MILESTONE 23

Mirror finish

Mirrors in the GEO600 gravitational wave detector. Image courtesy of Wolfgang Filser/Max Planck Society

Mirrors have a supporting role in most physics and astronomy research. When light strikes a mirror, it is usually reflected to somewhere more interesting — photons from a distant star, for example, might be focused onto a detector, or the beam from a nearby laser might be redirected to cool an atomic gas. But what happens to the mirror? This question is ignored in most research; however, in a small number of fields — such as the detection of gravitational waves and cavity optomechanics — the influence of the photon on the mirror is extremely important.

In an optical cavity or interferometer formed by two highly reflecting mirrors, momentum is transferred from the photons to the mirrors each time a photon is reflected. This 'radiation pressure' is usually insignificant compared with thermal fluctuations and other effects. However, it imposes limits on the performance of the kilometre-scale laser interferometers that have been built to detect gravitational waves, given that these devices have to measure exceedingly small changes in the distances between the mirrors.

Cavity optomechanics, by contrast, exploits the interactions between photons and mirrors in table-top experiments that should, one day, be able to shed new light on the boundary between classical and quantum mechanics. Moreover, cavity optomechanics might allow quantum behaviour to be observed in a macroscopic system, although a number of rival approaches are also closing in on this goal.

A typical cavity-optomechanics experiment consists of an optical cavity in which one of the mirrors is free to move, for example because it is mounted on a cantilever. When a laser beam is shone into the cavity, the light bounces back and forth between the mirrors, and the position of the 'free' mirror changes due to radiation pressure and thermal fluctuations. This changes the length of the cavity and, hence, its resonant frequency, which in turn changes the optical intensity in the cavity. When the frequency of the laser is lower than the nominal resonant frequency of the cavity, the overall effect is to cool the mirror by reducing thermal fluctuations. This process is called dynamical back-action (conversely, when the laser frequency is higher than the resonant frequency, the motion of the mirror is amplified).

In 2006, Markus Aspelmeyer and co-workers and, independently, Pierre-François Cohadon and colleagues used this approach to cool micromirrors mounted on cantilevers from room temperature to ~10 K; a third team, led by Tobias Kippenberg and Kerry Vahala, cooled a toroid microcavity by a similar factor. Reaching the quantum regime will require cooling to sub-Kelvin temperatures, which will necessitate increasing both the optical finesse and the mechanical quality factor of the experiments, whereas actually observing quantum behaviour will involve using photons to measure the position of the mirror while keeping the disturbance caused by radiation pressure to a minimum.

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