INNOVATIVE APPROACHES TO 3D MOTION CONTROL IN PLASMONIC NANOMOTORS WITH OPTICAL PULLING FORCES

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Momentum transfer in light-matter interactions gives rise to optical forces, which are pivotal in micro- and nanotechnology, especially for lab-on-a-chip applications [1]. While optical tweezers have been widely used to manipulate components like pumps and valves, their efficiency is frequently limited by the size, shape, and material properties of the objects they actuate. Recent advancements in nanomotor technology propose utilizing scattering forces from asymmetric plasmonic nanoantennas or dielectric metasurfaces to overcome these limitations [2,3]. These solutions have demonstrated success in enabling transverse two-dimensional motion. However, achieving control over motion along the longitudinal dimension remains a significant challenge [4].

Optical pulling forces, a phenomenon identified within the past decade, present a promising solution to this challenge. These forces, which require precise illumination and scattering conditions [5], have been theoretically realized using methods such as Bessel beams, plane wave pairs, and chiral light-matter interactions [6]. However, many of these strategies rely on impractical experimental conditions. A breakthrough by Li et al. in 2019 proposed the use of a dielectric cylinder to guide Bessel beams, thus enabling optical pulling effects over long distances with low-cone-angle Bessel beams, making the effect more feasible for practical use [7].

Here, we introduce a novel nanomotor design that facilitates both transversal and longitudinal motion control. Our system utilizes the coupling between an azimuthally polarized Bessel beam and a dielectric glass cylinder, which also serves as the structural chassis for the nanomotor. Asymmetric plasmonic dimers are embedded within the cylinder, arranged to minimize interaction with the pulling beam. This configuration allows lateral motion driven by scattering forces from the plasmonic dimers under plane wave illumination, while longitudinal motion is achieved through the optical pulling effect on the dielectric cylinder. The design provides enhanced flexibility in motion control, enabling pulling, pushing, and lateral movement by adjusting beam polarization or switching between different illumination strategies. Moreover, the optical pulling force in our system is resistant to external disturbances, including rotational and translational noise, thus improving its applicability for precision optical manipulation in practical scenarios.

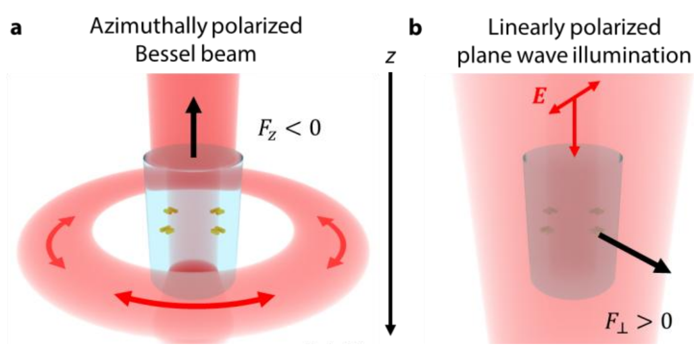

Figure 1 – Depiction of the nanomotor design, acting in its optical pulling (a) and lateral movement (b) configurations.

G. S. acknowledges funding from the Spanish government for his predoctoral contract grant (FPU21/02296). This work was funded by the MOPHOSYS Project (PID2022-139560NB-I00) from Proyectos de Generación de Conocimiento provided by the Spanish Agencia Estatal de Investigación.

REFERENCES

1. Glückstad, J., *Nature Materials* **3**(1), 9-10, 2004.
2. Tanaka, Y. Y., et al., *Science Advances* **6**(45), eabc3726, 2020.
3. Ardrén, D., et al., *Nature Nanotechnology* **16**(9), 970-974, 2021.
4. Wu X. et al., *Nature Nanotechnology* **17**(5), 477-484, 2022.
5. Chen, J., et al., *Nature Photonics* **5**(9), 531–534, 2011.
6. Li, H., et al., *Advances in Optics and Photonics* **12**(2), 288-366, 2020.
7. Li, X., et al., *Science Advances* **5**(3), eaau7814, 2019.