Supplementary information for "Coupling graphene nanomechanical motion to a single-electron transistor"

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This supplementary information includes the current anneal results, the Coulomb diamond, the comparison with a wider sample and larger dynamic range obtained from the wider sample.

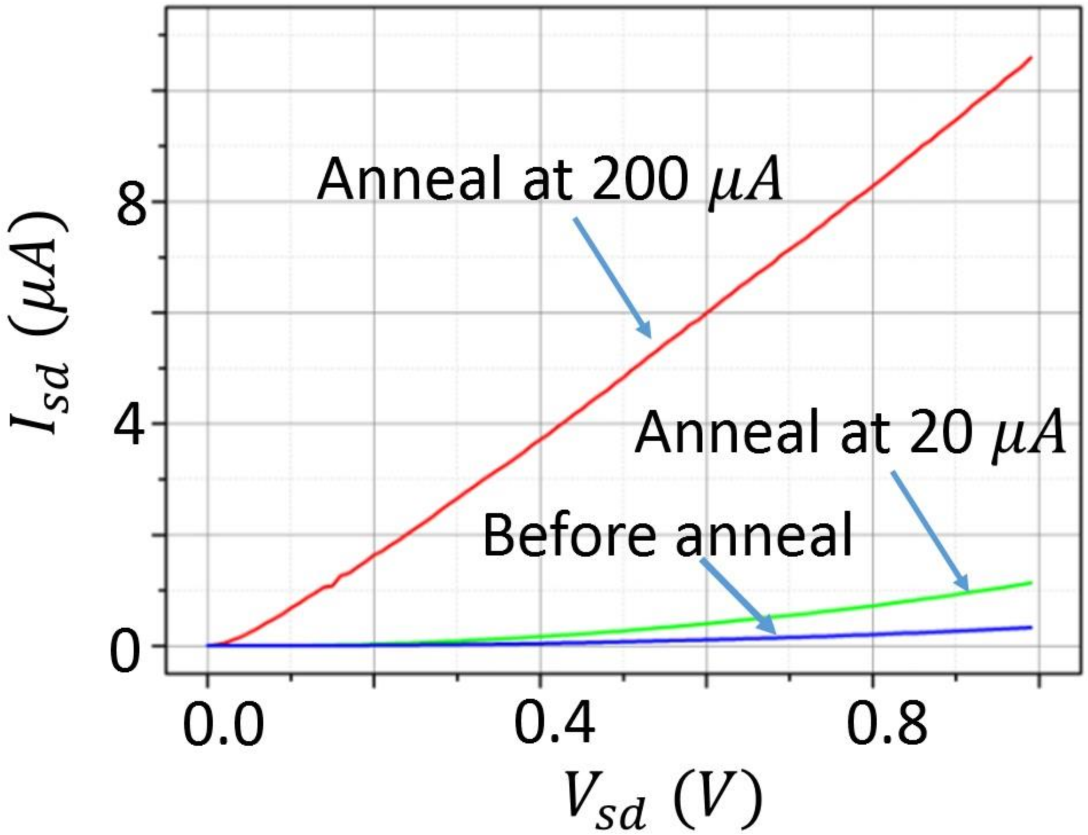

Figure S1: Current-voltage response after in-situ current annealing at low temperature.[1] The sample was annealed by fixing a large current flow for 3 minutes. The resistance at 0.5 V bias decreased from 10 MΩ (before anneal) to 83 kΩ (anneal at 200 μA).

