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Terahertz Emission from (100) p-InA

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Terahertz Emission from (100) p-InAs

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Abstract

Terahertz emission from (100) p-type InAs illuminated by ultrafast near-infrared pulses is investigated. A two-fold rotational symmetry was observed when rotated about the surface normal. A quadratic relationship was found for the emission dependence on optical pump power. These suggest the presence of photo-carrier transport and optical rectification mechanisms. The InAs emission was found to exceed that of a blackbody radiator for frequencies below 1 THz for nominal input power levels. The generated power was found to be roughly two orders of magnitude greater than a 1mm ZnTe emitter.

Introduction

Accessing the terahertz (THz) region of the electromagnetic spectrum has been the goal of many research groups around the world in recent years. The driving force has been the many possible applications that utilize the unique characteristics of this radiation. In order to make the majority of these applications possible, improvements in both the magnitude and bandwidth of sources is required.

Previous sources of THz emission came from incoherent black body emission such as the globar. At present the most common method of producing coherent THz radiation relies on illumination of an appropriate emitter by an ultrafast near-infrared laser. Generally there are three types of emitters, photoconductive switches (PCS), electro-optic emitters and semiconductor surface emitters.

PCS are often the preferred THz emitters due to the large power generated when compared to the other emitters. They usually consist of a photoconductor that is biased with electrodes. Greater power is achieved by the optimisation of electrode geometries[1]. The generation mechanism here is ultrafast charge carrier transport whereby the electron-hole pair is separated by the applied electric field parallel to the surface of the photoconductor[2]. Although PCS have traditionally been known for high emission but low bandwidth, there have been recent improvements in extending the bandwidth[3].

Electro-optic emitters have the advantage of broad bandwidth emission but suffer from low power. These emitters are simple in comparison to PCS as there is no requirement for microfabrication of electrodes.

The generation mechanisms of surface emitters are not yet fully understood. Like electro-optic emitters, these have the advantage of not requiring microfabrication. There has been much interest in InAs as a semiconductor surface emitter. Other groups have reported on the use of n and p –InAs[4], (111) n-InAs[5], (100) n-InAs[6] and (111) p-InAs[7, 8] as THz emitters. In this work we investigate (100) p-type InAs as a THz emitter.

Experimental details

The samples studied were p-type Zn-doped InAs with front surface epi-ready polished and normal to (100)$\pm$0.1°. Carrier concentration at 77 K was specified by the manufacturer to be (0.93-2.1) x 10^{16} cm^{-3} and etch pit density (1.9-3.7) x 10^4 cm^{-2}. In these experiments InAs was illuminated by 12-fs pulses of centre wavelength 790 nm produced by a mode-locked Ti:Sapphire oscillator (Femtosource compact[9]) at a repetition rate of 75 MHz. Lenses of 10 and 20cm focal lengths were used to focus the incident radiation. The InAs samples were irradiated in reflection geometry as shown in Figure 1. According to theory, the radiated power is dependent upon the incident angle, and the power was found to be maximum at the Brewster angle[10] or 75° in the case of p-InAs. This geometry was not always convenient in the experimental setup so an incident angle of 45° was also employed. A 1mm (110) ZnTe sample, used to a compare the emitter power, was irradiated in the transmission geometry (inset of Figure 1). The THz emission then passed through a 1mm thick polystyrene sheet and a 2mm thick silicon plate, used to filter out the remaining near infrared to reduce heating and protect the sensitive detector. The detection was achieved using a 4.2 K He-cooled bolometer with a cold 3-THz cut-off filter.

Spectra of the InAs emission were investigated separately, using both THz Time-Domain-Spectroscopy (TDS) and a Bomem DA3 fast Fourier-transform Spectrometer (FTS) with a 4.2 K He-cooled bolometer. The THz-TDS system used a 1mm (110) ZnTe detector in a balanced photodiode configuration.

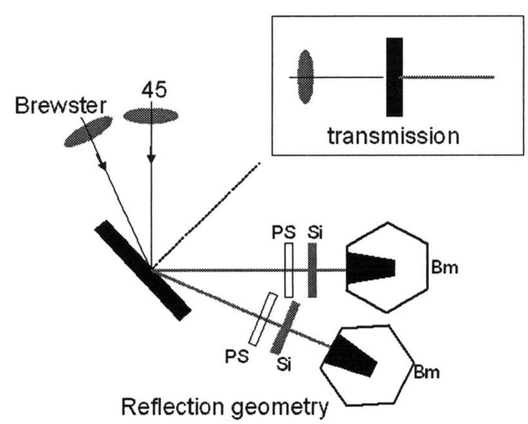

Fig. 1: Reflection geometry of InAs at both 45° and 75° (Brewster angle). Inset shows transmission geometry as used in measuring ZnTe. PS-polystyrene, Si-silicon, Bm-bolometer.

