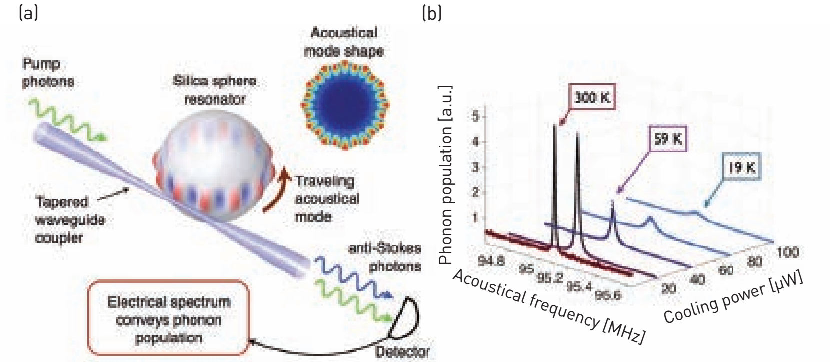
OPTICAL COOLING

Experimental Observation of **Spontaneous Brillouin Cooling**

Researchers can optically cool solids at the scale of individual atoms with fluorescence techniques, and the vibrations of entire devices with optomechanical techniques.[1,2] Our team developed a cooling method for the intermediate regime between atomic and device scale. This technique allows us to cool collective atomic motion in the form of acoustical waves by inverting the energy flow in the Brillouin scattering light-sound interaction.[3] In such interactions, incident photons are scattered to redder (Stokes) or bluer (anti-Stokes) frequencies, while heating or cooling the medium as required by energy conservation. It was thought that this cooling-heating balance is always tilted towards heating as governed by Planck distribution,[4] which is indeed true in bulk media where all photons are almost equally transmitted.

Brillouin cooling can be used in ultra-high Q optical microcavities, which allows selective resonant enhancement of the cooling anti-Stokes transition while rejecting the Stokes transition. In 2009, scientists achieved Brillouin Stokes scattering in such whispering gallery mode (WGM) optical resonators along with exciting 11-17 GHz vibrations.[5] However, phonons at these frequencies suffer from short lifetimes that preclude their ability to be cooled, since the relatively long-lived anti-Stokes photons can generate more phonons by scattering back to Stokes frequencies.

Our work showed that reversing the spatial scattering direction from back-scattering to forward-scattering enables access to lower frequencies where the acoustical Q (or phonon lifetime) is high. We measured an acoustical Q of 12,300 for a 95 MHz mode, bringing the Brillouin interaction into a regime where cooling is possible in accordance with the phonon-photon lifetime requirement.[3]



(a) Light is coupled in and out of the optical WGMs by a waveguide. Phonons are removed from the acoustical WGM by the anti-Stokes Brillouin scattering process, resulting in cooling. The beat note between pump and anti-Stokes photons provides phonon population measurement. (b) Phonon population decreases as a function of the input optical power. Linewidth broadening and the total area of the phonon population spectra are convenient measures of effective temperature of the acoustical mode.

Our experiment was based on a spherical fused-silica resonator with ultra-high optical Q of about 10^8 pumped at 1.5 μm. The device supports two optical WGMs and an acoustical WGM phase-matched to facilitate Brillouin scattering. The optical modes enhance cooling (anti-Stokes scattering) when the lower energy mode is pumped. This photon scattering removes phonons from the acoustical mode, broadening the acoustic linewidth, which helps to infer temperature.

Contrary to the belief that nonlinearity is enhanced with increasing pump power, the amount of scattered light decreases due to the waning Brownian phonon population. By measuring scattering from the thermal Brownian fluctuations, Brillouin scattering was shown to cool an acoustical mode from room temperature to 19 K with only 100 μW input power. OPN

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