Single-shot terahertz imaging

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Abstract. Single-shot detection of two-dimensional terahertz (THz) imaging was conducted using a half-cycle THz pulse generated from a large-aperture photoconductive antenna. The appropriate timing of the probe pulse for imaging an object was discovered. The single-shot imaging enables observation of ultrafast phenomena at a frame rate of 1000 frames/s.

1. Introduction

Imaging with electromagnetic pulses in THz region (10 GHz–10 THz) is attractive for real-world applications because it can provide a noninvasive monitoring method. Furthermore, it can be applied for time-resolved spectroscopy that has the potential to read out both amplitude and phase information simultaneously. Since the THz pulses have pulse widths less than 1 ps, they can be used in many types of time-resolved measurements. For the observation of ultrafast single-time events, such as explosion and melting, single-shot THz imaging should be introduced. Single-shot THz imaging can also be applied to real-time imaging of various objects. Two-dimensional simultaneous detection of THz electric field generated from an unbiased photoconductive antenna using electro-optic (EO) detection was first reported by Wu *et al*. [1]. Their readout time of the experiment was 0.133 s. Spatio-temporal detection with a higher frame rate was performed by Jiang and Zhang [2]. They achieved a capture rate up to 69 frames/s with an improved signal-to-noise ratio using the dynamic subtraction technique. The THz movie of a moving biological object was reported at a frame rate of 10 frames/s [3].

The essential components required for the single-shot THz imaging are a powerful THz source, a sensitive detection method, and a high-speed camera. We used a large-aperture biased photoconductive antenna to produce a high electric field. This source gives a simple output waveform, *i.e*., almost half-cycle shape at focus. The pulse width was about 500 fs. The waveform can change a great deal along its propagation, and deviate from the half-cycle pulse at the observation plane [4]. We found that there is a certain time window that is suitable for imaging at a fixed time delay. We adopted the optical heterodyne detection method in the EO sampling for sensitive field image detection [5,6]. We used a high-speed CCD camera, which enabled to capture one THz image for every THz pulse. Our system is run at a 1 kHz repetition rate. The raw data were passed through digital imaging processes to reduce noises.

2. Experiment

The imaging setup was similar to that described in a previous paper [5]. By scanning the delay time of the probe pulse, we found that images are clearly seen only at a specific time window. Interestingly, that is not the peak time of the THz pulse. In Fig. 1, the THz field waveforms observed at the focus and on the image plane are shown. The focal length of the lens was f = 98.5 mm, and the image plane was at 1.5f from the focus. From the plot, it is seen that the main pulse shape at the focus (dotted line) is almost half-cycle having a tail with a small negative value. The negative tail is attributed to diffraction of low-frequency components before being focused. At the object location, on the other hand, the pulse (solid line) is broadened. The long rise time shows diffraction of high-frequency components after being focused. The period when images were clearly observed corresponds to the time region where the THz field has steep transient, namely at the time delay 0–1ps in the figure, where the high frequency components dominate. By fixing the time delay at time delay 0.5ps, we succeeded in observing images in real time.

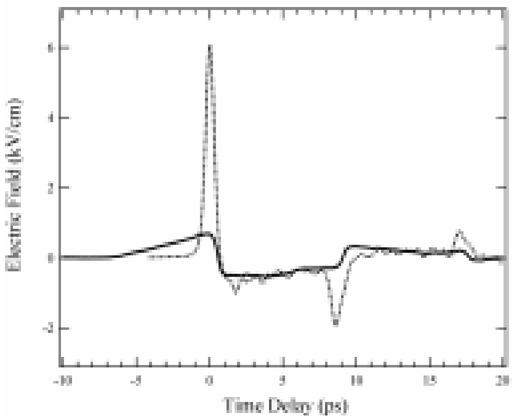

Fig. 1. On-axis temporal waveforms on the focal plane (dotted line) and on the image plane (solid line) measured using the conventional balanced detection method.

3. Results and Discussion

The THz pulses passed through an object sample that was placed at distance 3*f*. The image of the object was projected to a 18 x 20 mm^2 ZnTe crystal. The sample object was a metal rod of 2.6 mm in diameter. The rod was hung by a string and, when at rest, placed vertically at the center of the THz beam. Real-time images of the rod, while swinging, were obtained. The electric field images were calculated from the CCD data and divided by the reference image obtained when the sample was removed. By this procedure, the artificial pattern attributed to the characteristics of the focused THz beam itself was removed [7]. The resulted images contained noises which originated from the CCD camera and the instability of the laser. By processing the images using a Gaussian filter, good image quality was achieved. Two images of the rod selected from a series are illustrated in Fig. 2. The spatial resolution of the images is limited by the low central frequency of the THz pulses.

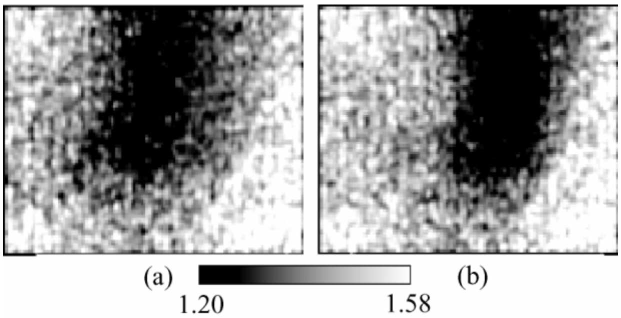

Fig. 2. Single-shot images of a metal rod which moved from left to right. Image (b) was obtained 20 ms after image (a). These images were divided by the reference image obtained without the sample object and processed using a Gaussian filter. The dimension of images is 8.8 x 7.4 mm^2. The bar indicates the gray scale showing in percentile range 10%-90%.

4. Conclusions

Using THz pulses from a large-aperture biased photoconductive antenna and a high-speed CCD camera, single-shot detection of THz images was achieved. Using this technique, we obtained a high-speed movie of a moving object in real time at a rate of 1000 frames/s. Potential applications of this technique include high-speed movies and time-resolved spectroscopic studies of single-time events in the THz frequency region.

References

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