1.55 μm ABSORPTION, HIGH SPEED, HIGH SATURATION POWER, P-I-N PHOTODETECTOR USING LOW-TEMPERATURE GROWN GaAs

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Abstract

By utilizing low-temperature grown GaAs (LT-GaAs) as the absorption material, subbandgap detection is possible due to mid gap defects and As precipitates. In this paper, the authors demonstrate the first 1.55 μm photodetector in GaAs based material. Due to the short carrier trapping time, a bandwidth of over 20 GHz and a saturation power exceeding 10 mW are measured in this photodetector.

Introduction

AlGaAs/GaAs is a well developed material and these photodetectors have been widely used in high performance integrated circuits, however, the high bandgap characteristics (E_g =1.42 eV, λ< 0.78 μm) limit the application to datacom communication only. For telecom communications(1.3~1.6 μm), the detectors are still fabricated and designed in Ge-, GaInAsP- or InP-based materials. Recently, it was shown that low-temperature grown GaAs (LT-GaAs) can absorb light below bandgap (1~1.6 μm) due to mid gap defects or As precipitates [1~4] and also the sub-picosecond carrier trapping time at 1.56μm excitation was observed[5]. Thus, it is possible to open up the integration of high speed receivers with GaAs electronics not only for short wavelength (~0.8 μm) but also for long wavelength (1.3~1.6 μm) systems. By using LT-GaAs, such photodetectors [6.7] with bandwidths above 500 GHz were demonstrated at wavelengths shorter than 0.82 μm. However, no high speed performance has been measured at the long wavelength regime. In this paper, we show the first 1.55μm LT-GaAs p-i-n photodetectors with high bandwidth and high saturation power performance.

Fabrication and experiment

A waveguide photodetector (WGPD) was designed and fabricated. The schematic diagram of the coupling edge is shown in Figure 1 (top). A p-i-n heterostructure (bottom of Fig. 1) forms the optical waveguide. All the material was grown in an MBE system. The active region is grown by LT-GaAs which is deposited at 215°C with As_2/Ga equivalent beam pressure ratio of 12 and subsequently *in-situ* annealed at 590°C for 10 minutes. The bottom $Al_{0.5}Ga_{0.5}As$ layer is used for the optical isolation from the bulk GaAs substrate. We used the same technique as our previous work [7] to process the standard p-i-n photodetector (including metalization, lithography, etching).

An optical component analyzer (HP 8703A, 0.13 ~ 20 GHz) was used for measuring the frequency response. The external light source was a 1.55 μm laser diode. Before coupling to the WGPD, the

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modulated light was amplified by an EDFA and filtered by an optical filter centered at 1.55 μm. The generated microwave signal was collected by a microwave probe.

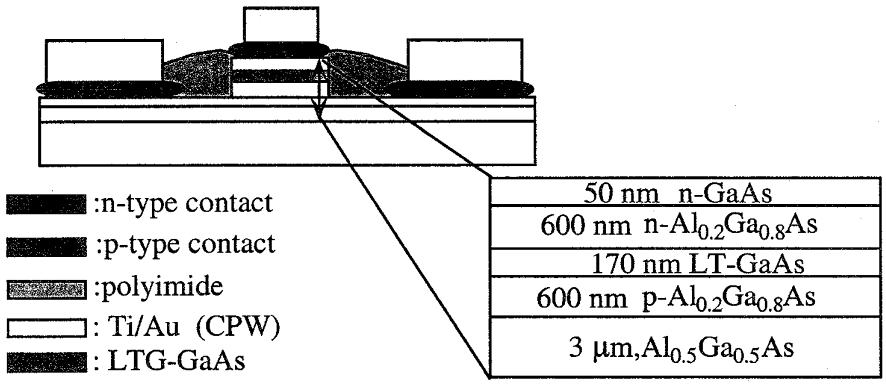

Fig. 1 (Top) the facet view of p-i-n photodetector,(bottom) the material growth structure.

Result and discussion

Two photodetectors (denoted A and B) with different lengths were fabricated and characterized. As shown in Fig.2, photodetector A (2μm wide and 35μm long) exhibits a flat frequency response within 2dB from D.C. to 20GHz. The response showed the same frequency dependence for various optical excitation powers ranging from 0.75 to 11 mW. And also, the quadratic relation (insert of Fig.2) between microwave and optical power indicates the photocurrent has linear dependence on optical power up to 20GHz. In the D.C. measurement, as shown in Fig.3, the optical power dependent photocurrent at different optical wavelengths (0.82 μm and 1.54 μm) shows a quite different saturation properties. The long wavelength shows linear detection, but the short wavelength one easily turns out to be saturated after 500 μW. However, low external quantum efficiency of 0.1% was measured. The reasons for this low efficiency are the low absorption coefficient combined with the short device length. To improve the efficiency, photodetector B (2μm wide and 300μm long) was fabricated. A quantum efficiency of 1% was obtained due to longer device (the internal quantum efficiency will be around 3% after extracting the coupling loss). The frequency response and the theoretical expectation (solid curve) are shown in Fig.4. The dependence of the frequency response on the excitation power shows ~4dB rolloff at 20GHz. It is very important to note that there are no power saturation effect up to 11 mW. The measured microwave loss is around 3.5 dB at 20GHz. Therefore, in such a long device, the microwave loss is responsible for the bandwidth limit.

