Quantum Well Infrared Photodetector with pHEMT structure

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1. Introduction

Quantum well infrared photodetectors (QWIPs) are used as a mid/far infrared (IR) photo detector and commercialized as potable cameras [1]. In recent years, quantum dot infrared photodetectors (QDIPs) have gained considerable interests because of their possible high temperature operation. However, most of these quantum structure infrared photodetectors (QSIPs) employ n-i-n diode structure (vertical structure) and their responsivities are about 1A/W and have small photoconductive gain [2, 3].

We propose quantum well infrared photodetector utilizing pHEMT structure which has very large responsivity (140 A/W @ 6 ㎛) due to pHEMT gain mechanism. This is named as lateral QWIP (LQWIP) because the photocurrent path is parallel to quantum structure interface. In this paper the current-voltage (I-V) characteristics and the large responsivity of LQWIP will be discussed.

2. Experiments and Results

Figure 1 shows energy band diagram of the LQWIP. LQWIP is consists of 4 periods $GaAs/Al_{0.3}Ga_{0.7}As$ (50Å/120Å) quantum well (QW) layer (absorption layer) and $In_{0.15}Ga_{0.85}As$ channel (transport layer). We deposited AuGe/Ni/Au for the drain source formation and succinic acid solution was used for the gate recess ($In_{053}Ga_{0.47}As/Al_{0.3}Ga_{0.7}As$ selective etching). Ti/Ni/Au was used for the gate metal. For the infrared light coupling, substrate was polished 45 ˚parallel faces on the sample ends. And backgate metal (Au) was deposited on the substrate to control the 2 dimensional electron gas (2DEG) density in $In_{0.15}Ga_{0.85}As$ channel. Figure 2 shows the epitaxial structure and bias notations of LQWIP

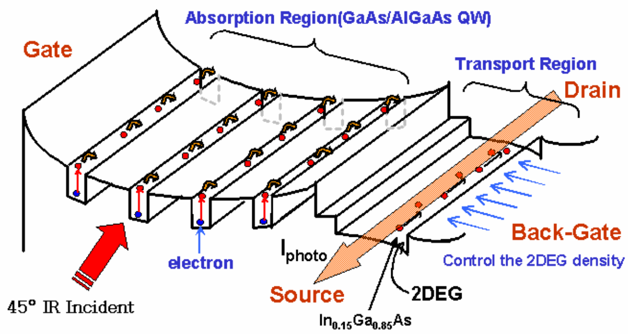

Fig. 1 Engery band diagram of LQWIP

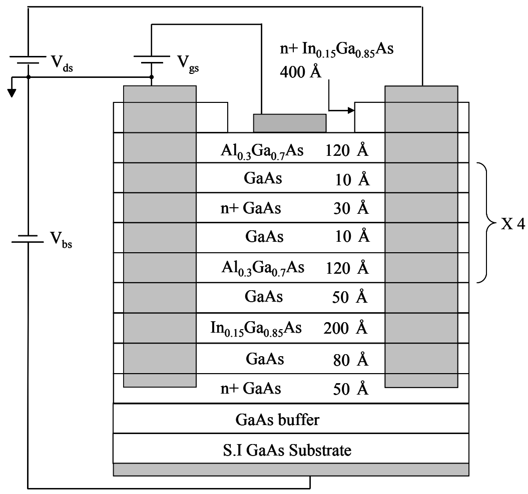

Fig. 2 Epitaxial structure and bias notations of LQWIP

The responsivity (R) of n-type vertical QSIP (VQSIP) is defined like this,

$$R = \eta \frac{e}{hv} g \qquad (1)$$

Where, e is the charge of single electron, hv is the energy of photon, g is photoconductive gain, and η is quantum efficiency. So, we can increase responsivity by increasing one of quantum efficiency and photoconductive gain. Quantum efficiency can be increased by increasing the periods of QW (or QD) layers, but this decreases photoconductive gain because the total device length becomes longer. This means we can't control the photoconductive gain and quantum efficiency independently in VQSIP. Therefore, regardless of the periods of QW (or QD) layers, the responsivity of VQSIP is about 1 A/W.

In the case of LQWIP, the photo-exited electrons from absorption layer are collected to the $In_{0.15}Ga_{0.85}As$ channel and transport through the drain and source. When the electrons are escaped from the absorption layer, the net charge of QWs becomes positive and this will increase the density of 2DEG in $In_{0.15}Ga_{0.85}As$ channel. Therefore, the photocurrent will be very large compared to the VQWIP.

