# Terahertz characteristics of InGaAs with periodically-positioned InAlAs insertion layers

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***Abstract*—We present terahertz (THz) generation and detection characteristics of InGaAs with periodically-positioned InAlAs insertion layers (InGaAs PPIL). A THz transmitter with the InGaAs PPIL showed three times higher than that of an InGaAs epilayer without the insertion layer at the current signal for THz generation properties. Also, the detection properties of a THz receiver with the InGaAs PPIL showed over twenty-five times higher than that of a simple InGaAs epilayer. Also current signals of the InGaAs PPIL was improved with increasing the number of the InAlAs insertion layers.**

## I. INTRODUCTION

The terahertz (THz) gap positioning between far-infrared and microwave in electromagnetic spectra has been still remained as one of challenging regions in terms of fundamental physics as well as device applications.

In this paper, we demonstrate the effects of multiple InAlAs insertion layers (ILs) on the THz generation and detection characteristics of InGaAs-based devices. For the applications of a THz transmitter (Tx) and a THz receiver (Rx), the lattice-matched InGaAs structure with periodically-positioned InAlAs ILs (InGaAs-PPIL) was grown on InP:Fe (100) substrates by using a molecular beam epitaxy with solid sources. As a reference, an InGaAs layer without the InAlAs IL was also grown. For a THz Tx, the growth temperature ($T_G$) for the reference InGaAs epilayer and the InGaAs PPIL was fixed at 480 and 400 °C, respectively. For an Rx, the $T_G$ for GaAs (LT-GaAs), InGaAs (LT-InGaAs), and InGaAs-PPIL (LT-InGaAs PPIL) was fixed to 250 °C, which is relatively low compared to normal $T_G$. The thickness of the InGaAs epilayer and the InAlAs IL were 500 and 10 nm, respectively. The number of the InAlAs insertion layers for the LT-InGaAs PPIL were 10 (IL10), 25 (IL25), and 50 (IL50). The distance between the adjacent InAlAs layers were 50, 20 and 10 nm for IL10, IL25, and IL50, respectively, resulting that total thickness of the active layer was same.

THz generation and detection for the samples were measured by using THz time-domain spectroscopy. A Ti:sapphire laser with a pulse duration of 30 fs and the repetition rate of 90 MHz was used to obtain THz generation and detection signal. The current signals were converted to frequency spectra by using the fast Fourier transform (FFT).

## II. RESULTS

Figure 1(a) shows secondary ion mass spectrometry (SIMS) depth profiles of the LT-InGaAs PPIL. Although the SIMS intensities of arsenic (As) and indium (In) were consistence, the curves for gallium (Ga) and aluminum (Al) were intersected each other. Figure 1(b) shows high-resolution x-ray diffraction (HR-XRD) curves of the LT-InGaAs PPIL and InGaAs PPIL. The periodic satellite peaks were clearly observed in the HR-XRD spectrum of the InGaAs PPIL. However, there is no satellite peaks for the LT-InGaAs PPIL, which can be explained by relatively poor crystal quality. In photoluminescence (PL) spectra of Fig. 1(c), the emission wavelength of the InGaAs PPIL was measured to be 1590 nm at 10K. But the PL spectrum was not observed for the LT- InGaAs PPIL. Figure 1(d) shows carrier lifetimes of the LT-InGaAs epilayer, InGaAs PPIL, and LT-InGaAs PPIL. The LT-InGaAs epilayer and LT-InGaAs PPIL showed relatively short carrier lifetimes compared to that of the InGaAs PPIL. From these results, we can expect for the increase in the characteristics of THz generation and detection. Carrier lifetimes of the LT-InGaAs epilayer, LT-InGaAs PPIL, and InGaAs PPIL were calculated to be 1.4, 0.95, and 3.6 ps, respectively. In addition, the carrier lifetime for the LT-InGaAs PPIL is shorter than the LT-InGaAs epilayer mostly due to the Al related non-radiative recombination center.

