Large-Aperture THz Emitter with Interdigitated Electrodes

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Abstract

We fabricated a large-aperture microstructured THz antenna array composed of seven units of 1-cm^2 photoconductive antennas having interdigitated electrodes with 10-μm lines and spaces on a semi-insulating GaAs substrate. By illuminating it with amplified femtosecond optical pulses, a large THz field comparable to that from conventional large-aperture emitters was obtained at a bias voltage as low as 30 V.

Introduction

Large-aperture photoconductive antennas excited by amplified femtosecond optical pulses have been studied and used for the generation of intense terahertz (THz) pulses [1-9]. They can emit half-cycle or monocycle intense THz pulses with a broad bandwidth, and have been used in real-time imaging [5-9] and other applications. The requirement, however, of a bias voltage as high as 10 kV or more with conventional large-aperture emitters has limited their usage. We fabricated a microstructured photoconductive antenna array with interdigitated electrodes which can overcome limitation of the conventional structure.

Emitter structure

The antenna array was composed of seven units of photoconductive antennas. They were fabricated on a 2-inch semi-insulating GaAs wafer. A schematic of the whole emitter structure is shown in Fig. 1(a). Each unit had separate electrodes and could be operated independently. Each unit had metal interdigitated electrodes as shown in Fig. 1(b). The line width and the separation of the electrodes were both 10 μm, and each unit had an area of 10 mm x 10 mm. Shadow masks were placed to allow excitation light to irradiate only every other electrode spacing. This enables constructive interference of the THz field emitted from the interdigitated electrode structure. SiO_2 was deposited on the electrodes for the insulation between the electrodes and the metal shadow masks. The electrode structure was fabricated using two methods, *i.e.*, lift-off and dry etching. Similar results were obtained from both samples and the experimental results shown below were obtained using lift-off samples.

Our device structure essentially follows the approach of Yoneda *et al.* [10] and Dreyhaupt *et al.* [11]. Yoneda *et al.* fabricated an interdigitated antenna array on diamond, which was excited by high-power KrF excimer laser pulses. The emitter of Dreyhaupt *et al.* had a size much smaller than the present one and was excited by unamplified laser pulses. The emitter reported in the present study had a size comparable to those of conventional large-aperture antennas, and was excited by amplified femtosecond Ti:sapphire laser pulses.

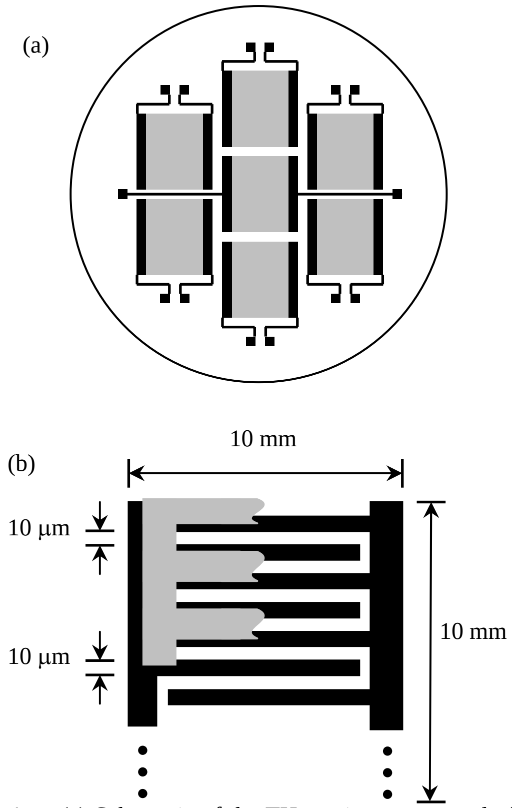

Fig. 1: (a) Schematic of the THz emitter composed of seven units of photoconductive antennas having an interdigitated electrode structure. (b) Structure of each unit.

