Circuit cavity electromechanics in the strong coupling regime

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arXiv:1011.3067

Optomechanically Induced Transparency

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Science **300**, 1520 (2010)

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The field of optomechanics has undergone a revolution in recent years with the successful harnessing of tiny radiation pressure forces to cool and control the motion of a variety of mechanical oscillators ranging in mass from kilograms to picograms [1,2]. A typical setup involves an optical cavity whose resonance frequency is parametrically coupled to the position of the mechanical oscillator. For example, one of the mirrors forming the cavity could be mounted on a flexible cantilever, or a flexible transparent membrane can be inserted into the middle of a cavity formed by fixed mirrors.

These ideas have recently been extended to the microwave regime using superconducting resonators coupled to a deformable mechanical element. In a beautiful paper, Teufel et al. have used sophisticated lithographic fabrication techniques to create an LC microwave resonator circuit in which one of the plates of the vacuum-gap capacitor has a mechanical drumhead mode with frequency of order 10 MHz. Because the plate spacing is only 50 nm, the capacitance is modulated relatively strongly by small motions of the drumhead. In this case the 7GHz electrical oscillator has its frequency shifted by a remarkable 56MHz for each nanometer of deflection of the drumhead mode. The quantum zero-point motion of the drumhead is vastly smaller than a nanometer yet still shifts the electrical resonance by 460 Hz. This shift is only about 1/2 of one percent of the electrical resonance line width. However by driving the electrical resonator with a tone red-detuned from the resonance by an amount equal to the mechanical frequency, Teufel et al. are able to enhance the effective strength of the parametric coupling. For moderate enhancements, the spectrum of transmission through the resonator shows a beautiful analog of EIT (electromagnetically induced transparency).

EIT was first seen in an optomechanical system in the recent remarkable paper by Weis et al. (See also the very recent interesting preprint by Safavi-Naeini et al. [3].) Building on this, Teufel et al. showed that for large off-resonant microwave driving, the system enters the strong-coupling regime where the effective coupling considerably exceeds the cavity line width. In this regime, the mechanical and electrical oscillators strongly hybridize and the spectrum of the resonator splits into two peaks.

The next step for the microwave experiments, already underway, will be demonstration of cooling towards the quantum ground state of the mechanical motion via the backaction of the microwave drive on the mechanical oscillator. In the quantum regime, the narrow EIT resonance could be used to produce the microwave analog of 'slow light' for storage of quantum states of the microwave field.

References:

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