Optical Excitation of Nanoelectromechanical Oscillators

Abstract:
We report a method of optical excitation of nanomechanical cantilever-type oscillators. The periodic driving signal with a controlled modulation amplitude was provided by 415 nm diode laser, wherein the laser spot was located at some distance away from the clamped end of the cantilever. The measured resonant response of the cantilever was obtained at distances in excess of 160 µm with varying oscillator dimensions. The effectiveness of the driving mode is studied for different combination of materials, namely Si-SiO₂ and Si₃N₄-SiO₂. These observations were considered within the theoretical framework of the mechanism of heat transfer. We show measurable amplitudes of vibrations can be obtained at temperature changes much less than one degree.

Summary:
Continuing developments in micro and nanoelectromechanical (MEMS and NEMS) systems has fueled a renaissance in the field of mechanical sensors [1-3]. Actuation of such devices can be done by thermal mechanical stresses, or electric and magnetic fields.

In our work, we present an experimental and theoretical description of long-range optical actuation of resonant electromechanical single crystal silicon and low stress silicon nitride devices [4]. This optical actuation approach provides an efficient method of actuation of arrays of mechanical devices without the need for additional on-chip structures.

140 nm thick single crystal silicon cantilevers were fabricated from silicon on insulator wafers and low stress silicon nitride with a sacrificial silicon dioxide layer. Surface micromachined devices with dimensions of varying length from 4 µm to 15 µm, width of 400 nm to 1 µm and thickness of 90 nm and 140 nm were fabricated using high-voltage electron beam lithography. Following lithographic definition, the device layer was etched using a CF₄ plasma chemistry. Hydrofluoric acid was then used to etch away the supporting silicon dioxide layer, releasing the cantilevers. Signal transduction was accomplished in vacuum by employing an optical interferometric system to measure the out-of-plane mechanical vibrations. Reflectance variations from the incident He-Ne laser focused at the free end of the cantilever beam were measured using a single cell photodetector. A spectrum analyzer was used to collect the output signal and apply a driving signal to the electro-optic modulator controlling the 415 nm diode laser used to excite the oscillator.

Data of the optically driven cantilevers demonstrate the substantial effect of the output response while varying the location of the diode laser spot. The observed amplitude of the silicon nitride devices was significantly lower and extended to smaller distances between the laser spot and the cantilever in contrast to single crystal silicon devices. We demonstrate a measured resonant response of the cantilever at distances up to 160 µm with varying oscillator dimensions. The dependence of the near field response was found to be first order exponential, strongly suggesting that the primary excitation mechanism is thermal. These observations were considered within the theoretical framework of the mechanism of heat transfer.

References:
Optical Excitation of Nanoelectromechanical Oscillators

CNF Project # 599-96

Principal Investigator(s): Harold G. Craighead

User(s):
Rob Ilic
Slava Krylov
Keith Aubin
Robert B. Reichenbach

Principal Investigator(s):
Harold G. Craighead

Affiliation(s):
1. Applied and Engineering Physics,
2. Cornell NanoScale Science and Technology Facility, Cornell University; 3. Department of Solid Mechanics Materials and Systems, Tel-Aviv University, Israel; 4. Electrical & Computer Engineering, Cornell University

Primary Funding:
NBTC, NSF and DARPA

Contact Information:
hgc1@cornell.edu
http://www.hgc.cornell.edu/

Figure 1, top right:
Schematic of the laser interferometric optical setup.

Figure 2, below left:
Dependence of the response amplitude between the source and the clamped end of the beam (see insert) between Si (squares) and SiN (circles). Dashed line represents a first order exponential fit.

Figure 3, below right:
Transfer characteristics between the drive signal and the measured photodetector output. Dashed line represents a linear regression fit. Inset shows a constant natural frequency of vibration for various driving signals.