High-Pressure Study of Deep Emission Band at GaInP/GaAs Interface

Toshihiko Kobayashi, Kazuya Takashima, and Kazuo Uchida*

Department of Electrical and Electronics Engineering, Kobe University, Kobe 657, Japan

** Department of Communications and Systems, University of Electro-Communications, Chofu 182, Japan*

We have measured the photoluminescence (PL) spectra of GaAs/GaInP single quantum wells at 77 K and at pressures up to ~5 GPa to investigate the characteristics of the 1.46 eV deep emission band. It shows a very long decay time, and might be attributed to spatially indirect recombinations of electrons and holes at the ordered GaInP/GaAs interface. With increasing pressure, the PL peak shifts towards higher energies at a rate slightly smaller than that of the 1.52 eV band from the GaAs well. The PL behavior observed at high pressures can be partly explained by the presence of repulsion between the Γ -folded energy states in ordered GaInP. [time-resolved photoluminescence, semiconductor, heterointerface, spatially indirect recombination]

1. Introduction

Optical properties of the quantum well (QW) of GaAs/Ga_{0.5}In_{0.5}P have been the subject of considerable study recently because of their promising device applications such as laser diodes. The growth of this QW structure by metalorganic vapor phase epitaxy (MOVPE) is often unsuccessful, and undesirable deep emission bands are often observed instead of the emission from the GaAs well structures [1-5]. Some attempts have been made to grow GaAs/GaInP QWs with thin GaP intermediate layers which are effective in obtaining QW emission [1,2,5]. In this paper we report time-resolved photoluminescence (TRPL) and continuous-wave photoluminescence (CWPL) spectra of GaAs/partially ordered GaInP single QW structures at 77 K and at pressures up to about 5 GPa. We investigate the characteristics and the origin of the deep emission band at ~1.46 eV and observe, for the first time, distinct effects of external pressure on the PL properties.

2. Experiment

Two types of GaAs/GaInP single QW structures were grown on GaAs substrates by MOVPE [5]. Sample 1 consists of a 100 Å thick GaAs well, partially ordered GaInP barriers and thin GaP layers sandwiching the GaAs well. Sample 2 was grown under the same conditions, but a 14 Å thick GaP layer was applied between the lower GaInP and GaAs layers only. The TRPL and CWPL measurements at pressures up to about 5 GPa were made with a diamond anvil cell, using standard procedures. Luminescence was excited at 77 K by either the pulsed or CW 488 nm line of an Ar⁺ laser.

3. Results and Discussion

Figure 1 shows the temporal evolution of TRPL spectra of (a) sample 1 and (b) sample 2, measured at 77 K and at atmospheric pressure. The spectra are taken for a constant time duration $t_w=100$ ns and at delay times t_d from 0 to 10 μ s after the pulsed excitation (6 mW) at 488 nm.

For sample 1, there are four emission bands having different PL-decay profiles at 1.52, 1.51, 1.49, and 1.46 eV. At 100 ns the emission band at 1.52 eV from the GaAs quantum well is dominant. Its energy is slightly higher than

the band gap energy of GaAs and was found to depend on the thickness of the GaAs well [5]. However, beyond 300 ns the peak due to the GaAs band-edge transition at around 1.51 eV and the impurity-related peaks at 1.49 eV are observable.

Fig. 1. TRPL spectra for a series of delay times t_d at atmospheric pressure. (a) sample 1 and (b) sample 2.

For sample 2, no QW-related emissions in the range between GaAs and GaInP band edge expected for the type-I heterostructures can be observed. The deep emission band at about 1.46 eV is dominant. Its decay time is very long (~700 ns). In CWPL measurements the energy of this emission peak was very sensitive to the excitation intensity, and showed a strong blue-shift with increasing intensity. No saturation of the peak intensity took place in the range of three orders of magnitude studied (0.01~40 mW). This indicates that the deep emission is not impurity- or defect-related recombinations in GaAs. Similar deep emission band at 1.46 eV is observed in sample 1, but its intensity is extremely weak. It is clearly demonstrated that the application of a thin GaP layer at both upper and lower interfaces is effective in both achieving emission from the GaAs well

Fig. 2. Typical CWPL spectra of sample 1 for a series of pressure. Excitation intensity is 10 mW.

Fig. 3. Evolution of a TRPL spectrum of sample 1 after pulsed excitation at 3.52 GPa.

and suppressing the 1.46 eV band. In other words, the presence of the upper GaAs/ordered GaInP interface with no thin GaP layer seems to be closely related to the appearance of the deep emission.

