Multifunctional and Hybrid Microsystems
Room 321 - Session MC-MoA

Multifunctional and Hybrid Microsystems: Optomechanics and Quantum Transduction

Moderators: Dr. Matthew Jordan, Sandia National Laboratory, **Prof. Dr. Yanan Wang**, University of Nebraska-Lincoln

1:30pm **MC-MoA-1 All-Dielectric Cavity Electro-Optic Systems for Quantum Sensing and Transduction***, Mihir Khanna,* ***Thomas Purdy****,* University of Pittsburgh **INVITED**

Currently, the best methods to manipulate microwave signals at the quantum level require complex, millikelvin temperature, superconducting electronics.Many platforms are being explored to couple microwave and optical systems, leveraging the quantum coherence inherent in room-temperature optical fields to enable quantum-limited readout and control of microwave devices.We are investigating how it is be possible to turn an electro-optic modulator, a workhorse of modern classical telecommunications systems for encoding microwave signals on laser light, into a transducer capable of efficiently moving quantum information between the optical and microwave domains.We have recently demonstrated bulk resonant electro-optic devices with photon-number transduction efficiency approaching unity, surpassing classical telecom modulators by more than six orders of magnitude. We are currently exploring how laser light in this room-temperature system can be used to manipulate and measure microwave devices in analogy to laser cooling in atomic and optomechanical systems, and via electro-optic parametric amplification.

2:00pm **MC-MoA-3 A Quantum Microwave-Optical Interface via Silicon Nanomechanics***,* ***Han Zhao****,* University of Central Florida **INVITED**

Optically interconnected networks of heterogeneous quantum hardware are milestones of future quantum information infrastructure. Integrating superconducting qubits as the prominent quantum processors in such a network requires microwave-optical interfaces with high conversion rate and low input-referred added noise. Here, we meet these requirements in an integrated electro-optomechanical device that utilizes electrostatic coupling between high-impedance microwave resonators and crystalline silicon nanomechanical oscillators [1]. Leveraging the small acoustic loss and low optical absorption heating of silicon, we demonstrate continuous quantum-enabled microwave-to-optical conversion with an external efficiency of 2.20 ± 0.06%, bandwidth of 88.9 ± 2.1 kHz, and a sub-photon input-referred added noise at 0.94 ± 0.03 [2]. Our device provides a realistic path towards optically heralded high-rate entanglement of superconducting quantum processors over long distances.

[1] A. Bozkurt, H. Zhao, C. Joshi, H. LeDuc, P. Day, M. Mirhosseini. A quantum electromechanical interface for long-lived phonons. Nat. Phys. 19, 1326-1332 (2023)[2] H. Zhao, W. D. Chen, A. Kejriwal, M. Mirhosseini. Quantum-enabled microwave-to-optical transduction via silicon nanomechanics. Nat. Nanotech. 20, 602-608 (2025).

2:30pm **MC-MoA-5 High-Performance 4H-SiC Optomechanical Resonators in the Sideband-Resolved Regime***,* ***Xirui Gou****, Qing Li,* Carnegie Mellon University

4H-silicon carbide (4H-SiC) has emerged as an exceptional material for integrated optomechanics, combining outstanding nonlinear optical properties with low acoustic dissipation. This work presents recent advances in the design, fabrication, and characterization of ultracompact, undercut 4H-SiC microdisk resonators operating in the sideband-resolved regime. These microdisks, with radii ranging from 2.1 to 2.7 microns, are fabricated through a combination of electron-beam lithography and fluorine-based dry etching to define the photonic structures. This is followed by a precisely timed isotropic buffered oxide wet etch to selectively remove the underlying silicon dioxide layer and achieve the targeted undercut ratios.

Optically, these microdisk resonators support both TE and TM modes with measured loaded optical quality factors consistently exceeding one million in the telecom band. Mechanically, the dominant mode is the fundamental radial breathing mode (RBM) at frequencies ranging from 1.5 to 2 GHz. At room temperature, the acoustic frequency is approximately eight times the optical cavity linewidth (~0.2 GHz), placing our system deep into the sideband-resolved regime. This is a critical prerequisite for resolving mechanical sidebands, enabling coherent optomechanical interactions, and advancing toward ground-state cooling.

A key focus of our investigation has been understanding and mitigating mechanical anchor loss. Using finite-element method (FEM) simulations alongside experimental validation, we analyzed the impact of the pedestal undercut ratio on the mechanical quality factor. Our simulations revealed a distinct local resonance where the anchor-loss-limited Q-factor exhibits a sharp maximum at specific pedestal widths. By tracking the mechanical Q-factor across consecutive undercutting rounds, we experimentally confirmed an optimal undercut ratio regime between 55% and 65%. This regime offers a critical balance between minimizing anchor loss and maintaining high fabrication yield. Engineering this balance allowed us to demonstrate mechanical Q-factors exceeding 15,000 at 1.58 GHz in ambient conditions. Leveraging these high-Q resonators, we observed strong nonlinear dynamics, including phonon lasing and the generation of a coherent harmonic frequency comb extending up to 70 GHz with only 1 mW of dropped optical power. These results highlight the vast potential of 4H-SiC microdisks as an integrated platform for low-noise microwave photonics and quantum interfaces.

