Low Dark Current SWIR Photodiode with InGaAs/GaAsSb Type II Quantum Wells Grown on InP Substrate

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We have developed a PIN photodiode with a type II quantum well structure, which can operate in the short wavelength region up to 2.5 µm. This photodiode will make uncooled operation possible. The absorption layer consisting of 250 pair-InGaAs(5nm)/ GaAsSb(5nm) quantum well structures was grown on InP substrates by solid source MBE method. The p-n junctions were formed in the absorption layer by the selective diffusion of zinc. Dark current density was 0.92 mA/cm^2 , which was smaller than that of a conventional HgCdTe detector. The responsivity at 2.2 µm was 0.6A/W.

Keywords: short wavelength infrared, quantum well, type II, photodiode

1. Introduction

Low dark current photodiodes (PDs) in the short wavelength infrared (SWIR) region (1.0-2.5 µm) are expected for many applications such as environmental gas detection, process check in chemical plants (e.g. pharmacy), and biodiagnostics. PIN-PDs with the cutoff wavelength up to 2.6 µm have been fabricated using In-rich lattice-mismatched InGaAs layers on InP substrates (1). HgCdTe is predominantly used as a focal plane array for imaging applications. However, because of high dark current, these devices require a cooler, which increases power consumption, size, and cost of the system. It was reported that InGaAs/GaAsSb quantum wells with type II staggered band alignments have optical response up to 2.5 µm (2). This material system is attractive for realizing low dark current PDs in the SWIR region, owing to lattice-matching to InP substrate (3), (4). In this work, we investigated GaAsSb growth condition and realized InGaAs/GaAsSb type II-PD with low dark current which was found to be more than one order of magnitude lower than that of conventional HgCdTe detector.

2. Experimental Procedure

Undoped AlInAs buffer layer (0.2 µm) and undoped GaAsSb layer (1 µm) were grown on Fe-doped (100) InP substrates by solid source molecular beam epitaxy (MBE) method. The growth temperature (Ts) was changed between 450°C and 520°C. The growth rates were 1.5 µm/hr for AlInAs buffer layer and 0.8 µm/hr for GaAsSb layer, respectively. Tetramer As_4 and monomer Sb_1 were used for group V beam sources. The V/III flux ratio for GaAsSb layer growth was changed between 12 and 42. X-ray diffraction (XRD) and room-temperature photoluminescence (PL) were utilized to characterize samples. A YAG laser with a wavelength of 1.06 µm was used as an excitation source of PL measurements.

Planar type PIN-PDs as shown in **Fig. 1** were fabricated for the evaluation of crystalline quality of GaAsSb. Si-doped InGaAs buffer layer (1.5 µm), undoped GaAsSb absorption layer (2.5 µm) and undoped InGaAs cap layer (1.3 µm) were grown on S-doped InP (100) substrates by MBE method. The growth rate of InGaAs layer was 1.8 µm/hr and the V/III flux ratio of it was 10. The p-n junctions were formed in the absorption layer by the selective thermal diffusion of zinc. SiN and SiON were used for passivation and anti-reflection, respectively. Diameter of light-receiving region was 140µm. AuZn alloy and AuGeNi alloy were used as p-electrodes and n-electrodes, respectively.

Planar type PIN-PDs with 250 pair InGaAs(5 nm)/ GaAsSb(5 nm) multi quantum well structures as the absorption layers were fabricated on S-doped InP (100) substrate by using the optimized MBE growth condition of GaAsSb. PIN-PDs with InGaAs absorption layer (2.5 µm) were also fabricated as references. The structure of PIN-PD was the same as that shown in **Fig. 1** except for the absorption layer material. The p-n junctions were formed in the absorption layer.

