Ring Formation of Focused Terahertz Pulse Intensity Generated from a Large-Aperture Photoconductive Antenna

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One important application of terahertz (THz) pulses is THz imaging. By using high electric field, THz beam profile can be visualized by the electro-optic (EO) sampling measurements in real time. In making the image of objects, the spatial distribution of the observed THz electric pulses should be known first. In this study, we have observed 2-D images of THz beam focused by an off-axis parabolic mirror at and around the focus. Simulations of THz field distribution based on diffraction integral were also conducted and the results were compared with those obtained by the experiments.

The large-aperture photoconductive antenna consists of a non-doped GaAs wafer and two aluminum electrodes mechanically attached to it with a spacing of 30 mm. Pulsed electrical voltage of 8 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 the off-axis parabolic mirror to obtain high peak field THz pulses. A small portion of the laser beam was used as a probe beam of the EO sampling. Spatial distribution of the THz intensity was measured by the EO sampling method with a spatially expanded probe beam. The spatial distribution of the probe intensity which has passed through the crossed polarizer setup was measured with a CCD camera.

When the time delay between the THz and the probe pulse was changed from zero, the distribution pattern of the focused THz beam was found to alter to a ring. Figure 1 shows the spatial THz intensity distribution on the focal plane as the time delay was changed. The images correspond to a 11.1×11.1 mm^2 area of the EO crystal. The ring formation of the THz pulse can be understood as follows. High frequency components of the THz beam are focused tightly on the propagation axis. Therefore at positions away from the axis appear only low frequency components. Consequently, the temporal duration of the pulse is larger off axis than on axis, which results that the THz field can become larger off axis than at the focus. By fixing a time at the origin (peak) and moving the detection crystal apart from the focus (0 mm), ring formation was again observed as shown in Fig.2. This can be explained by considering the path length of the THz radiation from the emitter surface to each observation point.

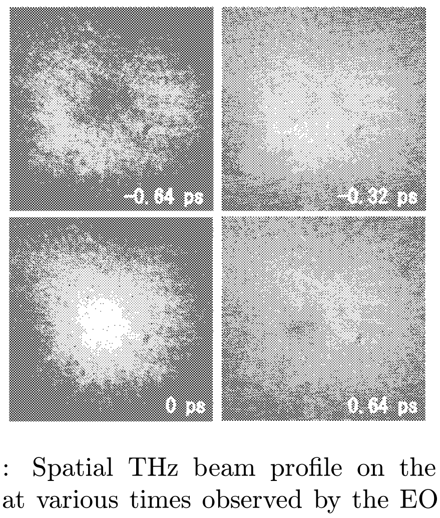

Fig. 1: Spatial THz beam profile on the focal plane at various times observed by the EO measurements.

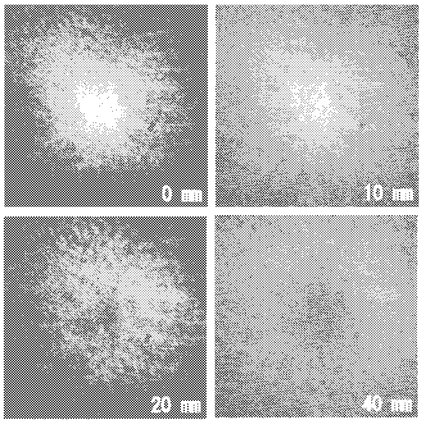

Fig. 2: Images of spatial THz beam profile of peak (0 ps) at various distances from the focus (0 mm).

In the simulation, the current surge model and the diffraction integral were used for the calculation of the THz field focused by the parabolic mirror. The simulated images agree well with the experimental results. Movies of simulated ring reformation can be seen at http://laserlab.bk.tsukuba.ac.jp/thz/.

In conclusion, with a THz imaging system, the ring formation of focused THz beam has been observed and confirmed by numerical simulations. Broadband spectrum of the THz pulses and the corresponding large central wavelength compared with optical elements play the major role in this phenomenon.