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Development of a Hybrid Optical-Electrical trap for levitated nanoparticles for quantum sensing and fundamental science

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Levitated optomechanics, the trapping and control of microscopic and mesoscopic particles in vacuum, has seen recent and widespread success including record torque sensitivity [1], and yoctonewton force sensing [2]. A levitated nanoparticle is ideal for a ‘macroscopic’ quantum platform due to its intrinsic mass and low coupling to the environment. This presents an exciting avenue for fundamental physics with macroscopic objects as well as providing a system for unparalleled precision sensing [3].

The quantum regime for optically levitated systems is primarily impeded by the photon-recoil-shot-noise from the optical levitation field [4], prompting the use of “dark”, non-optical, potentials. Recently, optically levitated systems in vacuum have entered the quantum realm with recent demonstration of cooling to the motional quantum ground state using passive (2D) and active feedback (1D) methods [5, 6, 7]. From here the new frontier is to utilize dark potentials to create non-classical states of motion, requiring both an expansion of the wave-packet and a non-linear interaction. Recent proposals investigate [8] and analyse [9] a double-well dark potential which provides both requirements natively.

We approach this problem with a hybrid planar trap design with a Point-Paul-Trap electrode configuration natively providing a double-well dark potential, and large optical access for a parabolic mirror yielding high quantum measurement efficiency. We will present numerical simulations matching our experimental setup and propose a modified protocol to produce the double-well dark potential which should be robust against the micromotion that usually plagues Paul traps. Finally, we will present results from our experimental implementation, in particular the cooling of the centre-of-mass motion using optical and electrical means, and trapping with RF electric fields and optical potentials. An on-chip hybrid trap would provide state-of-the-art quantum enhanced sensing with both squeezed states and non-gaussian states.

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