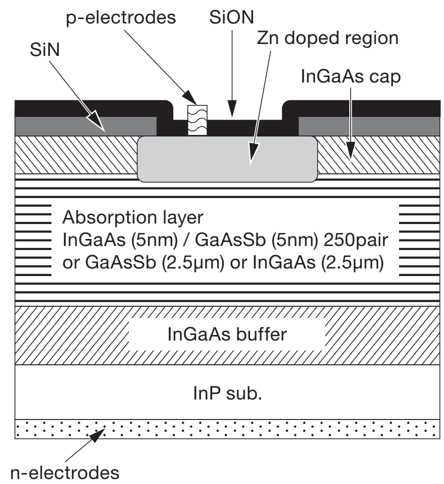

Fig. 1. Schematic device structure

3. Results and Discussions

3-1 Optimization of growth condition for GaAsSb layer

Figure 2 shows the dependence of GaAsSb PL intensity on the V/III flux ratio. In the case of V/III = 12 and V/III = 42, the PL intensity of specimen grown at Ts = 480°C was stronger than other growth temperatures. Compare to the case of V/III = 12, PL intensity increases at the V/III = 24. In the region of more than V/III = 24, PL intensity seems to be saturated. From the viewpoint of PL intensity, the growth condition with Ts = 480°C and V/III > 20 is preferable.

The temperature dependence of dark current of GaAsSb-PDs grown at 480°C with V/III = 12 and 24 is shown in **Fig. 3**. Dark current of the GaAsSb-PD grown with V/III = 24 is lower than that of PD grown with V/III = 12. The factor n calculated from the temperature dependence of dark current was 2.8 and 1.3 for the samples grown with V/III = 12 and 24, respectively. The ideal value of factor n is unity, and it increases according to the generation-recombination process via defects. Lower dark current and lower n value show crystalline quality of GaAsSb grown with V/III = 24 is superior to that grown with V/III = 12.

3-2 Characteristics of InGaAs/GaAsSb typeII PIN-PDs

Using the growth condition of GaAsSb with V/III = 24 and Ts = 480°C, we fabricated InGaAs/GaAsSb-PDs. As shown in **Fig. 4**, PL peak wavelength at room temperature was observed at 2.4 μm, which originated from type II heterointerfaces. **Figure 5** shows the I-V characteristic at room temperature. Dark current was 140 nA and dark current density was 0.92 mA/cm^2 at 1 V reverse bias. Although the device structure is different, this value is better than the former reported value [(3)]. Also, it is more than one order of magnitude lower than that of conventional HgCdTe-PD. This means that InGaAs/GaAsSb material

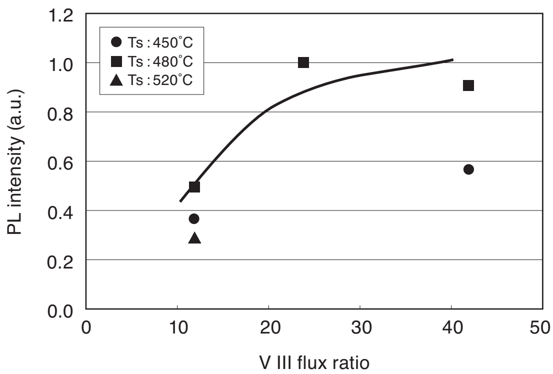

Fig. 2. V/III flux ratio dependence of PL intensity of GaAsSb at room temperature

