Optomechanics at microwave frequencies: mechanical resonators coupled to microwave cavities and superconducting qubits

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Micromechanical resonators affected by radiation pressure forces allow to address fundamental questions on quantum properties of mechanical objects, or, to explore quantum limits in measurement and amplification. A new setup for the purpose is an on-chip microwave cavity coupled to a mechanical resonator (Fig. 1a). Under blue sideband irradiation, we demonstrate the possibility of building a mechanical microwave amplifier [1], with noise properties approaching the quantum regime. On the red sideband side, we show how one can couple mechanical resonators via the cavity bus, while simultaneously cooling the mechanical modes very close to the ground state of motion [2]. A recent development in linear optomechanics is the coupling of graphene membranes to microwave-frequency cavities. Here, we observe radiation pressure back-action on the motion of graphene.

One can add intriguing features to the basic optomechanics setup by including a superconducting qubit made with Josephson junctions. The nonlinearity of the two-level system allows for much more rich physics than is possible with linear cavities. We have realized a superconducting transmon qubit interacting with a micromechanical resonator [3]. We operate the qubit in the circuit cavity quantum electrodynamics (circuit QED) architecture, where the qubit is coupled also to a microwave cavity. Hence, the combined setup represents an artificial atom coupled to two different cavities (Fig. 1b). We measure the phonon Stark shift, splitting of the qubit spectral line into motional sidebands, and coherent sideband Rabi oscillations. Another motivation the tripartite system owes from the challenges to increase the single-quantum coupling strength to exceed the cavity dissipation rate. Motivated by this goal, we present a new design of the circuit optomechanical experiment, where the on-chip microwave cavity includes a Josephson charge qubit [4]. The cavity is coupled to a micromechanical resonator whose motion is visible as charge, and hence affects the cavity frequency. This way we were able to boost the coupling in the setup by six orders of magnitude up to the MHz regime.

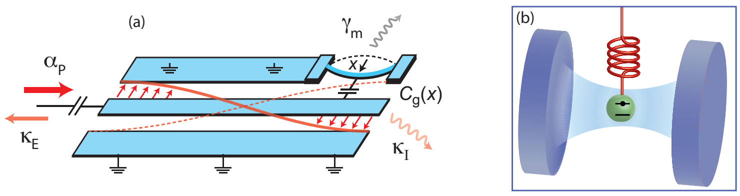

Figure 1: *(a) A microwave resonator can be coupled capacitively to an arbitrary number of mechanical resonators. (b) Idea of introducing nonlinearity in optomechanics. Inside the cavity (blue) there is a quantum two-level system (green) which is mechanically compliant (red).*

References

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