Time-Resolved 2-D Imaging of Focused THz Pulses

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Abstract. Focusing of broadband half-cycle terahertz (THz) pulses generated by a large-gap biased semiconductor antenna has been studies. The 2-D profile of the focused THz field depends on time. An annular feature was clearly observed corresponding to the significant contribution of long-wavelength contents. Simulations based on the diffraction integral confirmed the experimental results.

1. Introduction

Imaging with electromagnetic waves in THz region (0.1 THz-10 THz) is currently a strong interest because of its low energy resource and availability of the full information on amplitude and phase. In addition to these, THz wave is sensitive to water and can pass through non-conductive materials. In general, high power coherence THz source is complemented by a photoconductive antenna, high bias voltage, and femtosecond excitation laser pulses. The size of the electrode gap on the wafer and the strength of the bias voltage determine the output power. The electric field of the THz radiation generated by these components forms a half-cycle pulse at far field or after focusing [1]. This simple pulse shape allows phase-sensitive imaging whereas its large central wavelength on order of a millimeter. That is why it is necessary to know the characteristics of the half-cycle THz pulses for obtaining the real image of interested objects. We studied 2-D profiles of focused half-cycle THz pulses that are dependent on time and position. The observed profile of focused pulses is of interest because there is resemblance between the changes in space and time.

2. Experiments

We used a Cr-doped semi-insulating GaAs wafer as a photoconductive antenna. Photocarriers were generated by 150-fs pulses with a wavelength of 800 nm obtained from a regeneratively amplified Ti:sapphire laser system and consequently accelerated by the bias voltage applied across the 30-mm gap. The 2-D THz imaging set-up was constructed by a large-size electro-optic sensor and a CCD camera. In the experiment, a THz beam with a 1/e diameter of 18.4 mm was focused by an 80-mm diameter TPX lens onto ZnTe sensor crystal. The probe beam from the laser was expanded over the crystal. The detection components were those of ordinary electro-optic sampling measurement, which included a l / 4 plate for the optical heterodyne detection of electric field. The time delay between excitation and probe pulses was varied with a mechanical translation stage with a resolution of 0.03 ps.

3. Results and Discussions

The THz filed images were taken at the focal plane and nearby.

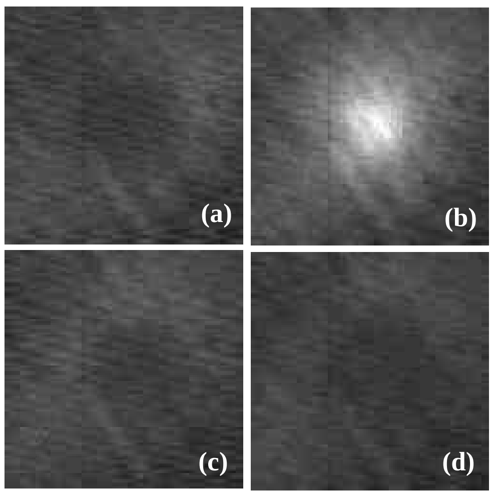

Fig.1 THz field images on the focal plane at (a) $t = -0.67$ ps, (b) $t = 0.0$ ps, (c) $t = 0.67$ ps, and (d) $t = 0.83$ ps. The frame size is 10×10 mm^2.

Figure 1 shows the change of electric field on the focal plane when the time delay was changed. One can see from the figure that the spatial distribution exhibits an annular profile before and after the peak, $t = 0$. In the other word, the field magnitude around the center is higher than the middle when the time delay is apart from the peak. In the other experiment, the time delay was fixed at the peak of the image sequence on the focal plane and the detector components were translated along the propagation axis, called *z*-axis. The spatial profile changes, not shown here, were similar to those depicted in Fig. 1. Briefly, images at the position besides the focus, $z \neq 0$,

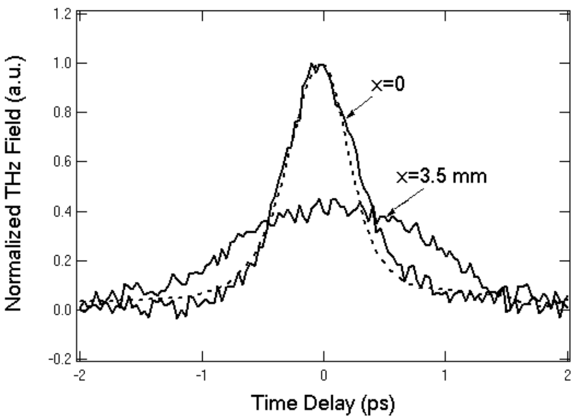

Fig.2 Temporal waveforms at the center, $x = 0$, and above, $x = 3.5$ mm, which were extracted from 4x4 pixels on the same positions of the set of time-dependent images. The dashed line is the THz pulse measured by the differential detection method.

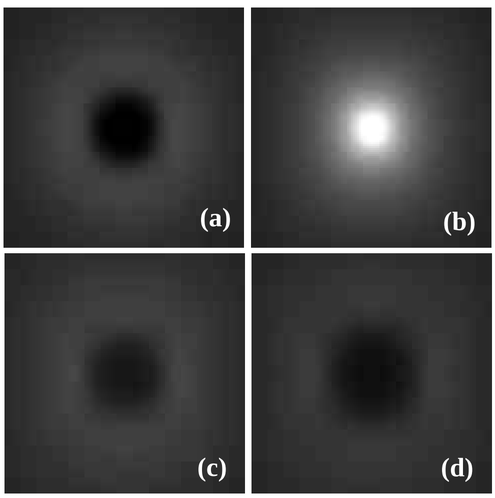

Fig.3 Simulated THz field images on the focal plane at (a) $t = -0.67$ ps, (b) t = 0.0 ps, (c) t = 0.67 ps, and (d) t = 0.83 ps calculated by diffraction integral.

showed a ring profile. The temporal waveform at the focus was also measured to confirm the data that were extracted from the images. In Fig.2, the consistence between the temporal waveform extracted from the center of images and that was measured by the conventional electro-optic detection method verifies the electric field detection of the optical heterodyne measurement. At the off-axis point $x = 3.5$ mm, for example, the pulse is broadened due to the lack of high frequency components. This confirms the Gaussian beam theory which shows that short wavelength waves are more tightly focused than longer ones. When $|t| \geq 0.5$ ps, the magnitude of the off-axis pulse is higher than that of the middle. It results annular ring pattern. In the case of the second experiment, the similar trend can be explained by noting that the pulse widths at observation time are larger than that at the focus. It can be shown that this phenomenon is observed because the central frequency of a half-cycle pulse locates near dc, and there is no destructive correlation as in laser pulses [2]. We also conducted simulations based on diffraction integral as shown in Fig. 3. We started the procedures from the calculation of the surface current at the antenna after photo excitation. Then the diffracted field on an ideal lens, and that on the observation planes in the final stage, were calculated sequentially. The results confirm the experimental data.

4. Conclusions

The field pattern of focused half-cycle THz pulses exhibited a donut-shape profile when the time or observation position is shifted from the peak or the focus, respectively. The wide range, which includes near-dc components, of the THz spectrum makes the feature observable. The ring profile might cause troubles in the observation of circular objects.

References

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[2] R. Rungsawang, K. Ohta, K. Tukamoto and T. Hattori, J. Phys. D: Appl. Phys. **36**, 229 (2003).