Scaling law

Since the intensity of THz radiation emitted from photoconductive antennas is saturated at a relatively small excitation fluence, the emitted field, E_{THz}, is expected to follow a simple scaling law:

$$E_{\mathrm{THz}} \propto A_{\mathrm{eff}} \cdot E_{\mathrm{bias}},$$

where, A_{eff} is the effective emitter area that is used for the THz field generation and E_{bias} is the bias field applied between the electrodes. The bias field applied to the small spacing between electrodes can easily be raised up to a 100 kV/cm level, and 500 kV/cm will be possible using the state-of-the-art microprocessing technology. In contrast, the bias field of the conventional large-aperture antenna has been limited at around 10 kV/cm due to discharge on the semiconductor surface. Although the effective emitter area of the microstructured antenna is about 25% of the whole area, it is easily scalable using larger wafers. Thus the microstructured antenna is the choice for the generation of intense broadband THz pulses.

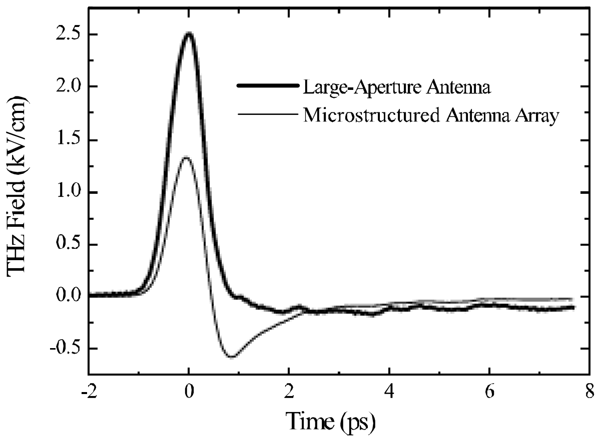

Fig. 2: THz field waveforms obtained from a conventional large-aperture emitter and the microstructured antenna array under typical operation conditions. The excitation fluence was over the saturation level, and the bias field was 2 kV/cm and 30 kV/cm for the conventional and microstructured antennas, respectively.

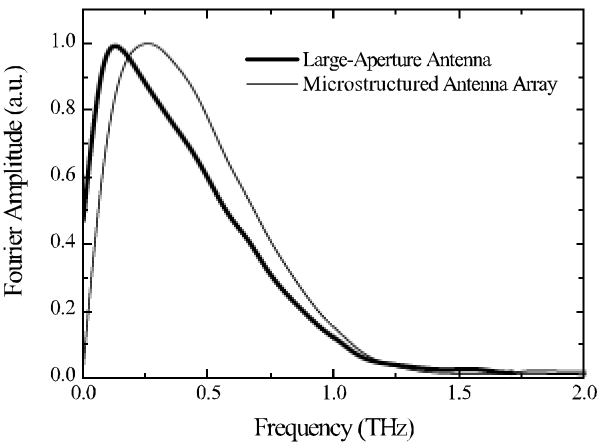

Fig. 3: Normalized Fourier amplitudes of the THz field emitted from a conventional large-aperture emitter and the microstructured antenna array.

Experimental results

The properties of the emitter were characterized by measuring the waveforms of the emitted THz field as a function of bias voltage and excitation light fluence. The results were compared with those of a conventional large-aperture antenna [5], which had a 3-cm spacing between the electrodes. The antennas were excited by amplified 150-fs, 800-nm Ti:sapphire laser pulses at a repetition rate of 1 kHz. Emitted THz field was focused by a TPX lens, and the field waveform was measured using an electro-optic sampling method. The microstructures antenna was biased by a dc voltage up to 30 V, which corresponds to a bias field of 30 kV/cm. It was observed that the THz field becomes unstable above this voltage level. The obtained peak THz field at this bias was about half of that obtained using a conventional large-aperture antenna at a bias field of 2 kV/cm, as shown in Fig. 2. This is about seven times lower than predicted by the scaling law. The waveform of the THz pulse from the microstructured emitter shows a monocycle profile, which is in contrast to the half-cycle pulse shape obtained from the conventional large-aperture antenna. The spectra shown in Fig. 3 reflect the difference in waveform. The spectrum from the microstructured antenna has a negligibly small Fourier amplitude at zero frequency, and a peak at a higher frequency. This difference is attributed to the effect of the electrode structure on the propagation of the THz waves.

Conclusion

A large-aperture microstructured photoconductive antenna array having 10-μm width and spacing of interdigitated electrodes was fabricated on semi-insulating GaAs, and the properties were characterized. Generation of THz pulses with a field amplitude comparable to those obtained with conventional large-aperture antennas was observed. The obtained field was not as high as expected from the scaling law, and the properties will be improved by optimizing the microprocessing procedure.

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