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# Investigation of THz emission by p-GaAsSb

## **Abstract**

With a suitable electric field imposed and under illumination by ultrashort pulses of near-infrared radiation, GaAsSb emits THz-frequency electromagnetic radiation. We conclude that high-temperature-grown GaAsSb is a new class of THz source.

## **Keywords**

thz, p, investigation, emission, gaassb

## **Disciplines**

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## Investigation of THz emission by p-GaAsSb

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With a suitable electric field imposed and under illumination by ultrashort pulses of near-infrared radiation, GaAsSb emits THz-frequency electromagnetic radiation. We conclude that high-temperature-grown GaAsSb is a new class of THz source.

### Introduction

Terahertz (THz =  $10^{12}$  Hz) science and technology is rapidly developing. THz spectroscopy is being used to characterize many materials, including packaging, explosives and drugs. Yet in spite of much study, THz emitters are not optimized.

Semiconductors such as ZnTe exhibit strong optical non-linearity and produce THz radiation by optical rectification (OR). Other semiconductors, such as InAs, emit THz radiation by a current surge (CS) effect. With suitable electrode or antenna structures, others again generate THz radiation by the photoconductive (PC) mechanism. Low-temperature grown (LT) GaAs is perhaps the best-known PC emitter.

Here we investigate acceptor-doped GaAsSb. Both LT-grown GaAs<sub>0.6</sub>Sb<sub>0.4</sub><sup>1</sup> and LT-grown GaAs<sub>0.81</sub>Sb<sub>0.19</sub><sup>2</sup> have been shown to produce THz radiation under suitable laser excitation. Alloying with Sb decreases the band gap relative to GaAs and so permits the use of longer-wavelength laser excitation than conventionally employed with LT-GaAs THz emitters. We have recently investigated the THz emission from Be-doped GaAs.<sup>3,4</sup>

### Experimental details

GaAsSb layers were grown lattice-matched on semi-insulating InP substrates by molecular beam epitaxy. X-ray diffraction showed the Sb fraction to be 0.487. The layers were nominally 1  $\mu\text{m}$  thick and annealed after growth at 400 °C in an H<sub>2</sub> atmosphere for 10 minutes. Details of the layers appear in Table I.

The layers were characterized by optical reflectance measurements using a Bomem DA3 rapid-scan spectrometer. The spectral resolution was 0.012 THz. For photoconductivity measurements, electrical connections were made either by Au paint electrodes,<sup>5</sup> or Au-on-Ti bow-tie antennas fabricated by standard UV photolithography followed by lift-off.<sup>6</sup> Optical excitation was provided by a 12-fs mode-locked Ti:sapphire laser of center frequency 790 nm and repetition rate 75 MHz. The emitted THz radiation was detected either using a pneumatic Golay cell (incoherent detection) or in a conventional time-domain spectroscopy arrangement using electro-optic (coherent) detection.

**TABLE I.** The GaAsSb samples used in this study. The mobility,  $\mu$ , and the charge-carrier concentration,  $n_v$ , as determined by Hall measurements, are given at the two temperatures 300 K and 77 K for the three intentionally-doped samples.

	A	B	C	D
GaAsSb layer thickness [nm]	800	900	900	900
Hall measurements at 300 K				
$\mu$ [ $\text{cm}^2/\text{Vs}$ ]		7564	4593	2401
$n_v$ [ $\text{cm}^{-3}$ ]	undoped	$2.04 \times 10^{17}$	$1.02 \times 10^{18}$	$9.24 \times 10^{18}$
Hall measurements at 77 K				
$\mu$ [ $\text{cm}^2/\text{Vs}$ ]		9288	5335	2643
$n_v$ [ $\text{cm}^{-3}$ ]	undoped	$1.94 \times 10^{17}$	$1.02 \times 10^{18}$	$9.59 \times 10^{18}$

## Results and Discussion

Reflectance data are shown in overview in Figure 1.

