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Editorial: Optical vortices: Generation and detection

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Editorial on the Research Topic
Optical vortices: Generation and detection

Vortices are typically characterized by singularities and represent an interesting phenomenon that occurs widely in nature, such as tornadoes, fluid eddies, spiral galaxies and even in black holes, etc. Like other types of vortices, optical vortices share the property of carrying orbital angular momentum (OAM), as proved by the seminal paper of Allen and coworkers in 1992 [1], which ignited the flourishing research field of structured light. As one of the most prominent candidates for structured light, optical vortices are arousing ever-increasing interest among both scientific and engineering communities due to their disruptive applications in an amazing variety of realms, ranging from stimulated emission depletion (STED) nanoscopy [2, 3] to both quantum and classical OAM-multiplexed optical communications [4–6] and more recently high-intensity vortex physics [7, 8]. In this Research Topic, different schemes and techniques, including complex reconstruction, metasurfaces, integrated log-polar mode sorters, etc., were proposed for the generation, modulation, and detection of various vortex fields. Also, some novel vortex fields, such as asymmetric vortex beams, perfect vortex beams, and anomalous vortex beams, etc., were also demonstrated. In addition, more exciting and promising applications were explored further, including OAM-based optical communications, optical manipulation, and remote sensing of rotating objects, etc.

Although vortex beams have been intensively studied during the past decades, a full knowledge of the basic physical mechanism, especially clear spatial and temporal dynamics, is still missing to some extent. By using the ray-tracing method based on geometric optics, Cai et al. analyzed and established an intuitive mathematical model for giving an explanation of the physical picture underlying the propagation and evolution of the dark fields of focused vortices. The results are helpful to intuitively understand the propagation behaviour of this special vortex beam. In addition, the method can be extended to other specific vortex beams.

Among different families of beams carrying OAM, perfect optical vortices [9] have gained increasing interest during the last decade due to the independence of their ring-like intensity profile from the carried amount of OAM. Jiang et al. reported a novel multi-foci integration method to overcome the critical limits of standard techniques for perfect vortices generation and produce beams without focus deviation, showing controllable spot arrays with custom phase distributions for intriguing applications in optical trapping and manipulation.

The paraxial local topological charge of anomalous vortex beam varies with propagation, which provides an additional degree of freedom. Therefore, the beams have potential applications in fields such as quantum information and laser shaping. However, the lack of optical devices to efficiently generate those beams hinders their applications. Huang et al. proposed a phase-only device called spiral axicons to efficiently generate anomalous vortex beams. The relationship between the spiral axicon parameters and the topological charge of anomalous vortex beams is given theoretically and experimentally. This will promote the application of anomalous vortex beams. Zhang et al. proposed a theoretical model of the partially coherent power exponential phase vortex beam, which enriches the variety of vortex beams. This work opens up opportunities for applications in beam shaping, optical trapping, and particle manipulation because of the asymmetric vortex beam. In addition, partially coherent beams have some unique advantages in applications.

Metasurfaces [10] represent the latest evolution of optical elements in terms of design and materials [11], and suggest new optical architectures and techniques for the advanced generation of optical vortices. Vogliardi et al. reported the design and simulation of new silicon metaoptics for the spin-controlled generation and focusing of beams carrying OAM. The combined control of dynamic and geometric phases *via* rotated nanopillars with different cross-sections allows encoding different functionalities on the two orthogonal circular polarizations, enabling the focusing of beams carrying different values of OAM at distinct points in space. Song et al. demonstrated an evolution of the previous metasurfaces with further engineered meta-atoms for generating achromatic focused optical vortex beams through a single germanium metasurface in the longwave infrared with high efficiency and high mode purity, where the chromatic aberration and polarization sensitivity are eliminated by superimposing a polarization-insensitive geometric phase and a dispersion-engineered dynamic phase. It has been shown that the longwave infrared corresponds to an atmospheric transparent window, which makes it an ideal range for optical wireless communications. Thus, this work makes a great significance for promoting the application of chip-level optical communications in infrared range based on OAM-multiplexing.

It has been well known that vortex beams, which are endowed with OAM, can be used as information carriers to increase the information capacity of optical communication channels at the same frequency, which requires mode sorters that can effectively distinguish among different vortex beam patterns. However, none of the currently known solutions can provide direct integration to other optical elements, or provide simple lithography procedures for various functionalities. Lightman et al. proposed a fabrication method that can provide high-quality and integrated log-polar mode sorters. This lays the foundation for construction of an optical fiber-based communication system. Conformal transformations represent an efficient and versatile method for the compact manipulation of OAM beams by using a cascade of two confocal phase elements [12, 13]. Li et al. presented a numerical study on the generation of OAM beams by using the so-called log-polar transformation [14] to wrap a rectangular intensity profile with a linear phase into a ring of light carrying an azimuthal phase gradient, proving the efficient generation and also mode detection of integer and fractional OAM beams with continuous tunability.

Since the seminal paper of Bozinovic et al. in 2013 [6], the stable propagation of OAM modes has been widely exploited both in commercial and special optical fibers. The review of Ma et al. summarizes the state-of-the-art in the generation, transmission, and exploitation of guided OAM beams, considering several types of optical fibers, as photonic crystal fibers, ring core fibers, fiber gratings and other all-fiber systems supporting OAM, and giving a final outlook on applications of OAM in cutting-edge disciplines, such as nonlinear optics, optical communication, particle manipulation and imaging. Zhao et al. proposed a method to reconstruct both the amplitude and phase profiles of OAM beams by collecting their interference patterns with two reference waves of different phases in a coherent detection scheme, proving the feasibility of the technique both numerically and experimentally and its robustness even under the presence of atmospheric turbulence.

In addition, vortex light had been utilized for remote sensing of rotating objects, both microscopic particles and macroscopic objects, based on the rotational Doppler effect (RDE). Qiu et al. presented an overview on the technical progress in measuring the rotating Doppler effect associated with OAM, giving the basic mechanism of RDE, the recent developments in rotational speed measurement ranging from macro-objects and molecular motion to quantum optical realms, and a summary of challenges and prospects. Recent years have witnessed a growing interest in vector vortex beams [15, 16]. Qiu et al. reported a flexible and robust scheme to generate the symmetric and asymmetric vector structured beams instead of conventional interferometer configuration, and they further demonstrated the spectrum observation of the rotational Doppler effect based on the coherent interaction between atoms and structured light in an atomic vapor.

In summary, vortex beams bring new degrees of freedom for photons due to their carried OAM and also complex spatial mode profiles. Also, various novel vortex fields and advanced control over vortex fields with more degrees of flexibility are explored. Furthermore, more and more exciting applications are expected in the future, with the advance of compact and integrated devices. This Research Topic collects the works of the large community working in those fields, showing the prominent role played by optical vortices and the still vivid and inspiring action of OAM beams 30 years later.

Author contributions

JY initiated this project, and JY, PZ, and GR wrote the draft. All authors contributed to reading, modification and final approval of the manuscript and also the whole project.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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