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Terahertz wave generation in air by femtosecond optical vortex pulses

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Terahertz (THz) radiation is of great current interest due to many applications such as nonlinear THz spectroscopy and imaging. One of the compact and effective methods to obtain very high THz field strengths and extremely broadband spectral widths is THz wave generation from plasma filaments formed in air by focused bichromatic femtosecond laser pulses consisting of the first and the second harmonics (FH, SH). Here we investigate the effect of an azimuthal phase modulation of the SH carrying an optical vortex charge on the intensity and phase distribution of the THz pulse emitted from the laser induced plasma filament in air. We present both experimental and theoretical results.

Our theoretical analysis, based on the plasma photocurrent model [1] shows that when the SH beam has vortex charge $l_{SH}=1$, the THz beam is expected to acquire an azimuthal phase modulation from 0 to 2π as well. However, it turns out that also the THz intensity is modulated along the azimuthal angle θ (see Fig.1 I). The modulation depth is frequency dependent, and the lower the THz frequency, the larger the modulation depth.

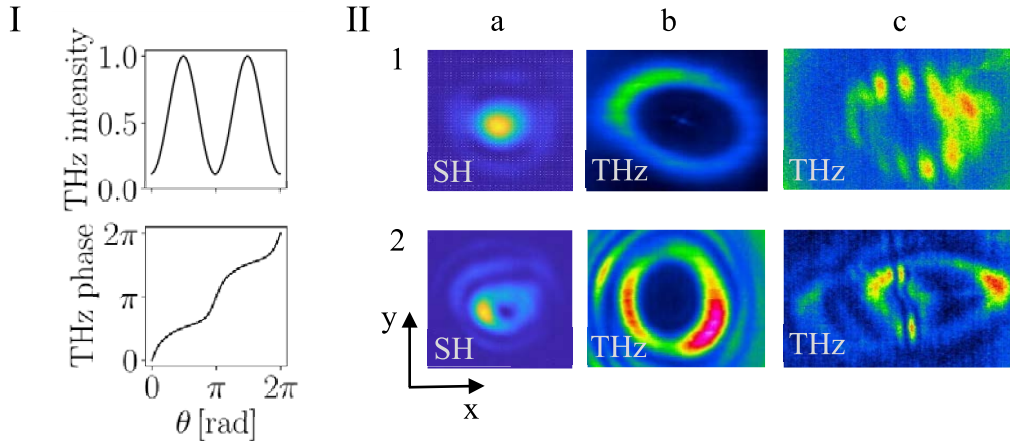


Fig. 1. Part I. Numerically obtained THz radiation intensity distribution (left pane) and its phase (right pane) as functions of the azimuthal angle θ for the SH charge $l_{SH}=1$. THz radiation wavelength has been taken as equal to $10\ \mu\text{m}$ (30 THz). Part II. (row 1) Experimental images of the intensity distribution of (a) SH Gaussian beam and (b) corresponding THz beam as well as (c) THz beam interference fringes. (row 2) Experimental images of the intensity distribution of (a) SH vortex beam and (b) corresponding THz beam as well as (c) its interference fringes. During the experiment the FH intensity distribution has always been kept as a Gaussian one.

For the experiments, we have used a 1 kHz repetition rate femtosecond Ti:sapphire chirped pulse amplification laser system (Legend elite duo HE+, Coherent Inc.), delivering 40 fs (FWHM) light pulses centred at 800 nm with maximal pulse energy of 8 mJ. FH was always kept as a Gaussian beam. Experimental imaging of the generated THz wave was performed with a thermal camera, detecting radiation in the range 0.1 – 40 THz ($3000 - 7.5\ \mu\text{m}$). The experimental results are summarized in Fig.1 II: row 1 for the Gaussian and row 2 for the vortex SH beam. Image b2 shows that the THz beam has two distinct maxima and two minima in the case of the vortex SH, confirming the theoretically predicted angular modulation. The shift of the interference fringes c2 as a superposition of the THz beam with its replica (obtained using slightly laterally shifted Michelson interferometer) proves that the opposite parts of the THz beam have indeed a phase difference of π .

In conclusion, our experimental results are in good agreement with the theoretical predictions when using vortex driver beams. We believe that the presented investigations will open new routes towards an active control of ultra-broadband THz beam properties.

References

- [1] I. Babushkin, W. Kuehn, C. Köhler, S. Skupin, L. Bergé, K. Reimann, M. Woerner, J. Herrmann, and T. Elsaesser, "Ultrafast Spatiotemporal Dynamics of Terahertz Generation by Ionizing Two-Color Femtosecond Pulses in Gases," *Phys. Rev. Lett.* **105**, 053903 (2010).