the current status of development. Worked is supported by grants from AFOSR and NSF.

3:00pm **MN+NS-WeA3 Single Laser Modulated Drive and Detection of a Nano-Optomechanical Cantilever*, Vincent Sauer***, *J.N. Bachman, Z. Diao, M.R. Freeman, W.K. Hiebert,* University of Alberta and The National Institute for Nanotechnology, Canada

Nano-optomechanical systems (NOMS) offer many advantages in transducing nanomechanical motion including very high displacement sensitivities and large frequency detection bandwidths due to their optical nature. It follows from this that NOMS are a promising avenue for on-chip nanomechanical mass sensing. To take full advantage of the operational frequency properties that NOMS devices possess it is important to drive the devices optically as well. Here, a single laser modulated drive and detection (SLMDD) system is modeled and demonstrated. The setup operates similarly to a traditional NOMS pump/probe system, but instead of using a separate probe laser with a constant output power, the probe laser is power modulated to coherently drive the nanomechanical resonator using an optical gradient force. Using the SLMDD system the second laser source and its optical filter can be removed from a standard NOMS measurement system reducing the cost and complexity. This results in signal mixing between the modulated optical pump power and the Lorentzian response of the nanomechanical cantilever. The response at 1f gives a fano-like shape, but we are still able to track this characteristic mechanical frequency within a phase-lock loop. This demonstrates that the device could still be used for inertial mass loading experiments which rely on mechanical frequency tracking. Interestingly, the SLMDD system also enables homodyne detection through the DC response. As such, this can circumvent some difficulties of measuring high frequency devices with lower frequency equipment.

3:20pm **MN+NS-WeA4 Optomechanical Limit Cycle Oscillations in Metallic Nanowires*, Roberto De Alba***, *T.S. Abhilash, R.H. Rand, J.M. Parpia,* Cornell University

Guitar strings are possibly the most common example of mechanical systems in which the frequency is temperature dependent. MEMS devices are similarly subject to thermal forces, and can be parametrically controlled by them under the correct conditions. Silicon domes and suspended graphene membranes are two systems that have been shown to self-oscillate when illuminated with intense laser light -- both resulting from optical absorption and associated temperature fluctuations. Here we study these optomechanical effects in metallized silicon-nitride nanowires with 50 nanometer square cross-sections and 40 micrometer length. We observe stable limit-cycle behavior with an amplitude of roughly one-eighth of the impinging laser wavelength, and characterize entrainment of this motion with inertial forcing. Lastly, we attempt to overcome viscous air damping in these nanowires using these optical interactions. In future MEMS designs, self-driven motion using on-chip optical sources could be a viable alternative to external drive electronics or active feedback circuits.

4:20pm **MN+NS-WeA7 Transducer Array with Optomechanical Read-out and Integrated Actuation for Simultaneous High Sensitivity force Detection*, Thomas Michels*** [*]*,* Ilmenau University of Technology, Germany*; B.R. Ilic, V. Aksyuk,* National Institute of Standards and Technology*; I.W. Rangelow,* Ilmenau University of Technology, Germany

Research and development of transducers based on cavity optomechanics is a topic of high interest particularly because these transducers enable measurement of mechanical motion down to the fundamental limit of precision imposed by quantum mechanics. We have developed an on-chip cavity optomechanical transducer array that combines high bandwidth and high sensitivity with compactness, robustness, small size, and potential for low cost batch fabrication inherent in MEMS. The parallelization of multiple probes within one transducer array allows the simultaneous measurement of serial forces or mass detection.

Our fully-integrated, fiber-pigtailed transducer array combine high sensitivity (≈ 0.5 fm $Hz^{-1/2}$ to ≈ 10 fm $Hz^{-1/2}$), high bandwidth optomechanical readout and built-in thermal actuation. We use a wafer-scale microfabrication process combining one e-beam patterning, six stepper, and three contact mask aligner lithography steps. These define the silicon nitride (SiN) cantilever, the single-crystal silicon-on-insulator (SOI) microdisk optical cavity with high optical Q (up to $2x10^6$), SOI optical waveguides, and the patterned gold layer for bimorph actuation. Back and front side anisotropic potassium hydroxide (KOH) silicon etch allows to overhang the cantilever over the edge of the silicon chip and to define v-grooves for single mode optical fiber attachment. Two sacrificial silicon dioxide layers are removed by an isotropic hydrofluoric acid (HF) etch to free the mechanically movable structures.

The SiN cantilever can be excited by an electrical signal supplied to an integrated thermal actuator. The cantilever is evanescently coupled to a high-Q optical whispering gallery mode of the optical microdisk cavity and the motion is detected by measuring the resonance frequency shift of the optical cavity mode. The actuator can be used to individually address the cantilever and dynamically move them as well as to tune the distance between the cantilever and the optical cavity, to change the sensitivity and range of measurement of the cantilever. One side of the cantilever overhangs the edge of the chip, where it can be easily coupled to a variety of off-chip samples and physical systems of interest. A 10 um long probe is currently designed to have a stiffness of 0.1 N/m to 5 N/m and a resonance frequency of 50 kHz to 2 MHz, while the design can be easily and broadly tailored for specific sensing applications.

4:40pm **MN+NS-WeA8 Magnetic Resonance Spectroscopy with Torsional Optomechanics*, Mark Freeman,*** University of Alberta and The National Institute for Nanotechnology, Canada **INVITED**

A broadband magnetic resonance spectrometer based on optomechanical detection will be described. Demonstrations of inductive detection of spin precession in the early 1940s launched magnetic resonance spectroscopy as a general-purpose tool. As an easily miniaturizable complement to this, a resonant AC torque on a mechanical torsion sensor is choreographed from the precessing transverse RF moment via frequency mixing and then recorded through optical interferometry.

Comprehensive electron spin resonance spectra of a single-crystal, mesoscopic yttrium iron garnet disk at room temperature will be presented to illustrate the approach. A key feature of the method is that it is broadband to DC, enabling measurements of the intricate magnetostatics of individual mesoscopic magnetic objects to be performed simultaneously with the spin resonance studies. Progress in enhancing the detection sensitivity with nanocavity optomechanics also will be reported.

Work performed in collaboration with J Losby, F Fani Sani, D Grandmont, Z Diao, M Belov, J Burgess, S Compton, W Hiebert, D Vick, T Firdous (University of Alberta and National Institute for Nanotechnology, Edmonton), M Wu, N Wu, P Barclay (University of Calgary and NINT), and K Mohammad, E Salimi, G Bridges, D Thomson (University of Manitoba, Winnipeg). We are grateful for support from NSERC, NINT, AITF, and CRC.

[*] **NSTD Student Award Finalist**

Author Index

Bold page numbers indicate presenter