Mechanics of Nanometer-Thick Suspended Carbon Materials

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Abstract

We fabricated nanoelectromechanical systems (NEMS) from graphene sheets by mechanically exfoliating thin sheets [1, 2] over trenches in silicon dioxide substrates. The thinnest resonator consists of a single suspended layer of atoms and represents the ultimate limit of a two dimensional NEMS.

Background

In collaboration with the McEuen and Davis research groups, we continue to work on patterning, control and suspension of carbon nanotubes, but our major focus has been on suspended thin films of graphite, down to single atomic layers of graphene.

![Figure 1: An optical micrograph of a suspended few-layer graphene sheet also measured to be 2 nm-thick by AFM.](image)

![Figure 2: A surface plot of the spring constant of a suspended graphene sheet vs. the location of the AFM tip.](image)

Summary of Research

An optical micrograph of a suspended few-layer graphene sheet is shown in Figure 1. This particular membrane was measured to be 2 nm-thick by atomic force microscopy (AFM). Vibrations with fundamental resonant frequencies in the megahertz (MHz) range are actuated either optically via thermal expansion and contraction [3], or electrically by applying a radio frequency voltage relative to a doped silicon back-gate [4]. Motion is detected optically by laser interferometry. We detect the thermal motion of the resonators, and use the equipartition theorem to calibrate the amplitude of motion with the optical signal. AFM and spatially resolved Raman spectroscopy are used to determine the thickness of the suspended sheets [5].

Mechanical properties are measured using calibrated AFM probes [6] to measure static deflections in response to a known point force. We have made a detailed study of the mechanical properties of these resonators including resonance frequency, spring constant, built in tension, and quality factor. Figure 2 shows a series of measured values for the effective spring constant across the surface of a stack of suspended graphene sheets which are shown in an AFM image in Figure 3 with a corresponding grid. On layered graphene sheets of thicknesses between 2 nm and 8 nm, we measured spring constants ranging from 1 to 5 N/m. Our data is fit to a model for doubly clamped beams under tension by plotting the spring constant, as measured in the center of the device, vs. $w(t/L)^3$ for eight different suspended graphite sheets. As shown in Figure 4, we can use this fit to extract a Young’s modulus of 0.4 TPa, compared to 1 TPa for bulk graphite along the basal plane, and tensions on the order of 10-7 N [7].

The unusually small mass, electrically active material and reasonable dynamic range indicate that graphite resonators would make excellent mass and charge sensors.

References