It is well known that GaInP alloys grown by MOVPE exhibit a CuPt-type ordered structure and the repulsion between the Γ -folded energy states causes the anomalous reduction in the direct band gap of GaInP as compared with that of the disordered alloys [6]. In CWPL measurements the weak emissions from GaInP are also observed at ~1.92 eV in both samples 1 and 2. The GaInP layers used in this study have a smaller band gap than that of the disordered GaInP (~1.98 eV) and are partially ordered [5,7-10].

With increasing pressure each spectrum shifts to higher energies. Figure 2 shows some typical CWPL spectra of sample 1 for a series of pressures up to 4.79 GPa. The PL spectrum is dominated by the emission from the GaAs well under excitation of 10 mW, and shifts almost linearly at a rate of ~105 meV/GPa, which is very close to that of GaAs band gap. At pressures above 3 GPa another emission peak is observed at the low-energy side of the main PL peak, and shifts to lower energies for pressures to 4.79 GPa. Figure 3 shows the temporal evolution of a TRPL spectrum after pulsed excitation at 3.52 GPa. The emission band at ~1.82 eV, which is attributed to the direct recombinations in the GaAs well, shows a fast decay time and almost disappears after $t_d=200$ ns. On the other hand, the emission band at around 1.65 eV can be observed even beyond 1 μ s. Since the pressure is close to that needed for the Γ -X crossover in ordered GaInP [7-9], this might be attributed to the indirect recombinations, GaInP(X_{1c})-GaAs(Γ_v), both in real space and in momentum space.

It is found that for sample 2 changing the excitation intensity in the range from 40 to 0.01 mW causes drastic changes in the shape of the PL spectrum and its spectral position. Figure 4 shows typical CWPL spectra of sample 2

Fig. 4. Typical CWPL spectra of sample 2 for a series of pressures. Excitation intensities are 10, 0.63 and 0.01 mW.

Fig. 5. PL peak energies of sample 2 as a function of pressure. Results for sample 1 are also shown for comparison. Solid lines represent results for descending X_{1c} states in GaAs and disordered GaInP obtained by Chen *et al.* [11].

for a series of pressure, measured under three different excitation intensities (10, 0.63, and 0.01 mW). Figure 5 shows the pressure dependence of the PL peak energies of sample 2, together with that of sample 1. Several important characteristics of the PL peak are immediately apparent. At 10 mW excitation the 1.49 eV peak, which has a rather fast PL decay component and might come from impurity-related recombination in GaAs, dominates at normal pressure. It shows a sublinear shift with pressure. The linear pressure coefficient obtained in the pressure range 0–2 GPa is about 90 meV/GPa, which is slightly smaller than that for the 1.52 eV band in sample 1 (~105 meV/GPa). Under low excitation below 0.63 mW the deep emission at ~1.46 eV dominates and has a very slow decay in TRPL. It also shows a strongly sublinear shift with pressure. However, the overall shifts obtained at 0.63 and 0.01 mW are smaller than that obtained at 10 mW. In addition, these results are quite different from those of the 1.52 eV emission band from the GaAs well in sample 1. It should be noted that the various PL features at high pressures are rather similar to those observed previously for the PL peak energy of partially ordered GaInP alloys at 77 K [7–9] which can be partly explained by the presence of repulsion between the Γ -folded energy states in partially ordered GaInP. This would imply that the presence of ordered GaInP layers plays an important role in the radiative recombination at 1.46 eV and the deep emission band is attributed to spatially indirect recombinations of electron and holes at the upper GaAs/ordered GaInP interface without GaP layer.

As described above, the PL spectra of sample 2 are very sensitive to the excitation intensity even at 77 K. The TRPL properties measured at high pressures and at lower excitation intensity may provide new insight into the nature of the deep

emission band at 1.46 eV, which is masked by the adjacent, overlapping 1.49 eV band of different nature at higher excitation intensity.

4. Conclusion

The GaAs/GaInP single QW structures were grown by MOVPE. An intense deep emission at 1.46 eV was observed for sample 2 with no thin GaP intermediate layer at the upper GaAs/ordered GaInP interface. Besides a strong blue-shift with excitation intensity and a very slow decay, a strongly sublinear and smaller shift of PL peak with pressure is obtained. This is quite similar to the results for GaInP alloys. We attribute the 1.46 eV peak to the transition of spatially separated electron-hole pairs in the interface, namely the radiative recombination between electrons in GaInP-side and holes in GaAs-side, and therefore we suggest the type-II band alignment in the ordered GaInP/GaAs interface under present growth conditions reported [5].

It is conceivable that the high-pressure TRPL measurements under intentionally lower excitation may be used as a tool for the study of luminescence mechanisms at lower temperatures and hence of the details of the microstructure and electronic band structure of GaAs/ordered GaInP interfaces.

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