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A narrow-band short wavelength type II InAs/GaSb superlattices photodetector with high performance

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Abstract

We have demonstrated a short wavelength type II InAs/GaSb supelattice photodetector with the wavelength in 1– 3 µm, using an AlSb layer inserting into the GaSb layer. At 77 K, the 50% cutoff wavelength is at 1.9 µm. The Jonson noise limited detectivty (D*) is 1.1 x 10^{13} Jones; at 300 K, the 50% cutoff wavelength is 2.1 µm with D* of 3.8 x 10^{10} Jones. The detectors show a high performance and a narrow-band feature. The δλ/λ is 10.3% at 77 K and 10.6% at 300 K. This narrow-band response feature is ascribed to the stronger absorption for the higher energy photons from the *n* region in the *p-i-n* detectors.

1. Introduction

Type II InAs/GaSb superlattice (SL) material has attracted tremendous interest for infrared photodetectors due to the suppressed Auger recombination rate [1], relatively long carrier lifetime [2,3], and large electron effective mass. The detection wavelength based on type II InAs/GaSb SLs has covered the range of 3 to 30 µm by tuning the thickness of InAs/GaSb and thickness ratio of InAs to GaSb. When it comes to the short wavelength smaller than 3 µm, it has been an important aspect of infrared detection for military and civil purposes. However, according to our numerical calculations, in order to achieve the detection wavelength smaller than 3 µm, the thickness of InAs and GaSb should be less than 3 monolayers. In this situation, interface intermixing has a strong affect on the detection wavelength, which will cause the wavelength redshift [4]. In this paper, we report using an AlSb layer inserting into the GaSb layer to realize a narrow band and short wavelength type II InAs/GaSb SL infrared photodetector. At 77 K, the 50% cutoff response wavelength is 1.9 um and D* is 1.1 x 10^{13} Jones and the δλ/λ is 10.3 %.

2. Design and Experiment

Based on our previous work [4], the InAs (8 A)/ GaSb (21 A) SLs can realize a short wavelength detection of 2.7 μm. A 4 Å AlSb layer is used to insert into the GaSb layer to obtain the wavelength shorter than 2 µm. Fig.1 (a) and (b) show the band structures and the wave-functions of InAs (8 A)/GaSb (21 A) (SLs a) and InAs (8 A)/GaSb (9 A)/AlSb (4 A)/GaSb (9 A) (SLs b), respectively. According to our 8KP calculations, the SL structure b can achieve the detection wavelength of 1.9 µm which is lower than 2 µm.

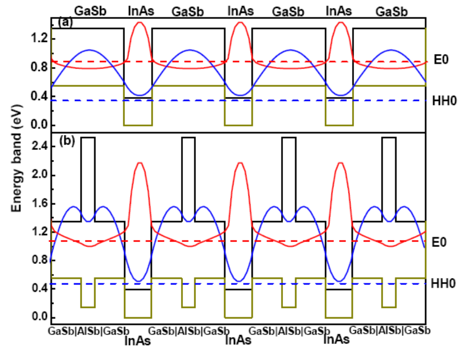

Fig. 1. Band structures of InAs (8 Å)/ GaSb (21 Å) and InAs (8 Å)/GaSb (9 Å)/AlSb (4 Å)/GaSb (9 Å) SLs, respectively.

A *p-i-n* infrared photodetector based on the structure b was grown on an unintentionally doped GaSb (001) substrate by molecular beam epitaxy using As and Sb crackers. The growth details can refer to Ref [4, 5]. After the growth, the as-grown sample was processed into a circular mesa structure by photolithography and wet chemical etching.

3. Results and Discussion

Fig.2 shows the x-ray diffraction (XRD) curve of the as-grown *p-i-n* sample. From the spacing between the satellites, the SL period is measured to be 30 Å, which is very close to our design. The full width at half maximum of the -1st satellite peak is only 25 arcsec and the average strain between the SL materials and the substrate is -2.5x10^{-3}.

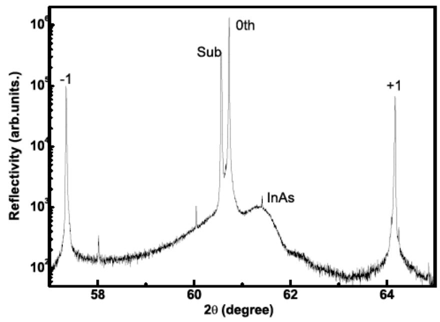

Fig.2 XRD curves of the *p-i-n* infrared photodetector.