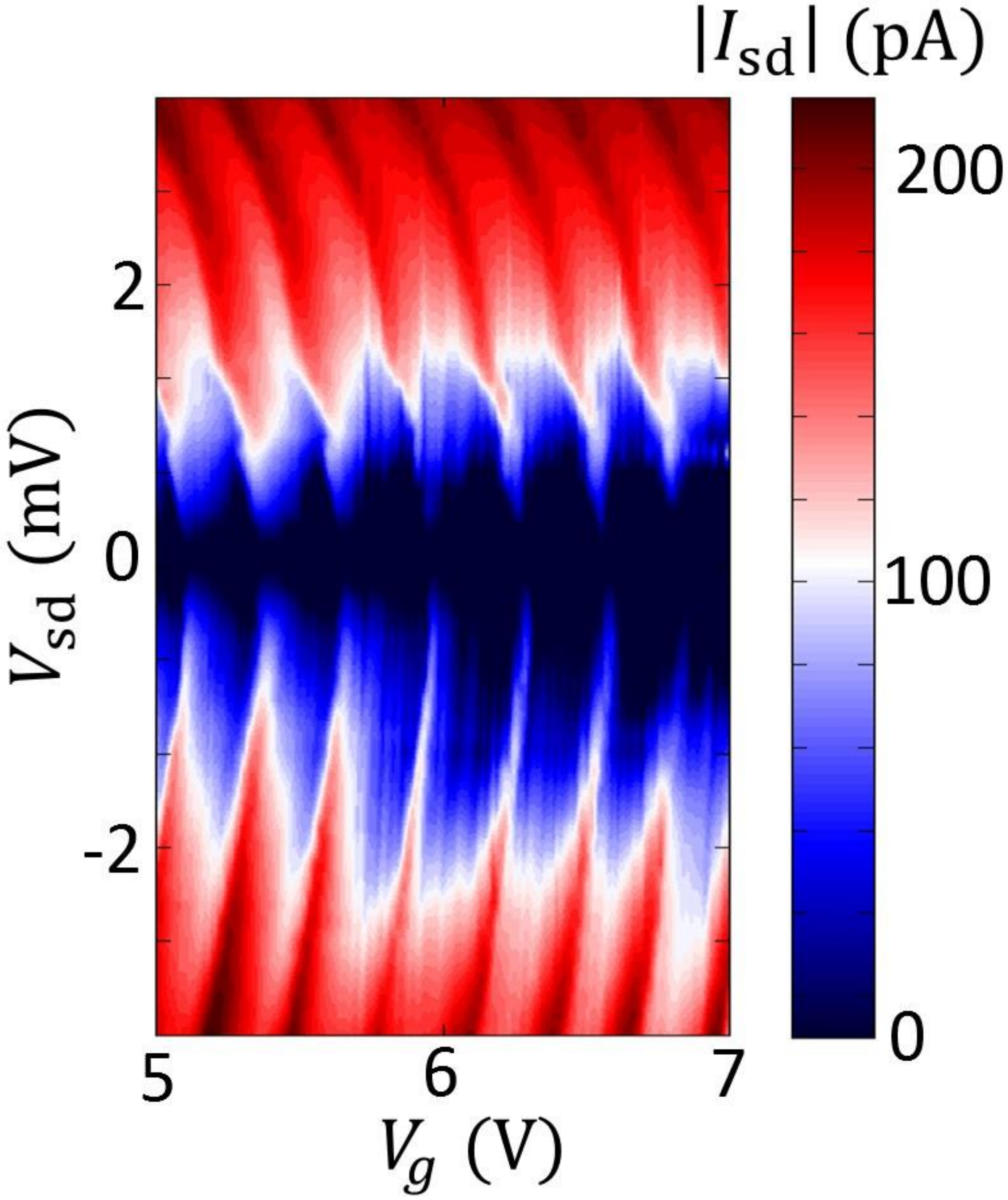

Figure S2: Coulomb diamond of the device used in the main-text. The charging energy is estimated to be approximately 1 meV, which is comparable to the etched quantum dots reported by our group.[2-4]