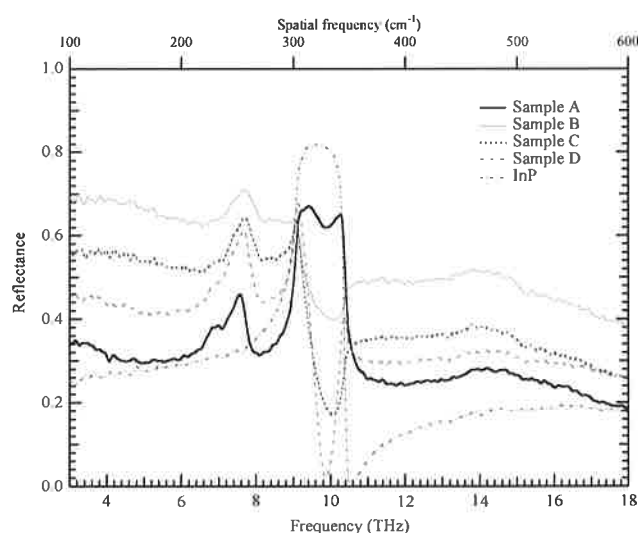


Figure 1. Overview of reflectance spectra of GaAsSb samples of different doping levels with Be acceptor. The spectrum for InP (substrate material) is shown for comparison.

The resonance from the GaAsSb layer (7.5 THz) is clear for all samples. The prominent feature from 9 to 10.5 THz is from the substrate. The notch in the InP reststrahlen deepens with increasing GaAsSb layer carrier concentration. A study by Lucovsky and Chen<sup>7</sup> shows the mixed-mode behavior. The data were fitted with a matrix model of optical reflectance as described previously.<sup>8</sup>

Figure 2 (a) gives the data for the nominally undoped sample, together with the model fit. Surprisingly, as this is the simplest sample, it gave the poorest of the fits to the data out of the series. There appears to be a mismatch of the layer reflection. Although the results for the layer were poor, the results for the substrate were as expected. While the layer is nominally undoped the observation of a notch in the InP reststrahlen peak is an unmistakable indicator of the presence of charge carriers.

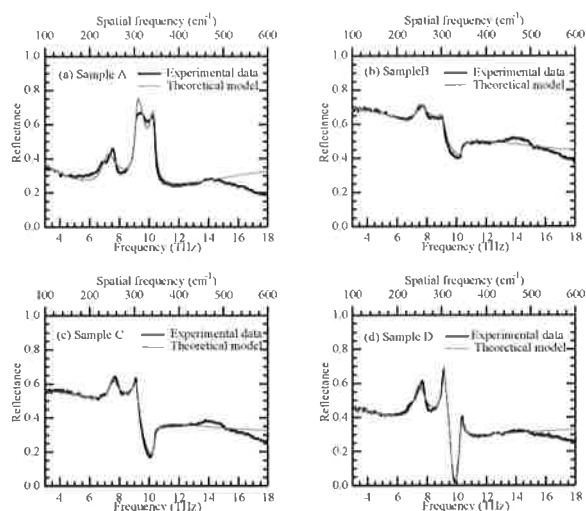


Figure 2. Reflectance spectra of GaAsSb samples of different doping levels with Be acceptor together with theoretical model.<sup>8</sup>

Figure 2 (b) gives the data and model fit for the least-heavily intentionally doped sample. The fitting parameters are in very good agreement with the interpolated values of the phonon energy and the dielectric constants of the alloy. The plasma frequency was predicted using the nominal value of the carrier concentration and a linearly interpolated value of the hole effective mass.<sup>9</sup> The data with fits for the two other samples are Figures 2 (c) and (d). The model generally accounts for the data well. Photoconductivity measurements were made under different levels of laser illumination (Figure 3).

In Figure 3 the current between the Ag paint electrodes is given as a function of applied bias under illumination of (i) 90 mW and (ii) 240 mW. The photoconductivity effect is much smaller than effects we have observed in GaAs.<sup>4</sup> The doped samples were tested for photoconductivity, but none of them gave a measurable response.

The THz emitted was first sought in a straight-through transmission geometry using a Golay cell as the detector, Figure 4. The amount of THz radiation emitted increases with applied bias and with optical excitation power, as is the case for GaAs.<sup>4</sup>

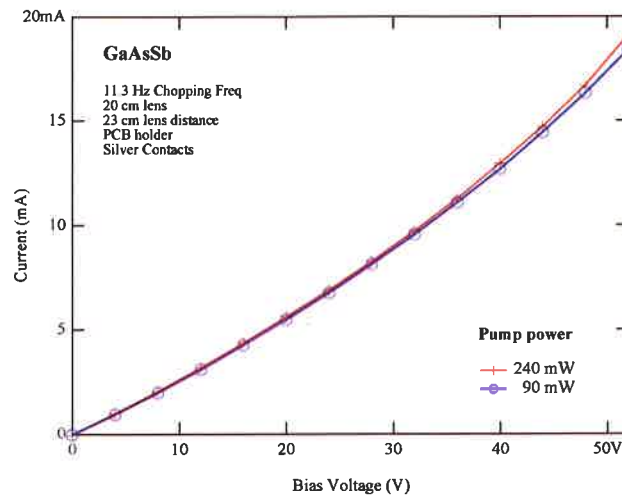


Figure 3. Photoconductive response of GaAsSb Sample A under pulsed near-infrared excitation.

