Nanoelectromechanical Oscillators (NEMOs)

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Motivation—Mechanical oscillators have been widely used in electronics as frequency sources in timing circuits or filters. The resonance frequency of the oscillator is determined by its material properties and its physical dimensions. Nanolithography permits the creation of nanoelectromechanical oscillators (NEMOs) with critical dimensions of only a few tens of nanometers. These oscillators have high resonance frequencies, in the radio frequency (rf) range, permitting their application in rf circuits. In addition, the low mass and high surface area of the oscillators makes them extremely sensitive to chemical adsorption, and this is useful for chemical sensing applications.

Accomplishment—We have successfully created NEMOs that have a unique structure using nanolithography and microelectromechanical systems (MEMS) surface micromachining of amorphous diamond (a-D). Examples of some of these NEMOs are shown in Fig. 1. These devices consist of an array of singly-clamped beams that are designed to oscillate in the film plane. In an effort to reduce coupling, each oscillator is paired to one neighbor, yet spaced far apart from its other neighbor. (In a future study, coupling between oscillators will be intentionally increased to explore collective behavior in large nanomechanical systems.) This structure is unique in that linear arrays of identical oscillators are actuated, as opposed to the actuation of individual isolated oscillators. Furthermore, the motion is in the film plane, in contrast to out-of-plane motion typically found for most cantilever oscillators. The use of a-D also permits high oscillator resonance frequencies due to the high elastic modulus of this material (about 70% that of crystalline diamond), and it allows the possibility of achieving low surface dissipation due to its atomically abrupt surface, i.e., no surface oxide.

The in-plane array of NEMOs that have been developed in this study permits a novel optical detection scheme. Optomechanical modeling performed by D. Carr (1769) has shown that these NEMO arrays exhibit strong modulation of the optical reflectance normal to the film plane at the oscillator resonance frequency. Measurement of subpicometer motion of the NEMOs is achievable using this technique (patent pending). Figure 2 shows an example of the measured resonance response for one particular NEMO array. The width of the resonance peak provides the quality factor, Q, which is an indication of the amount of internal dissipation in the oscillator. These measurements permit fundamental studies of the factors that control internal dissipation in nanomechanical structures - an important area of study for the development of nanomechanical systems coupled with nanoelectronics and for the development of nanomechanical structures used for single molecule sensing.

Significance—NEMOs are important for enabling miniaturized rf signal processing/ timing circuits, for fundamental studies of internal dissipation in nano-sized structures, for enabling studies of the complex dynamics of large systems using coupled nanomechanical elements, and for providing a platform for the development of extremely high sensitivity chemical or molecular sensors. The NEMOs developed in this work are unique in their design and material of construction and offer promise for rf electronics, sensing, and exploring physics at the nano-scale.

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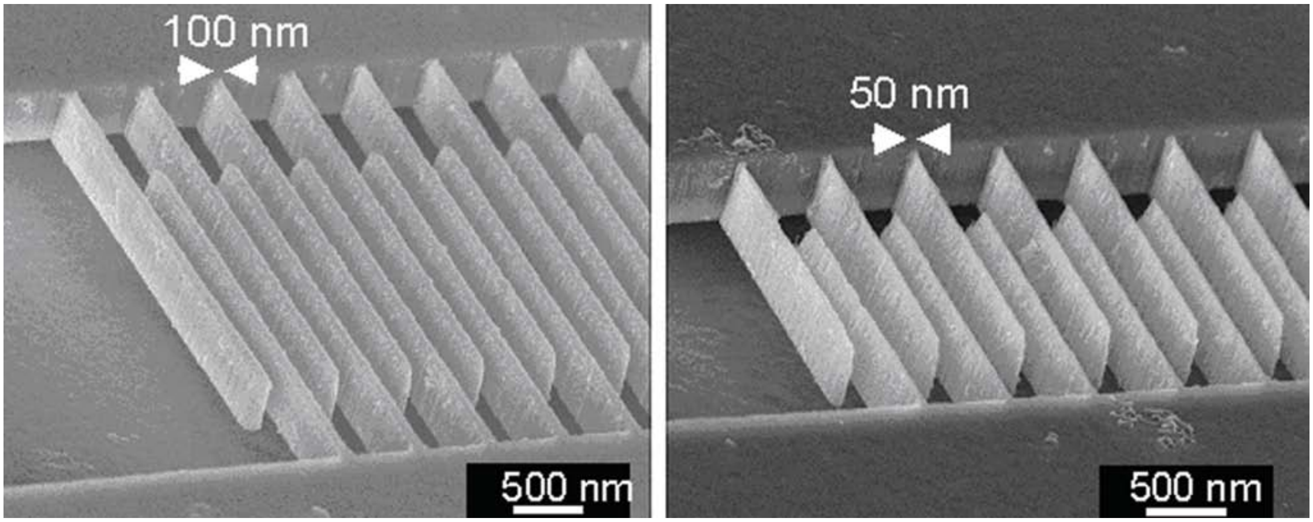

Figure 1. Two examples of NEMO arrays fabricated out of amorphous diamond. The array on the left consists of nanomechanical elements of 100 nm width and 3200 nm length with a design resonance frequency of 25 MHz. The array on the right consists of nanomechanical elements of 50 nm width and 1600 nm length with a design resonance frequency of 50 MHz.

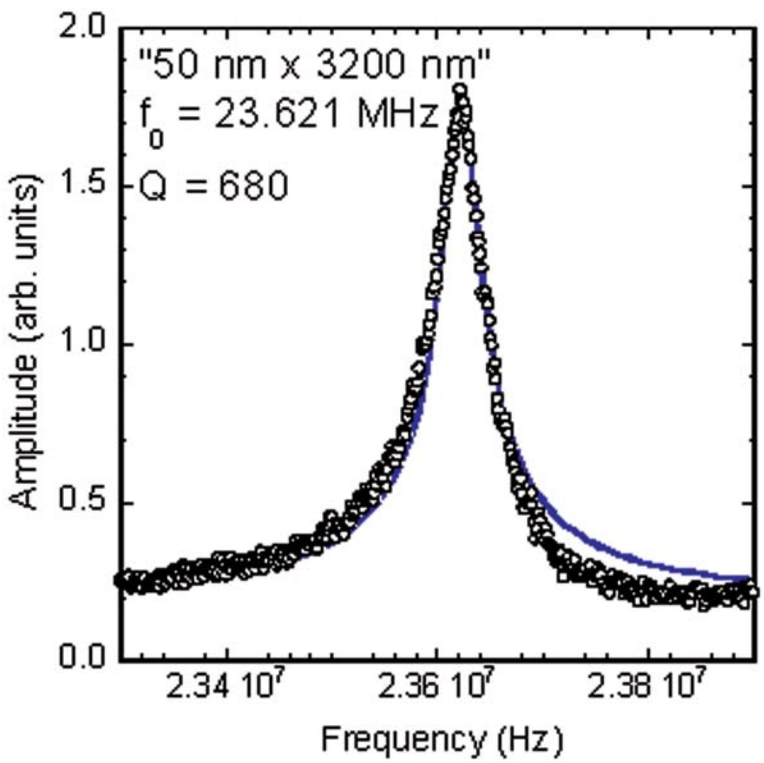

Figure 2. The measured amplitude vs. frequency for a NEMO array of 50 nm by 3200 nm oscillators. The resonance frequency is 23.6 MHz, and the width of the resonance peak is consistent with a quality factor of 680.