Optical excitation of in-plane modes of nanoelectromechanical oscillators for selective detachment of microspheres

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Manipulating dynamics of flexural and torsional vibrational modes of micro- and nanoelectromechanical systems (MEMS and NEMS) with external fields has long been a sought-after goal. A widely studied class of NEMS devices consists of surface micromachined mechanical oscillators made of thin film layers patterned into various shapes that operate by motion perpendicular to the plane of the thin film and substrate by bending in their thin direction. Conventional mechanical driving and motion transduction methods typically activate and detect only motion in this "out-of-plane", transverse direction. We previously demonstrated a robust method for driving and detecting the motion of micro- and nano-scale resonators by utilizing optical drive of resonant motion and interferometric detection of that motion by a separate laser. This technique allowed non-invasive activation and interrogation of individual oscillators or arrays of oscillators. We describe here an approach that can activate and detect the perpendicular, in-plane motion of such oscillators.

Optical excitation plays an important role in the actuation of higher flexural and torsional modes of nanoelectromechanical oscillators. We show that optical fields are efficient for excitation, direct control and measurement of in-plane motion of cantilever-type nanomechanical oscillators. As a model system, 200nm and 250nm thick single crystal silicon cantilevers with dissimilar lengths and widths ranging from 6 to 12μm and 500nm to 1μm, respectively, were fabricated using surface micromachining and dynamically analyzed using optical excitation and interferrometric detection (Figure 1). Three dimensional finite element analysis incorporating shear, rotational inertia, cross-sectional deplanation and non-ideal boundary conditions due to the structural undercut, adequately describe the dynamics of the nanomechanical structures (Figure 2). The quality factor of a particular in-plane harmonic was consistently higher than the transverse mode. The increased dissipation of the out of plane mode was attributed to material and acoustic loss mechanisms. We have demonstrated the controlled capture (Figure 3), detection and release of submicrometer particles (Figure 4) by the application of forces imparted by the in-plane motion of the resonators. In contrast, the out of plane motion, even in the strong non-linear impact regime, was insufficient for the removal of bound polystyrene spheres. Our results suggest that optical excitation of in-plane mechanical modes provide a unique mechanism for controlled removal of particles bound on the surface of nanomechanical oscillators.

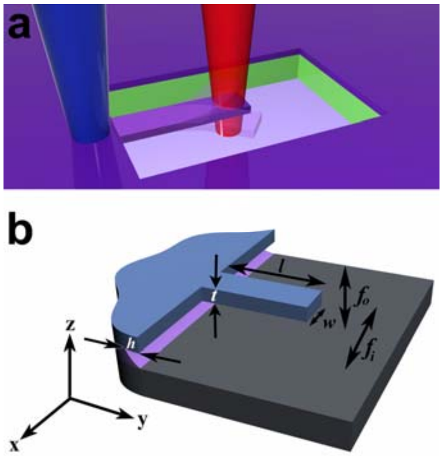

Figure 1. Schematic illustration of (a) the optical actuation and detection setup and (b) rectangular cantilever configuration with a h=1μm overhang.

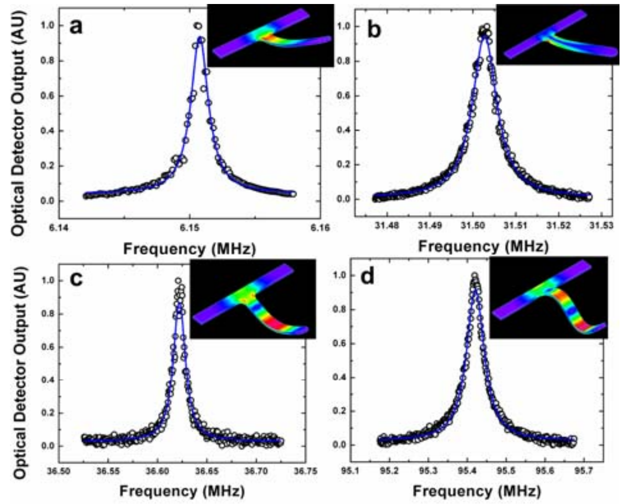

Figure 2. Measured frequency spectra (open circles) of a Si NEMS oscillator corresponding to various modes of vibration. The solid curve is a least-squares fit using a Lorentzian-type function. Insets represent accompanying modes of vibration calculated using finite element analysis. Colors illustrate the effective modal stress of the first (a) transverse and (b) inplane, (c) second and (d) third transverse modes.

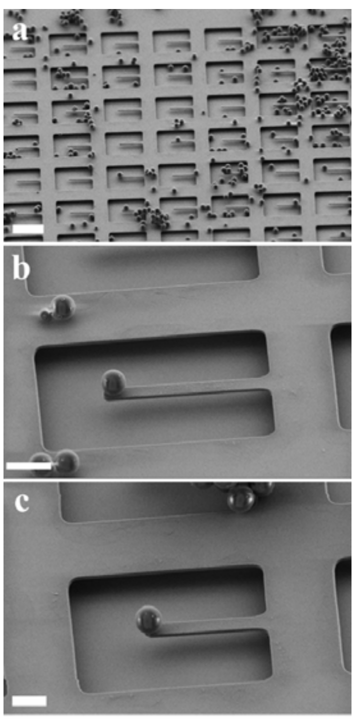

Figure 3. Oblique angle SEMs of suspended cantilever devices with attached polystyrene microspheres. Scale bar corresponds to (a) 10μm, (b) 3μm and (c) 2μm.

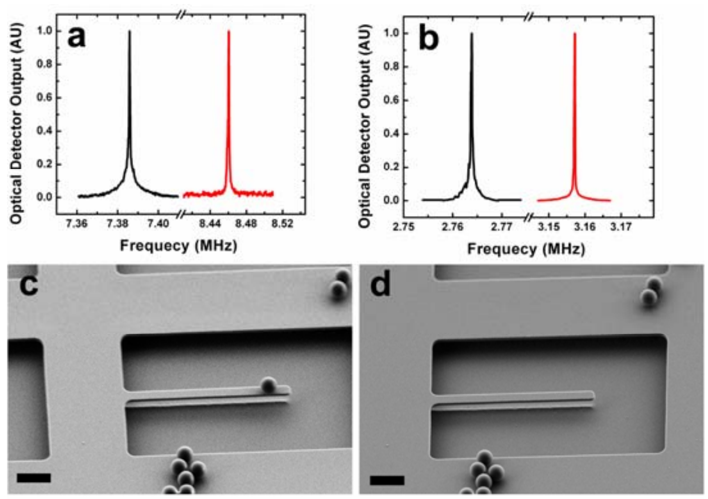

Figure 4. Measured frequency spectra before (black) and after (red) the detachment of the polystyrene sphere for the (a) in-plane and (b) transverse vibrational modes. Oblique angle scanning electron micrographs (c) before and (d) after the polystyrene sphere detachment from the surface of the corresponding NEMS device with dimensions of w = 601nm, l = 10.12μm and t = 250nm. Scale bar represents 2μm.