Mechanical Friction Induced by Single Electron Transport

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Hybrid systems with mechanical and electronic degrees of freedom are a promising ingredient for quantum information devices owing to long-lived phonon states and accessible charge states [1]. Here, we investigate an electromechanical resonator embedded with a quantum dot (QD). The harmonic motion of the resonator can be regarded as a coherent phonon ensemble interacting with the charge states in the QD. The measured quality factor Q of the resonator shows enhancement and suppression on the sides of the Coulomb peak. Since Q characterizes mechanical damping of the resonator, our observation demonstrates variable mechanical friction induced by the single electron transport.

Figures (a) and (b) show our hybrid device. A doubly-clamped electromechanical resonator of 50 μm length is fabricated from a GaAs/AlGaAs heterostructure sustaining a two-dimensional electron gas (2DEG). At one clamping point of the resonator, the QD is defined in the 2DEG using negatively biased top gates [Fig. (b)]. The gate electrodes A and B at the other side are used to excite and detect the mechanical motion piezoelectrically. In this device, the charge states in the QD is mutually coupled with the resonator via a piezoelectric field associated with the mechanical motion.

The charge states in the QD can be controlled through gate voltage $V_{\rm g}$ and source drain bias $V_{\rm sd}$ as manifested by a typical Coulomb diamond [Fig. (c)]. On the other hand, the mechanical motion can be excited by applying ac voltage on gate A, and is detected through voltage spectral measurements on gate B. Figure (d) shows a typical power spectrum of a Lorentzian peak corresponding to the fundamental mechanical mode with the resonant frequency $f_0 \approx 1.67$ MHz. The quality factor Q can be determined from the peak width Δf ($Q = f_0/\Delta f$).

The measured Q on the left (right) hand side of the Coulomb peak [Fig. (e)] is enhanced (suppressed) to $Q \approx 2.8 \times 10^5$ ($Q \approx 2.0 \times 10^5$). This change is comparable to the intrinsic value $Q \approx 2.4 \times 10^5$ of the resonator. The enhancement (suppression) of Q originates from in-phase (out-of-phase) mechanical backaction from the QD to the resonator. This unique in-phase (out-of-phase) backaction serves as a negative (positive) friction, which amplifies (suppresses) the mechanical motion. The deviation of Q is observed only at $V_{\rm sd} \neq 0$ while it vanishes at $V_{\rm sd} = 0$, indicating that the single electron transport plays a vital role in causing additional friction in the electromechanical resonator.

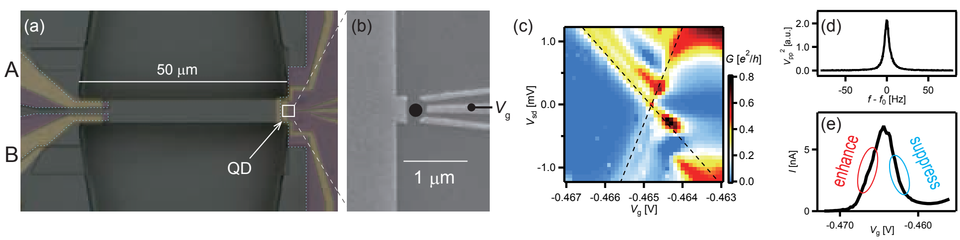

Fig.: (a) Optical and (b) electron micrographs of the device. (c) Coulomb diamond. (d) Power spectrum of the mechanical motion. (e) Coulomb peak at $V_{\rm sd} = 0.48$ mV.

[1] J.-M. Pirkkalainen *et al.* Nature **494**, 211 (2013).