MEMS and NEMS Group
Room 202B - Session MN+2D+AN+MP+NS-ThM

Optomechanics and 2D NEMS

Moderator: Max Zenghui Wang, University of Electronic Science and Technology of China

8:00am **MN+2D+AN+MP+NS-ThM-1 Towards Microwave to Telecom Wavelength Quantum Information Transfer using Cavity Optomechanics***, **John Davis**,* University of Alberta, Canada **INVITED**

The past few years have seen the rapid maturation of quantum information processors, particularly in the category of superconducting microwave circuits. With claims from leading companies that they will commercialize quantum processors in the next five years, we must wonder what quantum technologies should be developed in tandem to fully utilize these processors. For example, we are all acutely aware that while our personal computers are powerful, they are considerably more useful and interesting when networked together. So how can we likewise network quantum processors? Especially since the microwave signals of superconducting processors cannot be transmitted at room temperature without thermal decoherence. What if instead, one could link superconducting processors together through existing fiber-optic networks, which are already capable of long distance quantum information transfer? Hence the development of a transducer of quantum information from the microwave to telecom domain has become highly desirable. I will describe the current state of microwave to optical transducers, and how our lab is working towards this goal. Specifically, I will discuss the progress and challenges associated with the development of fiber-coupled telecom-wavelength cavity optomechanical resonators, and 3D superconducting microwave cavities, operating at millikelvin temperatures. I will also discuss ongoing collaborations that could enable implementation of quantum information transducers in a large-scale fiber network in Alberta.

8:40am **MN+2D+AN+MP+NS-ThM-3 1D/2D NEMS Quantum Information Processing***, **Guangwei Deng**,* Institute of Fundamental and Frontier Sciences, University of Electronic Science and Technology of China 610054, Chengdu, Sichuan, China.0 **INVITED**

In this talk, I will introduce our recent works on 1D and 2D NEMS, including carbon nanotube and graphene resonators. First, I will show our efforts on scaling 2D quantum dot chips with a microwave resonator [1, 2], where the resonator served as the quantum bus. Then we tried to explore nano-electromechanical resonators as phonon buses. I will introduce some works about strongly coupled nano-mechanical resonators based on carbon materials, such as carbon nanotube and graphene. These resonators have very high resonant frequencies and are highly tunable. We have experimentally realized the strong coupling between charge transport and mechancial motions [3, 4, 5], and also observed strong coupling between different modes of one mechanical resonator. Moreover, we realized the coherent phonon Rabi operation using the strong coupling [6] and we further implement a tunable distant strong coupling between two mechaical resonators [7]. These results have shown that the strongly coupled nano-mechanical resonators can provide a platform for the coherent electron-phonon interactions, the long distance phonon (electron) interactions and entanglement state generation, and we can exploit them as future quantum buses for solid state qubits, such as quantum dot based qubits [8].

References:

[1] Deng, G. W. et al., Charge number dependence of the dephasing rates of a graphene double quantum dot in a circuit QED architecture. Phys. Rev. Lett. **115**, 126804 (2015).

[2] Deng, G. W. et al., Coupling two distant double quantum dots with a microwave resonator. Nano Lett. **15**, 6620 (2015).

[3] Deng, G. W. et al., Strongly coupled nanotube electromechanical resonators. Nano Lett. **16**, 5456 (2016).

[4] Li, S. X. et al., Parametric strong mode-coupling in carbon nanotube mechanical resonators. Nanoscale **8**, 14809-14813 (2016).

[5] Luo, G. et al., Coupling graphene nanomechanical motion to a single-electron transistor. Nanoscale **9**, 5608-5614 (2017).

[6] Zhu, D. et al., Coherent phonon Rabi oscillations with a high-frequency carbon nanotube phonon cavity. Nano Lett. **17**, 915-921 (2017).

[7] Luo, G. et al., Strong indirect coupling between graphene-based mechanical resonators via a phonon cavity. Nature Commun. **9**, 383 (2018).

[8] Zhang, Z. Z., et al., Electrotunable artificial molecules based on van der Waals heterostructures. Sci. Adv. **3**, e1701699 (2017).

9:20am **MN+2D+AN+MP+NS-ThM-5 Characterization and Modeling of Radio Frequency Graphene Resonant Channel Transistor***, **Yuehang Xu**,* University of Electronic Science and Technology of China, China*; T Mei,* University of Electronic Science and Technology of China **INVITED**

Graphene's unique properties, including low mass and high stiffness, ultrahigh strength, and high electronic mobility, enable graphene nanoelectromechanical systems (NEMS) very suitable for low power high frequency circuits. Local gate graphene resonant channel transistors (G-RCTs) can reduce parasitic electromagnetic (EM) coupling and thus has good potential in high frequency integrated circuits. To develop the G-RCTs high frequency circuits, a compact model that can predict a G-RCT's performance and implement into standard circuit simulators is essential.

