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Photoconductivity with 1.55 μm excitation of InAs QDs embedded in InGaAs barriers on GaAs substrate

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Abstract

We have fabricated photoconductive antenna structure utilizing InAs quantum dots (QDs) layers embedded in strain-relaxed InGaAs barriers on GaAs substrate, and studied on its photoconductivity with 1.55 μm excitation. Mesa electrodes for the antenna structure were formed by photolithography and wet-etching processes. The photocurrent is almost linearly increased with an increase in excitation power. For 100 mW excitation, the current was 10 times compared to the dark current of 0.13 μA.

1. Introduction

InAs QDs in strain-relaxed $In_{0.35}Ga_{0.65}As$ barriers have ultrafast photocarrier relaxation (18ps) and absorption in optical communication band of 1.55μm [1]. Longer absorption wavelength compared to usual InAs QDs on GaAs is due to lowered potential height and reduced strain in InAs QDs. The ultrafast photo carrier relaxation comes from recombination at non-radiative centers induced by crystal defect due to the lattice-mismatch [1]. Furthermore, faster relaxation to 1.6 ps was achieved by direct doping of erbium to InAs QDs in $In_{0.35}Ga_{0.65}As$ barriers [2]. Due to these optical properties, the Er doped InAs QDs are attractive in applications for optical switch operating by light-gating of 1.55 μm. One of expected applications is photoconductive antenna (PCA) for THz band. Compared to conventional PCA materials such as bulky low temperature growth (LT) –GaAs for 0.8 μm gating and LT-InGaAs/InP for 1.55 μm gating, utilizing QDs structure to PCA may have advantage to more flexible design such as control of absorption wavelength by optimization of growth condition of QDs.

In this work, utilizing Er-doped InAs QDs layers embedded in strain-relaxed InGaAs barriers, we have fabricated photoconductive antenna structure with mesa electrodes formation by photolithography and wet-etching processes. And I-V characteristics and excitation power dependences of photocurrents were measured with excitation of 1.55 μm by CW semiconductor laser.

2. Experimental

The stacking structure of InAs QDs layers embedded in InGaAs barriers was grown on semi-insulating (001) GaAs substrates by molecular beam epitaxy. The schematic drawing of stacking structure is shown in Fig.1. Following the growth of GaAs buffer layer at 580 °C, $In_{0.35}Al_{0.65}As$ layer with 20 nm thick was grown for introducing of strain relaxation with misfit dislocation at 430 °C (indicated by thermocouple). The coverage of InAs QDs layer on $In_{0.35}Ga_{0.65}As$ layer was 3.4 ML. Er is directly irradiated during each sequence on InAs QDs layer growth only. Sheet resistance of grown sample was 8.3 MΩ /sq by van der pauw method.

Typical antenna pattern was formed by photolithography. The schematic pattern is shown in Fig. 2(a). For ohmic contact, Ti and Au were deposited on the as-grown surface by vacuum deposition. In order to suppress the dark current, electrodes were processed to mesa structure by wet etching using the mixed solution consisting of phosphoric acid, hydrogen peroxide, and water (1:1:6). The surroundings of electrodes except for the antenna gap centered at electrodes were etched with 1.3 μm depth from the surface. The depth reaches enough into the GaAs substrate since the total thickness of epitaxial layer is 0.8μm. The zoom-up image of the antenna gap with the mesa formation is shown in Fig. 2(b). The distance of the antenna gap was 4.4 μm, which is smaller than that of the designed value of 6 μm. To verify the effect of mesa formation, the resistance between electrodes was compared before and after the mesa formation.

For the antenna structure with the mesa electrodes, I-V characteristic and power dependence of photocurrent were measured in the dark and excited conditions. The excitation source was CW semiconductor laser of 1.55 μm, and the diameter of focused spot at the antenna gap was 60 μm. The excitation power was varied from 0 to 130 mW.

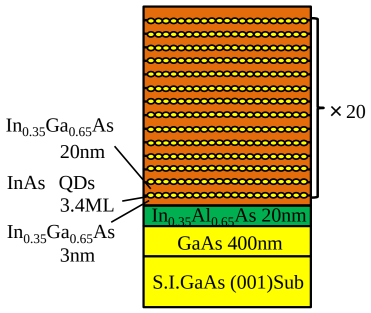

Fig. 1 Schematic drawing of stacking structure of InAs QDs layers embedded in strain-relaxation $In_{0.35}Ga_{0.65}As$ barriers.

