

Optically levitated particles and controlling the Center-of-Mass motion by structured wavefronts

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Optically levitated particles have a great potential to form the basis of novel quantum enhanced sensors. These systems have been used to demonstrate force sensing down to 10^{-21} N [1]. Optical levitation is very well suited for inertial sensing as the particles are almost completely isolated from the thermal environment. However, there are many challenges in the experimental realization and one of them is aberrations in the optical wavefront that affect the performance of these systems [2]. The trapping potential gets distorted by aberrations from optical elements or misalignment and leads to loss of the particle or unwanted nonlinearities in the system. We use Spatial light modulator (SLM) to implement the Zernike polynomials in our system and compensate for the optical aberration in our experimental setup. By iteratively changing the polynomial coefficients, we maximize the frequencies of the center-of-mass (CoM) motion, and using the frequency ratios as quality measure of the tightness of the focused beam. Furthermore, this scheme provides us with a versatile control of the trapping potential, from choosing the effective NA of the objective lens by changing the size of the trapping beam, to controlling the frequency separation between the two transversal degrees of freedom of the CoM. This technique can be used to stably trap the particle in ultra-high vacuum and cool the CoM motion effectively.

- [1] Liang, T., et al., Yoctonewton force detection based on optically levitated oscillator. *Fundamental Research*, 2023. 3(1): p. 57-62.
- [2] Yu, J.; Mao, X. Correction of Wavefront Distortion in Common Aperture Optical Systems Based on Freeform Lens. *Photonics* 2025, 12, 103

Figures

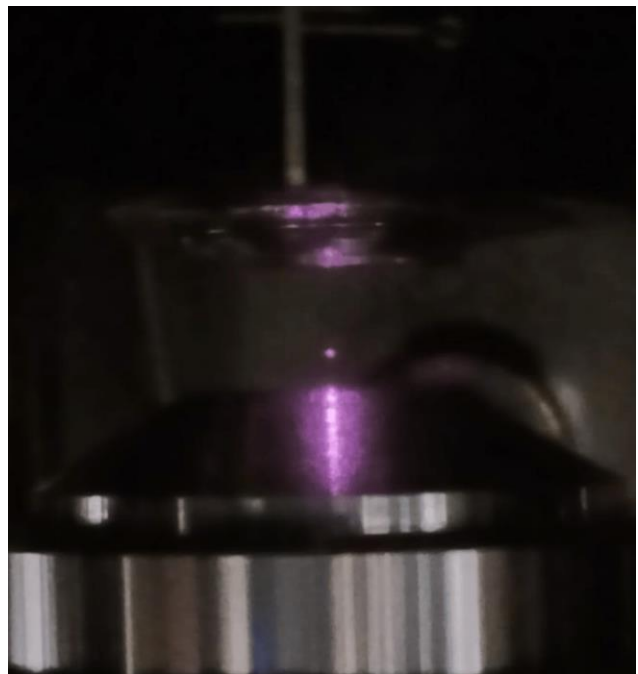


Figure 1: Optically levitated nanoparticle by a 1064nm laser beam inside a vacuum chamber. (Captured with mobile phone)

References