Nonlinear Generation of THz Vortex Beams with Tunable Orbital Angular Momentum in Si Microdisks

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We demonstrate waveguide-coupled microdisks that emit THz light with tunable orbital angular momentum. The topological charge of the THz light can be tuned by changing the driving infrared wavelengths in the difference-frequency generation process.

Integrated vortex beam emitters have shown great potential as a new light source for novel applications from spectroscopy to communications. Previous works have predominantly concentrated in the near-infrared regime, limited by the transparent range of the nanophotonic platforms. Here we demonstrate via numerical simulation that, the generation of freely propagating THz vortex beams by utilizing waveguide-coupled infrared incident beams and the nonlinear process of difference-frequency generation.

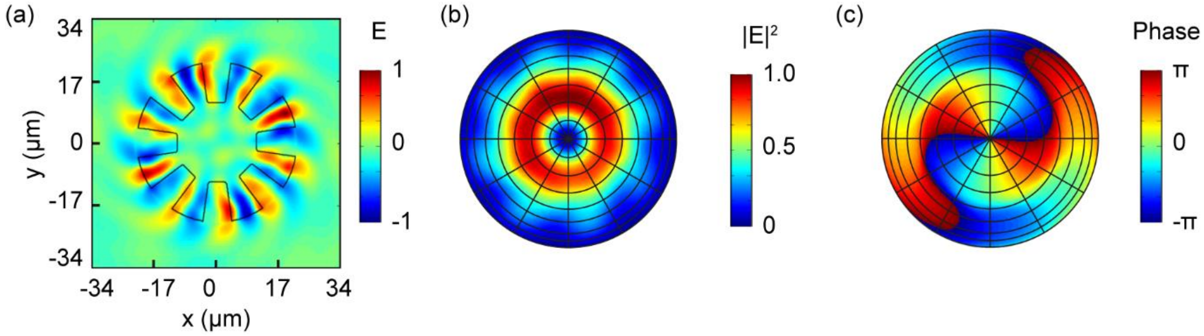

Fig. 1 Generation of a vortex THz light beam. The device shown here has a top grating with 8 elements, and is driven by two infrared light beams to generate a topological charge value of 2. (a) Electric field inside the Si microdisk showing the interaction between the generated THz light and the grating. (b) Intensity polar map of the output THz light, showing a doughnut-shaped profile typical for vortex beams. (c) Corresponding phase profile, clearly revealing the topological charge.

We have explored a series of designs and control methods, with a typical design shown in Fig. 1. The emitter contains a $LiNbO_3$ microring resonator that is driven by two incident infrared light beams fed through a bus waveguide. Difference-frequency generation inside the microring converts part of input energy into THz light, which is confined by an Au base film beneath the microring, as well as a Si microdisk and an Au grating on top of it. Depending on the THz frequency, there can be a mismatch between the azimuthal order of the confined THz light (10 in Fig. 1a) and the number of the grating elements (8 in the figure). As the grating emits the confined THz light into free space, the mismatch is revealed as the topological charge of the THz light (Figs. 1b and 1c).

A unique feature of this design is that it provides tuning in the output topological charge. By changing the frequencies of the input light, the THz frequency produced in the difference-frequency generation can be altered, resulting in a change in the azimuthal order of the confined THz light. This in turn results in modulation of the output topological charge. This relation between the input frequencies and the output topological charge is verified in three different device designs for topological charge ranging from 4 to -5. In addition to the control over the topological charge, fine details of the output beam can also be modified by changing the polarization of input light.

To summarize, the emitter design demonstrated here can impart a tunable topological charge to a freely propagating THz light beam, with a planar device dimension at the scale of the functional wavelength. It provides a high level of control over the emitted light, via modulating the wavelengths and polarization of the input light. These features may lead to useful applications in THz wireless communications and spectroscopy.

Reference

[1] H. Pi, T. Rahman. S. A. Boden, T. Ma, J. Yan, and X. Fang, "Integrated vortex beam emitter in the THz frequency range: Design and simulation," APL Photonics **5**, 076102 (2020).