Sub-Kelvin Parametric Feedback Cooling of a Laser-Trapped Nanoparticle

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Abstract: We trap a nanoparticle in high vacuum and cool its center-of-mass motion with a single laser by active parametric feedback. The scheme paves the way for testing quantum mechanics with mesoscopic objects and ultra-sensitive metrology.

Most of the mechanical systems studied so far are directly connected to their thermal environment, which imposes limits to thermalization and decoherence. As a consequence, clamped systems require cryogenic precooling. A laser-trapped particle in ultrahigh vacuum, by contrast, has no physical contact to the environment, which makes it a promising system for ground state cooling even at room temperatures [2,3]. Cooling of micron-sized particles to milli-Kelvin temperatures has recently been achieved by applying an active optical feedback inspired by atom cooling experiments [4]. A particle is trapped by two counter-propagating beams and cooling is performed with three additional laser beams via radiation pressure. However, because light scattering leads to recoil heating there is a limit for the lowest attainable temperature. To eliminate recoil heating as the limiting factor for ground state cooling one requires considerably smaller mechanical systems, such as single dielectric nanoparticles [2,3].

Here we demonstrate optical cooling of a fused silica nanoparticle of radius $R \sim 70$ nm from room temperature (RT) to ~ 50mK (compression factor of $\sim 10^4$). The scheme makes use of the optical gradient force of a single laser beam to both trap a single nanoparticle and to cool it in all three spatial degrees of freedom. Our parametric feedback is fundamentally different from previous active feedback schemes based on radiation pressure, which required a separate cooling laser for every oscillation direction [4]. We demonstrate that an optically trapped nanoparticle in high vacuum can be efficiently cooled in all three dimensions by a parametric feedback scheme. The parametric feedback makes use of a single laser beam and is therefore not limited by alignment inaccuracies of additional cooling lasers. Trapping times of more 60 hours have been achieved at pressures below 10^{-5} mBar indicating that the particle's internal temperature does not affect the center of mass motion and that melting of the particle is not a concern. The damping rate depends linearly on pressure as shown for pressures down to 10^{-5} mBar, where we measure ~ 10 mHz. This corresponds to an unprecedented quality factor of $Q = 10^7$. At lower pressures it is expected to be correspondingly higher. High Q-factors are a prerequisite condition for quantum ground state cooling at RT.

References

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