Room-Temperature Quantum Optomechanics with an Ultra-Low-Noise Cavity

RESEARCHERS

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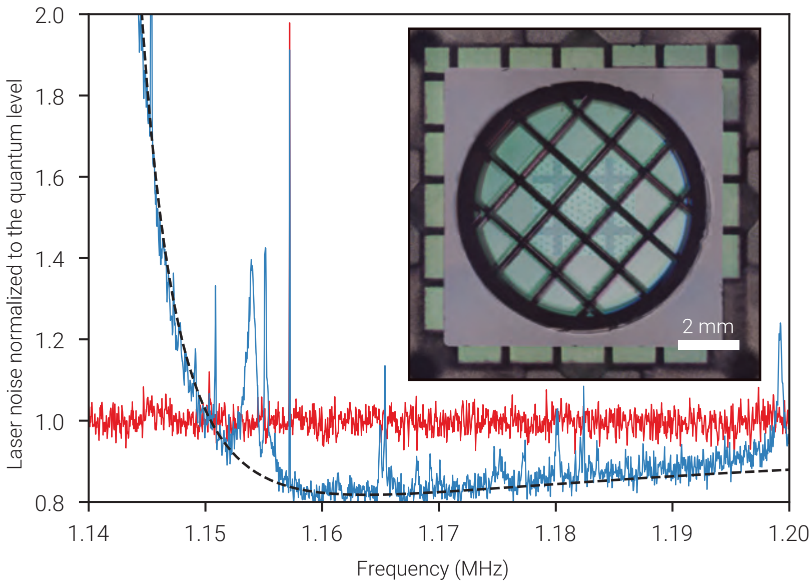
In recent decades, physicists have harnessed the radiation pressure of light to control macroscopic vibrations of microscale and nanoscale objects at the quantum level. This technique, which has developed into quantum optomechanics,[1] has led to new quantum sensors and experimental tests for fundamental physics at the macroscopic scale.

Achieving this level of precise quantum control at room temperature has been a longstanding challenge, both as a scientific goal and for practical reasons, as it would eliminate the need for cryogenic cooling and open the door for real-world applications. The challenge lies in distinguishing the subtle forces caused by the quantum fluctuation of light from the significant thermal forces present in the room-temperature environment. Moreover, elevated thermal fluctuations can lead to entirely different physical phenomena compared with those at cryogenic temperatures.[2]



Quantum noise reduction of light achieved in room-temperature experiments. Inset: Optical-microscope image of the device, consisting of two periodically cut mirrors sandwiching a drum that has nanopillars on the surface.

In work published this year,[3] we achieved multiple technical breakthroughs to allow the first observation of the quantum force of light at room temperature in a solid-state nanomechanical system. First, our team created a drum[4] that is significantly better isolated from the room-temperature phonon bath than previous designs. Next, we employed an optical cavity to greatly amplify the quantum force of light on the drum by several thousand times. To remove the thermal motion of the cavity mirrors as a source of noise, we patterned the mirrors with a periodic phononic crystal structure to form an acoustic band gap, reducing the noise at the frequency of the drum by about a thousand times. Finally, we used a specialized optical homodyne measurement technique to avoid unwanted nonlinear noise that arises at room temperature.

Our key result is that we successfully observed the quantum effect of light on our millimeter-scale, 7-ng drum, even at room temperature. We were able to squeeze the probing laser's noise below the laser shot noise, as the drum's motion is significantly influenced by the quantum fluctuation of light. Additionally, we measured the drum's motion to within a factor of 2.5 of the fundamental quantum limit on measurement precision, known as the Heisenberg limit.

We believe our study provides valuable insights into the physical processes that must be accounted for when performing quantum measurements with macroscopic objects at room temperature. Our mirror designs could be useful in other research areas where thermal vibrations pose fundamental limits to precision measurements. OPN