Observation of Four-fold Azimuthal Angle Dependence in the Terahertz Radiation Power of (100) p-InAs

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INTRODUCTION

Quite recently, p-type InAs has been shown to exhibit excellent terahertz (THz) radiation power compared with its more widely studied n-type counterpart. It was reported by Adomavičius, et.al., that the dominant terahertz (THz) radiation mechanism for (111) InAs is due to instantaneous polarization [1]. The report by Mendis, et.al., however, attributed the strong THz emission from (100) p-InAs to surge current [2]. In this work, four-fold symmetry was seen for the s-polarized THz power and a further folding of the usual two-fold symmetry for the p-polarized emission under a transverse 1-T field was observed. A tentative explanation pertaining to a magnetic field-enhanced L-valley carrier scattering is offered to account for the results.

EXPERIMENT

Van der Pauw-Hall measurements were initially performed to determine the carrier concentration and the carrier mobility of the p-type InAs (100) sample at room temperature. The sample had a carrier concentration of 7.1x10¹⁶ cm⁻³ and hole mobility of 150 cm²/(V·s). Primarily, THz time-domain spectroscopy (TDS) and excitation fluence dependence of the THz radiation were performed to obtain some information on the mechanism of THz radiation in the sample. The TDS experiments were performed in free space with an excitation wavelength of 800 nm from a mode-locked Ti-Sapphire laser of 100-fs pulse width and a repetition rate of 80 MHz. The angle of incidence of the laser was set at 45° with respect to the sample surface normal and the THz radiation was collected on the reflection direction using suitable optics. A 1-T permanent magnet, oriented parallel to the sample surface was used for the with-field experiments. Steady-state power measurements were also performed to investigate the azimuthal angle dependence of the THz radiation as described by Gu et.al. [3]. The azimuthal angle is defined as the angle between the crystallographic axis ([010] or [001]) and the reflection plane. In this procedure, the photoconductive antenna was replaced by an InSb hot-electron bolometer.

RESULTS AND DISCUSSION

The TDS waveforms for the B_up, B_down(= -B_up), and the no-field cases were taken. This offers an insight on the dominant THz radiation mechanism as previously reported [4]. Shown in Fig. 1 are the waveforms obtained by subtracting the TDS waveform of the no-field case from the B_up and B_down data. It is evident from the figure that the waveforms were π-shifted with respect to each other. Migita et.al. have shown that the Lorentz force-driven THz radiation due to the drift current will have a π-shifted TDS waveform when the applied magnetic field direction is flipped[4]. Moreover, excitation fluence dependence experiments revealed that up to a fluence of 1.2 mJ/cm², the dominant THz radiation mechanism is due to photocarrier diffusion as shown in Fig. 2.

![Fig. 1. Subtracted TDS waveforms for the B_up-No Field and B_down-No Field cases.](image)

![Fig. 2. Excitation fluence dependence of the emitted THz radiation. Saturation is at about 1.2 mJ/cm².](image)
This possible modification from a two-fold to a four-fold symmetry in (100) InAs has not been verified. The actual physical origin of the magnetic field induced susceptibility effect. At this point, this insinuates that this could not have come from a four-fold symmetry that was observed in the experiment. The calculation of the magnetization-induced nonlinear optical susceptibility in InAs. However, a magnetization-induced quadrupole response has yet to be observed in (100) InAs. This was ascribed to a very small absorption depth of InAs for 800nm optical excitation which is estimated to be about 100 nm.

A possible origin of the four-fold symmetry can be attributed to L-valley scattering of the photocarriers. This type of scattering is tentatively suggested to manifest as a four-fold symmetric, azimuthally dependent reduction of the THz radiation power since the L-valley is in the [111] crystallographic direction. The excitation energy (1.55 eV) is just above the L-valley energy of InAs it should be possible for this type of inter-valley process to occur. For InAs in a high magnetic field, the THz radiation has been argued to saturate due to induced L-valley carrier scattering brought about by the driving Lorentz force. Although saturation was not observed in this work due to a relatively low magnetic field strength, the periodic reduction of the THz power in accordance with a four-fold symmetry is temporarly ascribed to this scattering process. The dependence of this observation on the magnetic field strength, the crystallographic orientation of the InAs wafer, and the optical excitation energy are currently being investigated to possibly yield more plausible explanations.

**REFERENCE(S)**


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