Tuning Graphene Nanomechanical Resonators

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We demonstrate wide range tunability—up to 500% in fundamental frequency f_0 and 20× increase in quality factor —of graphene-based nanomechanical resonators, achieved through chemical modification of the graphene film. Ultra-thin films (~1 to 40 nm) of graphene oxide (GO) flakes are used as the starting material[1] . Tension of up to 400 MPa can be created within the deposited film by varying the concentration of oxygen atoms during a thermally-induced transformation from GO to reduced graphene oxide (rGO) (Figure 1). Together with electron-beam lithography and dry etching, we employ this strain engineering to fabricate drum-type nanomechanical resonators (figure 2). Quality factors up to 17,000 at room temperature are observed in rGO-based resonators with optimized thermal treatment, which exceeds the performance of pure graphene resonators[2] by almost two orders-of-magnitude. By comparing the Q values of highly tensioned rGO drum resonators to fully relaxed rGO cantilevers (figure 3), we conclude that the enhancement in quality factor stems from both: i) an increase of the elastic energy associated with tensile stress and ii) a decrease of internal friction in the film associated with modification of carbon-carbon bonds. In conclusion, we demonstrate that chemical modification of graphene-based films can be used as a general approach for preparing high-strength, ultra-thin films with tunable mechanical properties (e.g. built-in tension, density, Young's modulus, internal friction, etc.) for NEMS applications.

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1 J. T. Robinson *et al*., Nano Lett. **8**, 10, pp. 3441 (2008).

2 J. S. Bunch *et al*., Science **315**, pp. 490 (2007).

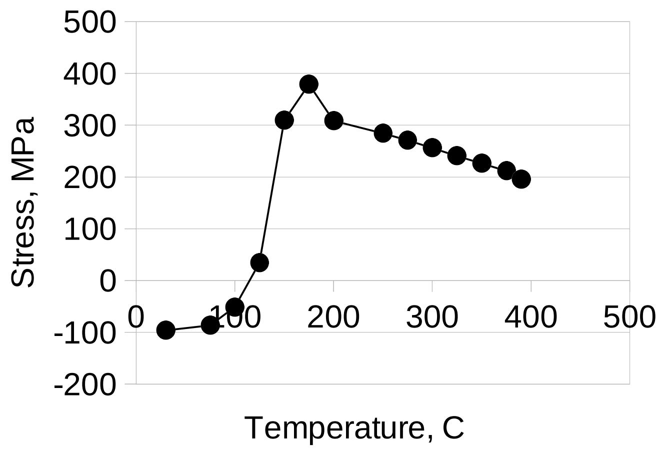

Figure 1: Stress evolution in a 25 nm graphene oxide film during thermal treatment, measured using the wafer bending technique. The tensile stress build-up at 175 C is attributed to desorption of epoxide-configured oxygen atoms.

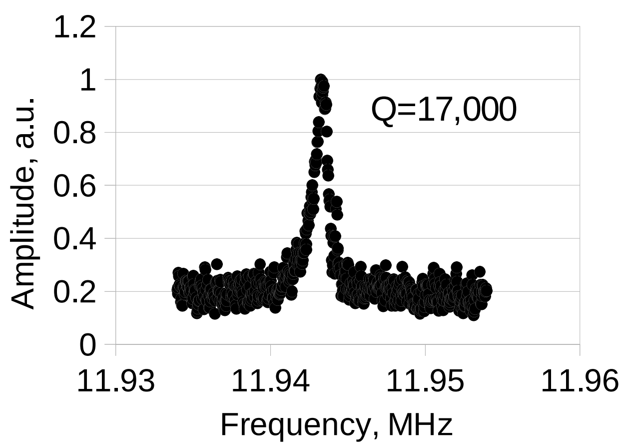

Figure 2: Resonant peak of a strain-engineered rGO drum resonator.

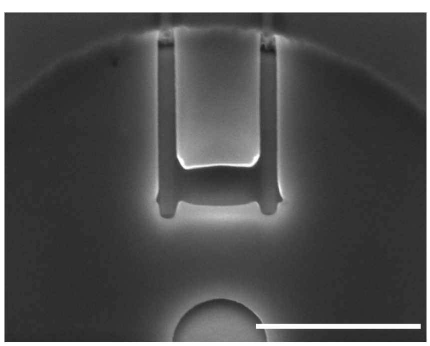

Figure 3: A cantilever micromachined from a rGO membrane using focused ion beam (FIB) milling. The scale bar corresponds to 5 μm. The film thickness is approximately 20 nm.