Chemical Sensors Based on Nanomechanical Resonators

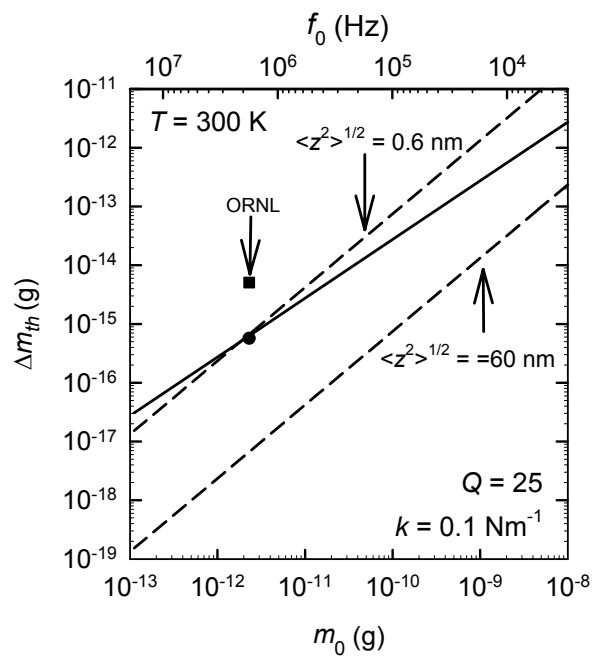
Low-cost, high performance nanosensor arrays

During the past decade, nanoscience and nanotechnology have been recognized as important research topics for the 21st century. Anticipated applications of nanotechnology are vast and they include a possibility to address many challenges of chemical, environmental, and biological analysis. One of the approaches to implement this possibility is associated with the use of nanomechanical resonators which may function as ultra sensitive transducers. Micromechanical and electromechanical resonators, such as flexural plates (FPs), quartz crystal microbalances (QCMs) and surface acoustic wave (SAW) devices have already found numerous applications as mass sensitive transducers in chemical and biological sensors. It is important to note that sensor designs based on QCM and SAW devices have been thoroughly refined over several decades and the demonstrated figures of merit closely approach their theoretical limitations. In the case of cantilever resonators, however, dramatic improvements in analytical figures of merit can be achieved merely by scaling their sizes down to the nanoscale.

Development of low-cost, high performnce chemical nanomechanical sensors

Our overall goal is to develop a low-cost, high performnce chemical nanomechanical sensor. Cantilever respond to stimuli by changes in their radius of curvature (bending), shifts in resonance frequency, changes in the amplitude and qualuty factor Q of their vibration. We have developed optical readouts that can sense positional changes of the cantilever. Resonating nanomechanical devices with very small mass and size have the potential for mass sensing at the level of individual molecules. We have demonstrated operation of nanomechanical resonators as mass sensors under ambient pressure and temperature and achieved femtogram level mass sensitivity. Our nanomechanical resonators were gold coated silicon cantilevers with resonance frequencies in the range of 1-10MHz, characteristic thicknesses of 50-100 nm and force constants of about 0.1 N/m. We used cantilevers as nanomechanical resonators with resonance frequency of 2.2 MHz which was excited photothermally and measured a mass change of 5.5 fg upon chemisorption of 11-mercaptoundecanoic acid.

In Figure 1 we show a comparison of mass detection thresholds for a resonating rectangular Si cantilever with $k = 0.1$ N/m defined by a fixed frequency instability of 10^{-4} (solid line) and by the cantilever intrinsic thermal noise (dashed lines). Thermally limited mass detection thresholds



Comparison of mass detection thresholds for a resonating rectangular Si cantilever with $k = 0.1$ N/m defined by a fixed frequency instability of 10^{-4} (solid line) and by the cantilever intrinsic thermal noise (dashed lines).

are calculated for the two cases: (i) z_{max} ($=\langle z^2\rangle^{1/2}$) = 0.6 nm, Q = 25, *i.e.* weakly excited resonator (upper dashed line) and (ii) strongly excited resonator with z_{max} = 60 nm, Q =25 (lower dashed curve). The experimentally measured mass change (solid square) is approximately 10 times larger than the mass detection threshold (solid circle) calculated for the cantilever with f_0 = 2.25 MHz used in our experiments.

Features

- **Nanomechanical detection – Can approach single molecule detection**
- **Can operate in vacuum, ambient air or liquid environment**

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