Propagation of Intense Terahertz Pulses through Metal Apertures

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The most promising antenna structure for the generation of intense terahertz electromagnetic pulses is the large aperture photoconductive (LAP) antenna. The peak THz field achieved by this method exceeds a few kV/cm, which is where non-linear effects of semiconductor materials arise. THz pulses have extremely broad frequency spectrum extending from DC to few THz, which results in propagation effects not commonly seen in optical pulses. We must first fully understand the propagation effects of these pulses in free space in order to observe nonlinear THz propagation in materials and consequently utilize the high peak field in various applications. In this study, we have conducted experiments to characterize the propagation of THz pulses through metal apertures.

The LAP antenna we constructed consisted of a non-doped GaAs wafer (thickness 350 μm) and two aluminum electrodes mechanically attached to it with a spacing of 30 mm. Pulsed electrical voltage of 12 kV was applied to the electrodes synchronously with the pump laser pulse. Regeneratively amplified Ti:sapphire laser pulses with a duration of 150 fs were used to pump the emitter. The generated THz pulses were focused by an off-axis parabolic mirror to obtain high peak field THz pulses. We utilized the electro-optic (EO) sampling method to measure the temporal electric field waveform of the emitted THz pulses.

Most often, focused THz pulse waveforms obtained with LAP antennas have been reported to have large negative tails. We have found that this negative tail is a consequence of the waveguide effects of the metal holder of the EO crystal or similar optical elements placed in the course of the THz pulse propagation. Therefore half-cycle pulses can only be achieved by focusing the THz pulses using carefully aligned optics.

The waveguide effects were demonstrated by placing an aluminum plate with a circular aperture of a 3.8 mm or 2.5 mm diameter in front of the EO crystal (ZnTe). The waveforms that were altered by these apertures and the corresponding Fourier amplitude are shown in Figs. 1 and 2 . By comparing these waveforms, the change in the negative tail of the waveforms is notable.

The waveguide effect of a metal aperture is characterized by a cutoff frequency ν_c determined by the size and the shape. Calculated minimum cutoff frequencies of these aperture structures are 46 GHz and 70 GHz, respectively (for the TE_{11} mode).

We have simulated the change of waveform by a simple model which takes in the existence of this single minimum cutoff frequency ν_c. The calculated results are also given in Figs. 1 and 2.

In conclusion, the focused THz pulse developed a negative tail in its temporal waveform when passed through a metal circular aperture, which was simulated by simply assuming a single cutoff frequency. We have generated intense nearly half-cycle THz pulses by considering this feature carefully. The knowledge of these propagation characteristics will prove to be useful in future experimental measurements of nonlinear material responses to intense THz pulses.

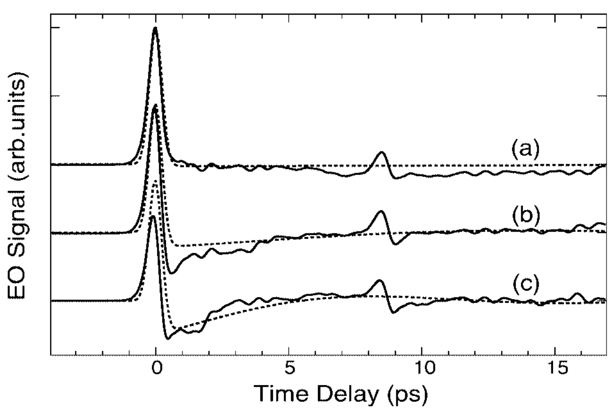

Fig. 1: THz field waveform change when passing through metal circular apertures. Solid lines show the measured curves, dotted lines show simulated curves. (a): without a metal aperture, (b): with a 3.8 mm aperture, and (c): with a 2.5 mm aperture.

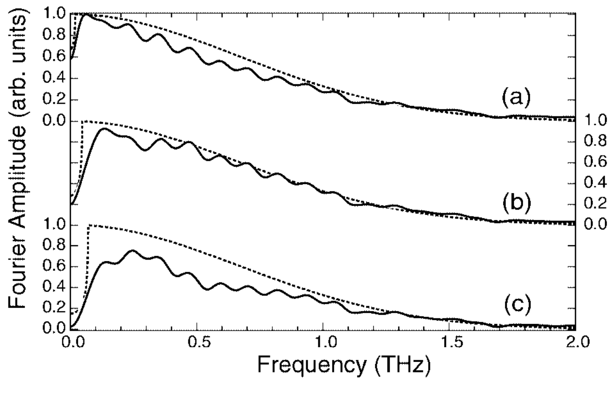

Fig. 2: Fourier amplitudes of the THz waveforms shown in Fig. 1.