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Steering laser-produced THz radiation in air with superluminal ionization fronts

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We demonstrate that pulsed THz radiation produced in ionized air by a focused ultrashort laser pulse at 800 nm can be steered to large angles or even in the backward direction with respect to the laser propagation axis. The emission angle is adjusted by the flying focus technique, which determines the speed and direction of the ionization front created by the laser pulse.

The filamentary plasma column produced by a femtosecond laser pulse propagating in air acquires a heavily damped oscillation responsible for the emission of a short THz radiation pulse peaked at the plasma oscillation frequency along a forward-oriented cone. It corresponds to the coherent transition-Cherenkov radiation of the ionization front propagating at the speed of light [1,2]. We demonstrate that a single-color ultrashort optical pulse generating a short plasma string in air can emit THz radiation along any direction with respect to its propagation axis. The emission angle can be adjusted by the flying focus technique [3,4], which determines the speed and direction of the ionization front.

To control the phase velocity v of the pump pulse at the focus, the pulse (10 mJ, 50 fs @ 800 nm) was chirped by detuning the grating compressor of the laser. This chirped pulse was then focused using a lens of focal length f = 30 cm with a calibrated chromatic aberration. We first characterized the displacement of the laser-induced ionization front with transverse diffractometry and determined velocities v ranging from -5c to +2c. We then characterized the radiation pattern at 0.1 THz from the plasma string for the different pulse durations corresponding to subluminal, luminal, and superluminal velocities of the ionization front v. The results are presented in Fig. 1. For v = c, the maximum emission is close to 30°, while for high velocities, the angle of the emission is close to 90°. We also note that for negative velocities, the maximum THz emission is in the backward direction.

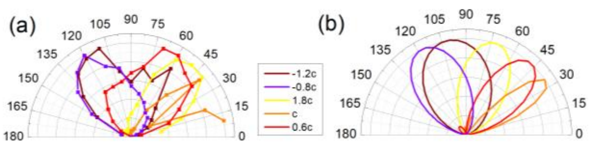

Fig. 1 Measured THz angular distribution for different ionization front velocities v (a). Corresponding calculated angular distributions are presented in (b). All diagrams are normalized and $\theta = 0$ corresponds to the laser propagation direction.

Results are in good agreement with a theoretical model for the THz emission, where we generalized the approach used in [1] to superluminal ionization front velocities. With superluminal ionization velocities v > c, the THz energy is increased by almost an order of magnitude over the transition-Cherenkov radiation obtained with v = c, and all THz frequencies are emitted along a narrow cone at large angle. The radially polarized THz emission corresponds then to a classical Cherenkov radiation [5], produced, not by a charged particle, but by a dipole moving in a dielectric medium at a velocity higher than the light velocity [6]. This mechanism is similar to the emission of superluminal quasiparticles in a plasma described in [7].

We also observe that the Cherenkov THz yield increases linearly with the laser input energy while keeping the same angular emission. Application of a static electric field to the plasma could further enhance the THz emission by two orders of magnitude.

The ability of this THz source to emit backward or around 90° could be very useful for remote spectroscopy, or THz imaging since the THz radiation is well separated from the intense laser pulse.

References

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