It is essential to understand the limit in performance of these devices. We used a distributed photocurrent model to fit the frequency response (solid curve of Fig.4). The distributed photogenerated charge is excited as light travels through the waveguide, where the model includes the velocity mismatching between the optical wave and microwave, the carrier trapping time in LT-GaAs and microwave loss and boundary reflection of the input and output ends. The response shows little dependence on the carrier trapping times for values from 100 fs to 1 ps. It reveals that the major factor affecting the bandwidth is not the trapping time. The measured microwave loss has a 3.5 dB drop up to 20GHz and the velocity mismatch factor ($v_{optical}/v_{microwave}$) is ~2. The loss and velocity mismatch are responsible for the limited bandwidth.

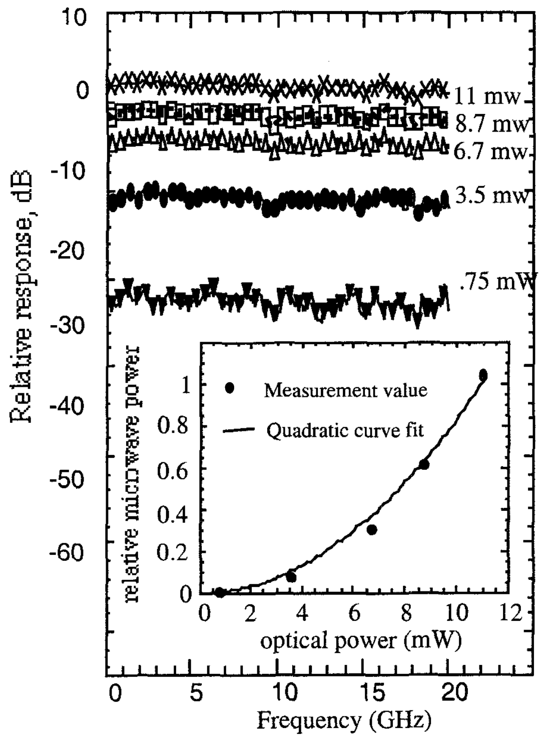

Fig. 2 Frequency response of photodetector A (30 μm long). The insert shows the quadratic relation between the microwave power and optical power.

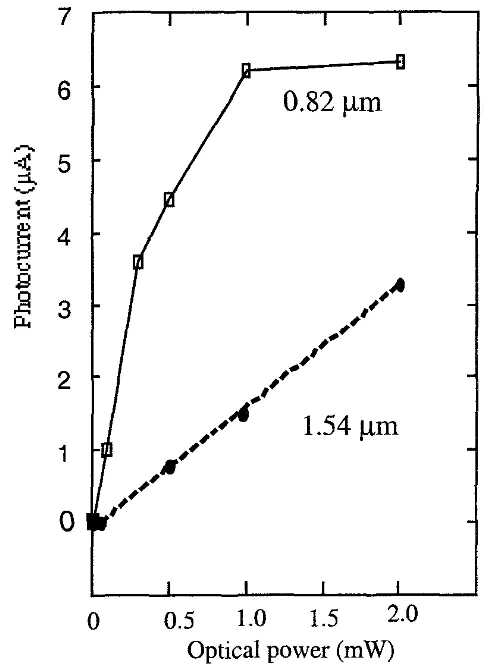

Fig. 3 D.C. photocurrent response of photodetector A (30 μm long) with different optical power at 0.82 and 1.54 μm optical wavelengths. The long wavelength detection shows a much higher saturation power.

Summary

In summary, we have successfully fabricated a novel GaAs-based p-i-n photodetector operating at 1.55 μm. The high speed (above 20 GHz) and high saturation power (above 10 mW) characteristics show that this kind of photodetector has potential application in the fields of long-wavelength-optical-fiber communication and for integration with GaAs integrated circuits.

Acknowledgments

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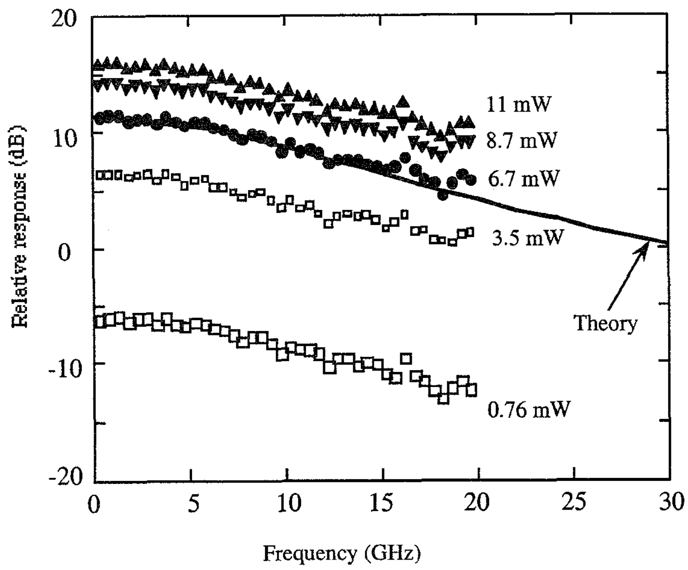

Fig. 4 Photodetector B (300 μm long) frequency response with the calculation (solid curve)