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A Study on Doping Density in InAs/GaAs Quantum Dot Infrared Photodetector

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1. Introduction

In recent years quantum dot infrared photodetectors (QDIPs) have gained considerable interest as a mid/far IR detector [1-3]. It is expected that QDIPs have two advantages over the conventional quantum well infrared photodetectors (QWIPs). Firstly, it can response to normal incident light due to three-dimensional confinement of QDs, which is verified experimentally [1]. More importantly, it can be expected to operate at near room temperature due to high photoconductive gain and low noise, which is confirmed in some papers [2].

Doping density is one of the most important parameters to control performances of QDIPs. However, it has not been studied systematically on the doping density. In this paper, we study the influence of the doping density and the resulting optimum operation voltage on the performance of QDIPs and we also confirm the possibility of high temperature operation of QDIP and response to normal incident light.

2. Experiments and Results

Figure 1 shows a schematic of the n-type vertical InAs/GaAs QDIP. The sample was grown on semi-insulating GaAs (001) substrate by MBE. Absorption region consists of 5 periods self-assembled InAs/GaAs QD and the GaAs spacer thickness is 50 nm, which reduce the dark current by suppressing the vertical tunneling. To supply electron into QD, 3 nm n-type (Si-doped) GaAs layer grown followed by 6 nm GaAs capping layer. Doping density for each sample is $5{*}10^{17}$ (#1), $1{*}10^{17}$ (#2), $5{*}10^{16}$ (#3) /cm^3, respectively. Mesa structures with diameters of 450 um were fabricated by standard photolithography and wet etching techniques, and then the ohmic contacts were formed from alloyed AuGe/Ni/Au. Photoluminescence measurements reveal QD was well formed for all samples, and relative doping density for each sample can be confirmed by measurements of the dark current, which increases with increasing doping density.

Figure 2 shows the temperature dependence of the photocurrent (PC) spectra of #2 QDIP. PC spectra were measured under normal incident geometry using a grating monochromator, long pass filters, SiC IR source, preamplifier, and lock-in amplifier. Three gratings were used due to wide spectral response, and long-wavelength -pass filters were used to reject the harmonics for each grating. Our spectra are somewhat noisy. This is expected to be due to grating monochromator instead of FT-IR monochromator.

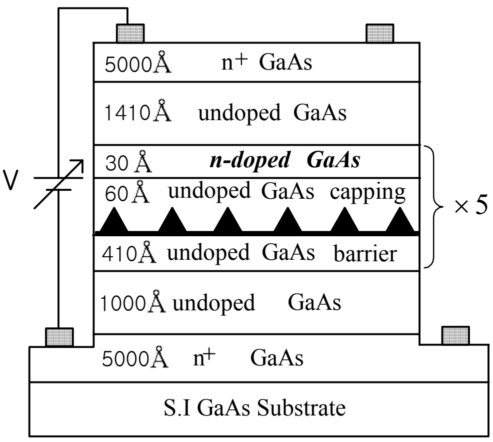

Fig. 1. Schematic of the n-type vertical InAs/GaAs QDIP.

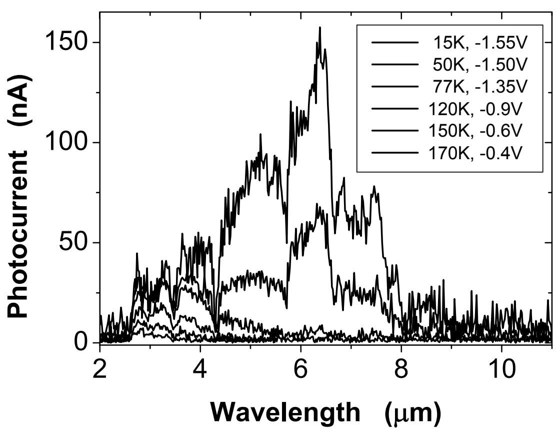

Fig. 2. Temperature dependent photocurrent spectra of the QDIP (#2).

