Mechanical detection of the vibrations of Carbon Nanotube and Graphene Resonators

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Carbon nanotubes are often recognized as the ultimate material for high-frequency mechanical resonators. For instance, nanotube resonator devices hold promise for ultralow mass detection or quantum electromechanical experiments. However, the detection of the mechanical vibrations remains very challenging. We have developed a novel detection method for nanotube vibrations, which is based on atomic force microscopy [1]. This method enables the detection of resonances up to 3.1 GHz with subnanometer resolution in vibration amplitude as shown in figure 1. Importantly, it allows the imaging of the mode-shape for the first, second and third eigenmodes, as shown in figure 2.

We have also applied this method to study suspended graphene sheets [2]. As shown in figure 3, we have found a new class of exotic nanoscale vibration eigenmodes not predicted by the elastic beam theory, where the amplitude of vibration is maximum at the free edges. The edge modes are frequently, but not always, observed in resonators for which the suspended sheet displays local buckling. To understand the relationship between local buckling and the edge modes, we have calculated the effect of strain with simulations based on the finite element method. Figure 3 shows that the resonance frequencies and shape modes of the model are in reasonable agreement with the measurements.

Simulations based on the finite element method show that these edge eigenmodes are the result of non-uniform stress, which is generated during fabrication. The shape of these exotic eigenmodes and the corresponding stress must be taken into account in future experiments and applications, such as the determination of the Young's modulus[3] and the accurate calibration of mass, force, or charge sensing[4-6]. It may also be possible to manipulate the eigenmode shape by varying the strain during measurements via electrostatic tuning[4].

References:

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Figures:

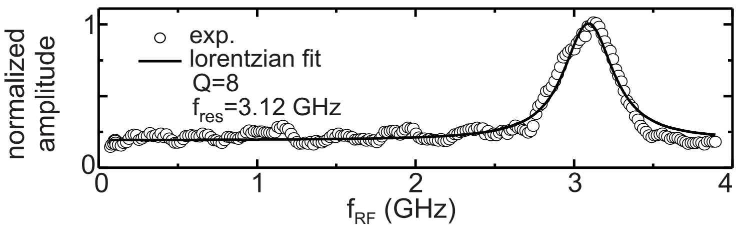

Figure 1. Resonance peak of the fundamental eigenmode for a 265 nm long MWNT resonator.

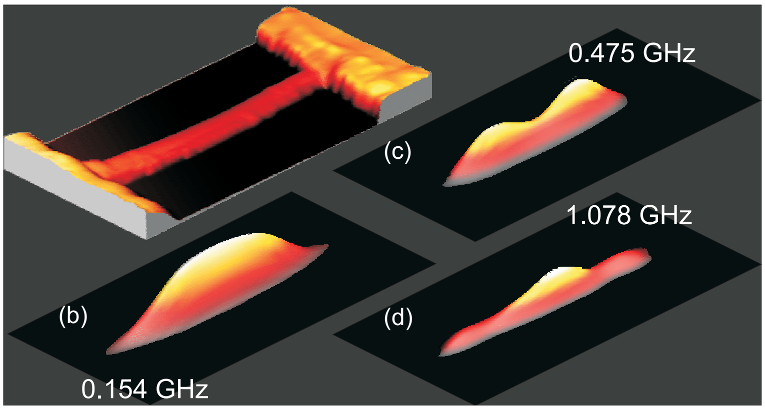

Figure 2. (a) Topography and (b)-(d) vibration images for a 770 nm long MWNT resonator. The images (b), (c), (d) correspond to the first, second and third eigenmodes.

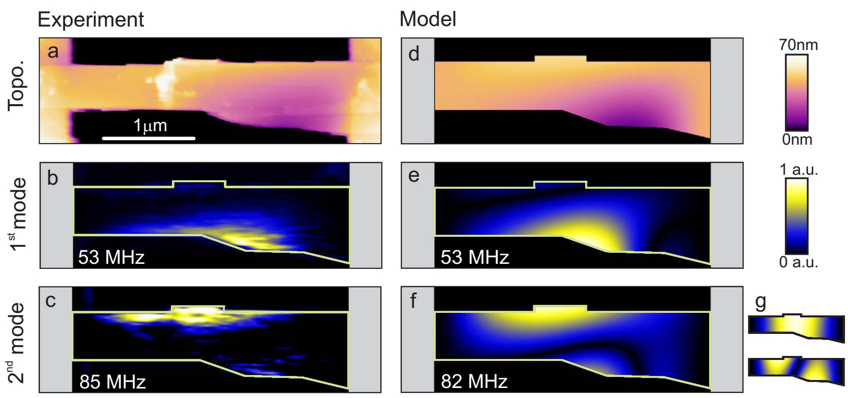

Figure 3. Graphene resonator with local buckling. (a) Measured topography. (b) Shape of the first eigenmode (raw data). (c) Shape of the second eigenmode (raw data). (d) Topography obtained using FEM simulations on a stressed graphene sheet. (e) Shape of the first eigenmode using FEM simulations. (f) Shape of the second eigenmode using FEM simulations. (g) Shape of the two first eigenmodes using FEM simulations without any stress. The resonance frequencies are 17 and 46 MHz.