2:45pm **MC-MoA-6 Parametrically Coupled Nanomechanical and Macroscopic Mechanical Resonators***,* ***Chris Ligato****, Thomas Purdy, Youssef Tawfik,* University of Pittsburgh

We develop a novel hybrid mechanical system that leverages an acoustic intermediary for high-precision optomechanical sensing. The motion of a macroscopic silicon tuning fork resonator is measured and manipulated by coupling to a nanomechanical high-stress silicon nitride (SiN) string. We fabricate these devices from a high-stress, SiN-coated silicon wafer by using double-sided photolithography and reactive-ion etching to pattern the SiN, followed by through-wafer KOH wet etching to define the tuning fork and release the string. This process yields centimeter-scale, milligram-mass tuning forks with kHz-frequency modes, bridged by an MHz-frequency, nanogram-mass string stretched across the tines. Vibrations of the tuning fork stretch the string, modulating its mode frequencies. This interaction is similar to cavity optomechanics, where mechanical motion modulates the modes of an electromagnetic resonator. Following this analogy, we demonstrate cooling of the tuning fork, sensitive detection of its motion, and phonon swapping between the tuning fork and string. We drive the system with a piezoelectric shaker. When the drive is red-detuned from the string frequency by the tuning-fork frequency, phonons transfer from the tuning fork into the string and dissipate into the environment, cooling the tuning fork. By reading out the string using an optical interferometer, we can detect the motion of the tuning fork imprinted on the string with high sensitivity. Driving the string harder allows us to enter the strong-coupling regime, where the string and tuning-fork modes hybridize. We aim to explore this system's potential for high-precision accelerometry and measurements at quantum limits.

3:00pm **MC-MoA-7 Magnetic Nanostructures for Coupling and Control of Defect Spin Qubits***,* ***Jesse Berezovsky****,* Case Western Reserve University **INVITED**

Defect spin qubits, such as the nitrogen-vacancy (NV) defect in diamond, perform splendidly as single qubits. With a coherence time that can exceed 1 s at room temperature, defect spins provide an excellent basis for single qubit devices, such as nanoscale magnetometers. But to go beyond single qubits, we require an efficient scalable platform for controlling defect spin qubit registers, and controllably coupling qubits to engineer entanglement. In this talk, I will describe recent advances in our understanding of how magnetic materials and structures couple to defect spin qubits, and how this opens an avenue towards engineering the magnetic environment of the spins for control and coupling. Magnetic nanostructures such as nanoisland arrays and nanoscale magnetization textures such as magnetic vortices provide strong, local magnetic field gradients that can be controlled dynamically for addressable control of qubits [1]. Coupling between qubits may be enabled by a magnon-mediated process. On the other hand, spin-magnon interactions can lead to enhanced spin relaxation or decoherence (e.g. [2]). I will review recent work exploring the interactions of defect spins with magnons in adjacent magnetic structures and discuss the implications for proposed technologies incorporating coherent spins with proximal magnetic elements.We acknowledge support from NSF awards No. 2326528 and 2403743[1] Wolf, M. S., Badea, R., and Berezovsky, J. “Fast, Nanoscale Addressability of Nitrogen-Vacancy Spins via Coupling to a Dynamic Ferromagnetic Vortex” Nature Communications 7, (2016): 5.[2] Trimble, J., Gould, B., Heremans, F. J., Zhang, S. S.-L., Awschalom, D. D., amd Berezovsky, J. “Relaxation of a single defect spin by the low-frequency gyrotropic mode of a magnetic vortex" J. Appl. Phys. 130, (2021).

3:30pm **MC-MoA-9 Robust Topological Phonon Transport in Suspended Hexagonal Boron Nitride Waveguides***, **Sanchaya Pandit**,* University of Nebraska - Lincoln*; Jaesung Lee,* University of Central Florida*; Yanan (Laura) Wang,* University of Nebraska-Lincoln

Topological concepts, originally developed in electronic condensed-matter systems, have recently been extended to bosonic platforms such as photons and phonons, enabling new approaches for robust wave transport in engineered media. These concepts have opened pathways toward designing waveguides that suppress backscattering and maintain stable propagation even in the presence of structural disorder, which is essential for scalable integrated phononic circuits. In this work, we demonstrate a quasi-one-dimensional Su-Schrieffer-Heeger (SSH) topological phononic waveguide based on suspended hexagonal boron nitride (h-BN), a mechanically robust two-dimensional material suitable for high-frequency phonon propagation. By engineering the unit-cell geometry, we construct two distinct phononic lattices representing trivial and nontrivial topological phases with matched band structures. At the interface between these two phases, a confined phononic state emerges within the bandgap, analogous to topologically protected edge states in electronic systems. Furthermore, geometric optimization of the unit cells—including variations in hole shape (circular and oval) and feature size (diameter)—is used to tune the phononic bandgap and control the spectral position of the interfacial mode. The robustness of this mode is systematically evaluated under variations in strain and membrane thickness, and it remains stable, confirming its topological origin rather than defect-induced localization. Overall, the proposed h-BN-based platform provides a promising route toward robust and low-loss phononic transport and may enable future hybrid optomechanical systems through integration with defect-based quantum emitters.

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