Active-Cavity Laser Optomechanics

The coupling of an optical field and a mechanical oscillator through forces induced by light has been a subject of long-standing interest and an important tool to study fundamental physics. Numerous experiments have used light-induced forces in optical cavities to demonstrate phenomena such as laser cooling and regenerative oscillation. The prevalent research focuses on passive optomechanics, in which a passive optical cavity housing a mechanical oscillator interacts with a population of circulating photons produced by an external laser.

In 2015, we experimentally demonstrated a scheme with an active optical oscillator (laser) and mechanical oscillator integrated in the same cavity. The resultant impacts are twofold. First, this marks a new era for optomechanics, from passive to active cavities. Compared with a typical passive optomechanical system, active cavities show an orders-of-magnitude stronger light–matter interaction, with regenerative mechanical oscillation having an amplitude 1,000 times larger than typical.

Second, the optomechanical laser is able to self-sweep its wavelength across 23 nm without any need for external modulation. The sweeping frequency can be as large as a few megahertz. This fast, wide-range laser self-swept source is ultra-efficient in power consumption and super compact—exactly what is needed for frequency-modulated continuous-wave lidar, optical coherence tomography and 3-D cameras.

The optomechanical laser is implemented by a high-contrast-grating (HCG), electrically pumped vertical-cavity surface-emitting laser (VCSEL) at 1,550 nm. The HCG is an ultra-lightweight (130 pg) grating with near-wavelength period and less than 200 nm thickness, designed to reflect more than 99.5 percent of the surface-normal light and serve as the top mirror of the VCSEL. The mirror is held by a micromechanical spring.

Once the VCSEL is DC-biased above threshold, the laser causes the HCG to move by radiation pressure. This optomechanical coupling can sustain self-oscillation of the HCG mirror with an unprecedented amplitude of more than 550 nm. We believe that the work could open up new research and applications.

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