A Detection of Photogenerated Carrier Leakage from GaInNAs/GaAs SQW

GaInNAs/GaAs SQWからの光励起されたキャリアの漏れの検出

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Abstract

The GaInNAs/GaAs single quantum well (SQW) structure is remarked as a suitable material of an optical fiber communication. We have carried out the piezoelectric photothermal (PPT) and the surface photovoltage (SPV) measurements for Ga_{0.65}In_{0.35}N_{0.005}As_{0.995}/GaAs single quantum well (SQW). Since only the PPT measurement at 100K could observe the signal from the first quantized level, but not for the SPV we conclude that the observed PPT signal is related to the leak of the photogenerated carriers from GaInNAs/GaAs SQW.

1. Introduction

New compound of GaInNAs was proposed and grown by Kondow et al. as new candidate materials for a laser diode with a light emission wavelength of 1.3 or 1.55 µm. GaInNAs/GaAs single quantum well (SQW) structure has high emission efficiency and excellent temperature characteristics for LED application were accomplished by a strong carrier confinement through the large conduction band offset. The PPT measurement has high sensitivity for the photo-thermal signal by a nonradiative recombination. This results in a powerful methodology for the optical absorption coefficient of transparent semiconductors with very thin sample thickness or very low absorption coefficient. Surface photo-voltage (SPV) measurement detected the variation of surface and interface potential, when the photogenerated carriers escape from quantum well and they drift between the surface and the substrate. Since the device emission efficiency decreases by nonradiative recombination and carrier leak, we have applied PPT and SPV measurement for investigating the carrier leak from the thin quantum well structures of GaInNAs. We have already obtained the optical absorption spectra of GaInNAs with the thickness of 10 nm by using the PPT technique. The observed PPT spectra showed a typical step like density of states for each discrete two-dimensional quantum level. For the as-grown GaInNAs/GaAs SQW, we reported that the critical energy for the quantized states and exciton binding energy were determined. Furthermore the observed step-like spectra correspond to the two-dimensional density of states of SQW. The observed signals include both the exciton and the band-to-band absorption. For the observed PPT spectrum, we decomposed into them. We found that the PPT measurement can detect carrier recombination both inside and outside of the quantum well and SPV measurement detected the variation of surface potential by escaped carrier from quantum well at 100K.

2. Experimental Procedure

The high quality SQW samples grown on GaAs substrate by using a solid-source molecular-beam epitaxy (SS-MBE) were prepared. The sample thickness of Ga_{0.65}In_{0.35}N_{0.005}As_{0.995} layer was changed from 10 to 3 nm. This layer was sandwiched by the n-GaAs cap (0.15 µm thick) and buffer layers (0.3-0.5 µm thick). For the PPT and the SPV measurements, the probing-light from a grating monochromator was mechanically chopped and focused on the substrate side of the sample at room temperature. The PPT signal was detected by the piezoelectric transducer (PZT) on the film side of the sample. For the SPV measurements, the sample was sandwiched between the cold finger of the cryostat and an indium tin oxide (ITO) film. The indium tin oxide (ITO) electrode set the GaInNAs layer side and the probing light was incident to the GaAs substrate side.

3. Results and Discussion

Figure 1 shows the PPT and photovoltage spectra with the 5nm thickness at room temperature. The observed step-like spectra correspond to the two-dimensional density of states of SQW. The observed signals include both the exciton and the band-to-band absorption. For the observed PPT spectrum, we decomposed into them. We found that the e1-to-hh1 and the e2-to-hh2 transition were 1.087 eV, 1.326 eV, respectively.
PPT signal obtained around 1.23 eV is the transition of the light hole band (e1-to-lh1). The PPT and photovoltage spectra were almost same except above 1.4 eV. This means that the PPT and the SPV measurement detect the signal of the same quantized levels. For the quantum well structure, the SPV measurement detected the changed surface potential, when the photogenerated carriers escape from quantum well and they drift between the surface and the substrate. On the other hand, the PPT measurement detects the thermal signal by the carrier recombination. Since the PPT measurement uses the PZT as the detector, the PZT detects the electric field when the electric field is generated by a photovoltaic effect. Therefore, the PPT measurement detects simultaneously the thermal signal by carrier recombination and the photovoltage signal in sample. As a result, the obtained PPT spectra include the thermal signal by the carrier recombination and the generated photovoltage signal.

Figure 2 shows the PPT and the photovoltage spectra for 5nm thickness at 100K. The PPT spectrum at 1.14 eV is the exciton and the e1-hh1 transition. This signal at 1.14 eV is not detected in the SPV measurement. However, in the SPV measurement in the 10 and 3nm thickness sample, the e1-hh1 transition of the photovoltage spectrum at 100K is not detected. This may be understood by considering that the electron-hole pairs cannot flow out of the quantum well and the electron-hole pairs recombine within the quantum well. Thus, we conclude that the PPT measurement observe the thermal signal by the recombination of the photo-generated carriers in the quantum well because of the photogenerated carriers completely confined. The SPV measurement detects the variation of surface potential by photogenerated carrier that leak from the quantum well and the PPT measurement can observe the thermal signal by the recombination of the carriers in and out of quantum well.

4. Conclusion

The PPT and the SPV measurements of GaInNAs SQW are carried out. We found that the PPT measurement can detect carrier recombination in and out of quantum well and SPV measurement detected the variation of surface potential by photogenerated carrier leak from quantum well at 100K. Therefore the PPT measurement is a powerful tool for obtaining the optical absorption spectra of extremely thin quantum well structures.

References