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Editorial

Special Issue on Light Control and Particle Manipulation: An Overview

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Since Dr. Arthur Ashkin first proposed and demonstrated optical tweezers, they have been widely studied in the fields of chemistry, biomedicine, and physics to measure the properties of particles, identify cancer cells, and investigate the interactions between light and matter. In recent years, we have witnessed rapid developments in the use of structured light with specific polarization, amplitudes, and phases in optical tweezers. Structured light adds more possibilities for optical trapping, facilitating more diversified particle manipulation, such as rotating, pushing, and pulling. Meanwhile, structured materials possess localized or discrete modulation capabilities, providing new opportunities for the generation of structured light and expanding the degree of freedom for particle manipulation. This Special Issue, "Light Control and Particle Manipulation", was created to demonstrate the latest research and innovations in the field. Based on the three topics, we compiled the following sixteen original research papers and one review.

Conventional optical tweezers primarily use optical gradient force produced by a tightly focused laser beam to capture microparticles. This requires a series of complex optical devices to modulate the beam to extend the range of optical manipulation. Nowadays, with the rapid advances in photonics, novel structures, systems, models, and devices have been proposed to realize optical trapping. Li et al. used a high-reflective-index core–shell structure to excite high-order multipoles and explored the interaction between different order multipoles [1]. They found that when two specific multipoles are equal and dominated, there exist some scattering angles that can increase the spin Hall shift, which provides new insights to understand the interaction between light and particles. Pu et al. designed a microparticle vacuum chamber based on the micro-electro-mechanical system [2]. They proposed a detection technique with an electromagnetic drive without outer lead bonding. By monitoring the air pressure in the chamber, it is possible to provide a precise vacuum environment for the optical levitation and rotation of microparticles. Bai et al. used an annular slit to excite surface plasmon polaritons under the irradiation of vector light fields [3]. Under the irradiation of symmetrically linearly polarized beams, the rotation and movement of the microparticles can be realized by rotating the polarized beams and varying the phase differences. Under the irradiation of radially polarized light, high-intensity focus can facilitate the capture of microparticles with different materials and radii. Xu et al. introduced a Kalman filter into optical traps to suppress the noise signal and extract the motion information of each axis of the particle [4]. The root-mean-square error of the detected signal decreased from 12.64 nm to 5.18 nm, and the feedback cooling performance improved by about 27%. These works provide novel techniques, methods, and ideas for the field of optical tweezers, opening up a new avenue for the study of particles in liquid, air, and vacuum, which are significant in biomedicine and nanotechnology. Moreover, Savelyev et al. proposed a microstructure to generate structured light [5], which can obtain single or groups of optical traps on the optical axis in the near-diffraction region.

As an optical field that modulates polarization, amplitude, and phase, structured light is becoming a major aspect of various research areas such as quantum information processing, optical tweezers, and optical communications. Its unique physical properties give

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rise to a plethora of new fundamental light–matter interactions and device applications. Several recent works have investigated the underlying theories, principles, and methods for studying structured light. Wei et al. proposed a circle-Cassinian optical coordinate transformation based on polarization invariance [6]. They used three isotropic phase plates to generate an elliptical symmetry radially polarized beam that can independently adjust the linear polarization direction and the amplitude of the electrical field. Liu et al. theoretically and experimentally studied the effect of twisting phases on the polarization dynamics of a vector optical field [7]. They proved that a vector vortex beam and its polarization states can be dynamically manipulated by twisting phases. The appearance of the twisting phases leads to some interesting phenomena such as the rotation of the polarization states and linear to circular polarization conversion. Chen et al. employed a counter-rotating bicircular light field to induce valley-selective excitation, bringing valleytronics to layered van der Waals materials [8]. They concluded that the sub-periodic valley dynamics can be manipulated by modulating the light field. Asadpour et al. proposed a scheme to exchange optical vortices [9]. The scheme is based on four-wave mixing in a five-level atomic system, which is composed of two Λ subsystems coupled via a weak driving field. They used the resulting Autler–Townes splitting to replace the original electromagnetically induced transparency, and the energy conversion efficiency of optical angular momentum between different frequencies greatly increased. Gladyshev et al. used a hollow-core silicon fiber filled with gaseous D_2 to generate a supercontinuum source [10]. The supercontinuum source covers the bandwidth from 0.65 μm to 3.3 μm at the −30 dB level using an ultrashort laser pumped at 1.03 μm. Nearly 14% of pump quanta was converted to the wavelength range above 2 μm. Gao et al. theoretically and numerically studied the propagation properties and interactions of Airy beams in an inhomogeneous medium with periodic potential [11]. They sought ways to control the breathing period and morphology of Airy beams, providing a theoretical basis for their propagation and manipulation. These works provide guidance for the study of light propagation properties in complex physical systems. It is worth noting that the development of structured light cannot be separated from the progress of structural materials. Therefore, we selected several papers on this topic as follows.

