## MEMS and NEMS
## Room 205 ABCD W - Session MN2-FrM
## 2D and NEMS

**Moderators: Marcel Pruessner**, Navel Research Laboratory, **Yanan Wang**, University of Nebraska-Lincoln

10:30am **MN2-FrM-10 Optomechanical Resonant Pixels with Metasurface and Phonon Engineering for Uncooled Infrared (IR) Detection*, Philip Feng,*** University of Florida **INVITED**

In this invited talk, we will present experimental demonstration and theoretical analysis of ultrathin trampoline-shaped nano-optomechanical resonators with strong potential for uncooled ultrasensitive infrared (IR) detection. We analyze and design trampoline resonators with high opto-thermal-mechanical transduction responsivities, strong thermal isolation, and multiple high-Q nanomechanical resonances that are suitable for low-noise optical transduction. We explore optimized designs by analyzing and understanding the multiple engineering tradeoffs involving both properties of the constitutive materials and parameters of geometric design and fabrication processes.We demonstrate resonant pixels enabled by various ultrathin trampoline designs, made of both silicon nitride (SiN) and atomically thin 2D materials. 05

11:00am **MN2-FrM-12 Controlled Thinning of Semiconductor Membranes Using Low-Fluence Laser Pulses at MHz Frequencies*, Shahadat Hossain,*** *Renato Camata,* University of Alabama at Birmingham

Free-standing ultrathin membranes of two-dimensional (2D) materials exhibit distinct mechanical, electronic, and optical properties compared to their bulk counterparts, making them promising for novel nanoscale devices. Controlled thinning of these membranes is an effective approach for customizing them to nanoelectromechanical systems (NEMS). In this study, we show that low-fluence laser pulses at MHz frequencies allow precise thinning of molybdenum disulfide ($MoS_2$) membranes.

$MoS_2$ flakes exfoliated from bulk crystals are freely suspended over 5-µm diameter circular wells of 285-nm depth, etched on silicon wafers. The thinning process is monitored using Fabry-Perot interferometry (633-nm laser), which allows measurement of the resonance frequency and Q-factor of the membranes. The fluence of the MHz frequency-modulated thinning laser (405 nm) ranged from 10 µJ/cm$^2$ to 30 µJ/cm$^2$, which is significantly lower than that of single-pulse laser irradiation techniques typically used in 2D material thinning.

We employ existing models from thin plate elasticity theory and tension-dominated membrane theory to predict the resonance frequencies of plate-like and membrane-like resonators. This provides insight into the frequency scaling of 2D membranes as a function of the number of atomic layers. We validate the models by experimental resonance frequency measurements. This combined experimental-theoretical approach enables accurate layer differentiation and Q-factor extraction, permitting basic studies of the nanomechanical properties of our resonators. Our experimental system integrates charge-coupled device imaging with resonance frequency analysis, allowing layer quantification. In a typical experiment, the resonance frequency of a plate-like resonator initially measures 47 MHz but suddenly drops to 25 MHz. The resonance frequency then increases monotonically with time until it reaches 51 MHz as the Q-factor varies from 5.5 to 71. The abrupt frequency drop corresponds to a sudden change in the number of layers from 130 to six. The six-layer membrane is then gradually thinned until eventually reaching monolayer thickness after multiple hours of irradiation. These findings reveal a variation in mechanical stiffness consistent with a shift between plate and membrane regimes. In the plate regime, the abrupt resonance change is likely driven by laser-induced superheating, whereas in the membrane regime, material removal via sublimation results in a gradual frequency evolution. This MHz variant of laser thinning allows precise control over $MoS_2$ layer thickness down to the monolayer limit and may contribute to advancing NEMS fabrication in next-generation devices.

