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Quantum Dots Infrared Photodetector Using Modulation Doped InAs Self-Assembled Quantum Dots

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1. Introduction

Semiconductor quantum dots have attracted much attention from both scientific and engineering point of view. The Stranski-Krastanov growth mode makes it possible to fabricate the high density and high quality quantum dots (self-assembled quantum dots) without any complicated processing. Among the many proposed devices using self-assembled quantum dots, quantum dots infrared photodetector (QDIP) is one of the most promising devices. The operation principle of QDIP, like quantum well infrared photodetector (QWIP), is based on the intraband excitation of carrier.

With compare to QWIP, QDIP has two distinct merits. First merit is that QDIP has sensitivity against the normal incident infrared light ,whose electric field is parallel to the plane of sample, due to its three dimensional carrier confinement. Another merit is that the higher gain is expected in QDIP due to the longer life time of excited state.

Recently the mid or far infrared photoconductivity in self-assembled quantum dots were investigated [1, 2]. But their interpretations are not clear due to their complex sample structures and the polarization dependence of the photoconductivity is not reported even though it will give us the clear evidence of the intrasubband transition in quantum dots by infrared excitation.

In this paper we report the infrared photoconductivity and its polarization dependence in the modulation doped InAs self-assembled quantum dots. Using the modulation doping rather than the direct doping in ref. 1 and 2, we can avoid the effect of the impurity on the energy level in InAs dots and interpret the photoconductivity spectrum much more easily.

2. Device Structure and Experimental

Figure 1 shows the sample structure. The sample was grown by molecular beam epitaxy (MBE) on a GaAs (100) semi-insulating substrate. The sample has ten layers of InAs self-assembled quantum dots. The InAs dots layers were separated by 30 nm GaAs barriers. The 10 nm GaAs in the center of the barrier was doped by Si to 1×10^{17} cm^{-3}. The dot density is 1×10^{11} cm^{-2}. The average diameter and height of the dots are 20 nm and 5 nm, respectively. The doping concentration was set such that one InAs dot contains one electron. These layers are sandwiched by Si-doped 500 nm GaAs top and bottom contact layer whose doping density is 5×10^{17} cm^{-3}. The 30 nm GaAs spacer layer was inserted between the InAs dots layer and the contact layer.

The device was mesa-isolated by wet etching. The mesa size was 1 x 1 mm^2. The top and bottom contact consist of the alloyed AuGeNi/Au. The edge of the device was polished to 45°.

The photoconductivity was measured using lock-in technique. The FTIR instrument was used as the infrared light source. The infrared light was modulated by the chopper and injected normally to the 45° polished edge (inset of Fig. 2) in order to increase the effective infrared excitation in InAs dots layers by multireflection.

