Micro-optomechanical device vibrates at record rates

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Optical electrostriction in microelectromechanical systems enables vibration at 11GHz and allows resonance frequency scaling with wavelength rather than device size.

Devices resonating both optically and mechanically can exhibit coupled mechanical and electromagnetic modes.1 Optomechanical interactions have recently been mediated through light forces applied to one of the device elements. However, as a result, the resonant frequency of microelectromechanical systems (MEMS) has become inherently limited by miniaturization of the relevant element, while the vibration frequency is determined by the element’s sound-crossing time. For example, to generate > 1GHz vibration, fabrication resolution of better than 1μm is generally needed.

To scale mechanical-vibration frequencies irrespective of fabrication resolution, we need to apply the driving force on smaller scales than the device size. Optical electrostriction is another type of radiation pressure operating in bulk materials. However, its exploitation has not yet been reported in MEMS. In the context of optical electrostriction, incoming light can define a train of virtual electrodes with spacings related to the operating wavelength and independent of device size. These virtual electrodes can collectively apply the electrostrictive force needed to excite a high-frequency mode. The resulting mechanical mode (the time-varying strain) photo-elastically changes the optical dielectric constant, which leads to scattering of light. The difference between the frequencies of the scattered and input light is the mechanical frequency, which is set by the mechanical-mode-induced Doppler shift.2 For this process to work in a resonator, all three frequencies (the pump, red Doppler-shifted light, and mechanical-vibration frequencies) must be device resonances.

We excited a very-high-order mechanical mode using optical electrostriction.3 The resulting mechanical deformation caused approximately 1000 acoustical wavelengths to resonate along the equatorial line and propagate azimuthally (‘west’): see Figure 1. We designed and fabricated a spherical resonator with optical resonances at both the pump and red Doppler-shifted frequencies. We experimentally demonstrated and theoretically calculated a mechanical mode at 11GHz, excited by an optical mode, which we probed optically through beating between the incoming (pump) and red Doppler-shifted (Stokes) light scattered from the mechanical vibration.

Our experiment (see Figure 1) used a 100μm-diameter spherical whispering-gallery-mode cavity made of a silica fiber with CO2-laser reflow.4 The sphere exhibited an optical quality factor of 300 million, measured from the resonance width. A pump laser was coupled via a tapered fiber5 to an optical whispering-gallery resonance, providing the power to drive the mechanical mode. The scattered signal from the mechanical mode was backward-coupled, while the pump was forward-coupled. We, therefore, had the freedom to measure both outputs (Stokes signal and transmitted pump) separately.

To show excitation of mechanical modes at X-band (11GHz) rates, we measured the frequency with a photodiode connected to an electrical-spectrum analyzer. Combining forward and

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backward outputs allows measuring the mechanical frequency through the optical beat note between pump and Stokes signals. The measured frequency (linewidth 0.7MHz)—see Figure 2(a)—deviated only 2% from that calculated numerically for the mechanical mode, which is well inside the experimental error for measuring the size of our device. We then measured the power of the scattered optical signal as a function of the input power—the powers as $\omega_s$ and $\omega_p$ in Figure 2(b), respectively—to provide a slope efficiency of 90%, starting at a 26μW threshold: see Figure 2(c). Part of the light is monitored continuously during our measurements (with an optical-spectrum analyzer) to verify that the cavity is devoid of other optical effects.

In summary, to increase the frequencies of photonic MEMS we exploited optical electrostriction. Our MEMS operates continuously at room temperature and pressure. The vibration is self-excited, without any need for external modulation or feedback. Our approach allows excitation of high frequencies and scales inversely with optical wavelength, irrespective of device size. We will next explore shorter-wavelength UV lasers and materials with fast sound velocity, which will allow future photonic MEMS vibrating at frequencies > 100GHz.

**References**