Two Graphene Mechanical Resonators Coupled by a Nanotube Beam

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Abstract

Mechanical resonators can be coupled [1] in order to create new systems featuring a rich variety of nonlinear dynamics. These nonlinearities give rise to interesting behaviors, such as vibration localization [2], synchronization [3], chaos [4], and parametric mode splitting [5]. Furthermore, coupled mechanical resonators also offer new strategies to improve the quality factor [6], as well as to detect charge [7] and mass [8] with high sensitivity. These devices have been fabricated from metallic and silicon-based materials using top-down micromachining.

Alternate materials endowed with interesting mechanical properties are carbon nanotubes and graphene. A nanotube is a one-dimensional wire whose diameter can be as low as 1 nm, and graphene is a one-atom thick, two-dimensional sheet. Single mechanical resonators based on individual nanotubes and graphene sheets have been fabricated [9,10,11,12,13,14]. These resonators possess a wide variety of useful properties: they can be employed as sensitive mass detectors [15], their resonance frequency can be above 10 GHz [16], they exhibit strong mechanical nonlinearities [14], and their mechanical vibrations can efficiently couple to electrons in the Coulomb blockade and the quantum Hall regimes [10,11,17]. The coupling between two vibrating nanotubes has been studied by gluing several nanotubes on a tip and by imaging them in a transmission electron microscope [18]. However, because nanotubes and graphene cannot be structured as easily as other materials, it has not been possible to use them as building blocks to create coupled resonator devices.

In this work, we demonstrate a multi-element resonant structure consisting of two graphene plates linked by a nanotube beam (Fig. 1). Each graphene plate is clamped by two metal electrodes, so that mechanical vibrations can be both actuated and detected electrically using the mixing technique [9,19]. Two mechanical eigenmodes are measured, each corresponding to vibrations localized in a different graphene plate. The coupling between the eigenmodes is evaluated by measuring the shift of the resonance frequency of one graphene plate as a function of the estimated vibration amplitude of the other plate (Fig. 2).

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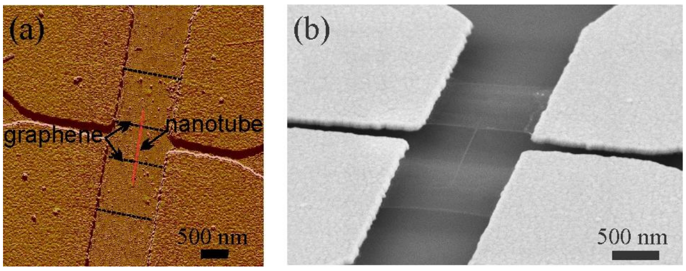

Figure 1 (a) Atomic Force Microscopy image of the device before removing the substrate. **(b)** Scanning electron microscope image of the device at the end of the fabrication process.

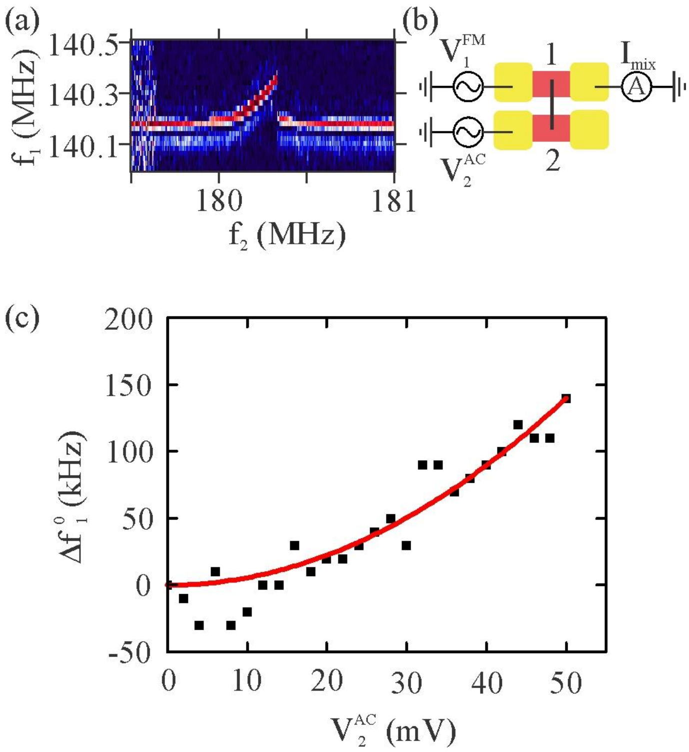

Figure 2 Pump-probe experiment to study the coupling between the eigenmodes. **(a)** Resonance frequency of graphene plate 1 as a function of the frequency of the force applied to plate 2. The plot is obtained by continuously measuring the mixing current of plate 1 as a function of the frequency f_1 of the probe force, while sweeping the frequency f_2 of the pump force. **(b)** Setup of the measurement scheme. **(c)** Shift of the resonance frequency of plate 1 as a function of the pump voltage applied to plate 2.