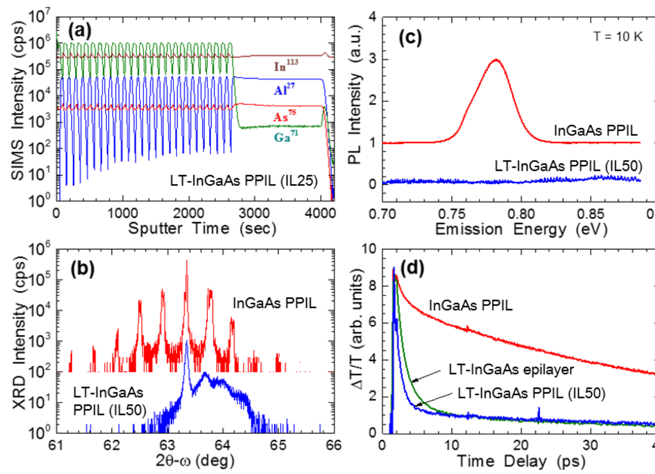

**Fig. 1.** (a) SIMS depth profile, (b) HR-XRD curves (c) PL spectra, and (d) decay curves.

Figure 2(a) and (b) show the current signals and spectra of THz generation, respectively, from a semi-insulating (SI)-GaAs substrate, the InGaAs epilayer, and the InGaAs PPIL with the InAlAs periods of 50. The current signals for the SI-GaAs, an InGaAs epilayer, and the InGaAs PPIL were measured to be 36, 1.6 and 5 nA, respectively. Figure 2(c) and (d) show the current signals and spectra of THz detection from a LT-GaAs epilayer, an LT-InGaAs epilayer, and LT-InGaAs PPIL with different periods of the InAlAs IL. The current signal of the LT-GaAs was measured to be 22 nA. The current signal for the LT-InGaAs eipilayer was shown to be 0.5 nA, which is significantly small compared to that of the LT-GaAs epilayer. Surely, inserting InAlAs into the LT-InGaAs is likely to the increase in resistance and the decrease in carrier lifetime. However, although only ten InAlAs layers were periodically inserted into the LT-InGaAs layer, the current signal at the Rx was drastically increased to 8 nA. Also current signals were increased from 10.5 to 13 nA with increasing the number of periods from 25 to 50. The InAlAs layers can provide high photoconductive effect for THz devices due to high resistance and trapping effect without influencing the cutoff frequency.

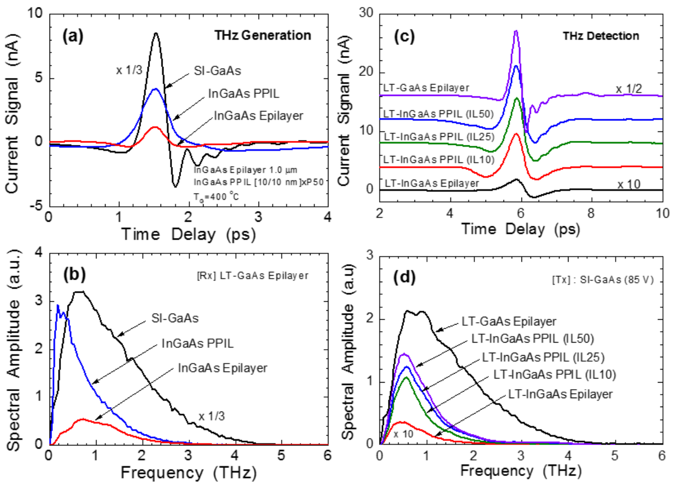


**Fig. 2.** (a) THz current signal (b) FFT spectral amplitude for the Tx structure. (c) THz current signal and (d) FFT spectral amplitude for the Rx structure.

## III. SUMMARY

We report the improved THz generation and detection characteristics by periodically inserting InAlAs into InGaAs. The THz generation using InGaAs PPIL was increased by three times compared to that of the simple InGaAs epilayer. The responsivity of the THz detection for the LT-InGaAs PPIL was over twenty-five times higher than that of an InGaAs epilayer. In addition, THz detection was increased by increasing the number of InAlAs periods. This can be explained by deep levels generated from the InAlAs layers, resulting in the high resistance and increase in carrier trapping.

## REFERENCES

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