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Infrared Photodetector with Self-Organized InAs Quantum Dots

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1. Introduction

The detection of long-wavelength (λ=8–12 μm) infrared has numerous applications such as satellite imaging and medical thermography. HgCdTe detectors are used in this range but such a small bandgap materials are difficult to handle and process. For large area 2-D array the III-V quantum devices are promising. A quantum well (QW) device using a intersubband transitions in conduction band has lack of normal incidence response due to selection rule. For this reason, p-type QW device[1,2] and extra grating[3] were studied. The infrared detector using quantum dots (QD) has been expected that they are intrinsically very sensitive to normal incident radiations. Also is expected to have very small dark current due to their spike like density of states. Recently, high quality QDs has been successfully formed by coherent Stranski-Krastanow growth mode.[4-6] Normal incidence far- and mid-infrared photo response of the embeded QDs has been reported.[7-9] However, until now there was no report on the response in the range of 8-12 μm. In this work, we report a modulation doped QD infrared photodetector which is sensitive in the range of 8-12 μm. This detector utilizes intersubband transitions in QDs, lateral photocarrier transport and possibly photoconductive gain mechanism.

2. Fabrication and Results

A detector structure was grown by using a Riber 32P MBE system on semi-insulating GaAs (exact 100) substrates for long wavelength infrared detection. Fig. 1 shows the grown layer structure and device structure. Growth rates were 0.8 μm/hr for GaAs and superlattice buffer layers, 0.1 μm/hr for InAs, and 0.2 μm/hr for undoped GaAs spacer, n-doped AlGaAs layer, and GaAs cap layer. Arsenic beam equivalent pressure was 2.5×10^{-5} Torr. After oxide desorption GaAs and superlattice buffer layers were grown at a substrate temperature of 580 ℃. A 5-stacked InAs/GaAs QD layer which are grown on the buffer layer with the growth temperature of 450 ℃. At the same condition AFM image of single layer is depicted in Fig. 2. The nominal each InAs layer thickness was ~2 ML and the GaAs barrier layer thickness was 60 Å. A 5 s interruption was given after InAs QD growth. After growing undoped 50 Å GaAs spacer, Si-doped AlGaAs layer were grown for modulation doping with the doping concentration of 1×10^{18} cm^{-3}. Finally GaAs capping layer were grown with $n=5\times10^{18}$ cm^{-3}. Ohmic contact, mesa, and recess were formed on the prepared wafer for fabricating detector. The distance between two electrodes was 6 μm and the width of the electrode was 200 μm. The devices were wire bonded for measurement.

Long-wavelength infrared photoconductivity responses were measured using a EG&G 5209 lock-in amplifier, HR320 monochrometer, and glowbar source. The infrared from monochrometer was chopped at the frequency of 500 Hz and directly and normally illuminated on the front side of QD detector through ZnSe window. The window has 70% transmittance in the range of 0.6-22 μm. The lock-in amplifier was synchronized with the chopper and the output was read by electrometer. The electrometer was interfaced to Mac by GPIB. We used Igor software to control the grating and to read the electrometer output. Measurement were performed at the holder temperature of 10 and 70 K in cryostat chamber. We estimated the device temperature was about 10 K higher than the holder temperature. A 200-Ω load resistor was used

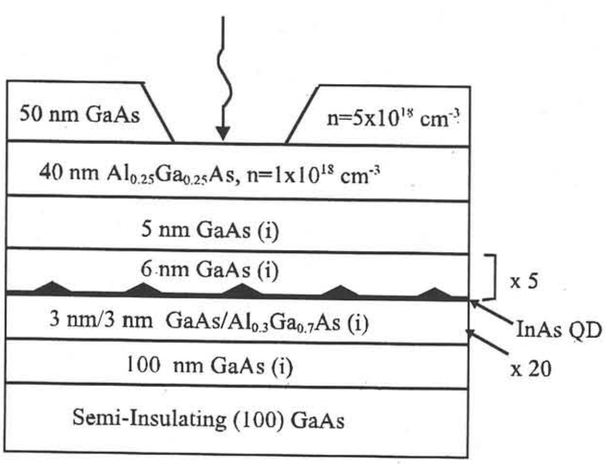

Fig. 1 Schematic of QD IR detector layer and device structure.

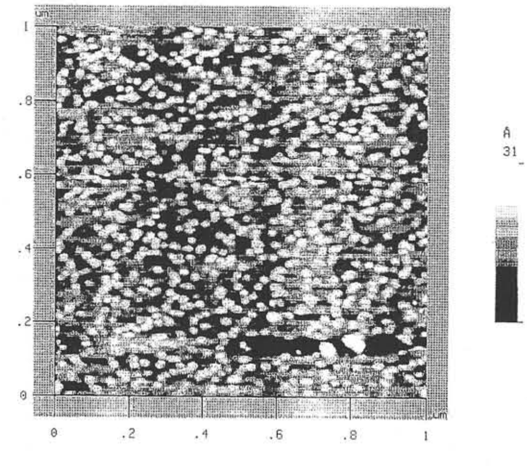

Fig. 2 AFM image of InAs QDs. The estimated density, diameter, and height are 1×10^{11}cm^{-2}, 180 Å, and 70 Å, respectively.

