Nanoscale Electromechanical Resonators and Oscillators

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Nanoscale devices with mechanical degrees of freedom offer compelling characteristics that make them not only interesting tools for fundamental studies, but also intriguing candidates for technological applications. In particular, nanoelectromechanical systems (NEMS) *vibrating* in their *resonant* modes provide promising opportunities and advantages for developing novel transducers and sensors, in the previously inaccessible regimes. In fundamental physics, recently there have been considerable interests and intensive efforts in exploiting such NEMS devices for quantum measurements. In technology development, significant milestones have been achieved using prototypical devices and systems, and rapid progresses are currently being made in resonant sensing; plus other interesting applications are emerging. At the juncture from understanding fundamentals to creating practical technologies, there are great challenges and also enormous opportunities for the *engineering* of NEMS resonators and oscillators.

This tutorial will give an introduction to fundamentals of NEMS and an overview of recent efforts in developing and engineering nanoscale electromechanical resonators and oscillators. After discussing the basic ideas and fundamental aspects of such devices, I shall introduce prototypes of devices enabled by the state-of-the-art nanofabrication techniques, including both top-down and bottom-up approaches. Related and enabling materials, along with their interesting properties and relevant challenges, will also be discussed. I will then discuss device characterization techniques and introduce recent advances in very-high and ultra-high frequency (VHF/UHF) NEMS resonators and oscillators, along with important challenges such as noise and integration. Finally, I will review and discuss some representative areas of applications, latest highlights and new possibilities in this field, and their interesting and promising interactions with a few of today's mainstream technologies.