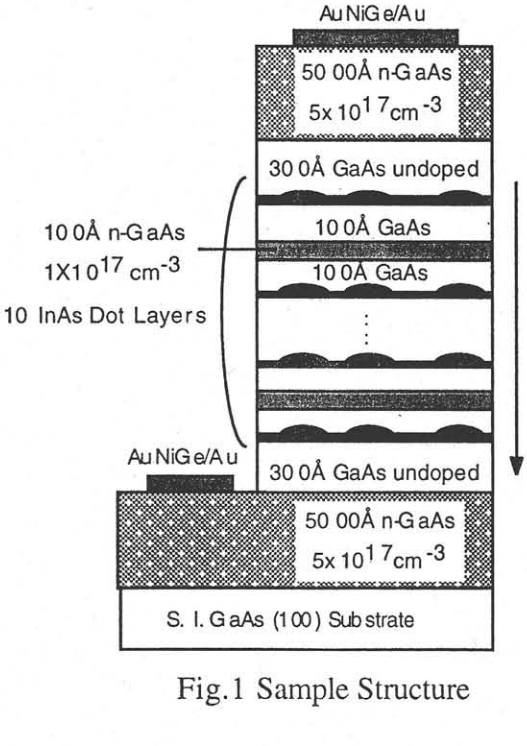

Fig.1 Sample Structure

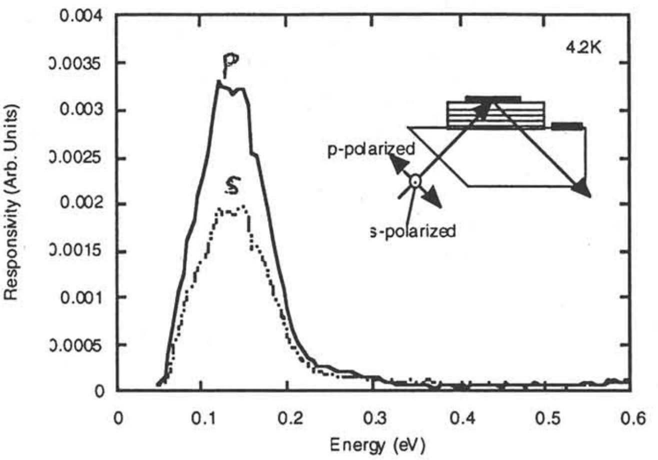

Fig. 2 Responsivity spectra for s and p-polarized infrared light. The inset shows the experimental geometry. The infrared light is injected through 45° polished edge.

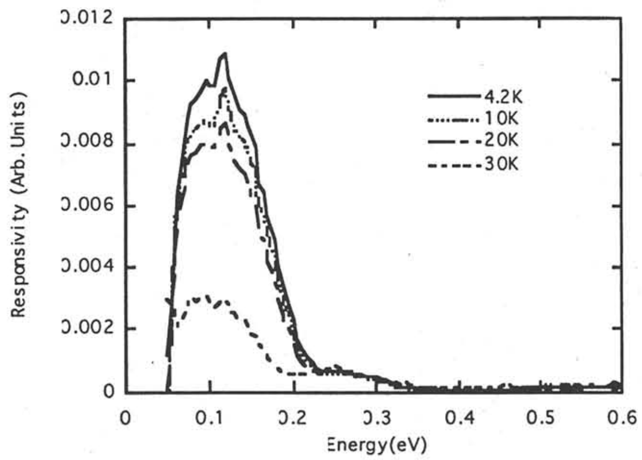

Fig. 3 Temperature dependence of the responsivity with respect to non-polarized infrared light. The applied bias is 0.1 V.

3. Results and Discussion

Figure 2 shows the responsivity spectra (photocurrent normalized by incident infrared power) measured at 4.2K. The applied bias between top and bottom contact was 0.1 V. For both s-polarized light (electric field parallel to the layer plane) and p-polarized light (perpendicular to the layer plane), a single strong peak was observed at 120 meV. No strong peak was observed in the reference sample which has no InAs dots layer. The observation of the peak for both polarizations indicates that the photocoductivity around 120 meV comes from the infrared excitation in the quantum dots. In QWIP the photoconductivity is not observed for s-polarized light [3]. In addition to that, it is shown in our previous capacitance-voltage measurement that the average energy difference between the ground state in InAs dots and GaAs conduction band edge was estimated to be 120 meV [4]. Therefore, the peak at 120 meV can be explained by the infrared excitation of electrons from the ground state in InAs dots to GaAs conduction band edge.

The temperature dependence of the spectra for non-polarized light is shown in Fig. 3. The operation of QDIP was confirmed at the temperature up to 30K. Increasing the temperature above 30K, the maximum intensity of photocurrent decreases rapidly. The decrease of photocurrent is caused by the drastic increase of the dark current. This dark current is expected to be reduced by optimizing the device structure.

4. Conclusion

We have succeeded to observe the infrared photoconductivity in QDIP using modulation doped InAs dots up to 30K. From its peak energy and its polarization dependence the photoconductivity can be assigned to the infrared excitation between the ground state in InAs dots and the GaAs conduction band edge.

Acknowledgments

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