Generation of high-quality tunable terahertz vortices based on difference frequency generation

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Abstract

We demonstrate a high-quality tunable terahertz (THz) vortices generation based on difference frequency generation in combination with Gaussian and vortex modes. THz vortex outputs with a topological charge of $\ell_{THz} = \pm 1$ were obtained in a frequency range of 2-6 THz. The maximum average power of the THz vortex output reached up to ~3.3 μW at 4 THz.

1. Introduction

An optical vortex[1] carries an annular intensity spatial profile and an orbital angular momentum characterized by a topological charge, ℓ, which allows us to explore various research fields, including optical trapping, optical telecommunication, fabrication of structured materials[2] and super-resolution microscopy. In particular, terahertz (THz) vortex will provide new advanced spectroscopic technologies, such as 2-dimesional identification of the biomaterials with a high spatial resolution beyond the diffraction limit.

The generation of THz vortices was already demonstrated by using several optical devices based on wavefront conversion, such as a molded phase plate composed [3], and a spiral phase plate (SPP)[4,5]. However, these devices are typically designed for a specific frequency, which inherently constrains the wavelength tunability of the THz vortices.

In this presentation, we report a tunable THz vortices generation with a frequency range of 2-6 THz at a topological charge of $\ell_{THz} = \pm 1$, based on the 1.5μm optical vortex pumped difference frequency generation (DFG) from a 4'-dimethylamino-N-methyl-4-stilbazolium tosylate (DAST) crystal [6].

2. Experiments and Discussion

Figure 1 shows the experimental apparatus of a tunable THz vortex source consisting of the 1.5 μm dual-wavelength pumped DAST-DFG. A homemade picosecond laser (wavelength, 1064nm; average output power, ~5W; pulse width, 7.4ps; PRF, 1MHz) was used for a pump laser; its output was delivered to two injection-seeded optical parametric amplifiers (OPA1, 2) formed from periodically poled stoichiometric lithium tantalite (PPSLT) crystals (15 x

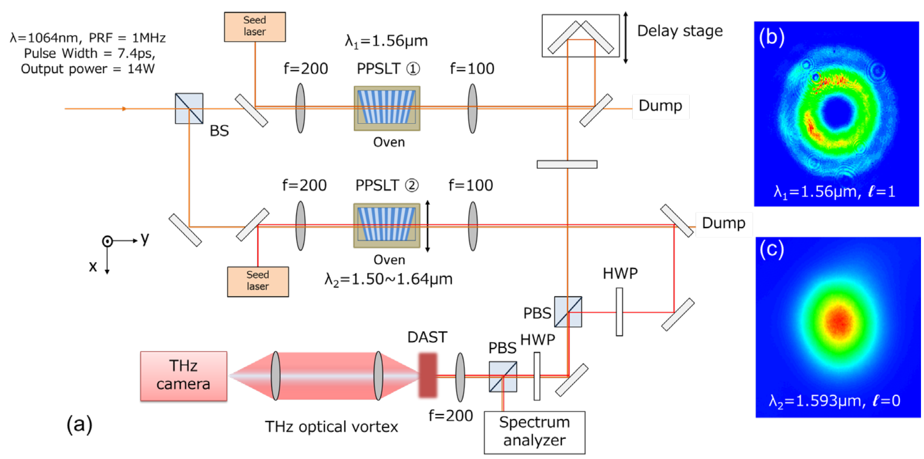

Fig.1 (a) Experimental setup for tunable THz vortex generation based on 1.5 μm dual wavelength pumped difference frequency generation in combination with a DAST crystal. (b) Spatial profile of λ_1, which was converted to an optical vortex using SPP at a topological charge of 1. Its wavelength was fixed to be 1.55μm. (c) Spatial profile of λ_2, at a wavelength of 1.583μm. Its tuning rage exhibited 1.50-1.64μm.

1 x 35mm, Λ = 29-31 μm). The OPA1 output was converted into an optical vortex (ℓ = 1) by using a SPP for 1.56 μm (Fig. 1(b)); its wavelength, λ_1, was then fixed to be 1.56 μm. The OPA2 output exhibited a Gaussian spatial form (Fig. 1(c)), and its wavelength, λ_2, was tuned within a wavelength range of 1.50-1.64 μm. The OPA1 and OPA2 outputs were then focused on to a DAST crystal, thereby generating a THz vortex output as a difference frequency mixing. The intensity distributions of the THz vortices were measured by a THz camera (NEC IRV-T0831).