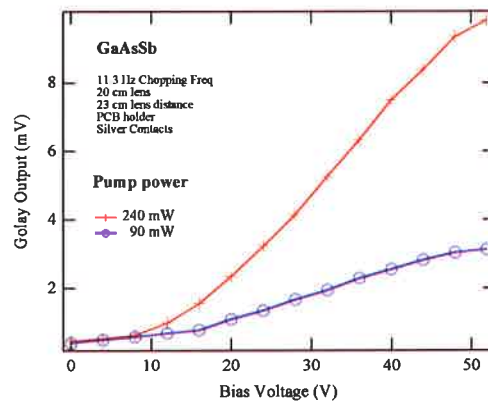


Figure 4. THz signal from GaAsSb Sample A as a function of applied bias and optical excitation power.

The THz emission was investigated using time-domain spectroscopy. In Figure 5, the magnitudes of the detected THz electric fields are comparable in the two data sets shown, but the Ag paint data are for a higher applied bias (12 V) than the Au antenna data (5 V). In general, the Au antennas produced a much stronger THz signal than the Ag-paint electrodes for a given applied bias.

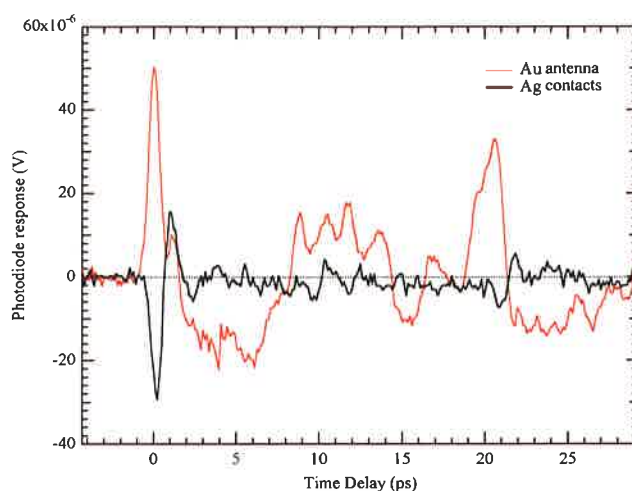


Figure 5. Time-domain spectra (Sample A) for Ag and Au contacts.

Figure 6 shows that the bandwidths of the two types of electrode structures are similar.

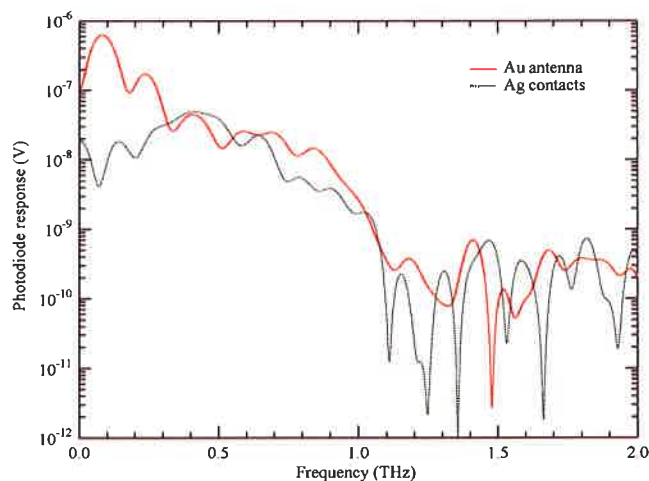


Figure 6. Frequency-domain spectra (Sample A); Ag and Au contacts.

Finally, all samples were extensively tested as CS emitters in a similar configuration as that used for the well-known CS emitter *p*-InAs.<sup>10</sup> GaAsSb gives, at most, very little THz signal as a CS emitter, in contrast to GaAs, where we observe strong CS emission.

### Conclusion

The emission of THz radiation has been demonstrated in undoped, high-temperature-grown GaAsSb to take place by a photoconductive mechanism.

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