PHOTONICS INSIGHTS

Breaking boundaries in optical manipulation: beyond Nobel-Prize-winning tweezers

Pavana Siddhartha Kollipara[a] and Yuebing Zheng[a,b,*]
[a]Walker Department of Mechanical Engineering, The University of Texas at Austin, Austin, USA
[b]Materials Science and Engineering Program and Texas Materials Institute, The University of Texas at Austin, Austin, USA

Richard Feynman's famous 1959 lecture "There is plenty of room at the bottom" inspired scientists and engineers to focus on manipulating matter at the nanoscale[1]. Optical tweezers, groundbreaking tools that use light to trap and move small particles with nanoscale precision, have revolutionized many fields such as materials science, biology, physics, and nanotechnology[2,3]. For example, optical tweezers have enabled researchers to investigate the mechanical properties of biological molecules, study the behavior of colloidal suspensions, explore the movement of motor proteins, and investigate the directed assembly of nanoscale structures[4–6]. Furthermore, the combination of optical tweezers with other techniques such as fluorescence microscopy and microfluidics has led to the development of more sophisticated experimental setups and the observation of previously unobservable phenomena. While other manipulation techniques have emerged, optical tweezers have maintained their prominent position due to their unique attributes, including contact-free operation, real-time control, and the ability to manipulate multiple objects simultaneously. The versatility of optical tweezers, particularly in their application to biological systems, was acknowledged when the Nobel Prize in Physics was awarded to its inventor, Arthur Ashkin, in 2018. Optical manipulation techniques have come a long way since the advent of optical tweezers, with recent advancements overcoming many of the limitations of earlier methods. These advancements have resulted in expanded working modes, increased versatility in working environments, and the ability to target a wider range of materials[7,8]. Along with minimal sample damage and reduced optical power requirements, these advanced techniques have opened new avenues for scientific exploration and engineering applications.

In a recent review paper published in *Photonics Insights*, Min Qiu and colleagues provide an extensive overview of optical manipulation and its applications[9]. The authors begin by discussing the physics behind trapping forces and torques of laser beams in both Rayleigh and Mie regimes, as well as the origin of light-induced phoretic forces such as thermo-electricity, thermophoresis, and photo-phoresis. The authors also examine recent advances in optical manipulation on solid interfaces, including lattice oscillations and thermo-capillary forces. Furthermore, the authors summarize the experimental evidence for manipulating various particles using a combination of conventional optical tweezers and light-induced tweezing mechanisms such as opto-thermo-electric[10], opto-refrigerative[11], plasmonic[12], and electrohydrodynamic tweezers[13]. The authors also provide representative applications that define the scope of optical manipulation, ranging from gravitational wave detection to optical waveguides.

In addition, the authors discuss promising directions for the future of optical manipulation, including pulsed laser light, multiphysics coupling, and adhesive environments. Multiphysics coupling and adhesive environments are particularly promising, as they enable strong control over optical manipulation by synergistically controlling diverse force fields. The adhesive environment also allows researchers to reduce particle motion as the size approaches the nanometer scale, which opens new potential applications. However, implementing optical manipulation in solid media requires significant research and overcoming theoretical and experimental obstacles, such as developing a modeling framework and preparation protocols[14].

In conclusion, this review paper provides a comprehensive and timely guide for researchers, whether they are new to or experienced in the field of optical manipulation. It covers fundamental concepts and describes various applications of optical manipulation. The paper is a valuable resource for those seeking to deepen their understanding of the field or explore new research directions.

*Address all correspondence to Yuebing Zheng, zheng@austin.utexas.edu

 [DOI: 10.3788/PI.2023.C04]

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