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Levitated optomechanics in vacuum using hollow core photonic crystal fibers and optical cavities

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Abstract:

Optically levitated nanoparticles provide a promising platform for numerous sensing applications as well as fundamental tests of physics. This thesis explores novel approaches for manipulating and controlling such particles in different pressure regimes using nanophotonic structures and optical cavities.

In the first part, a novel optical trap for nanoparticles utilizing hollow core photonic crystal fibers is presented. The optical control and read-out allows particle transport over unprecedented distances and feedback cooling inside the fiber, which are relevant for loading nanoparticles into ultra-high vacuum. Using the levitated nanoparticle as a localized pressure sensor, also allows to directly study the hydrodynamic properties of the hollow core fiber channel. Our measurements are confirmed by DSMC simulations of the nonlinear Boltzmann equation and rule out previous, simplified models of the pressure distribution in narrow channels.

In the second part, an optically trapped nanoparticle is coupled to a Fabry-Pérot cavity at high vacuum. This is achieved by overlapping an optical dipole trap with the TEM00 mode of a compact high-finesse cavity. Three-dimensional feedback cooling inside the dipole trap allows stable operation of the optomechanical system in high vacuum. Compared to our previous experiments, the new architecture reduces the mechanical losses by at least six orders of magnitude and shows a promising route towards room-temperature quantum control.