Bipolar Photogenerated Terahertz Radiation in Biased Photoconductive Switches

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Abstract

The characteristics of optically induced bipolar THz radiation in biased photoconductive switches were investigated systematically by using free-space electro-optic sampling technique. The emitted radiation shows nearly symmetrical waveform with broadband frequency spectrum spanned over 0.1-3 THz. It is observed that the bipolar nature and the emitted frequency spectrum distribution remained unchanged by varying the optical excitation fluences, strength of biased fields and the emitter gap spacing. The dynamics of emitted THz transient are in agreement with the optically induced ultrafast charge transport process driven by the biased field.

Key words: terahertz radiation; free-space electro-optic sampling ; photoconductive switches

Photogenerated broadband coherent terahertz (THz) radiation from biased photoconductive switches after excitation by an ultrafast laser pulse has been popularly approached,[1,2] and the emitted THz waveforms and frequency spectrum were studied by several groups.[3,4] Under some particular conditions, bipolar THz waveforms were obtained either in large or in small aperture photoconductive switches. The mechanism of the photoinduced THz radiation, however, is still a matter of debate.

In this paper, THz radiations obtained from biased photoconductive switches with varying emitter gap spacing, applied bias fields and optical excitation fluences are reported. Our results showed that with the gap spacing ranging from 10-500 μm the emitted radiations were all bipolar in nature. Furthermore, the waveform and the frequency spectrum distribution do not depend on the optical excitation fluences and strength of biased fields. It is suggestive that the THz radiation obtained in the current set-up is originated from essentially the same mechanism intimately associated with the ultrafast charge transport process during the pulsed laser illumination. Namely, by biasing a constant voltage across the gap spacing of the emitter, carriers photoinjected into the gap by ultrafast laser pulse will be accelerated, leading to the emission of a THz transient and broadband frequency radiation. The generation and detection of THz radiation using free-space electro-optic sampling technique[5,6] is setup on a mode-locked Ti:Sapphire laser operating at 800 nm (1.55 eV) with a 75 MHz train of 20 fs pulses.

Figure 1 shows the typical photogenerated THz signals as a function of the scanning delay time obtained from the semi-insulating GaAs photoconductive switches with a biased field of 2 KV/cm. The average pumping power (fluence) is 130 mW (0.8 μJ/cm^2) and 1 mW (60 nJ/cm^2), respectively. The gap spacing of this emitter is 500 μm. The inset of Fig. 1 plots a series of emitted bipolar THz radiations as a function of average pumping power. Nearly symmetrical THz waveforms were observed by varying the pumping power from 1 mW to 130 mW. It is interesting to note that, though the pattern of the waveform remains unchanged, the amplitude varies linearly with the average pumping power. The signal-to-noise ratio (SNR) is about 10^3 (10^6 in power) for 130 mW case. Whereas for 1 mW case, strong noise was observed before delay time t=0 due to the signal amplification factor.

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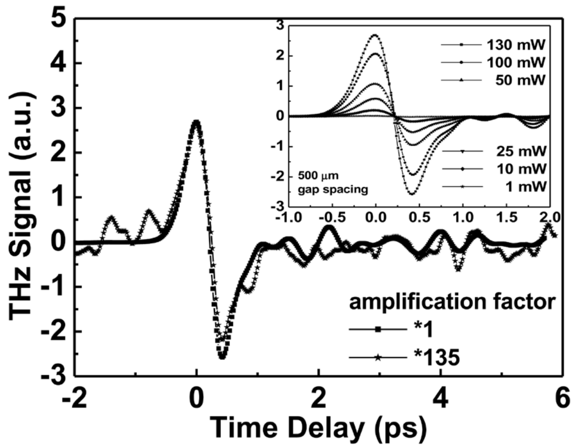

Fig. 1. Transient THz waveforms for 500 μm emitter. The average pumping power is 130 mW (full square) and 1 mW (full star) respectively. The inset shows a series of emitted THz waveforms obtained by various average pumping power.

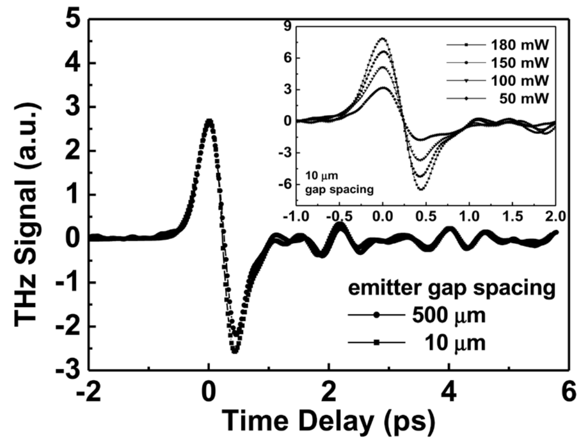

Fig. 2. Transient THz waveforms for a 500 μm (full square) and a 10 μm (full circle) emitter. The output THz signal is amplified for 10 μm emitter. The inset shows a series of emitted THz waveforms obtained by various average pumping power for 10 μm emitter.

The absence of amplitude saturation, as observed by Darrow et al.,[1] may be due to the relatively smaller excitation fluences used here.

Figure 2 compares the emitted THz waveforms for a 10 μm gap spacing photoconductive switches with that of the 500 μm one. As can be seen, the waveforms in both cases are essentially the same, except that the shape is relatively asymmetrical in 10 μm case. The inset of Fig. 2 plots a series of emitted bipolar THz radiations as a function of average pumping power for the 10 μm wide photoconductive switch. For 100 μm gap spacing photoconductive switches (not shown here), similar behaviors were also observed. The current results display no signature of unipolar to bipolar waveforms transitions.[3] From the power spectrum derived by Fourier transforming the THz waveforms, the radiation frequency spectrum spanned over 0.1-3 THz. The central frequency is 0.7 THz and the bandwidth of half maximum (BWHM) is around 1.1 THz. In addition, experiments have shown that the waveforms and frequency spectrum of the emitted radiation displayed no dependence on the strength of biased fields. The robust characteristics of the emitted radiation, is indicative that the same underlying physical mechanism is prevailing in all cases.

In fact similar results have been reported by Lu et al.[5] in a 2.5 mm wide emitter using free-space electro-optic sampling technique. These, however, are in sharp contrast with some of the results reported in literature. It has been proposed that bipolar waveforms of THz radiation which can only appear in large aperture photoconductors with high optical excitation fluences, is a consequence of space-charge screening to the bias field.[4] On the other hand, Pederson et al.[3] studied the effects of carrier density on the emitted waveform for a 50 μm wide emitter and concluded that the emitted radiation will change from unipolar to bipolar with increasing photoexcited carrier density. Since the bipolar nature of the THz radiation obtained in the current set-up has been persisted in virtually every case studied, the current results can thus be interpreted consistently with the mechanism associated with the ultrafast charge transport process during the pulse laser illumination. The apparent discrepancies mentioned above may just arise from detection and sampling techniques.

Acknowledgements

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