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. 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.\textsuperscript{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. 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 $\omega$ 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 $\sim 1\text{-}\mu\text{m}$-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 $m_{\text{eff}} \sim 3.7 \times 10^{-21} \text{g}$. The spring constant is obtained to be $k \sim 0.11 \text{N/m}$. With a quality factor of $\sim 10000$, we obtain a force sensitivity to be $F_{\text{min}} \sim 9.8 \times 10^{-19} \text{N/(Hz)}^{1/2}$, and this value is about 3 times larger than that of the 50-nm-wide resonator (for force detection, the smaller $F_{\text{min}}$ is, the better). The mass resolution is estimated to be $\delta m \sim 3.7 \times 10^{-21} \text{g}$.

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

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