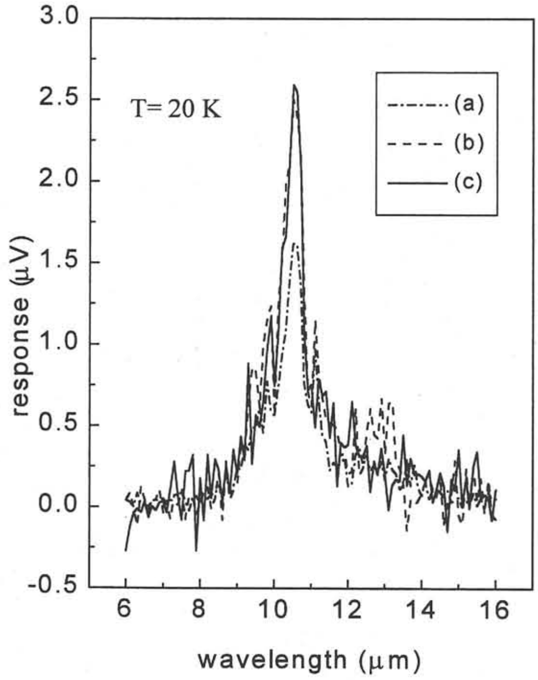

Fig. 3 Photoconductive response at the device temperature of 20 K for the bias current of (a) 0.3 mA, (b) 0.5 mA, and (c) 1 mA. The peak is appeared at λ=10.5 μm

to convert the photocurrent signal to voltage signal and put into the cryostat chamber to reduce the thermal noise from the resistor.

Measured data are shown in Fig.3 and 4 at the device temperature of 20 K and 80 K, respectively. These figures

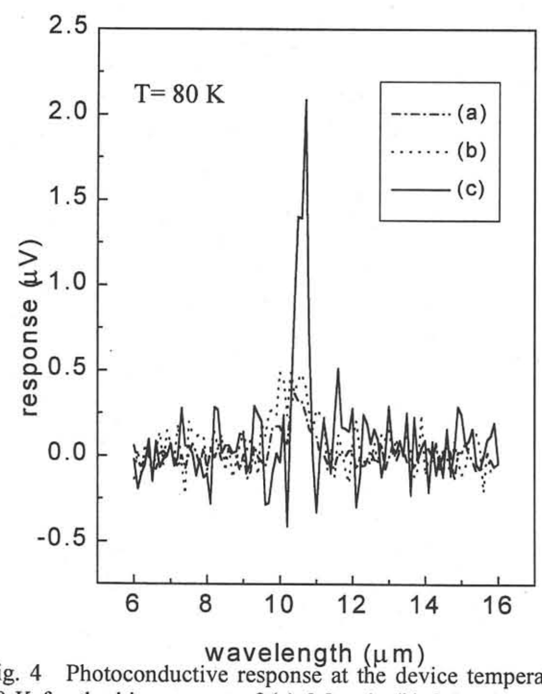

Fig. 4 Photoconductive response at the device temperature of 80 K for the bias current of (a) 0.3 mA, (b) 0.5 mA, and (c) 1 mA. The peak is appeared at λ=10.5 μm

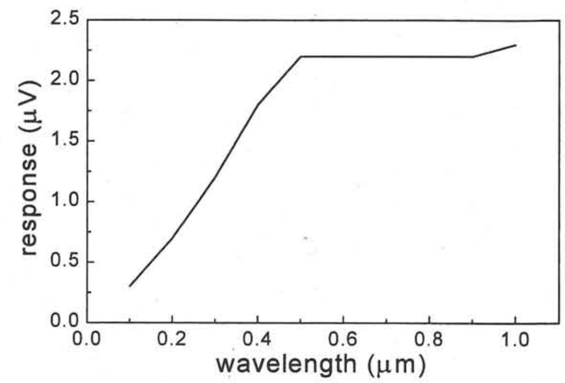

Fig. 5 The bias current dependency of the response at λ=10.4 μm and T= 20 K

obviously show the peak at near the wavelength of 10.5 μm. The peak increase as the bias current increase. But above some critical bias current, the increment of peak value becomes negligible. Fig. 5 shows the peak value with bias current at T=20 K. The critical bias current will be changed with temperature. At T=20 K the critical bias current is near 0.5 mA and at T=80 K the critical bias current will be higher as shown in Fig. 4.

3. Conclusion

5-stacked self-organized InAs QD was grown by MBE system and long-wavelength infrared photodetector which has peak at the wavelength of 10.5 μm was fabricated using the modulation doped embeded QD layer for the first time. We believe that the observed response is due to intersubband transitions in QDs. After optimizing the device structure we expect a high detectivity and higher temperature operation.

Acknowledgments

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