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Editorial

Special Issue on Novel Insights into Orbital Angular Momentum Beams: From Fundamentals, Devices to Applications

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1. Introduction

It is well-known now that angular momentum carried by elementary particles can be categorized as spin angular momentum (SAM) and orbital angular momentum (OAM). In the early 1900s, Poynting recognized that a particle, such as a photon, can carry SAM, which has only two possible states, i.e., clockwise and anticlockwise circular polarization states. However, only fairly recently, in 1992, Allen et al. discovered that photons with helical phase fronts can carry OAM, which has infinite orthogonal states [1]. In the past two decades, the OAM-carrying beam, due to its unique features, has gained increasing interest from many different research communities, including physics, chemistry and engineering [2,3]. Its twisted phase front and intensity distribution have enabled a variety of applications, such as micromanipulation [4–6], laser beam machining [7–9], nonlinear matter interactions [10–12], imaging [13–15], sensing [16,17], quantum cryptography, and classical communications [18–23].

2. Special Issue Papers

This special issue aims to explore the novel insights of OAM beams. It focuses on state-of-the-art advances in fundamental theories, devices, and applications as well as future perspectives of OAM beams. The collected papers have well accomplished these goals by contributing leading-edge derivation, analysis, and experiments with significant results. The topics cover OAM generation and reception, multiplexing and de-multiplexing, device and system. The frequencies range from radio frequency (RF) to infrared wave, while the techniques behind extend from integrated photonics, fiber optics, free-space optics, to dielectric. The special issue consists of three review papers, one communication and five research articles.

More specifically, from the physical perspective, Prof. Barnett and his group have a review paper on the helicity of light, and how it can be both produced and used in light-matter interactions [24]. The paper starts from the form of the helicity density and its associated continuity equation in free space, in the presence of local currents and charges, and upon interaction with bulk media, leading to the characterization of both microscopic and macroscopic sources of helicity.

Regarding OAM beam generation technologies, Prof. Liu's group reviews the generation of OAM modes using fiber systems [25]. This review paper first introduces the basic concepts of fiber modes and the generation and detection theories of OAM modes. Next, fiber systems based on different devices are introduced, including long-period fiber grating, mode-selective coupler, microstructured optical fiber, and the photonic lantern. Finally, the key challenges and prospects for fiber OAM mode systems are discussed.

Another review paper, focusing on tunable OAM generation, is contributed from Prof. Wu's group [26]. The authors classify the tunable OAM mode generation methods into three categories, according to the OAM and polarization states. The fiber-based and free-space generation methods are categorized into three types according to the controllable variables, respectively. Last, the pros and cons of each generation method are analyzed and the key challenges for tunable OAM modes are discussed.

Most fiber-based or free-space OAM beam generators are bulky, slow, and cannot withstand high powers. Prof. Litchinitser's group design and experimentally demonstrate an ultra-fast, compact chalcogenide-based all-dielectric metasurface beam converter, which has the ability to transform a Hermite–Gaussian (HG) beam into an OAM beam at near infrared wavelength [27]. The topological charge carried by the output OAM beam can be switched between positive and negative values, and the device provides high transmission efficiency.

For the reception of OAM radio waves, Dr. Klemes contributes a communication article using pseudo-Doppler interpolation techniques [28]. The method can be used to receive OAM waves in the far field of an antenna transmitting multiple OAM modes, each carrying a separate data stream at the same RF. The frequency domain method provides a higher signal-to-noise ratio (SNR) than using spatial-domain OAM reception techniques. Moreover, no more than two receiving antennas are necessary to separate any number of OAM modes in principle.

In OAM communications systems, different OAM beams can carry multiple data channels, boosting the spectral efficiency and capacity significantly. Consequently, the simultaneous processing of OAM beams is necessary, and OAM multiplexing/de-multiplexing devices are key enablers of such systems. Prof. Li et al. contribute an article on mode-selective photonic lanterns for OAM mode division multiplexing [29]. The authors design a three-mode OAM mode-selective photonic lantern by optimizing the taper length with small mode crosstalk, which employs only a single mode fiber port to selectively generate each OAM mode.

In a more integrated manner, Prof. Romanato and his group explore holographic Silicon metasurfaces for OAM de-multiplexing based on OAM-mode projection [30]. The device uses Pancharatnam-Berry optical elements (PBOEs) and can de-multiplex beams with different polarization and OAM states at the wavelength of 1310 nm. The geometric-phase control is achieved by inducing a spatially-dependent form-birefringence on a silicon substrate, patterned with properly-oriented subwavelength gratings.

There are two experimental demonstrations for free-space OAM communications systems, one in the 1550 nm optical regime, and the other on 28 GHz RF frequency band. Dr. Qu and Prof. Djordjevic investigate turbulence mitigation methods in free-space optical OAM communications system based on coded modulation [31]. Adaptive optics, channel coding, Huffman coding combined with low-density parity-check (LDPC) coding, and spatial offset are used for turbulence mitigation, achieving a total data transmission capacity of 500 Gbps.

Finally, Dr. Lee and colleagues evaluate the performance of OAM-based wireless communications systems [32]. To overcome the beam divergence of OAM multiplexing, the authors use a combination of multi-input multi-output (MIMO) and OAM technology, achieving a new milestone in point-to-point transmission rates at 100 Gbps for a 10 m transmission distance.

3. Perspectives

It has just been 27 years since the discovery of OAM by Les Allen and his co-workers. Within this fairly short period of time, an extensive research community has been established globally, and OAM theories have been further improved. Especially during the past decade, OAM related devices and applications have experienced significant growth. From this trend, we are expecting the OAM field to continue grow with novel and unique applications to debut one after another. Hopefully, more OAM related technologies can be commercialized in the near future to enable new industry and serve society.

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