Dynamic detection of nanoelectromechanical spectral characteristics through non-linear interactions with micromechanical probes

B. Ilic[1], S. Krylov[2], L. M. Bellan[1] and H. G. Craighead[1]

[1] School of Applied Physics, Cornell Nanoscale Facility and Nanobiotechnology Center, Cornell University, Ithaca, NY, 14853
Electronic Mail : bi22@cornell.edu
[2] Department of Solid Mechanics Materials and Systems, Tel Aviv University, ISRAEL

The desire to understand and control dynamical properties of nanoelectromechanical systems [1] (NEMS) has inspired great interest in a wide spectrum of applications, including force detection, chemical and biological sensing, mechanical mixers and filters. Generally, dynamic detection of forced deflection or out-of-plane translational vibrations is generally accomplished by either optical interferrometry or optical deflection techniques. A fundamental constraint in optical detection is encountered when the device dimensions approach the diffraction limit of the optical system. In this regime, for a diffraction limited laser spot size at the position sensitive detector and noise dominated by shot noise, reduction of the total laser power reflected from the surface of the nanomechanical device significantly degrades the signal to noise ratio. To circumvent these restrictions, we used scanning probes as an approach to enhance and exploit the dynamical response of the NEMS through coupled, non-linear, mechanical interactions. This was based on an approach in which interactions between harmonically driven nanomechanical structures and an AFM probe in tapping and non-contact modes were used to illustrate the dynamics of the coupled system (Figure 1). For these experiments, suspended, surface micromachined single crystal, high frequency (f~1-15MHz) silicon NEMS cantilevers were fabricated and used in conjunction with commercially available AFM probes (f~50-100kHz).

Measurement of the natural harmonic was performed in non-contact and intermittent contact mode. In the former case, the AFM probe tip was positioned above the NEMS structure at a known distance. The AFM piezo extended to a distance below an adjustable set-point in cycles at a frequency of 3.98Hz (Figure 2a). The frequency of the piezo-actuator was scanned from sub-resonance up to values above that of the expected NEMS natural harmonic. Intermittent contact imaging data show quantitative linear classical resonance behavior (Figure 2b). Additionally, non-contact AFM interrogation revealed the initiation of interaction between the two oscillators providing a qualitative description of the resonant response (Figure 2c). The dynamic response of the coupled system was modeled through a combination of long range Van der Walls and contact forces using the Derjaguin-Muller-Toporov model. Furthermore, we also measured NEMS spectral characteristics using tapping mode imaging by scanning across the free end of the NEMS structure with the slow scan axis (Figure 3). Measured spectral response of the NEMS was in good agreement with optical characterization and modelling results. This method opens new possibilities for spectral detection of suspended nanomechanical resonant structures.

1. H. G. Craighead, Science **290**, 1532 (2000).
2. B.V. Derjaguin, V.M. Muller and P. Toporov, J. Colloid Interface Sci., **53**, 314 (1975).

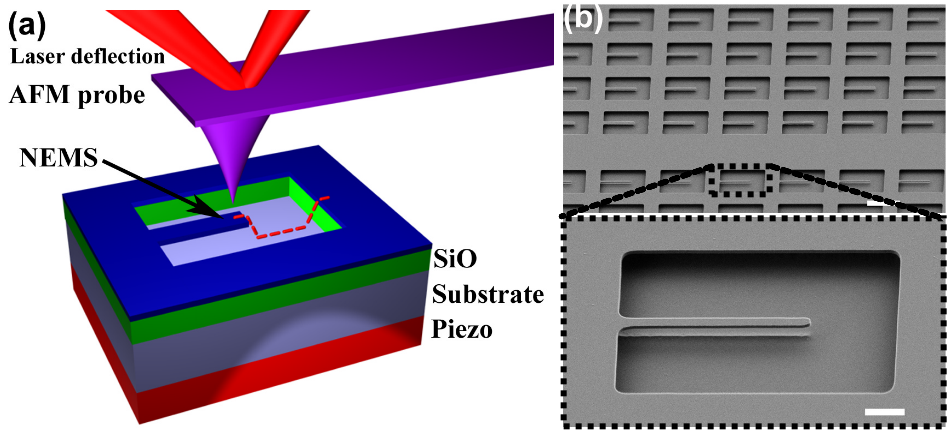

Figure 1. (a) Illustration of the experimental apparatus emphasizing the weakly coupled, non-contact and scanning modes of operation. The red dashed line initiating from the free end of the cantilever structure indicates the length of the AFM scan during tapping mode imaging of the interactions. Oblique angle scanning electron micrographs of (b) arrays of 205nm thick single crystal silicon suspended cantilever devices. Scale bar corresponds to 10µm. Inset shows a zoomed in released structure with dimensions of *l*=9.86µm, *w*=540nm. Scale bar corresponds to 2µm.

