Fabrication of Nanomechanical Oscillators for Chemical and Biological Sensing

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Abstract:

Cantilevers are commonly used as transduction mechanisms for sensing purposes. For the main focus of this project, the nanoelectro-mechanical (NEMS) oscillators will be used to detect chemical and biological species. In this work, devices composed of silicon nitride suspended above silicon are fabricated and tested. The cantilevers are fabricated using both optical lithography and electron-beam lithography methods. The widths of the devices range in size from 150 nm to 1 μm and the lengths range in size from 6 μm to 12 μm. Gold dots are used to achieve adhesion via thiolate self-assembly.

The objective of this research is to detect a difference in resonance frequency before and after the addition of the attached mass; the change in resonance frequency will give information about the adhered mass. The basic model can be related to the equations involved in Hook's law regarding a rectangular leaf spring.

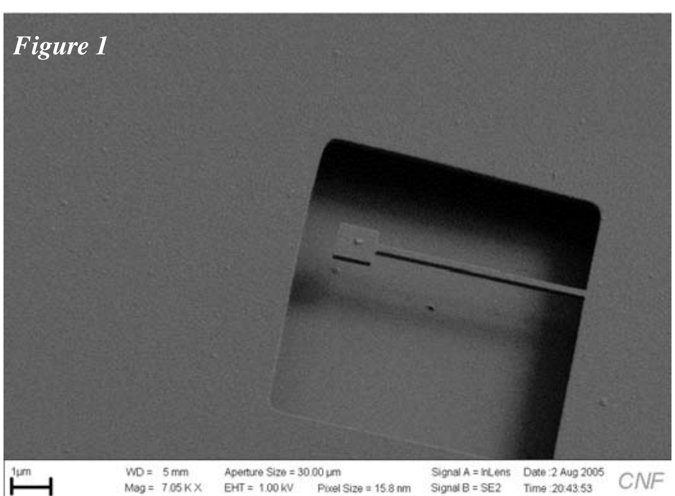
Introduction:

MEMS or NEMS sensors operate by detecting changes in the mechanical characteristics of a micromechanical transducer. These changes are caused by physical, chemical, or biological stimuli. One form of detection involves measuring an oscillator's change in resonance frequency. Cantilevers are highly sensitive devices that are attached at one end, and thus are enabled to oscillate freely. As opposed to other sensors, cantilevers are also more reliable, smaller, and have higher accuracy. Both cantilevers and bridges of various widths and thicknesses can be fabricated in order to test for their unique resonance characteristics.

The resonance frequency of the cantilever is dependent upon its mass and spring constant. The higher its spring constant is, the higher its resonant frequency will be. Also, shorter cantilevers can detect smaller amounts of bound materials. Less stiff cantilevers are also more susceptible to thermal noise, giving inaccurate frequencies. Binding of various biological materials may be studied by measuring the changes in resonant frequency of the harmonic oscillators.

Interferometry has become a popular method for MEMS readout because of its ability for high-bandwidth high-resolution mapping of oscillations by small cantilevers.

Figure 1



Fabrication Process:

This was a multi-layer process, beginning with nitride and thermal oxide on silicon wafers. The nitride was measured to be about 200 nm using ellipsometry. Photolithography was used to make the devices. Larger areas of the device were exposed using optical lithography and the small cantilever devices and gold adhesion surfaces were exposed using e-beam lithography. An etch mask was constructed with 25 nm of chrome. The exposed nitride was removed using CF_4 plasma. The fluorinated chrome was then removed using oxygen plasma, and the remaining chrome was removed using a chrome etch wet chemistry. Gold was used for the binding sites, with chrome as an adhesion layer. The oxide was then removed using HF. Figure 1 shows a released cantilever.

Experimental Procedure:

Interferometry was used to measure the frequency of oscillation of the cantilevers. The cantilevers were encapsulated in a vacuum to achieve a high quality

