Contribution ID: **94** Type: **Invited Talk**

Hybrid quantum systems with ultrahigh-Q nanomechanical resonators

Tuesday 21 February 2017 10:12 (36 minutes)

We report a multimode optomechanical system with quantum cooperativity ▯_q = 4▯ˆ2/▯▯ ≫ 1 already at moderate cryogenic temperature T˜10 K [1]. Here, ▯ = ▯B▯/ℏ▯ is the quantum decoherence rate of the mechanical system, and Q˜10ˆ7 the mechanical quality factor. In this regime, the quantum backaction of the optical measurement dominates over the thermal Langevin noise. As a consequence, optical measurements create quantum correlations between the optical and mechanical degrees of freedom, which are measured as ponderomotive squeezing (-2.4 dB) of the light emerging from the cavity. In the multimode setting investigated here, we observe optically-induced hybridisation of mechanical modes, and the generation of squeezed light by hybrid modes [1].
Furthermore, we have implemented a hybrid system by combining this optomechanical system with a room-temperature atomic ensemble [2]. A light beam probes the spin state through Faraday interaction, and subsequently the motion of the nanomechanical membrane. We show that it is possible to cancel part of the measurement's quantum backaction by appropriately tailoring the light-spin, and subsequent light-mechanical interaction.
Finally, we report on the development of a novel type of membrane and string resonators with dramatically reduced decoherence [3]. By patterning a phononic crystal directly into a stressed SiN membrane we realise a "soft clamp"for a localised defect mode. Its engineered mode shape exhibits reduced curvature and therefore dissipation, reaching room-temperature Qf-products in excess of 10ˆ{14} Hz—the highest reported to date—as well as Q˜10ˆ9 at T˜4 K. The corresponding room temperature coherence time approaches that of optically trapped dielectric particles, and for cryogenic operation becomes comparable (˜1 ms) to that of trapped ions. Extensive characterisation through laser-based imaging of mode shapes [3] and stress distribution [4] confirms a model that quantitatively predicts the quality factors over a wide parameter range.

References

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