Cavity Quantum Optomechanics with Optical Microresonator

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The mutual coupling of optical and mechanical degrees of freedom via radiation pressure has been a subject of interest in the context of quantum limited displacements measurements for Gravity Wave detection for many decades. The pioneering work of Braginsky predicted that radiation pressure can give rise to dynamical backaction, which allows cooling and amplification of the internal mechanical modes of a mirror coupled to an optical cavity. Experimentally these phenomena remained however inaccessible many decades due to the faint nature of the radiation pressure force. In 2005, it was discovered that optical microresonators with ultra high Q, not only possess ultra high Q optical modes, but moreover mechanical modes that are mutually coupled via radiation pressure(1). The high Q of the microresonators, not only enhances nonlinear phenomena – which enables for instance optical frequency comb generation(2) as well as temporal soliton formation via the Kerr nonlinearity – but also enhances the radiation pressure interaction. This has allowed the observation of radiation pressure phenomena in an experimental setting and is an underlying key principle of the now fast developing research field of cavity quantum optomechanics(3, 4).

Figure: SEM image of a toroid resonator and the optomechanical coupling between the optical and mechanical degree of freedom mediated by radiation pressure.

In this talk, I will describe a range of optomechanical phenomena that we observed using high Q optical microresonators. Radiation pressure back-action of photons is shown to lead to effective cooling(5-8) of the mechanical oscillator mode using dynamical backaction. Cooling to the quantum regime is possible using sideband resolved cooling, with passive of cryogenic precooling to ca. 700 mK, which enables cooling the oscillators such that it resides in the quantum ground state more than 1/3 of its time(9). Increasing the mutual coupling further, it is possible to observe quantum coherent coupling(9) in which the mechanical and optical mode hybridize and the coupling rate exceeds the mechanical and optical decoherence rate (7). This regime enables a range of quantum optical experiments, including state transfer from light to mechanics using the phenomenon of optomechanically induced transparency(10). In addition experiments are described that utilize the optomechanical coupling for highly efficient force measurements using nanomechanical oscillators(11), as well as elements enabling switching, slowing or advancing of radiation(12). The optomechanical toolbox developed in the past years enables to extend quantum control to mechanical oscillators. New frontiers that are now possible include the generation of non-classical states of motion via post-selection(13) as well as the use of ground state cooled oscillators to create quantum limited amplifiers that use the damped mechanical oscillator as a engineered reservoir(14).

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