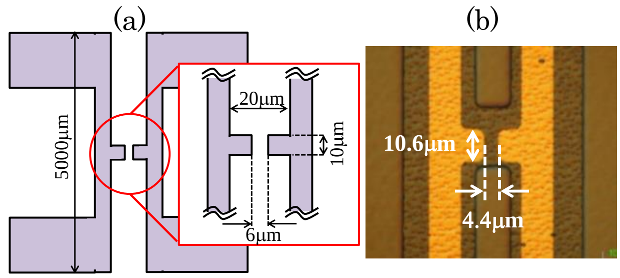

Fig. 2 (a) Schematic drawing of a dipole antenna pattern (b) zoom up of the center of antenna with mesa formation

3. Results

Figure 3 shows I-V characteristics of the dark current with and without mesa formation. Without mesa formation, the measured resistance was 22 KΩ, while the resistance with mesa formation was 2.9 MΩ. Without the mesa formation, the estimated resistance between electrodes over the total antenna length is 33kΩ, so the low resistance is due to the extra dark current over the total length of the antenna. The mesa formation achieves remarkable suppression of the extra dark current except for the dark current via the antenna gap, since the estimated resistance of the antenna gap from the sheet resistance of 8.3 MΩ/sq is 2.9 MΩ, which is equal to the measured value.

Figure 4 shows I-V characteristics for dark and excitation conditions with bias voltage from -15V to 15V. The I-V characteristics slightly deviate from linearity. Kincs in the I-V characteristic with high power excitation of 100.4 mW appear at +/- 1V. As the estimated electric field at the antenna gap is 2 KV/cm for 1V bias, it is likely that the mobility is reduced due to the high field effect.

Figure 5 shows excitation power dependence of photocurrent at +0.9V. The measured current almost linearly increases as an excitation power increases from dark to 130mW. Photocurrent at 100 mW excitation is about 10 times to that of the dark current of 0.13 μA.

4. Conclusion

We have fabricated photoconductive antenna structure utilizing InAs QDs layers embedded in strain-relaxed InGaAs barriers on GaAs substrate. The formation of mesa electrodes produces the marked suppression of the extra dark current. And the photocurrent with 1.55 μm excitation is linearly increased with an increase in excitation power. Therefore, InAs QDs layers embedded in strain-relaxed InGaAs barriers are expected to the application in photoconductive antenna on GaAs substrate operating by 1.55 μm gating.

Acknowledgements

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References

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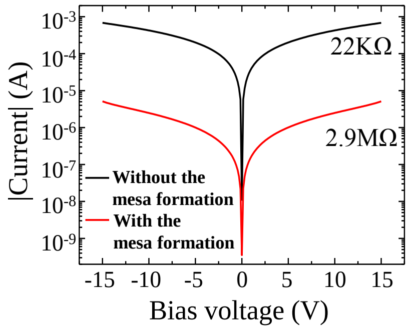

Fig. 3 I-V characteristics of the dark current before and after mesa formation

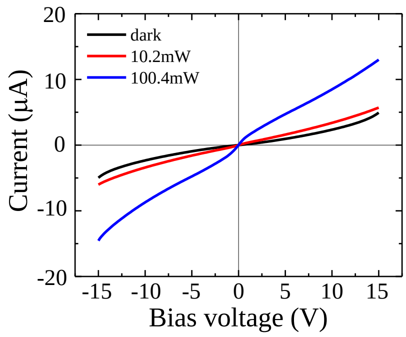

Fig. 4 I-V characteristics for the dark and excited conditions after mesa formation

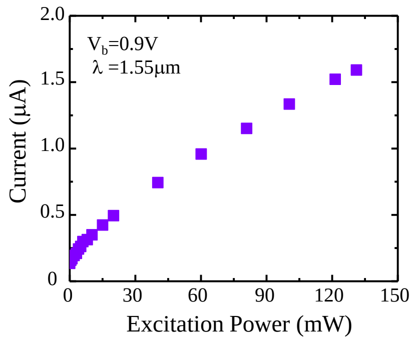

Fig. 5 Excitation power dependence of current with bias voltage of 0.9V