MEMS and NEMS
Room: 102 A - Session MN+NS-MoA

Optomechanics, Photonics, and Quantum Nanosystems
Moderator: S.L. Burkett, The University of Alabama

2:00pm **MN+NS-MoA1 Silicon Integrated Optoelectronics**, *M. Hochberg*, ***W. Baehr-Jones***, University of Delaware **INVITED**

CMOS-compatible silicon is not an obvious material system for building high-performance optical devices. But, over the last ten years, it has become possible to build fairly complex integrated optical systems at telecommunications wavelengths on electronics-compatible silicon substrates. In fact the complexity of these systems has been approximately doubling every year, and this trend is projected to continue for at least the next several years. With a combination of CMOS electronics and photonics, we can gain control of both photons and electrons, while preserving the powerful economics of the VLSI revolution. The focus of this talk will be on the OPSIS project, which is a new initiative led out of UW aimed at creating an open infrastructure for building fully integrated optoelectronic devices in silicon, and on some of the new science and engineering that are enabled by these devices.

2:40pm **MN+NS-MoA3 Multiplexed Nanomechanical Devices with Single Wavelength Nanophotonic Actuation and Detection**, ***V.T.K. Sauer***, *Z. Diao, M.R. Freeman, W.K. Hiebert*, University of Alberta and The National Institute for Nanotechnology, Canada

Nano-optomechanical system (NOMS) devices offer great opportunity for use in on-chip inertial based mass sensing. They have demonstrated large displacement sensitivity, and their large operational bandwidth allows for very high frequency measurements. These properties are conducive to the transduction of very small nanomechanical resonator motion, and smaller nanomechanical resonators allow for smaller detectable masses. The ultimate goal is to create on-chip sensors that are as sensitive as time-of-flight mass spectrometers. Integrated NOMS systems see a nanomechanical structure modulate the optical properties of a nanophotonic device. This is detected with very high sensitivity by a single probe beam travelling along an integrated nanophotonic waveguide. Optical systems are advantageous in detecting multiplexed arrays of devices due to the reduced complexity of integration. Unlike electrical devices, multiple devices can be probed using a single input and output. This is done by designing the devices to respond to different wavelengths through isolated optical cavities. As a result, multiple signals can be sent along the same waveguide at different wavelength channels to reduce the overall complexity of the design. Here, a multiplexed system is investigated where cantilever and doubly clamped beam nanomechanical resonators are detected using racetrack resonator optical cavities. These devices can also be optically pumped using a modulated laser power in the waveguide which modulates the optical gradient force present on the nanomechanical beam. This is usually done at a wavelength different to the probe laser so the pump signal can be filtered prior to the photo detector. This dual laser pump/probe system can be simplified further using a single beam to act simultaneously as both the pump and probe. Here, the probe laser itself is modulated in power to pump the mechanical motion of the beam. This acts as a homodyne system where the modulated probe power is mixed with the signal created by the nanomechanical beam's motion. This would further simplify implementation of a multiplexed nanomechanical resonator system due reducing the number of input signals. This homodyne signal is implemented in a phase locked loop using a lock-in amplifier, and the frequency stability is tracked to estimate the mass sensitivity of a single beam driven and detected device.

3:00pm **MN+NS-MoA4 Photonic Readout of Higher Flexural Modes of Nanomechanical Doubly Clamped Beams**, ***Z. Diao***, *V.T.K. Sauer, J.E. Losby*, National Institute for Nanotechnology and University of Alberta, Canada, *M.R. Freeman*, University of Alberta and The National Institute for Nanotechnology, Canada, *W.K. Hiebert*, National Institute for Nanotechnology and University of Alberta, Canada

In the past few years nanophotonic transduction, in which a nanomechanical resonator is coupled to a high finesse optical cavity and its displacement is monitored through the cavity near-field has been demonstrated as a highly flexible, ultra-sensitive, wide bandwidth scheme for nanomechanical resonator displacement readout. A common design of the so-called nano-optomechanical devices (NOMS) involves either releasing a part of a nanophotonic waveguide in a race-track optical cavity, so the evanescent field of the guided mode is coupling to the remaining substrate [1], or laterally coupling a doubly clamped mechanical beam to an optical cavity [2]. In both cases, only the fundamental flexural mode is usually investigated [3].

The quest for large bandwidth mass sensors draws attention to higher flexural modes of nanomechanical resonators. Compared to the fundamental flexural mode, higher modes of a mechanical beam offer much higher operating bandwidth while incurring only a modest (or no) increase in its effective mass, depending on the boundary conditions. Higher modes of nanomechanical devices are also of interest for realizing cavity-optomechanics in the resolved-sideband limit [4], and nonlinear modal coupling among different mechanical modes has recently attracted renewed attention [5]. Hence, there is a demand to fully understand the behaviour of higher flexural modes in NOMS devices.

