# Terahertz Radiation from InAs/$Al_xGa_{1-x}Sb$ (x = 0.5) heterostructures

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## Introduction

Terahertz (THz) electromagnetic waves radiated from several semiconductor materials excited by femtosecond laser pulses have been widely studied as a solid-state THz emitter. Recent observation of THz radiation from two-dimensional (2D) plasmons in a GaAs/AlGaAs single interface heterojunction opened a door to realize a *tunable* THz source since the frequency of the radiation can be controlled by the variation of carrier density in the 2D electron gas (2DEG) [1, 2].

In this paper, we report on the THz radiation properties from InAs/$Al_xGa_{1-x}Sb$ (x = 0.5) heterostructures by a time-domain THz emission and detection system.

## Experimental

We grew InAs/$Al_xGa_{1-x}Sb$ (x = 0.5) heterostructures by molecular beam epitaxy (MBE). The buffer layer grown at 600 ˚C consisted of a 300-nm-thick GaAs, a 10-nm-thick AlAs, a 100-nm-thick AlSb, a 300-nm-thick GaSb, and a 15 periods of AlSb (6 nm) / GaSb (6 nm) superlattice, and a 200-nm-thick AlGaSb barrier layer. A 8-nm-thick AlSb, a 15-nm-thick InAs channel layer, a 15-nm-thick AlGaSb layer, and a 10-nm-thick GaSb layer were grown on the AlGaSb buffer layer at 450 ˚C. The structures were nominally undoped and were grown on (100) semi-insulating GaAs substrates. A 2DEG is formed in the InAs channel layer. The typical 2DEG mobility and concentration were around $1.22 \times 10^4$ $cm^2/Vs$ and $3.47 \times 10^{12}$ $cm^{-2}$ at room temperature, respectively.

Femtosecond laser pulses produced by mode-locked Ti:sapphire laser were used as optical source. The pulse width was about 100 fs at full-width at half maximum (FWHM). The repetition rate was 82 MHz and the center wavelength was around 790 nm. The excitation laser pulses were focused onto the sample surface with an incident angle of 45 degree. The THz radiation was collimated and focused onto a detector by a pair of off-axis paraboloidal mirror and silicon superhemispherical lens. A bow-tie type photoconductive antenna made of a low-temperature MBE grown GaAs was used as the detector. The detector was gated by trigger pulses that were split off from excitation pulses by a half mirror. The detail setup of the system was reported elsewhere [3].

## Results

We successfully observed THz radiation from the sample as shown in Fig. 2(a). Excitation laser power was about 50 mW in average. The pulse duration of the main peak was about 720 fs at FWHM. Complex structures were observed in the waveform between 5 ps and 40 ps. These structures may be caused by multiple reflections in the layers of the sample. Figure. 2(b) indicates the frequency spectrum of the THz radiation obtained through the fast Fourier transformation (FFT) of the time-domain waveform between –10 ps and 60 ps. The THz radiation had frequency component up to 1.8 THz with the maximum peak frequency at 0.1 THz. Figures 2(a) shows the observed time-domain waveforms of THz radiation from the sample with a magnetic field. Excitation laser power was about 50 mW in average. Solid line indicates the THz radiation without a magnetic field. Dotted and dashed lines indicate the waveforms with a magnetic field of 70 mT with opposite directions parallel to the surface normal (+B and –B, respectively). Dotted and Dashed lines in Fig. 2(b) are subtraction of the dotted and dashed line from the solid line in Fig.2(a) (+B and –B, respectively). Since opposite magnetic fields bend carriers in opposite directions, the polarizations of the radiation was