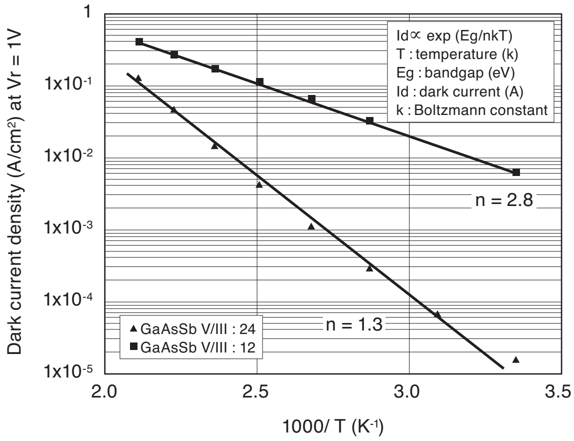

Fig. 3. Dark current density as a function of temperature of GaAsSb-PDs

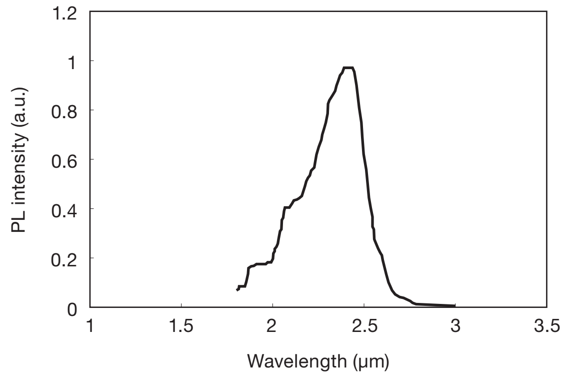

Fig. 4. PL spectrum of InGaAs/GaAsSb type II quantum wells at room temperature

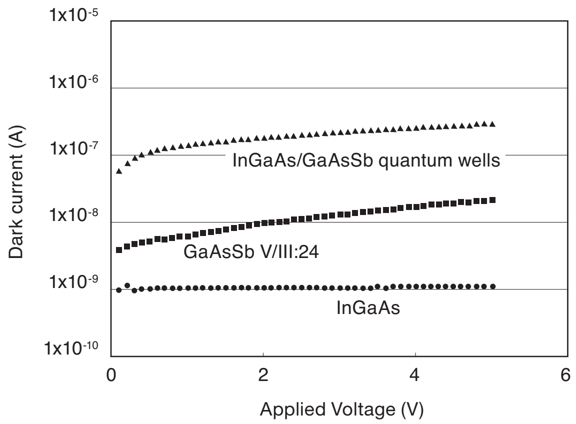

Fig. 5. I-V characteristics in reverse bias voltage of PDs at room temperature

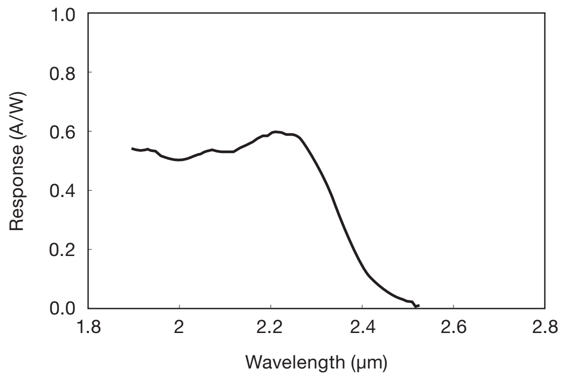

Fig. 6. Response of InGaAs/GaAsSb type II-PD at room temperature

systems have a potential of the uncooled operation of PDs. It should be mentioned that dark current of InGaAs/ GaAsSb-PD can be further reduced by optimizing the formation of InGaAs/GaAsSb heterointerface, since dark currents of GaAsSb- and InGaAs-PD are much lower than that of InGaAs/GaAsSb-PD. Finally, the photoresponse of InGaAs/GaAsSb-PD is shown in **Fig. 6**. The measurement was carried out without a reverse bias voltage. Responsivity was recognized up to 2.5 μm at room temperature. The maximum response was about 0.6 A/W. To improve the response, it seems to be necessary to have quantum wells with more than 250-pair and to improve heterointerface quality.

4. Conclusions

We have successfully demonstrated planar type InGaAs/GaAsSb type II quantum well PDs. Dark current was 140 nA at 1 V reverse bias for a 140 μm-diameter device. Low dark current was obtained as a result of the improvement of GaAsSb crystalline quality. It was shown that InGaAs/GaAsSb type II quantum well PDs have a potential of uncooled operation in the application such as image sensing.

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