Results

Figure 2 shows the dependence of THz power emitted from InAs as a function of the azimuthal angle θ, about the surface normal. The samples were irradiated at angles of incidence of

45° and 75° and the power measured with a He-cooled bolometer. The data presented here is normalised to the average of the larger 75° signal. The initial optimum signal (for each geometry) was achieved by the manipulation of the bolometer position and more critically, the position of the lens. The relative strengths of the two geometries verify that the maximum THz output is found at the Brewster angle[10]. The azimuthal angle dependence shows a small component with two-fold rotational symmetry consistent with optical rectification in the (100) direction[6]. There is also a large constant component whose origins are believed to be due to photocarrier transport related effects[6, 7]. Although this dependence shows the presence of both photocarrier and optical rectification contributions, further investigation is required to identify the exact mechanisms responsible.

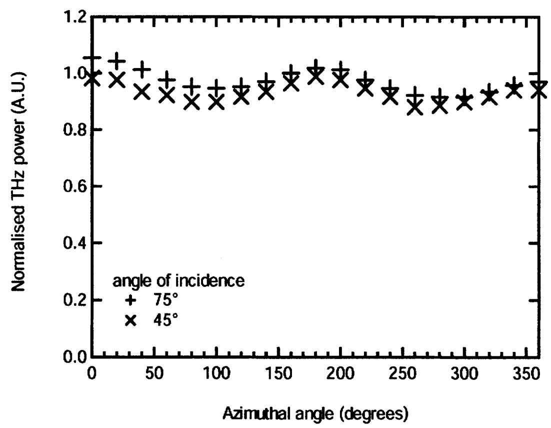

Fig. 2: Dependence of THz power on the azimuthal angle for (100) p-InAs.

Figure 3 shows the normalised THz power as a function of the excitation pump power, measured at 0° azimuthal angle from figure 2. Measurements were taken at both 45° and 75° angles of incidence. This shows a near quadratic relationship of the THz field characteristic of the optical rectification process. The power dependence was also measured for the minimum signal (θ = 90°) from Figure 2 showing a similar dependence. This is in contrast to results reported in references [6] and [7] which show sub-linear dependencies of the THz field for (100) n-InAs and (111) p-InAs respectively. These differences may be explained by a dissimilar excitation on the sample.

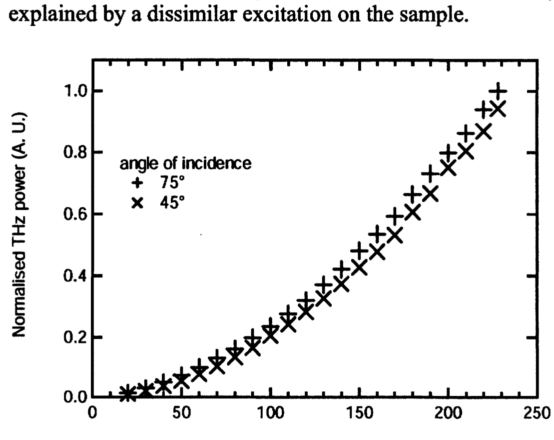

Fig. 3: Dependence of THz power on the pump power for (100) p-InAs at 45° and 75° angles of incidence. Orientation of sample is such that θ = 0° in figure 2.

The spectra of the InAs emission have been measured using both THz-TDS and Bomem FTS and yield comparable results. A preliminary investigation of increasing excitation fluence using the Bomem FTS has shown a shift in the peak position to higher frequencies. These results need further understanding in terms of the actual excitation mechanisms.

The Bomem FTS was used to obtain spectra from a blackbody emitter (globar). This and the InAs spectra were directly compared. Initial results show that the absolute power of the InAs emission exceeds that of the blackbody emission for frequencies below approximately 1 THz.

The sample temperature dependence of the emission was measured, showing an increase in the emitted power with decreasing temperature. The underlying mechanism is yet to be modeled.

The THz power from our current (110) ZnTe emitters were measured in a direct comparison to the InAs. This is not an exact comparison as ZnTe is used in transmission geometry compared to the reflection geometry of InAs. It was found that there is roughly two orders of magnitude increase in the THz power at the Brewster angle from the InAs over the ZnTe.

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