Detection of Brownian-motion via a Quantum Dot Coupled to a Highly Miniaturized Mechanical Oscillator

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Coupling a single-photon emitter to a mechanical resonator is a promising route toward operations involving a single photon and a single phonon. The challenge lies in reaching the resolved-sideband regime with a large coupling rate and a high mechanical quality factor. Semiconductor quantum dots (QDs) can be coupled to mechanical motion via deformation potential coupling. So far, QD-mechanical coupling in the GHz-regime has been shown several times [1][2]. However, the coupling between the two systems could only be measured by external driving of the mechanical resonator.

Here, we approach this issue by coupling self-assembled InAs QDs to mechanical membrane-resonators with a large number of phonons, i.e, $\langle n_m \rangle$ = 58-3050. We present two mechanical resonator designs, see Fig. 1(a-b): a freely suspended beam [3], and a nanophononic crystal beam [4]. Our membrane design hosts a heterostructure diode to control and stabilize the QD's charge state. This results in narrow optical linewidths (≈450 MHz) and an increased mechanical sensitivity. Our nanostructure designs allow the investigation of QD coupling to mechanical modes from the unresolved- to the resolved-sideband regime.

We probe the Brownian motion at low temperature, 4 K, of the mechanical resonator via the resonance fluorescence from a single quantum dot. The mechanical noise imprinted on the QD's photons is extracted via an autocorrelation ($g^{(2)}$) measurement and subsequent Fourier analysis, see Fig. 1 (c-d).

The highest mechanical frequency that we report ($\Omega_m/2\pi$ = 1.466 GHz) exceeds the emitter's excited-state decay rate by a factor of ten, $\Omega_m \approx 10\Gamma_r$. Significantly, the mechanical quality remains at a high level, 2×10^3, due to the implementation of a phononic bandgap structure and low intrinsic losses. We determine a coupling rate per phonon from our simulations of up to $g_{ep}/2\pi$ =3 MHz. Together with the high mechanical frequency, this puts the system into the resolved sideband regime.

Our results represent a major step towards quantum control of the mechanical resonator via a single-quantum emitter.

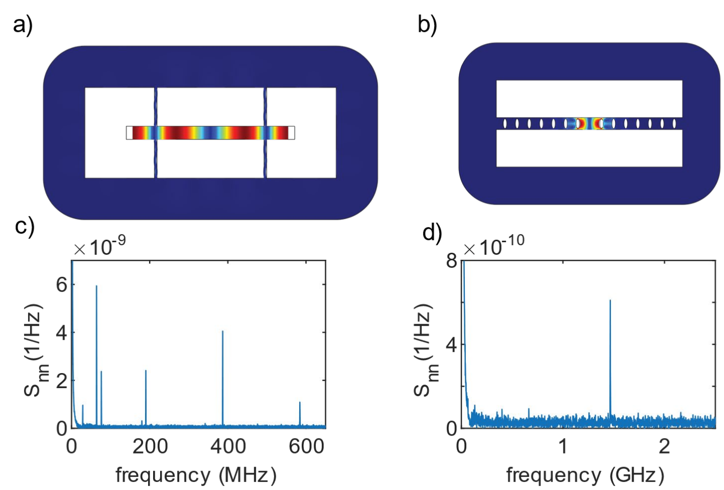

Fig.1. Normalised displacement profile of the mechanical membrane resonators simulated using COMSOL Multiphysics: **(a)** freely suspended beam, and **(b)** phononic crystal beam. For each resonator, the highest mechanical mode that we observe is displayed. **(c-d)** Brownian-motion measurements of the resonators shown above. A series of mechanical modes is observed in (a), one prominent in (b). The mode in (b) is well into the resolved-sideband regime.

References

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