11:15am **MN2-FrM-13 Electrical Tunability of AlN Nanoelectromechanical Resonators*, Sariha Azad,*** *Tahmid Kaisar, Timothy Caplice,* University of Florida*; Philip X.-L. Feng,* University of Florida, Gainesville

Electrical tunability in piezoelectric resonators is essential for applications requiring reconfigurable frequency control, including radio-frequency (RF) communications, sensing, and analog computing. Among available piezoelectric materials, aluminum nitride (AlN) stands out due to its CMOS compatibility, low dielectric loss, and high acoustic velocity, making it a strong candidate for integration into tunable MEMS platforms. Prior work has demonstrated voltage-induced frequency modulation in AlN resonators through piezoelectric field coupling, and strain-mediated deformation. Contour-mode AlN resonators with DC-bias-induced stress have shown frequency tuning ranges of 10–50 kHz under 20–80 V, with performance constrained by anchor loss and $Q$ degradation[1] Laterally vibrating AlN resonators have demonstrated similar shifts, with tuning rates of 100–300 ppm achieved using field-induced strain, though these effects become increasingly nonlinear at higher voltages[2]. In AlN, the modest electromechanical coupling limits tuning efficiency, with practical frequency shifts typically below 100 ppm under DC biases approaching the dielectric breakdown threshold, ranging from 40 to 120 V for 100–150 nm thick films depending on quality and deposition conditions. In this work, we show a comparative study of out-of-plane flexural mode AlN resonators. Two device architectures have been fabricated, the first type is a buckled membrane, comprising a compressive-stress 120 nm-thick AlN layer on top of a tensile low- or high-stress SiN base (50–100 nm). The second type is a non-buckled membrane, formed without SiN to create a flat, mechanically neutral structure. Both types incorporate a symmetric Pt/AlN/Pt stack with 25–75 nm-thick electrodes. The resonators have been characterized with applied DC polarization voltage swept between 0 and 5 V to analyze the voltage responsivity of resonance frequency. The experimental results show that buckled AlN membrane NEMS resonators exhibit negative voltage responsivities ranging from −3.58 to −6.33 kHz/V over resonance frequencies of 5–9.4 MHz. On the other hand, the non-buckled membranes demonstrate a positive voltage responsivity of 2.83 kHz/V over the resonant frequency at 1.78 MHz. Across both device types, frequency shifts of ~20 kHz have been achieved under low tuning voltages (up to +/-5V), without reaching nonlinearity.

[1]G. Piazza et.al. “Piezoelectric Aluminum Nitride Vibrating Contour-Mode MEMS Resonators,” *J. Microelectromechanical Syst.*, vol. 15, no. 6, pp. 1406–1418, Dec. 2006

[2]R. Tabrizian and F. Ayazi, “Laterally-excited silicon bulk acoustic resonators with sidewall AlN,” pp. 1520–1523, Jun. 2011

11:30am **MN2-FrM-14 Probing Velocity Limits of Resonant SiC Electromechanical Cantilevers*, Aswathi Madhu*,** *Philip Feng,* University of Florida, Gainesville

In inertial sensing applications harnessing resonant micro/nanoelectromechanical systems (MEMS/NEMS), maximizing velocity while ensuring structural integrity poses important challenges in design, fabrication, and characterization of the resonant transducers. This study aims to explore the limits of velocity of such devices built on a SiC thin film platform to exploit the excellent elastic properties of SiC including its high fracture limit. We report on analytical modelling and computer simulations, combined with experimental investigation of the velocity limits of singly-clamped SiC NEMS cantilevers lithographically patterned on a 500 nm-thick 3C-SiC film on top of 500 nm $SiO_2$ insulating layer on Si substrate. The specific goal is to determine the highest achievable velocity by enhancing displacement amplitude without exceeding the material’s fracture limit.

In this study, first theoretical analysis is done to explore the trade-off between maximum displacement amplitude and resonant frequency, and the results are validated using finite element simulations in COMSOL Multiphysics™. The fundamental resonant frequencies of SiC cantilevers, with dimensions 8 µm × 200 nm × 500 nm, are 3.25 MHz for in-plane and 6.32 MHz for out-of-plane motion. The preliminary results from initial measurements show a linear dependency between peak amplitude and applied actuation gate voltage, indicating the potential for scalable performance. These results provide insight into the dynamic range limitations MEMS structures operating near their mechanical limits.

To further study the material-dependent performance, the results are also compared with experimental data from 4H-SiC cantilevers fabricated using bulk micromachining and focused ion beam (FIB) milling. The comparison shows how the yield stress and fracture limit of 3C-SiC and 4H-SiC affect the estimation of the maximum achievable velocity. This work offers valuable guidance for designing future high-performance SiC inertial devices that balance velocity and structural robustness.

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