Structured materials, including metamaterials, metasurfaces, and photonic crystals, provide new research opportunities for optical manipulation and structured optical field generation beyond the capabilities of bulk optics approaches. Furthermore, interactions between structured optical fields and matter on the sub-wavelength scale will produce new physical effects, such as spin–orbital momentum coupling. Ermolaev et al. demonstrate that layered van der Waals materials can overcome the diffraction limit of light without optical losses due to their large optical anisotropy [12]. In particular, waveguides with molybdenum disulfide and tungsten disulfide claddings can operate in a transparency region slightly above the diffraction limit, which opens a route for photonic integration based on layered materials. Cen et al. fabricated self-aligned double-layer gratings via electron beam lithography [13]. The interference between out-of-plane plasmonic resonances and diffraction modes excites surface lattice resonances. By changing the refractive index of the surrounding medium or the incident angle, the resonances can be tuned from 500 nm to 1000 nm. Maidi et al. designed a photonic crystal fiber sensor for detecting sulfuric acid at different concentrations [14]. At the optimum wavelength of 1.1 μm, the relative sensitivity was more than 97% and confinement loss was about 10–12 dB. Khan et al. proposed a polarization-insensitive coded metasurface to achieve conformal stealth [15]. By optimizing the arrangement of metaatoms, it can integrate the absorption, polarization conversion, and diffusion mechanisms to realize ultra-wideband radar cross-section reduction. Jiang et al. proposed a VO_2-based THz tunable absorber composed of a split-ring structure and an I-shaped metamaterial [16]. It is bending-insensitive and achieves nearly perfect absorption at 0.24 THz. At 0.46 THz, it is bending-sensitive and the bending angle is in the range from 0 to 50 degrees. These latest progresses in structured materials offer new opportunities for structured light generation at the nanoscale. The integration of optical elements at the nanoscale has great potential for applications in biochemical sensors, absorbers, and other optical devices, which have been widely studied. Last but not least, structured materials have been applied in optical tweezer systems due to their merits of miniaturization, multi-function, and integration. Finally, we carried out a review of the latest progress in the field of optical tweezers with metasurfaces [17]. Metasurfaces provide new possibilities for optical tweezers, and a large number of works have been carried out to accelerate the development of this field.

In summary, the topics covered in this Special Issue represent the vibrancy of light control and particle manipulation techniques, helping investigate how microscopic effects affect the macroscopic world. The development of optical tweezers is closely related to structured light, which adds new dimensions and functionalities to optical trapping. The progress of structural materials promotes that of structured light. Structural materials bring new vitality to optical tweezers. They are in the community of micro-/nano-optics, mutually contributing to the development of each other. The prospects for and advances in these fields indicate that the works presented are cutting-edge and representative of the field, and of value for public reading. With the continuous development of new techniques and tools for optical trapping and their application in multidisciplinary areas, the future of these fields is promising. It is hoped that this Special Issue will appeal to a broad audience with an interest in this area, and that more research and exploration can be carried out.

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