Materials and Geometry Optimization for the Development of Ultra-High Sensitive Nano-Mechanical Resonators

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Due to their ultra-small volumes, high sensitivity, and high operating frequencies, nano-mechanical resonators have numerous applications including mass sensing, chemical or biological molecule detection, RF communication and in precision time standards. Among fundamental unresolved scientific issues are the factors that control the intrinsic quality factor (Q) of these resonators, which determines the sensitivity of the ultimate devices. Several factors have been reported to influence the Q of resonators including the thermoelastic properties of the resonator material, surface properties, point/line defect movement etc. However, the dominant loss mechanisms influencing the Q are very poorly understood and subject to considerable debate in the literature. Design at the nanometer scale poses new challenges because some of the continuum assumptions used in conventional models break down and the role of surfaces becomes increasingly important.

To this end, we are pursuing a two-pronged effort, with modeling and experimental work going hand-in-hand to develop high Q nano-mechanical resonator. We have optimized the geometry of a particular type of resonator known as the "double-paddle oscillator" and are currently studying the behavior of micrometer-scale structures. Performance comparisons will be made to micrometer and nanometer-scale resonators with other geometries. Novel materials choices as well as fabrication methods are also key factors for high Q. We have fabricated nano-mechanical resonators using single crystalline materials with very different mechanical and chemical properties, namely Si, AlN and GaN. Electron-beam lithography and micromachining techniques are used to fabricate the resonators. Evaluation of resonator designs has been carried out by measuring the frequencies and quality factors of the various resonance modes using a laser Doppler vibrometer and a network analyzer. Additional detailed optical, AFM and SEM characterization of the fabricated structures has been carried out, in order to elucidate some of the fundamental energy dissipation mechanisms within these nano-mechanical resonator structures.