Empowering Semiconductors: The Dual Path of Nanomechanics Innovation and Integration

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Abstract: Semiconductor nanomechanics has been pivotal in advancing transistor technology by improving carrier mobility through lattice strain. The intricate correlation between electronic and mechanical properties in semiconductors—evident in the interplay between band structure, conductivity, strain, and elasticity—opens vast opportunities for engineering innovation. This extends beyond solid-state electronics, enabling diverse applications such as stable mechanical clocks, tunable infrared detectors, nonreciprocal acoustic waveguides, and microwave frequency combs.

Despite significant progress in developing transformative devices that rely on semiconductor nanomechanics, integrating them into standard semiconductor platforms for seamless operation alongside mature electronic circuits remains a major challenge. The key obstacle is the absence of efficient nanoscale transducers in standard nodes, which are essential to fully unleash the potential of mechanics on the chip.

In this talk, I will introduce novel nanomechanical devices in silicon (Si) and silicon-germanium (SiGe) platforms that exploit electronic effects to create clocks[1] with stability comparable to atomic standards, as well as frequency-selective SiGe-Si heat engines[2] and refrigerators for self-amplification and noise cooling. I will also discuss recent advances in developing CMOS-based piezoelectric transducers using phase-engineered hafnia, enabling the integration of nanomechanical devices on advanced semiconductor chips[3,4]. Finally, I will demonstrate how these efforts converge with innovative device architectures to realize the first massively scaled array of hafnia-on-semiconductor microwave filters and oscillators.[5,6]

[1]S. Dabas, et al., and R. Tabrizian, "Ultra-High Q Self-Ovenized AlScN-on-Si X-Lamé Resonator for Stable Clock Generation," IEEE MEMS 2024, doi: 10.1109/MEMS58180.2024.10439464.

[2]F. Hakim, et al., and R. Tabrizian, "A Self-Amplified Silicon-Germanium Nanomechanical Resonator with Piezoresistive Heat Engines," Solid-State Sensors, Actuators, and Microsystems Workshop (Hilton Head 2024).

[3]M. Ghatge, et al., and R. Tabrizian. "An ultrathin integrated nanoelectromechanical transducer based on hafnium zirconium oxide." Nature Electronics 2019. DOI: 10.1038/s41928-019-0305-3.

[4]T. Tharpe, et al., and R. Tabrizian. "Nanoelectromechanical resonators for gigahertz frequency control based on hafnia–zirconia–alumina superlattices." Nature Electronics 2023. DOI: 10.1038/s41928-023-00999-9.

[5]F. Hakim, et al., and R. Tabrizian. "A ferroelectric-gate fin microwave acoustic spectral processor." Nature Electronics 2024. doi: 10.1038/s41928-023-01109-5.

[6]R. Tabrizian, "Three-dimensional acoustic resonators for massively scalable spectral processors." Nature Electronics 2024, doi: 10.1038/s41928-023-01110-y.

Bio: Roozbeh Tabrizian is an Associate Professor and the NELMS Rising Star Endowed Professor at the Department of Electrical and Computer Engineering, University of Florida. He received his B.S. (2007) degree in Electrical Engineering from Sharif University of Technology, Iran, and the Ph.D. (2013) degree in Electrical and Computer Engineering from the Georgia Institute of Technology. He was a Post-Doctoral Scholar (2014-2015) at the University of Michigan. His research interests include semiconductor micro- and nano-electro-mechanical systems for frequency control applications; microwave acoustics; and novel ferroic materials and devices. Tabrizian has received the DARPA Director's Fellowship Award (2021), a DARPA Young Faculty Award (2019), and an NSF CAREER Award (2018). He is an Associate Editor of the IEEE Journal of Microelectromechanical Systems (JMEMS) and Sensors and Actuators A: Physical. Tabrizian's research has resulted in more than 90 journal and refereed conference papers and 10 patents. Tabrizian and his students are recipients and finalists of multiple outstanding paper awards at top-tier conferences such as IEEE MEMS, IEEE IFCS, IEEE IEDM, IEEE NEMS, and Transducers.

Host: Professor Sunil Bhave, bhave@purdue.edu, 765-496-0547

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