Atomically Thin Nanoelectromechanical Systems (NEMS): Nanofabrication Techniques, Challenges, and Perspectives

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Emerging two-dimensional (2D) semiconductors (such as transition metal dichalcogenides (TMDCs) and black phosphorus), along with their heterostructures (particularly with graphene and hexagonal boron nitride (h-BN) layers), offer compelling platforms for creating new resonant nanoelectromechanical systems (NEMS) for multiphysics transducers, where the unconventional properties of these crystals can be harnessed for engineering both classical and quantum signal processing and sensing schemes. In this presentation, we will describe a holistic view of our latest endeavors and results on advancing nanofabrication techniques for realizing resonant NEMS based on 2D materials and van der Waals heterostructures – from individual devices without and with individual electrical addressability and/or optical accessibility, to arrays of devices with nanofabricated local gate electrodes and even multiple local gates for enhanced control and tuning. We will first review the important basic strategies and techniques for fabricating high-quality resonant 2D NEMS using a combination of advanced photo/e-beam lithography processes, and state-of-the-art all-dry transfer techniques with precision alignment and control. We then discuss representative examples of such devices and the effects from fabrication process. We will then focus on discussing latest efforts on exploring pathways toward scalable fabrication for making large arrays of high-quality 2D NEMS with high reliability and robustness, by exploiting latest advances in both top-down nanofabrication and bottom-up assembly paradigms.

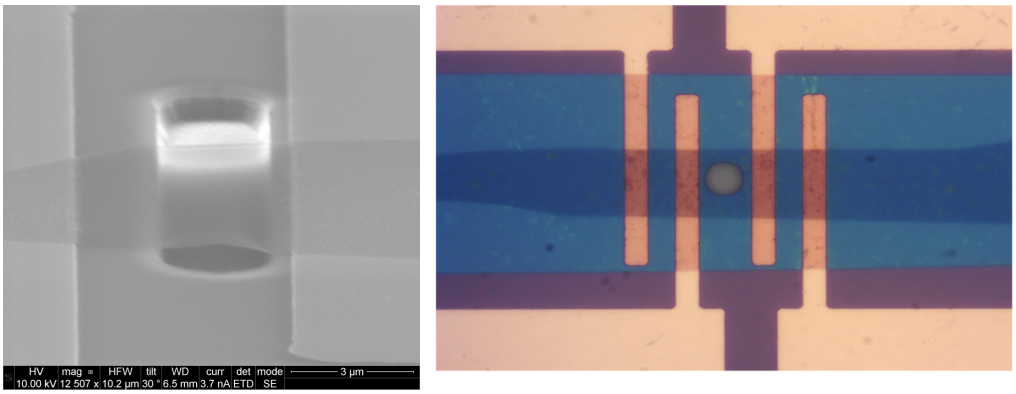

Figure 1: Examples of atomically thin 2D NEMS. (Left) SEM image of atomic layer MoS_2 membrane suspended over a microtrench. (Right) Optical microscopy image of a graphene/h-BN heterostructure circular drumhead.