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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 spanning over 0.1–3 THz. It was observed that the bipolar nature and the emitted frequency spectrum distribution remained unchanged on varying the optical excitation fluence, strength of biased field 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.

Keywords: 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 both in large and 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 various emitter gap spacings, applied bias fields and optical excitation fluences are reported. Our results showed that with the gap spacing ranging from 10 to 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 fluence or strength of biased field. This suggests that the THz radiation obtained in the current setup originates from essentially the same mechanism as that associated with the ultrafast charge transport process during 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 transient and broadband frequency THz 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.

Fig. 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 (fluences) are (a) 130 mW (0.8 μJ/cm^2) and (b) 1 mW (60 nJ/cm^2). The gap spacing of this emitter is 500 μm. Nearly symmetrical THz waveforms are observed by varying the pumping power from 1 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. In contrast, for the 1 mW case, strong noise is observed before delay time $t = 0$. The absence of amplitude saturation, as observed by Darrow et al. [1] may be due to the relatively smaller excitation fluences used here.

Fig. 2 shows a series of emitted bipolar THz radiations as a function of average pumping power for the 10 μm wide photoconductive switches with a biased field

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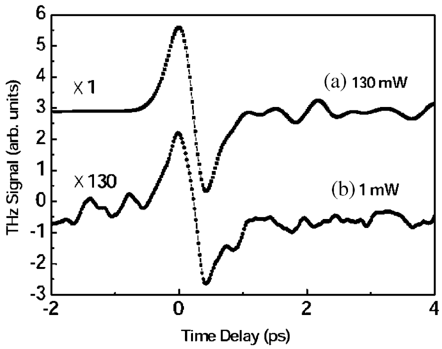

Fig. 1. Transient THz waveforms for 500 μm gap spacing photoconductive switches. The average pumping power are: (a) 130 mW and (b) 1 mW.

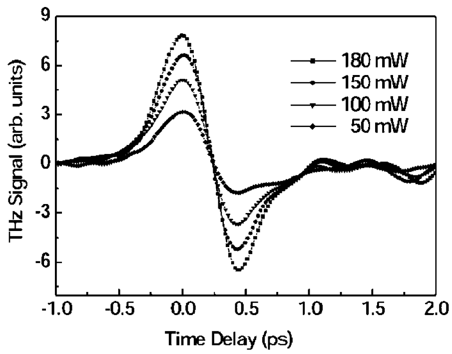

Fig. 2. A series of emitted transient THz waveforms for 10 μm wide photoconductive switch.

of 20 kV/cm. As can be seen, the slightly unsymmetrical THz waveforms remain intact over the whole range of optical excitation fluences studied. Nearly the same ratio of the THz pulse for the positive lobe to that for the negative lobe is obtained under different optical excitation fluences for a 10 μm emitter gap spacing. 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].

Since the waveforms are essentially the same for all cases, it is suggested that the broadband frequency spectrum of the emitted radiation is not dependent on either the excitation fluences or the emitter gap spacing. In addition, experiments have shown that the waveforms and frequency spectrum of the emitted radiation display no dependence on the strength of the biased field. Viewing of the power spectrum derived by Fourier transform of the THz waveforms, the radiation frequency spectrum spanning over 0.1–3 THz. The central frequency is 0.7 THz and the bandwidth of half maximum (BWHM) of the frequency spectrum is around 1.1 THz. In our measurement configuration, the optical pumping (800 nm) is incident normal to the emitter substrate so that the radiation output is independent of surface depletion and difference frequency mixing due to the surface χ^2 of photoconductors. 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] for 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, are a consequence of space-charge screening of 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 changes from unipolar to bipolar with increasing photoexcited carrier density. Since the bipolar nature of the THz radiation obtained in the current setup persists in virtually every case studied, the current results can be interpreted consistently in terms of the mechanism associated with the ultrafast charge transport process during the pulse laser illumination. The apparent discrepancies mentioned above may arise merely from detection and sampling techniques.

Acknowledgements

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References

[1] J.T. Darrow, et al., IEEE J. Quantum Electron. 28 (1992) 1607.
[2] P.R. Smith, et al., IEEE J. Quantum Electron. 24 (1988) 255.
[3] J.E. Pedersen, et al., Appl. Phys. Lett. 62 (1993) 1265.
[4] G. Rodriguez, et al., Opt. Lett. 21 (1996) 1046.
[5] Z.G. Lu, et al., Appl. Phys. Lett. 71 (1997) 593.
[6] P.I. Lin, et al., in preparation.