An ultra-degree-of-freedom structured vector beam

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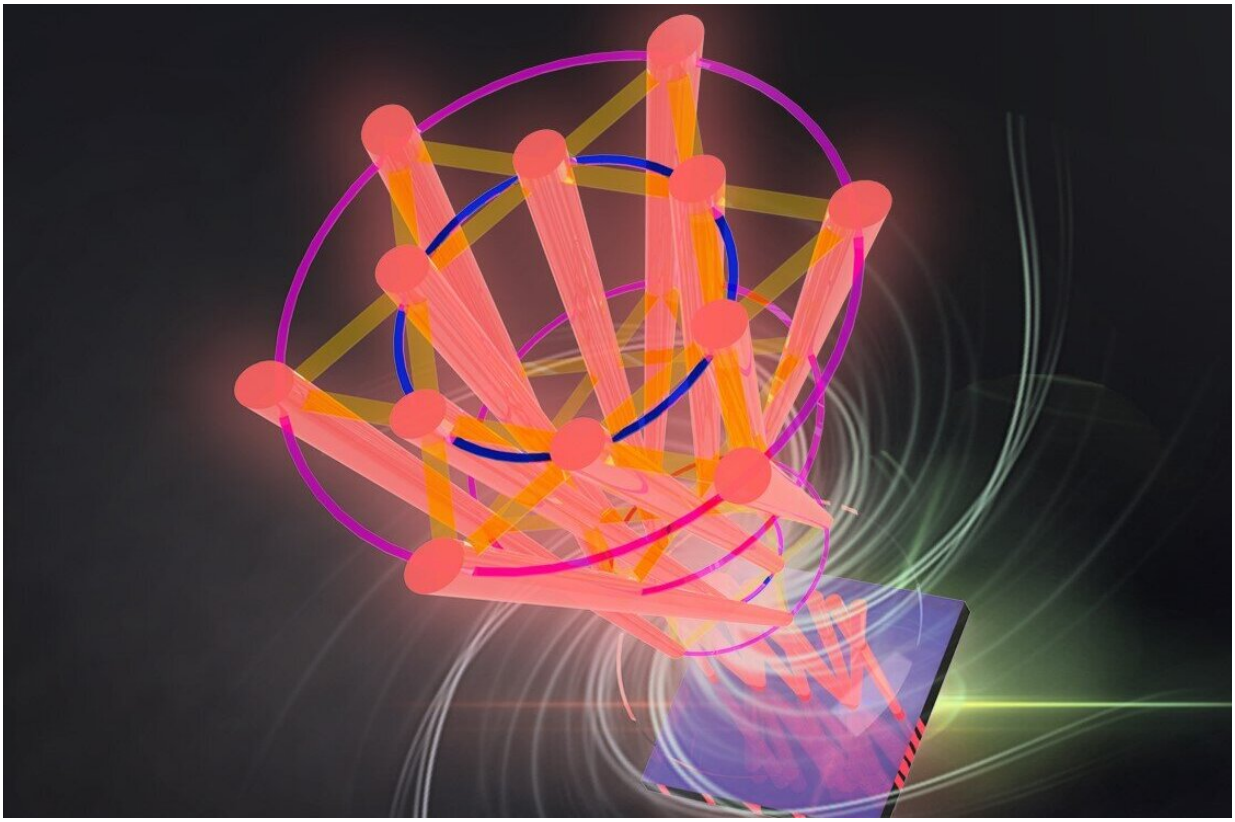

Credit: Yijie Shen

Optics Express recently published research demonstrating a laser that is able to produce a new type of vector beam. This so-called vector-ray-wave beam with 5 degrees of freedom breaks the paradigm of the

conventional vector vortex beam, which opens the way to manipulating new quantum-to-classical phenomena for high-capacity communications.

Typically, light emitted from standard lasers has a controllable degree of freedom that can be conferred through polarization or beam shape. By suitably manipulating a laser with the introduction of specialized optical components, an output with 2 degrees of freedom, such as vector vortex beams with controllable polarization and orbital angular momentum (OAM). The term "vector" describes a structured change in the polarization across the beam and "vortex" describes the twisting of the phase in the beam (OAM), much like a tornado. Transcending 2 degrees of freedom from a laser was not possible. By exploiting ray-wave duality in a frequency-degenerate laser, a vector beam with 5 degrees of freedom can now be selected.

The concept of ray-wave duality inside lasers may be described as a mode wave pattern that is associated with a periodic ray trajectory. A standard laser has a mode pattern that oscillates between the center of two mirrors on a straight path that is perpendicular to the mirrors. However, in the case of a periodic trajectory, the mode pattern also oscillates between two mirrors but follows a non-perpendicular path, similar to a zig-zag pattern. Prior studies have only reported on a single trajectory with a certain transverse size; however, this work demonstrated the selection of two trajectories with different transverse sizes and oscillating phases, associated with astigmatic transformation. This exotic output constitutes 4 degrees of freedom, namely, periodic number (number of rays), transverse index (number of output rays), oscillating phase, and astigmatic degree. This results in a vector-structured output and in turn, the fifth degree of freedom. With this, the output is transformed into a twisted trajectory by converting the transverse index into one that possesses orbital angular momentum with an external astigmatic mode convertor.

Importantly, this ray-wave structured output is said to be non-separable, akin to the quantum mechanics description of entangled states, in the orientation angle between the transverse indices. "We believe it holds great novelty, because the creation of such ultra-degrees-of-freedom, vectorial light is highly beneficial in describing and further exploring fundamental physical phenomena such as optical spin Hall effects for extending new applications in optical tweezers and communications and to manipulate new quantum-like classical states," says Dr. Shen.

The experimental demonstration comes from an otherwise "empty" laser cavity, the absence of specialized optical components. This poses an additional benefit in that the laser consists of a simple architecture, yet outputs a vector beam with 5 degrees of freedom, far beyond an incremental advance. "The number of rays in the twisted output may be easily be manipulated by careful control of the laser parameters such as the distance between the mirrors and the pump position, which provides a simple, compact and elegant at-the-source solution," says Dr. Darryl Naidoo of the CSIR.

"South Africa and China are already partners under BRICS, with plans for a virtual photonics center to be established under this program. The present work has highlighted what is possible when you bringing together teams from the best institutes in China (Tsinghua U.) and South Africa (CSIR and U. Witwatersrand). We hope that such collaborative initiatives can continue into the future," says Prof. Andrew Forbes of WITS University.

The laser concept is likely to attract interest from both the academic and industrial communities. This output holds promise to conveniently extend applications in the vector beam space and having such beams on demand from a laser will certainly open up new application areas.

More information: Zhaoyang Wang et al, Astigmatic hybrid SU(2)

vector vortex beams: towards versatile structures in longitudinally variant polarized optics, *Optics Express* (2020). DOI: 10.1364/OE.414674

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