Ultimate and Practical Limits to Micro- and Nanomechanical Frequency-Shift-Based Sensing

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Frequency-shift sensing has emerged as the basis for important new applications in metrology employing micro- and nano- electromechanical systems (MEMS/NEMS). Prominent among these are new approaches to magnetic resonance [1], radiation detection [2], and chemical and biological analyte detection by inertial mass sensing in gas [3], liquid [4], and vacuum [5,6]. I will briefly review recent achievements in these areas, and then describe the physics underlying the ultimate and practical limits of frequency-shift sensing with MEMS/NEMS. Unlike their macroscale counterparts, these devices permit detection down to the thermodynamic, even quantum, noise floor in the mechanical domain. At the other end of their dynamic range, NEMS can easily be driven well beyond the onset of mechanical nonlinearity. The smallest of NEMS devices, which provide unprecedented mechanical responsivities useful for sensing, have a vanishingly small linear dynamic range [7]. Hence, it becomes important to consider the operation of NEMS sensors well into the regime of nonlinear response. Such operation is conventionally avoided, given the increased phase noise that usually arises in this regime. I will describe three new, robust, and very general paradigms to harnessing *nonlinear* nanomechanical dynamics to achieve substantial performance gains with ultra miniature frequency-shift-based sensors [8,9,10].

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