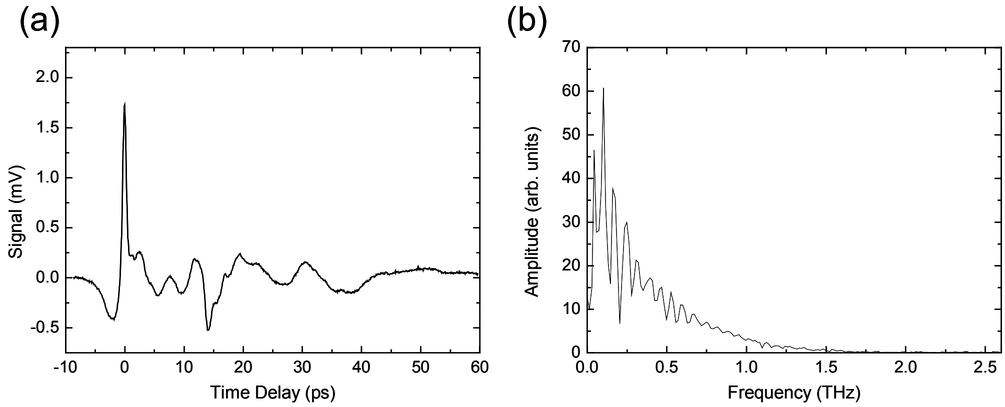


**Fig. 1.** (a) Observed time-domain terahertz waveform from sample and (b) Frequency spectrum of the radiation obtained through fist Fourier transformation of the time-domain waveform.

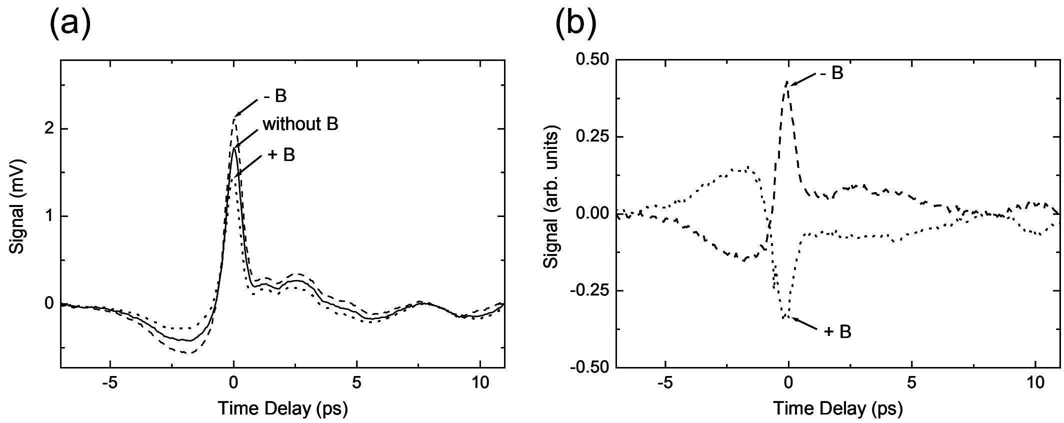


**Fig. 2.** Terahertz radiation from the sample with a magnetic field. (a) Solid line indicates the time-domain waveform of terahertz radiation without a magnetic field. Dotted and Dashed lines indicate the waveforms with a magnetic field of +70 mT (+B) and –70 mT (-B) parallel to the sample surface normal, respectively. (b) Dotted and Dashed lines are subtraction of the dotted and dashed line from the solid line in Fig. 2(a) (+B and –B, respectively).

reversed. This result indicates that the THz radiation form our sample is mainly due to the carrier acceleration by the depletion field formed in the sample layers [4].

## Summary

We successfully observed THz radiation from InAs/$Al_xGa_{1-x}Sb$ heterostructures. The magnetic field dependence of the waveforms indicated that the radiation is mainly caused by carrier acceleration in the internal electric field of the sample.

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## Reference

[1] M. Voβebürger *et al.*, J. Opt. Soc. Am. B, **13**(5) pp. 1045-1053, 1996.
[2] N. Sekine *et al.*, Appl. Phys. Lett., **74**(7) pp. 1006-1008, 1999.
[3] T. Kiwa *et al.*, Jpn. J. Appl. Phys., **40**(1A/B) pp. L38-L40, 2001.
[4] X. –C. Zhang *et al.*, J. Appl. Phys., **71**(1) pp. 326-338, 1992.