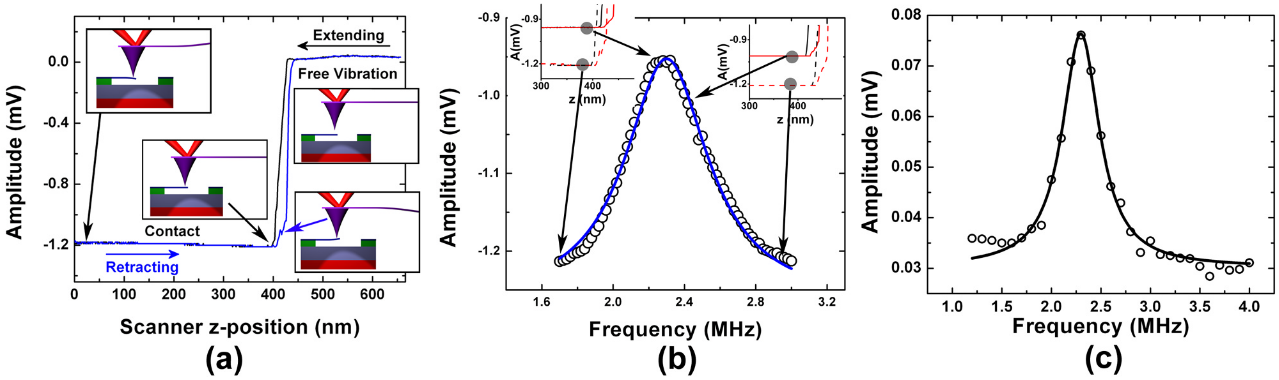

Figure 2. (a) Measured extension-retraction cycle of the probe amplitude versus the z-piezo scanner position. (b) Measured vibrational amplitude (open circles) of the probe, near the vicinity of the point of contact, versus drive frequency of the cantilever structure with dimensions *l*=12µm and *w*=500nm. (c) Measured vibrational amplitude (open circles) of the probe, in the free vibration regime (hovering mode), as a function of the drive frequency of the cantilever with dimensions *l*=12µm and *w*=500nm. The solid lines represent a least square fit using a Lorentzian function.

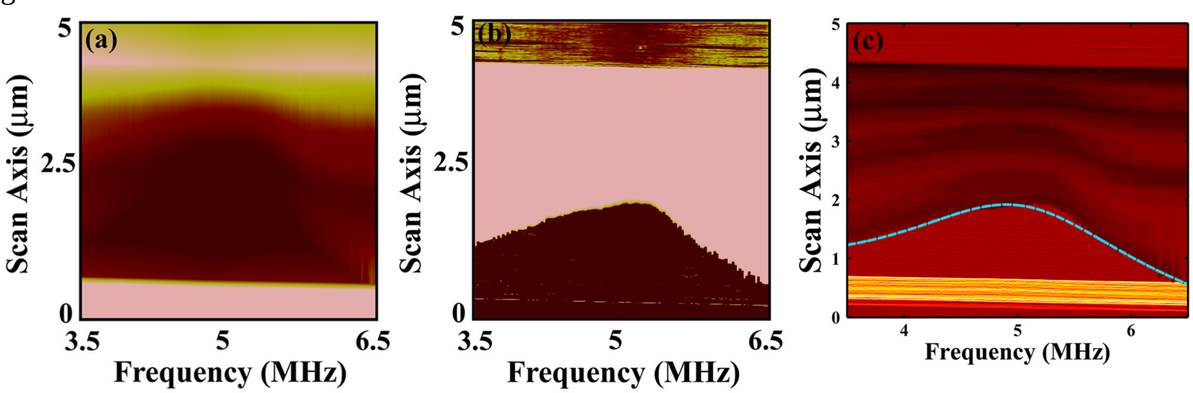

Figure 3. Tapping mode AFM scans across the piezo-driven cantilever between 3.5-6.5MHz. (a) The height image displacement is due to the resonant coupling of the interacting system. (b) Phase contrast and (c) amplitude images show the spectral characteristics of the nanomechanical oscillator. Dashed blue line is a fit to a Lorentzian function.