Bias field modulation of photoconductive antenna for emission and detection of terahertz electromagnetic waves

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Abstract

We succeeded in increasing the S/N ratio of the terahertz electromagnetic waves emitted from a photoconductive antenna by a factor of 2 by modulating the polarization of the bias field applied to the photoconductive antenna.

In the experiments of the terahertz (THz) electromagnetic waves, femtosecond laser pulses are often used to excite a photoconductive (PC-) antenna that works as a THz wave emitter. In this case, an optical chopper is often used to modulate the intensity of the femtosecond laser pulses to obtain the temporal waveforms of the THz electromagnetic waves with a good S/N (a lock-in detection method).

To evaluate the response of a material in the THz electromagnetic region, it is often used to compare the temporal profiles of the THz electromagnetic wave before the incidence and after it passes through the material (or after it is reflected from the material). However, the evaluation is not easy due to the problem of S/N when the amount of the change between the two temporal profiles is small.

Here, we improved the S/N of the temporal profiles of the THz electromagnetic waves by modulating the bias electric field applied to the PC-antenna instead of modulating the intensity of the laser pulses that excite the PC-antenna. In our method, not only the magnitude of the bias field but also the polarization of the bias field was modulated to obtain THz electromagnetic waves.

Bias field modulation of PC-antenna was performed by T. Yasui et al [2]. However, they only modulated the magnitude of the bias field at high frequency (100 kHz), and did not considered the effect of the mechanical vibration of the optical table.

In the experiment, a PC-antenna was used to generate THz electromagnetic waves and a ZnTe crystal was used to detect the emitted THz electromagnetic waves.

The method of modulating the direction of the polarization of the femtosecond laser pulses is suitable for the EO crystals such as ZnTe, as this method changes the sign of the THz electromagnetic waves and increases effectively the amplitude of the THz electromagnetic waves [2].

However, this method is not suitable to PC-antennas as the polarization modulation only changes the amplitude of the THz electromagnetic waves. As the result, we obtain a signal with a poor S/N than that obtained with a lock-in detection method using an optical chopper.

In the present experiment using a PC-antenna as a THz wave emitter, the polarization of the THz electromagnetic waves can be reversed by reversing the polarization of the bias voltage. As a result, the size of the signal doubles in the effect.

To obtain a linear dependence of the magnitude of the THz electromagnetic waves on the bias voltage including the bias-voltage-polarization, a spatially symmetric excitation of the antenna gap with laser pulses is favorable.

We excited the whole gap (~10μm) of the PC-antenna that had a dipole structure. This excitation condition is favorable also to avoid the shortening of the device lifetime of PC-antennas.

Figure 1 shows the bias field dependence of the peak amplitude (including the sign) of the THz wave at the bias voltage from -14 to +14 volt. The peak amplitude of the THz electromagnetic wave depends almost linearly on the bias voltage. The deviation from a perfect linear dependence may be attributed partly to the size of the laser spot size and also to the position of the excitation point within the antenna gap. If we excited the antenna gap with laser pulses of ~μm spot size, the THz electromagnetic waves will not show similar amplitude for both the polarization of the bias field [3,4], and the PC-antenna will be easily damaged or the device lifetime will be shortened due to the high fluence of the laser pulses.

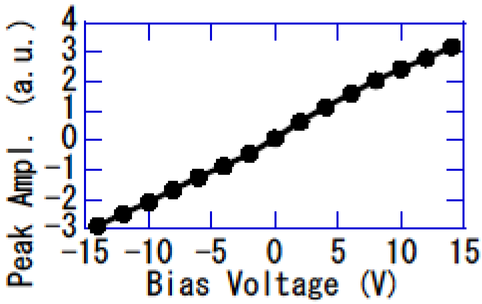

Fig.1 Bias field dependence of peak amplitude

The THz electromagnetic waves detected by an optical chopper method (dotted line) and the bias modulation method (solid line) are shown in Fig.2. The modulation frequency was 1.2 kHz for both methods, and other parameters were the same. Both waveforms were normalized to unity. The inset is a section (time region from 0 to 3 ps) of the THz electromagnetic waves expanded vertically to illustrate the difference of the S/N between the waveforms detected by the two methods. We clearly see that the S/N of the signal detected by bias field modulation is better than that detected by the optical chopper modulation. Thus the bias field modulation improved S/N of the signal compared to the optical chopper modulation.

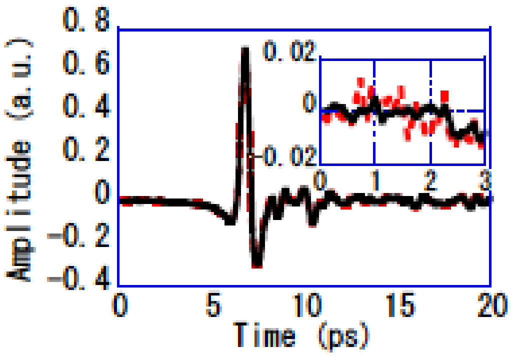

Fig.2 Temporal waveforms of THz electromagnetic waves

As the optical table has a large mass, it is expected that it will transfer less mechanical vibration from the floor to the optical components as the vibration frequency increases. Therefore, we expect that the temporal waveforms will show a better S/N ratio as the modulation frequency increases.

Unfortunately, we cannot increase the modulation frequency of an optical chopper due to the mechanical problem (The motor lifetime will become short when the modulation frequency is high. Actually, Stanford Research Company recommends using the optical chopper with the frequency less than 2 kHz.).

On the other hand, the frequency can be raised further in the bias field modulation without such problems encountered when we use an optical copper.

Figure 3 shows the temporal waveform of the THz electromagnetic wave obtained with 2.0 kHz frequency (dashed curve) and that with 6.0 kHz frequency (solid curve). Both waveforms were normalized to unity as in the case of Fig. 2. The inset is a section (time region from 0 to 3 ps) of the waveforms expanded vertically to illustrate the difference of the S/N between the waveforms detected with the two different frequencies. To make clear the difference of the S/N between them, we added mechanical vibrations to the optical table and increased the noise. The temporal waveform measured at 6.0 kHz frequency showed a better S/N than that measured at 2.0 kHz frequency.

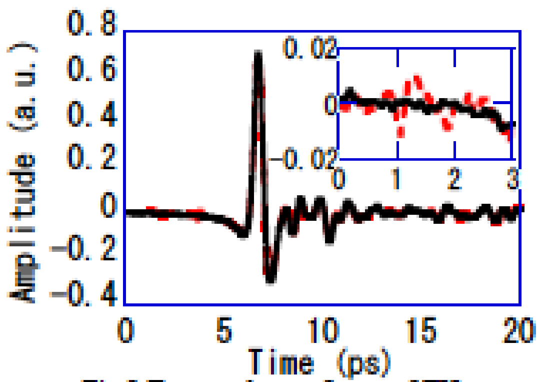

Fig.3 Temporal waveforms of THz electromagnetic waves

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Key words:
Terahertz (THz) emission
THz emission by ultrashort laser pulse