Fig. 3(a) and (b) show the photocurrent spectra for samples a (based on SL structure a) and b (based on SL structure b) at 77 K at 0 V. The photoresponse maximum is at 2.34 µm for sample a and is 1.84 µm for sample b while the 50% cutoff wavelength is 2.56 µm for sample a and is 1.92 µm for sample b. Indeed, insertion of the very thin

AlSb layer into the GaSb constituent layer has pushed the response wavelength shorter than 2 μm. At 77 K, the $\delta\lambda/\lambda$ is about 22% for sample *a* and is 10.3% sample b. Both the response spectra show a narrow-band feature. However, the $\delta\lambda/\lambda$ becomes narrower when the detection wavelength is shorter. For a p-i-n detector using the interband transition, the photoresponse should typically be broadband-like. Therefore, it is surprising that we observe a narrow-band response feature for our SW photodetector.

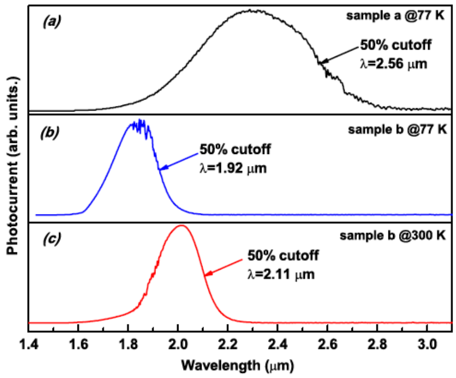

Fig. 3 (a), photocurrent spectrum of sample a measured at zero bias at 77 K. (b) and (c) are photocurrent spectra of sample b at zero bias at 77 K and 300 K, respectively.

In order to account for the narrow band feature, Fig. 4(a) shows the simulated distribution of the photon flux with respect to λ after the infrared light passes through the n region and arrives at the interface between the n and i regions. It is shown that low energy photons can pass through the n region when the wavelength is larger than a certain value while absorption occurs for the high energy photons with the wavelength smaller than a certain value. Fig. 4(b) depicts the simulated distribution of the photon flux with respect to λ when the infrared light is only absorbed by the *i* region, showing a broad-band absorption feature. Fig. 4(c) shows the result which is consistent with the response spectra. This narrow band feature is ascribed to the the stronger absorption for the higher energy photons from the n region.

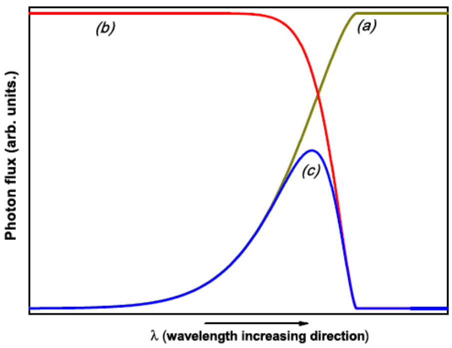

Fig. 4 (a) is the simulated distribution of the photon flux with respect to λ after the light passes through the n region and arrives at the interface between the n and i regions. (b) is the simulated distribution of the photon flux with respect to λ when the infrared light is only absorbed by the i region. (c) is the simulated photocurrent or QE spectrum of the p-i-n detector.

The responsivity at the response maximum is 0.63 A/W at 77 K and is 0.42 A/W at 300 K. The quantum efficiency (QE) is 42% at 1.84 μm at 77 K and is 28% at 2.01 μm at room temperature. Using the QE and R_0A data, the Johnson noise limited detectivity D* of sample b was calculated at 77 K and room temperature. The D* at the response maximum of 1.84 μm is 1.1x 10^{13} Jones at 0 V at 77 K while the D* at 2.01 μm reaches 3.8 x10^{10} Jones at 0 V at room temperature, indicating a high device performance.

4. Conclusions

We have demonstrated that type II InAs/GaSb SL photodetector can reach the detection wavelength shorter than 2 μm by inserting thin AlSb barriers. At 77 K, the 50 % cutoff wavelength is 1.92 μm and the quantum efficiency at the response maximum of 1.84 μm is about 42% and the corresponding responsivity is 0.63 A/W. The Johnson-noise limited detectivity D* is 1.1x10^{13} Jones at 77 K while reaches 3.8x10^{10} Jones at room temperature. The detector exhibits a narrow-band photoresponse feature ($\delta\lambda/\lambda$= 10.3%). We show that unlike a typical broad-band response feature using the interband transitions, for a p-i-n detector working in the SW range, a narrow-band response feature is the case, which is ascribed to the stronger absorption for the higher energy photons from the n region.

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