In this work, we fabricate NOMS devices by releasing parts of a nanophotonic waveguide in a race-track optical cavity. Sensitive photonic transduction allows thermomechanical noise of odd flexural modes (up to 50 MHz limited by our measurement electronics) to be observed. However, the transduction responsivity diminishes for even modes, due to the geometrical symmetry of the device design. We show that breaking this symmetry can increase the transduction responsivity for even flexural modes. The nanophotonically transduced displacement responsivity for different modes is also compared to that measured using a free-space interferometry setup. We further discuss the internal stress of the devices and its influence on the mode frequency, shape and transduction responsivity.

[1] W. H. P. Pernice *et al.,Opt. Express* **17,** 12424 (2009).

[2] O. Basarir *et al.,Opt. Express* **20,** 4272 (2012).

[3] M. Li *et al.,Appl. Phys. Lett.* **97,** 183110 (2010).

[4] G. Anetsberger *et al.,Nature Physics* **5,** 909 (2009).

[5] M. H. Matheny *et al.,Nano Lett.* **13,** 1622 (2013).

3:40pm **MN+NS-MoA6 Progress in Coupling a Superconducting Qubit to Light**, *A.N. Cleland*, ***J. Bochmann***, University of California, Santa Barbara **INVITED**

My group at UC Santa Barbara has been developing a chip-based, fully integrated microwave-to-optical frequency up-converter based on a piezoelectrically-actuated optomechanical crystal. The device is designed to use the 1550 nm telecommunications wavelength band, trapping photons of that wavelength in an optomechanics crystal, then modulating the frequency of these photons through interactions with GHz-frequency phonons, the latter generated using the piezoelectric response of the crystal. We hope to use this device to create optical frequency entangled photons, produced using entangled microwave-frequency phonon states, generated by a superconducting qubit. This will enable the transfer of quantum information from a millikelvin cryostat to a fiber optic transmission line, with the potential of coupling hybrid quantum systems. I will report on our progress in developing this novel device.

4:20pm **MN+NS-MoA8 Silicon Carbide (SiC) Optical Interferometry for Ultrasensitive Motion Transduction of High Frequency Mechanical Resonators**, ***Z. Wang***, *J. Lee, T. He, P. X.-L. Feng*, Case Western Reserve University

We report on the first experimental demonstration of an ultrasensitive laser optical interferometric technology based on thin-film silicon carbide (SiC) micromechanical and nanomechanical resonant systems, which offer motion transduction with displacement sensitivities down to the sub-10fm/rtHz level, at room temperature.

Position and motion detection with advanced optical techniques have been widely used for studying the static and dynamic motions of various systems, ranging from the classical scanning probe microscopes to the emerging resonant nano/microelectromechanical systems (NEMS/MEMS). In particular, in recent years significant efforts and advances [1,2] have been made in developing laser optical interferometric systems based on various NEMS/MEMS resonators, with constituting materials in Si, SiN, GaAs, AlN, and more recently two-dimensional (2D) crystals such as graphene and MoS_2. These advances have kept enabling very sensitive detection of motions in various NEMS/MEMS resonators, with ever improving displacement sensitivities, from ~nm/rtHz to ~pm/rtHz levels. In many of these systems, there are limitations intrinsic to the device structures and constituting materials. For instance, light absorption and parasitic heating effects can compromise these interferometric systems from achieving better sensitivities.

In this work, we explore new optical interferometric techniques by exploiting some unique properties of SiC thin films, particularly the high transparency and ultralow photon absorption (60 times lower than Si) in the wide visible range, as well as the excellent thermal conductivity. The SiC thin films are prepared by low-pressure chemical vapor deposition (LPCVD) on various substrates, which enables us to develop a novel SiC-on-SiO_2 material platform. The suspended MEMS/NEMS devices fabricated in this thin-film platform all share important features such as smooth surfaces and a uniform interferometric gap. These structural features, combined with SiC's outstanding physical properties, have permitted us to demonstrate unprecedented displacement sensitivities at ~5-10fm/rtHz levels, better than other MEMS/NEMS-based optical interferometric techniques reported to date. We demonstrate such ultrasensitive techniques for motion detections in high frequency SiC microdisk resonators and nanocantilever resonators. In both systems, we have measured the undriven, intrinsic thermomechanical resonances up to high-order modes.

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[1] W. K. Hiebert, et al., *J. Micromech. Microeng.* **20**, 115038 (2010).

[2] J. Lee, et al., *Proc. IEEE Inter. Freq. Contr. Symp. (IFCS2012)*, DOI: 10.1109/FCS.2012.6243742.

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