PC is observed up to 170 K, and PC in the longer wavelength decreases more rapidly as the temperature increases. These tendencies are shown in the all samples. It is thought that the thermal activation is dominant effect to determine the temperature dependence of QDIP performance. As the energy level difference between QD and GaAs barrier in conduction band is smaller, which correspond to the longer wavelength, the thermal activation becomes easier.

Figure 3 shows peak responsivity and detectivity as a function of the bias voltage at 14 K. The peak responsivity was obtained using a standard MCT detector, whose spectral response was well known and noises were measured by lock-in amplifier. The maximum responsivities are more than 1 A/W in the all samples. This is quite large responsivity. This originates from large photoconductive gain due to low capture probability of QDs [3]. However, the detectivity is relatively small due to large noises.

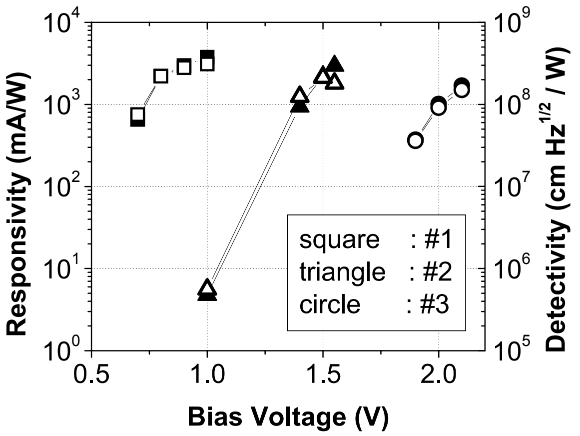

Fig. 3. Bias dependent peak responsivity and detectivity for each sample at 14 K. Solid symbol is for the responsivity and the hollow is for the detectivity.

In general, as the doping density increases, responsivity and quantum efficiency increase since the number of electrons in QDs increases, however, dark current and noises also increase. So, detectivity, which is proportional to the ratio of responsivity and noise, has a complex dependence on the doping density. In our experimental results, note that the operating voltage, at which responsivity and detectivity showed the maxima, becomes smaller as the doping density increases, although the maximum responsivity and detectivity of each sample is the similar. We know that it is necessary to lower the operating voltage by increasing the doping density since lower operating voltage allows low noises.

Peak responsivity and detectivity of each sample as a function of temperature are shown in figure 4. The possibility of high temperature operation of QDIP is confirmed from clear IR responses up to 170 K. QDIPs can operate at higher temperature than QWIPs, since density of states in QD is discrete and the thermal activation is mainly generated by scattering with LO-phonons which have a sharp energy distribution. It is necessary to increase doping density since both responsivity and detectivity are improved

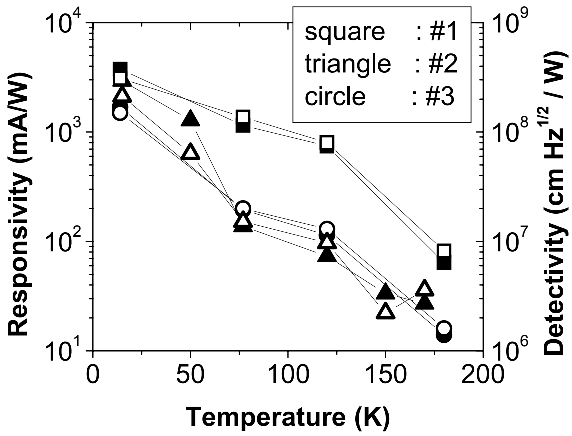

Fig. 4. Temperature dependent peak responsivity and detectivity for each sample. Solid symbol is for the responsivity and the hollow is for the detectivity.

3. Summary

The performance of QDIPs is investigated as a function of doping density. The possibility of room temperature operation of QDIP and response to normal incident light are demonstrated. It is found that the optimum operation voltage is lowered with the increase of doping density. The small operation voltage reduces the noise in devices and allows high detectivities.

Acknowledgments

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