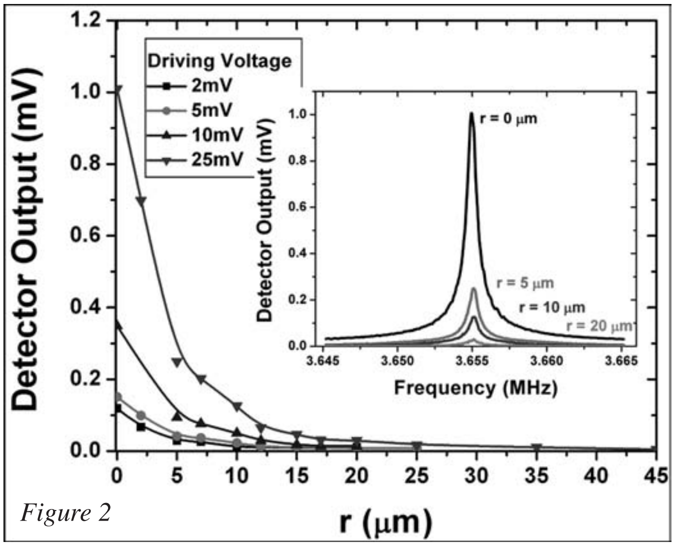


Figure 2

factor. A modulated blue laser thermally excites the cantilever at its base and a red laser is used to detect the motion in conjunction with a single cell photodetector. Shown in Figure 2, as the excitation laser is placed further from the base, the amplitude of vibration diminishes with the resonant frequency remaining constant. This implies the driving signals were constrained within the linear regime. The quality factor, a factor related to damping and which is inversely proportional to the change in angular frequency(Δ_ω), is increased by encapsulating the cantilever samples in a vacuum chamber. *Baculovirus*, an insect virus, is uniformly attached to the oscillators.

Results and Conclusions:

A definite frequency shift was observed in all of the cantilevers, see Figure 3. The black graph to the right represents the frequency before a material was attached; the grey graph to the left represents the frequency after the material was attached. This is an indication that the virus adhered to all of the cantilevers, as planned. Due to time constraints, the mass was not calculated. We also found that several of the longer, thinner cantilevers had problems with sticking to the silicon substrate after being released. This was due to their lack of stiffness.

Different frequency peaks were also found by analysis of the photo detector. Theoretically, we found the approximate values for the 1st, 2nd, and 3rd harmonics. Other peaks were also detected. Although they gave weak signals, they are believed to be in-plane peaks. The first of these peaks was located at 19.45 MHz. Some torsional motion may also have been detected. Theoretically the frequency is directly proportional to the thickness of the cantilever, and the frequency of the in-plane motion (the primed frequency) is directly proportional to the width of the cantilever. Using the experimental values for the width and thickness, see Figure 4, we see that the theoretical value is relatively close to the experimental value.

Future Work:

The future of this project could include the optimization of the in-plane motion of the cantilevers and analyzing the fundamental limits of sensing biomolecules by way of mass-based detection. Ultimately, we hope to encapsulate these oscillators in fluidic networks where functionalization takes place *in-situ*.

Acknowledgments:

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References:

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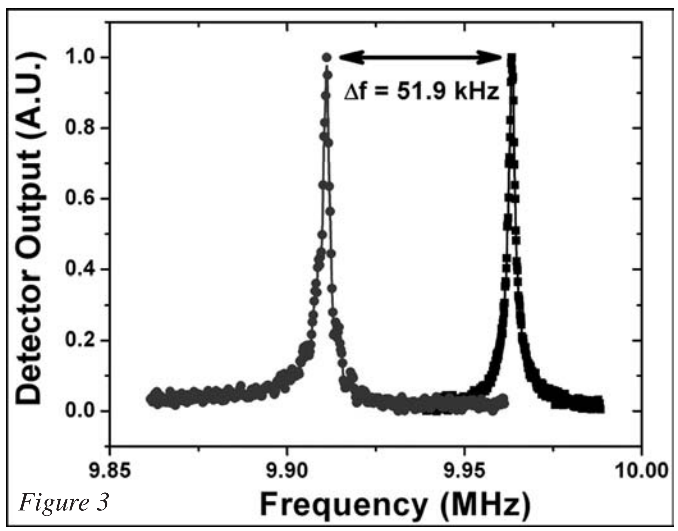

Figure 3

$$f_i = \beta_i^2 \frac{1}{2\pi}\left(\frac{E}{12\rho}\right)^{\frac{1}{2}} \frac{t}{l^2}$$

$$f_i \propto t; f_i' \propto t'; w = t'$$

$$\frac{f_i'}{f_i} = \frac{w}{t} = \frac{1\mu m}{0.220\mu m} \approx 5$$

$$f_i' \approx 5 f_i = 5(3.84MHz) \approx 19.2MHz$$

$$f_{1measured} = 3.84MHz$$

$$f_{1measured}' = 19.45MHz$$

Figure 4