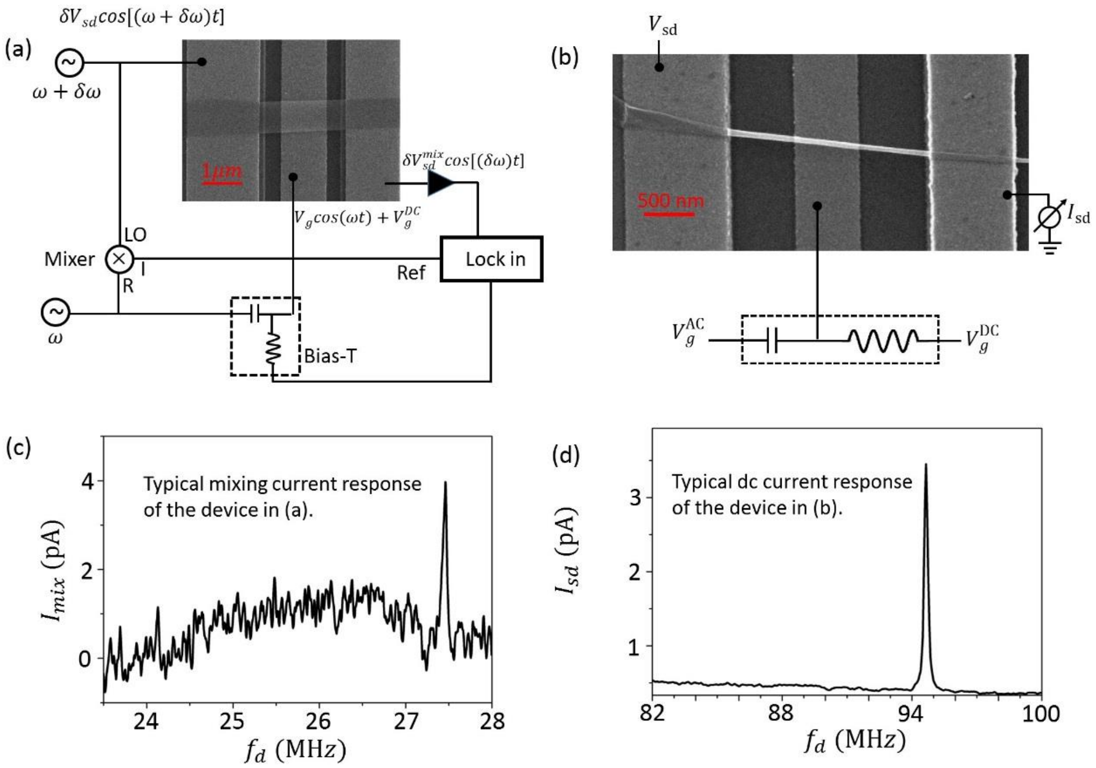

Figure S3: Comparison between a 5 layer, ~1-μm-wide resonator and the 50-nm-wide resonator (used in the main-text). (a) Typical mixing current measurement setup for graphene mechanical resonator.[5] One microwave source was used to apply microwave with frequency $\omega+\delta\omega$ to the source port and another source was used to apply microwave with frequency ω to the bottom gate; the resonator operated as a mixer and the mixing down signal with frequency $\delta\omega$ can be detected by a lock-in amplifier at the drain port. (b) Measurement setup used in the main-text. The setup is simpler compared to panel (a). A bias voltage was applied to the source port and a multi-meter was used to detect the transport current. (c) Typical mixing current response as a function of driving frequency for the 1-μm-wide resonator. We cannot obtain any resonance signal if we measure this sample by dc method used in panel (b). (d) Typical mixing current response as a function of driving frequency for the 50-nm-wide resonator. The quantum dot operates as a very sensitive detector and can easily reach a high signal to noise ratio.

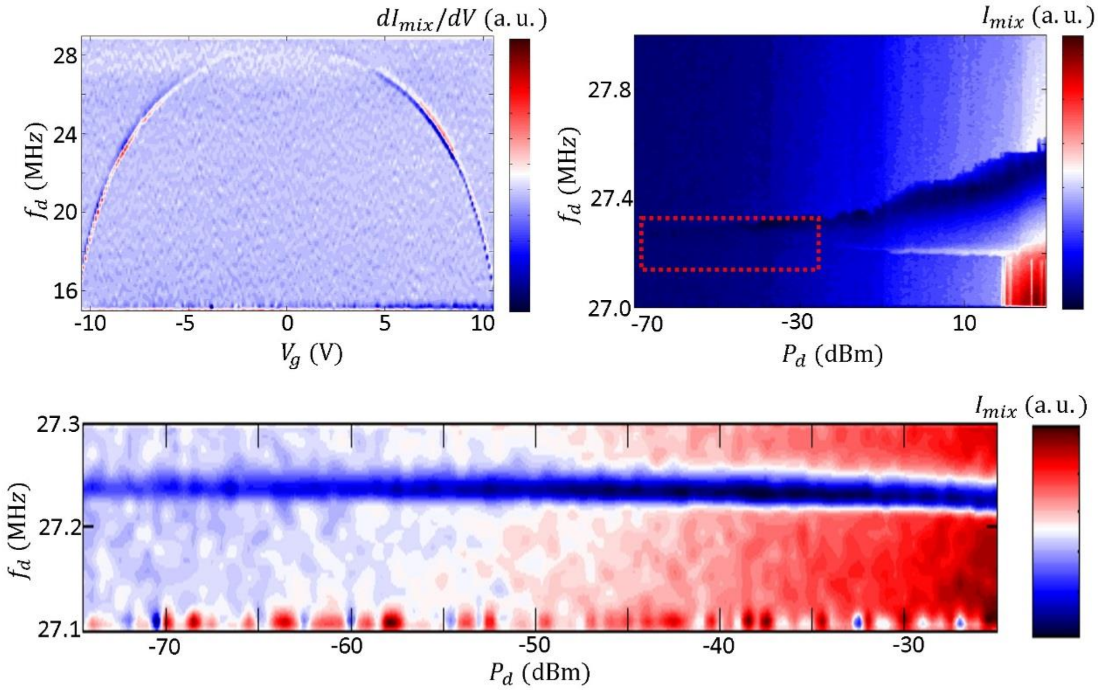

Figure S4: Resonance results of the ~1-μm-wide resonator. (a) Mixing current response as a function of the driving frequency and the gate voltage. (b) Mixing current as a function of the driving power and frequency, which shows Duffing nonlinearity at very large power. (c) Detailed measurement of the dashed boxed part in panel (b). We find a dynamical range at least 40 dB, before the existence of nonlinearity. The effective mass is estimated to be $m_{eff} \sim 3.7 \times 10^{-21}\ g$. The spring constant is obtained to be $k \sim 0.11$ N/m. With a quality factor of ~10000, we obtain a force sensitivity to be $F_{min} \sim 9.8 \times 10^{-19}$ N/(Hz)$^{1/2}$, and this value is about 3 times larger than that of the 50-nm-wide resonator (for force detection, the smaller F_{min} is, the better). The mass resolution is estimated to be $\delta m \sim 3.7 \times 10^{-21}\ g$.

Table S1: Comparison of the parameters between 1-μm- and 50-nm-wide resonators

width	Q	f_0 (MHz)	m_{eff} (kg)	k(N/m)	DR(dB)	$\delta m(zg)$	F_{min}[N/(Hz)$^{1/2}$]
50 nm	$\sim 3 \times 10^4$	~100	1.85×10^{-19}	0.05	20	0.55	1.9×10^{-19}
1 μm	$\sim 1 \times 10^4$	~20	3.7×10^{-18}	0.11	40	3.7	9.8×10^{-19}

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