Using optomechanics to store light

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When radiation pressure couples photons and phonons, vibrations can be used as a memory for light pulses.

Light is an ideal candidate for information processing and transmission. Optical interconnects open possibilities for unique parallel computing architectures, as well as information transmission capacity orders of magnitude higher than that attainable by copper wire. However, one obstacle to all-optical information processing is the difficulty of storing light.

To date, several avenues for light storage have been explored. Using atomic degrees of freedom, light can be stored in spin excitations or electronic energy excitations. Light has also been stored in the acoustical mode of a fiber and in photonic crystals. Despite these successes, significant drawbacks remain. Atomic systems can store light only at specific wavelengths, making them difficult to tailor to systems that use many wavelengths. In addition, acoustical modes in a fiber damp quickly, limiting storage lifetime.

We have demonstrated a new technique for light storage in an optomechanical resonator, where light in a cavity couples to a mechanical vibration via radiation pressure. Optomechanical light storage has a unique property that the mechanical mode can couple to any optical mode of the resonator. This allows for light to be read in and out of the system at almost any desired wavelength. Additionally, optomechanical systems can be fabricated with much lower damping than other systems, allowing significantly longer storage times.

We use a fused silica microsphere as a physical realization of an optomechanical system. Our 30μm-diameter spheres support optical whispering gallery modes (WGMs), where the light orbits the inner circumference of the sphere at glancing angles (see Figure 1). These spheres are in the resolved-sideband (RSB) regime, meaning the width of the optical mode is much smaller than the mechanical breathing mode frequency of the sphere.

The procedure to store light involves three pulses: a signal pulse (to be stored), a writing pulse, and a reading pulse. The signal pulse arrives at the microsphere simultaneously with the writing pulse, which causes the combined light to ‘blink’ (beat) on and off at the vibrational resonance frequency. This facilitates conversion of the signal pulse to mechanical vibration of the sphere via radiation pressure. At a later time, the reading pulse reverses the process, extracting the original signal pulse from the mechanical vibration.

Light in WGMs couples to the radial breathing modes of the sphere through radiation pressure. When vibrations are present in the sphere, they modulate the intracavity optical field, creating sidebands spaced one mechanical mode frequency above (anti-Stokes) and below (Stokes) the central laser frequency. Photons move from the central input laser frequency to the

Figure 1. (a) Evanescent wave from a tapered fiber couples light into the whispering gallery mode (WGM) of a microsphere. (b) Radiation pressure force ($F_{rad}$) imparted by internal reflections. (c) WGM perspective. (d) Finite element simulation of mechanical breathing mode.

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ant-Stokes sideband by absorbing a phonon, while photons in the Stokes sideband move from the central input frequency by generating a phonon.

At the beginning of the storage process, the simultaneous presence of a signal pulse at the optical resonance frequency and a writing pulse tuned one mechanical frequency below the optical resonance in an initially non-vibrating sphere creates a beating of the optical field at the mechanical resonance frequency. The beating of the optical field coherently drives a mechanical oscillation by means of radiation pressure, effectively mapping the signal field intensity into a mechanical vibration.

At a later time, a reading pulse tuned to one mechanical frequency below the optical resonance is sent to the sphere. The presence of the reading pulse in the now vibrating sphere creates anti-Stokes and Stokes sidebands. The RSB regime ensures that the Stokes sideband is strongly suppressed since it is far away from the optical resonance, while the anti-Stokes sideband is enhanced since it sits on the optical resonance frequency (see Figure 2). The generation of the anti-Stokes sideband from the mechanical vibration is the recovery of the signal field.

We demonstrated light storage in a sphere with a mechanical damping rate of 38kHz, providing light storage for up to 15μs (see Figure 3).3

In conclusion, light storage through optomechanics offers a promising avenue for future technologies. In addition to long storage lifetimes, the presence of many optical resonances in optical resonators allows optomechanical light storage to map many wavelengths to a mechanical excitation, and read them out at any other wavelength. Thus, light storage can also be used for wavelength conversion, an endeavor we are currently pursuing. In the future, we hope to use arrays of optomechanical cavities to store phase information of light, opening the door for quantum state transfer and quantum computation.

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References