Large-scale arrays of single-layer graphene resonators

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Graphene's unparalleled strength, small mass per unit area, ultra-high aspect ratio, and unusual electronic properties make it an ideal candidate for nano-electro-mechanical systems (NEMS)[1,2,3,4], but the lack of control over resonance frequency and low quality factor have been major challenges to overcome.

Using graphene grown by chemical vapor deposition (CVD) on copper foils, we developed novel fabrication techniques to produce large arrays of suspended, single-layer graphene membranes on arbitrary substrates. With these fabrication methods, we produced large, high-yield arrays of both doubly-clamped graphene membranes with lengths and widths between 1 and 5 microns, and fully-clamped circular and square graphene membranes with sizes between 2 and 30 microns (See Figure).

With these membranes, we used both optical and electrical actuation and detection techniques to conduct systematic measurements of mechanical resonance as a function of size, clamping geometry, temperature, and electrostatic tensioning. We find that the CVD graphene produces tensioned, electrically-conducting, highly-tunable resonators with frequencies in the megahertz. In addition, we demonstrate that clamping the graphene membrane on all sides reduces the variation in the resonance frequency and makes the resonance frequency more predictable[5].

While doubly clamped resonators typically show quality factors of 25-150, we find that the quality factor of fully clamped membranes show a striking improvement of the membrane quality factor with increasing size[6]. At room temperature, we observe quality factors as high as 2400 ± 300 for a circular resonator 22.5 microns in diameter.

Using electrically-contacted, doubly-clamped, graphene resonators, we find the resonance frequency is tunable with both electrostatic gate voltage and temperature. In addition, the quality factors improve dramatically with cooling, reaching values up to 9000 at 10 K.

These measurements show that it is possible to produce large arrays of CVD-grown graphene resonators with reproducible properties and the same excellent electrical and mechanical properties previously reported for exfoliated graphene. In addition, we also demonstrate that the quality factor of fully clamped graphene resonators relative to their thickness are among the highest of any mechanical resonator demonstrated to date.

References

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Figures

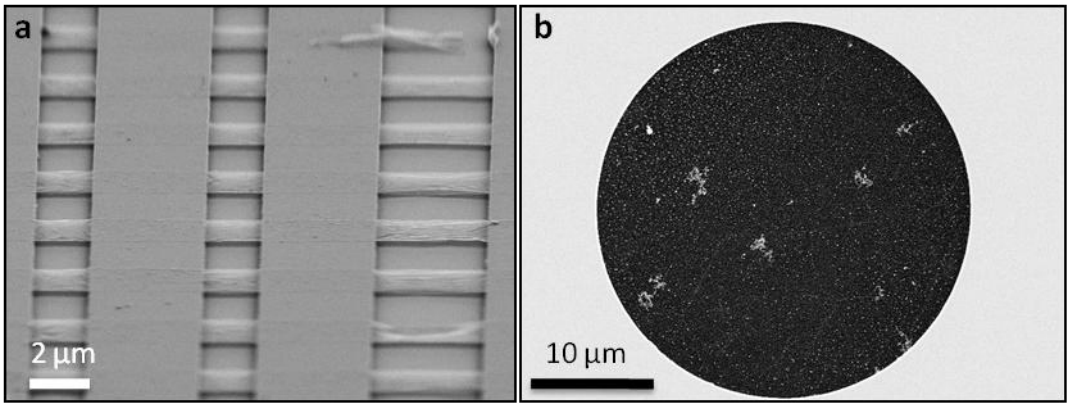

Figure 1: a) Angled SEM of array of doubly clamped single layer graphene membranes. b) SEM of large, circularly-clamped graphene membrane. Contaminants are clearly visible on the surface.