At room temperature, I-V characteristics of LQWIP are similar to that of pHEMT. However, LQWIP has two different I-V characteristics at low temperature as shown in Figs. 3 and 4. Firstly, in I_{ds}-V_{ds} characteristic, the electrons transporting along the $In_{0.15}Ga_{0.85}As$ channel can be trapped in the QW region when $V_{gs} > 0$ V and this decreases I_{ds} as shown in Fig. 3. This trapping effect was also reported in AlGaAs/GaAs HEMT at low temperature [4]. Secondly, in

I_{ds}-V_{gs} characteristic, I_{ds} increases step by step. The electrons in $In_{0.15}Ga_{0.85}As$ are come from the QW region and the doping layer below the channel. If the temperature is higher than a certain value (~65 K), the electrons in QW region are escaped by thermal activation. But at lower temperature than 65 K, the number of escaping electrons is dependent on the V_{gs} because the electrons can be escaped from QWs by electric field when thermionic emission is suppressed. As shown in Fig. 4, intervals between V_{gs} that make I_{ds} steady are equal because the QW layers are grown periodically.

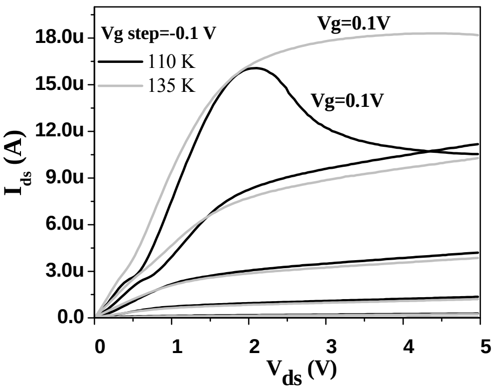

Fig. 3 I_{ds}-V_{ds} characteristics at 110 K and 135 K, when V_{ds}= 4 V

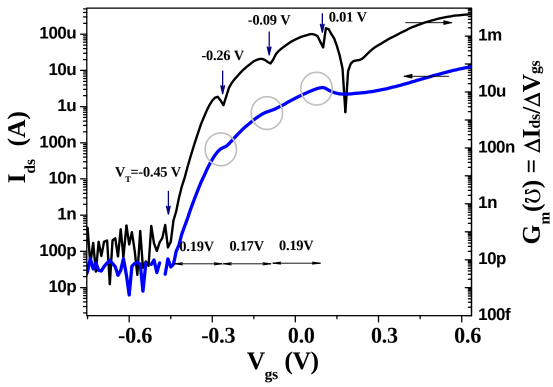

Fig. 4 I_{ds}-V_{gs} characteristics at 23 K when V_{ds}=4 V, V_{bs}=0 V

Figure 5 shows the responsivity spectra with different V_{bs} when V_{ds}=4 V, V_{gs}=-0.6 V at 23 K. The responsivity spectra are calibrated with standard MCT detector whose responsivity spectrum is well known. We calculated the responsivity from the quantum efficiency of QW layer and G_m.[5]. At 7.5 ㎛ (cutoff wavelength), we could get g=474, η=2.85 % when V_{bs}= 15 V, V_{ds}=4 V, G_m= 1.28×10^{-4} A/V [5].

The maximum responsivity is 140 A/W at 6 ㎛. This is hundred times larger than that of VQWIP.

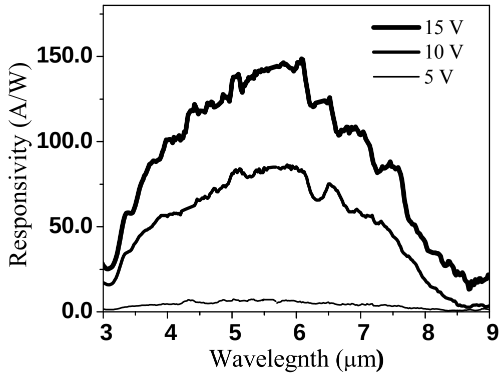

Fig. 5 Responsivity Specra of LQWIP, when V_{bg}=15, 10, 5 V, V_{ds}=4 V, V_{gs}=-0.65 V

3. Summary

We fabricated LQWIP with pHEMT structure. LQWIP has very large responsivity (140 A/W) and high detectivity (10^{10} cmHz$^{1/2}$/W) at 6 um, 24 K. The maximum operating temperature was 65 K and the large responsivity results from the transconductance (G_m) of pHEMT structure. The LQWIP shows not only the high responsivity but also the possibly to be used as addressing circuits in focal plan arrays

Acknowledgements

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