Figure 2 (a) shows the frequency tunability of the THz vortices output from the optical vortex pumped DAST-DFG; the blue and red lines indicate the sign of the topological charge $\ell_{THz} = \pm 1$, respectively. In the case of $\lambda_2 < 1.56$ μm (λ_1 is fixed at 1.56 μm), the magnitude relation of the two pump wavelengths is switched; thus the sign of the topological charge of the THz vortices, ℓ_{THz}, is inverted according to the conservation law of the topological charge. By sweeping the wavelength of λ_2 in the range of 1.50-1.64 μm, THz vortices with positive and negative signs of the topological charge can be generated seamlessly between 2-6 THz. The THz vortex output with ℓ_{THz} = 1 is slightly lower than the negative sign (ℓ_{THz} = -1) due to the characteristic of λ_2 wavelength output spectrum. The frequency tuning range of the THz vortices output is mostly determined by the frequency tuning range of the OPA2 output. The maximum average power at the 4 THz vortex output was measured to be 3.3 μW at a 1.5 μm pump power of 1 W, corresponding to an optical-optical conversion efficiency (from 1.5 μm dual-pump output to THz vortex output) of ~3.3 x 10^{-4} %.

The experiment spatial distributions of the 4 THz vortex are summarized in Fig.3. The DFG output at the 4 THz exhibited an annular spatial profile with a topological charge of $\ell = \pm 1$, as evidenced by a twin-lobed far-field rising to the left or right, observed by an astigmatic focusing method (Fig. 3 (c-d)). Also note that the undesired higher-order radial modes of the THz output were suppressed owing to soft-aperture effects in the DFG process.

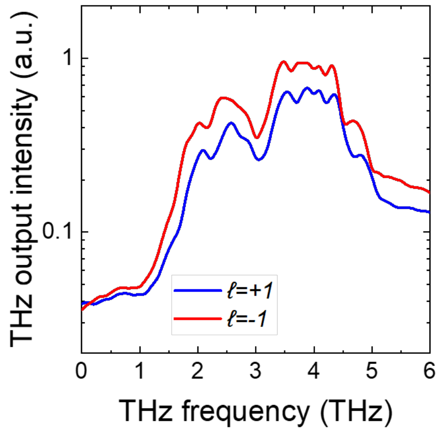

Fig. 2 Frequency tunabilities of the THz vortex output from DAST-DFG.

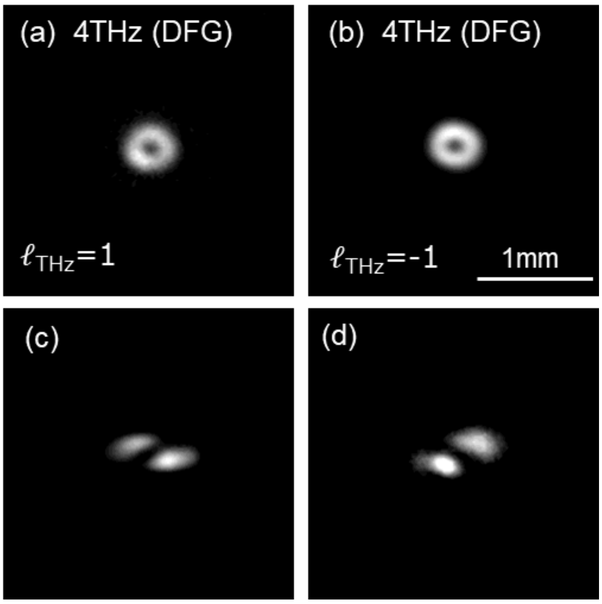

Fig. 3 Spatial distributions of the 4 THz vortex outputs focused by ((a), (b)), a conventional lens, and ((c), (d)), a tilted lens, at the topological the topological charge of $\ell_{THz} = \pm 1$, respectively.

3. Conclusions

We have demonstrated the generation of widely tunable THz vortices with high-quality formed of DFG of vortex and Gaussian beams. The system produced THz vortices output with $\ell_{THz} = \pm 1$, and continuously tuned within the frequency range of 2-6 THz. We also realized a seamless control of the sign of the THz vortices by merely sweeping the pump wavelength of λ_2.

Acknowledgements

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