This paper presents a high-frequency nonlinear equivalent circuit model of G-RCTs including a nonlinear electromechanical model of doubled clamped graphene mechanical resonators. To describe the temperature-dependent modal dispersion, both bias- and temperature-dependent effects are considered. The temperature-dependent built-in strain, the bias-based electrostatic force and the spring restoring force including the nonlinear term upon deformation are used to describe the mechanical motion of the suspended beam. Good agreement between simulated and measured results can be achieved as shown in Fig.1. Moreover, the nonlinear effects including harmonic distortion, third-order intermodulation distortion (IMD), and the hysteresis and nonlinear behavior of G-RCTs are also studied. Fig.2 and Fig.3 are results of mechanical nonlinear characteristics and duffing nonlinear behavior of G-RCTs, respectively. The results in show that the mechanical nonlinearity has strong effects on nonlinear distortion for G-RCTs. The proposed nonlinear equivalent circuit model could be useful for Graphene NEMS in the applications of high frequency integrated circuits.

11:20am **MN+2D+AN+MP+NS-ThM-11 Reconfigurable Resonant Responses in Atomic Layer 2D Nanoelectromechanical Systems (NEMS)***, **Zenghui Wang**,* University of Electronic Science and Technology of China, China*; R Yang, P Feng,* Case Western Reserve University

Atomic layer semiconducting crystals have emerged as a new class of two-dimensional (2D) materials, exhibiting great promises for both fundamental research and technological applications. Their outstanding electromechanical properties make these materials ideal for constructing novel 2D NEMS, providing opportunities for leveraging their unique device properties across multiple information-transduction domains, at scales down to individual atomic layers. One particularly interesting category of 2D NEMS is 2D nanoelectromechanical resonators, which hold potentials for making the next generation RF signal transduction and processing components, with miniaturized size, ultra-low power consumption, and compatibility with transparent and flexible circuits.

Towards future applications in the 5G era, multi-band RF signal handling capability is desired, as the number of bands each mobile device need to have access to significantly increases, and it would be impractical to simply increase the number of RF components that can only function under one RF frequency, as the space required for mounting such components scales with the number of bands. Therefore, ultralow-power tunable and reconfigurable RF devices that can adapt to different frequencies would be one solution to this challenge.

Here we present experimental demonstration of nanomechanical resonators based on layered MoS_2 atomic crystals that have reconfigurable resonant responses. By carefully studying the temperature-dependent frequency response in such MoS_2 resonators[1], we discover clear, repeatable hysteretic behavior as the device temperature is changed[2]. Leveraging this phenomenon, we achieve switchable resonance frequency f_{res} in such devices by using heating and cooling pulses. Specifically, for an example MoS_2 resonator, during heating pulses, the f_{res} decreases to ~20MHz. Once the device recovers to room temperature, f_{res} stabilizes at ~26MHz. During cooling pulses, f_{res} increases to ~29MHz, and upon reverting to room temperature f_{res} stays at ~24.5MHz, which is clearly different than the other room temperature state. Our findings suggest that such atomic-layer MoS_2 NEMS resonators could be used towards developing reconfigurable RF components whose frequency response can be switched between different states.

[1] R. Yang, et al., *IEEE UFFC, pp 198-201,* 2015. [2] Z. Wang, et al., *IEEE UFFC*, *pp* 783-786, 2015.

11:40am **MN+2D+AN+MP+NS-ThM-12 Cavity Optomechanics: Dynamics and Applications***, **Eyal Buks**,* Israel Institute of Technology, Israel **INVITED**

The field of cavity optomechanics deals with a family of systems, each composed of two coupled elements. The first one is a mechanical resonator, commonly having a low damping rate, and the second one is an electromagnetic cavity, which typically is externally driven. Both radiation pressure and bolometric force can give rise to the coupling between the mechanical resonator and the cavity. In recent years a variety of cavity optomechanical systems have been constructed and studied, and phenomena such as mode cooling, self-excited oscillation, and optically induced transparency have been investigated. The first part of the talk will be devoted to some dynamical effects including synchronization and intermittency. In the second part some applications of optomechanical cavities for sensitive sensing will be discussed.

Author Index

Bold page numbers indicate presenter