Generation of tunable order Bessel beams with cascaded metasurfaces

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Abstract

A variorder Bessel beam generator is experimentally demonstrated with two metasurface devices. Two cascading metasurfaces are employed to generate Bessel beams in the terahertz range. The order of generated Bessel beam can be turned by rotating the metasurface. The order of the Bessel beam is changed from zero-order to fourth-order when the rotation angle of metasuface components from 20 degrees to 80 degrees.

Bessel beam which is a kind of diffraction-free beams with superior self-healing capability has many potential applications in the fields of optical particle control, microscopy, nonlinear optics, materials processing, and quantum communication [1-4]. Generally, an axicon is used to generate Bessel beam. In 2015, Wei et al. demonstrated a high-order terahertz Bessel beam using a polymer spiral axicons with different topological numbers, which is fabricated with 3D printing technique [5]. In 2017, Wu et al. further generated a zero-order terahertz Bessel beam by using a terahertz quarter wave plate and Teflon axicons [6]. However, this method is rather inefficient, because large size of axicon is unprofitable for devices miniaturization. Recently, rapid developments of metasurface provide new opportunities to realize ultracompact and high-efficiency terahertz devices. Metasurfaces are ultrathin artificial structures composed of sub-wavelength meta-atoms with arranged in a special sequence, which have extraordinary capabilities to control electromagnetic wavefront based on Huygens' principle [7-8]. In 2017, Chen et al. designed a wavelength-independently subwavelength Bessel beams using metasurfaces, they experimentally achieved the meta-axicons with a high NA up to 0.9 capable of generating Bessel beams with full width at half maximum about as small as $\sim\lambda/3$ [9]. Whereas, this device is static, which means that the order of Bessel beam is non-tunable once the opening angle of axicon is fixed.

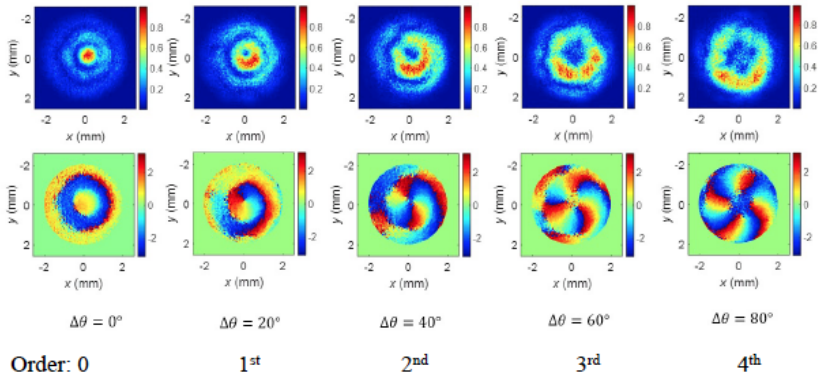

Fig. 1 Experimentally measured intensity and phase distributions of Bessel beams with different orders.

Here, a device which consists of two metasurface components placed face to face is designed to generate Bessel beams with tunable order in the terahertz range. The order of Bessel beam can be changed linearly by rotating one of metasurface relative to another metasurface. The basic elements of the designed metasurface are silicon pillar with heigh of 300 μm and

variable diameters changing from 30 μm to 160 μm, which was fabricated on a silicon substrate with heigh of 700 μm and periodic of 200 μm using the reactive ion beam etching technique. The performances of the device are measured with a home-build terahertz focal plane imaging system. Experimental results demonstrate that a zero order Bessel beam is obtained when the rotation angle between two metasurfaces is zero, and the order of Bessel beam can be changed from first-order to fourth-order when the rotation angle is increased from 20 degrees to 80 degrees with a step of 20 degrees. The measured intensity and phase distributions are shown in Fig. 1, it can be seen the Bessel beams with different order have been generated well.

This work demonstrates an approach to generate tunable special field distributions with radially symmetric and provide a way to construct active metasurface devices.

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