Optoacoustic quantum signal processing

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Abstract: We use the interaction of light with acoustic vibrations, in particular stimulated Brillouin-Mandelstam scattering (SBS), to store and process optical information. We present the experimental realization of cavity-free strong coupling between groups of photons and phonons in a continuous optoacoustic system. We experimentally demonstrate efficient cooling of traveling acoustic phonons from room temperature and propose a Brillouin-mediated entanglement scheme that is particularly resilient and high-temperature-implementable. Acoustic waves can also serve as efficient memory – a concept we use to store few-photon states.

Photonics has the potential to advance modern quantum technologies and high-speed applications such as communications and the processing of large amounts of data. A new promising approach to manipulate light all-optically is to use the link of optical waves with acoustic vibrations. Our research experimentally investigates how traveling sound waves can be used to process states of light in the classical and quantum regime.

Via the nonlinear effect of stimulated Brillouin-Mandelstam scattering (SBS), acoustic waves can be created all-optically by counter-propagating optical signals. In the context of optomechanics, light has successfully been strongly coupled to discrete mechanical resonances of an optomechanical cavity [1]. In our work, we make use of anti-Stokes SBS to demonstrate cavity-less strong coupling in an optical waveguide [2]. In this process, energy from the acoustic field is transferred to the scattered blue-detuned photons. We observe mode-splitting of the system under a strong pump (Fig. 1 (a)), which is one of the signatures of the system entering into the strong coupling regime and is well confirmed by our theory (Fig. 1 (b)) [3,4]. With a novel experimental technique, we perform forced detuning measurements, which allow to measure avoided crossing points - a signature of strong coupling - in waveguides (Fig. 1 c). In order to enter the regime of quantum signal processing, cooling of traveling acoustic phonons is an essential precondition and we show experimental results of optomechanical cooling by 220K starting from room temperature [5] and from 77K [6]. This experimental work will path the way to optical-fiber-based and chip-integrated quantum optoacoustic control for application to photon-phonon entanglement [7] and quantum memory [8]. With help of acoustic waves, we also implement several building blocks for photonic neuromorphic computing [9-11], working in the frequency and spatial domain such as for orbital angular momentum modes [12-14].

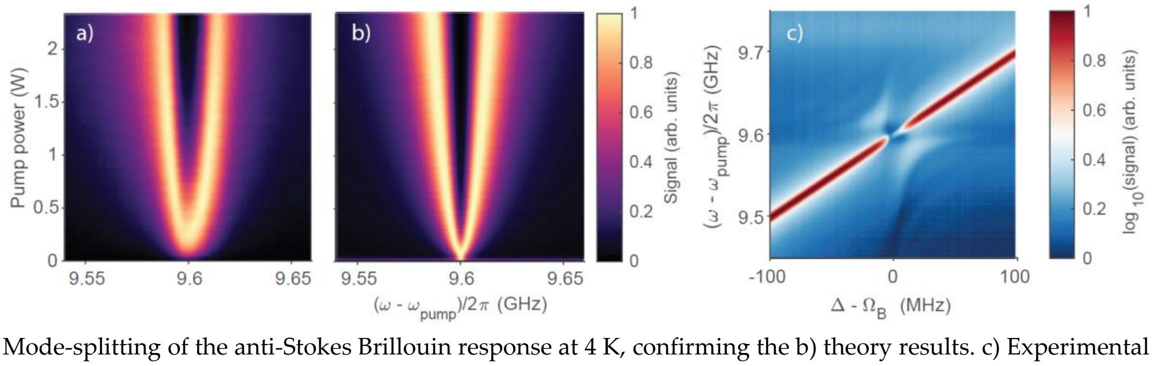

Fig. 1 a) Mode-splitting of the anti-Stokes Brillouin response at 4 K, confirming the b) theory results. c) Experimental result of the avoided crossing point at the anti-Stokes resonance.

References

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