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Photoreflectance Study of GaAs/GaAsP Strained-Barrier Quantum Well Structures

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GaAsP strained-layer quantum well structures grown by metalorganic vapor phase epitaxy have been investigated using photoreflectance spectroscopy. We have focused our attention on GaAs/GaAsP "strained-barrier" quantum well structures on GaAs(100) substrates. We have determined the band offset at the heterojunction and its dependence on the phosphorus composition. It was found that the band offsets are almost linearly dependent on the phosphorus composition in the range of $x \leq 0.23$. In addition, it was derived that the conduction band offset ratio $Q_c = 0.57 \pm 0.05$.

1. Introduction

For more than ten years, a considerable number of studies have been made on GaAsP strained-layer system.[1)-3)] In particular, there have been several studies on the band offset at the heterointerface because it is of great importance for applications. In spite of these efforts the band offset at the heterointerface and its dependence on the phosphorus composition or the strain have not been clarified yet.

In the present study, we have investigated GaAs/GaAsP "strained-barrier" quantum well (SBQW) structures. In GaAs/GaAsP SBQW structures the GaAsP barrier layer is strained and its band structure is modified owing to the elastic strain while the GaAs well layer is not strained and the band structure does not change.

In order to determine the band offset in the heterostructures and its dependence on phosphorus composition, we have used photoreflectance (PR) spectroscopy which allows us to observe not only the lowest optical transition but also higher transitions. Information about the higher transitions is considerably useful for determining the band offset accurately.

2. Experimental

GaAsP strained-layer quantum well structures used in this study were grown by low-pressure (60 Torr) metalorganic vapor phase epitaxy. Details of the growth procedure have been previously described.[4)] GaAs/GaAsP single SBQW structures were grown on GaAs(100) substrates. The well width and the phosphorus composition were 5–20 nm and 0.15–0.23, respectively. The structure of the samples was determined accurately by double-crystal x-ray diffraction.

PR measurements were carried out at room temperature to observe the optical transitions in quantum well. We have used Ar ion laser (488 nm) as a pump beam chopped at 210 Hz.

3. Results and Discussion

In Fig. 1, we show a typical PR spectrum of the GaAs/GaAsP SBQW structure. The well width and the phosphorus composition were 15.9 nm and 0.23, respectively. The label mnh (or mnl) shown in this figure denotes the transition between the mth conduction subband and the nth valence subband of heavy-(h) or light-(l) hole character. As seen in this figure, optical transitions between conduction and valence subband up to $n = 3$ are distinctly observed, as well as the transitions correspond-

ing to the splitting band gaps of the strained GaAsP barrier layer.

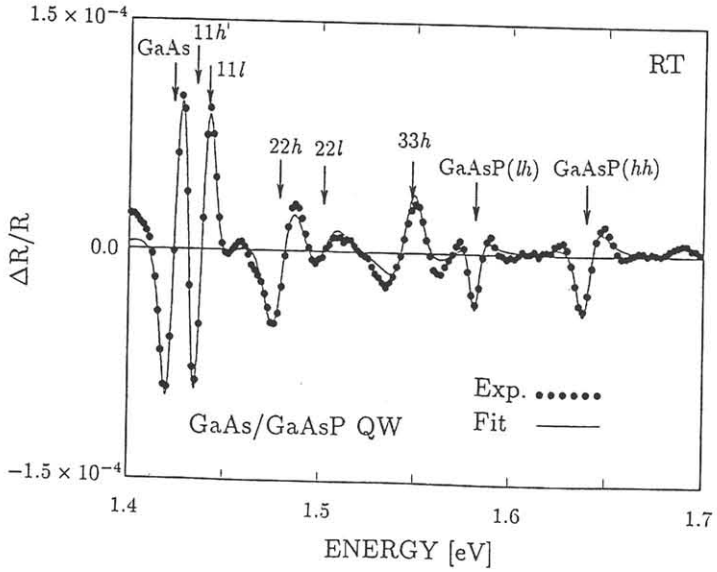

Fig. 1
Photoreflectance spectrum of $GaAs/GaAs_{1-x}P_x$ strained-barrier quantum well structure (L_z = 15.9 nm, x = 0.23) measured at room temperature.

Third derivative functional form (TDFF)[5] was used for deriving the optical transition energy from PR spectra. The solid curve shown in this figure was obtained by fitting TDFF to experimental data. Shanabrook *et al.*[6] suggested that first derivative of a Lorentzian is appropriate for describing optical transitions in quantum well because the transitions are excitonic in nature. Although we fitted the first derivative function to PR spectra in stead of TDFF, similar results were obtained concerning the positions of transition energy. Therefore, the fit was performed by using TDFF.

Figure 2 shows the band diagram of GaAs/GaAsP SBQW structure. Valence bands split owing to the elastic strain and spin-orbit interaction. Since GaAsP barrier layers are extended to the lattice constant of GaAs, electron–light hole ($J = 3/2, M_J = 1/2$) band gap becomes smaller than electron–heavy hole ($J = 3/2, M_J = 3/2$) gap. Conduction, heavy-hole valence and light-hole valence band offsets are defined as ΔE_c, ΔE_{vh}, ΔE_{vl}, as shown in this figure.

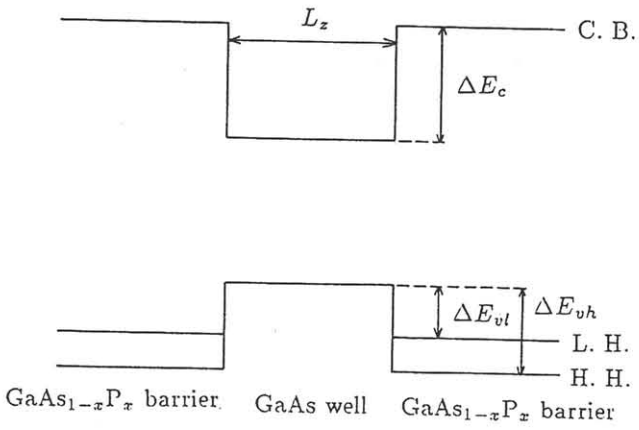

Fig. 2
Band lineup of GaAs/GaAsP strained-barrier quantum well structure. Valence bands split owing to the elastic strain and spin-orbit interaction.

By comparing the PR results with the calculation based on the square-potential model, we have determined these band offsets. It should be noted that the energy of higher optical transition, such as $33h$ is sensitive to the band offset while that of the lowest transition is not so sensitive. The band offsets determined by this analysis are shown in Fig. 3. Band offsets are almost linearly dependent on the phosphorus composition in the range of $x \leq 0.23$. In addition it was found that the conduction band offset ratio $Q_c(= \Delta E_c/(\Delta E_c + \Delta E_{vh})) = 0.57 \pm 0.05$.

Gourley and Biefeld [2] investigated quantum size effects in GaAs/GaAsP strained-layer superlattices. The zero stress valence-band offset between GaAs and GaP was evalu-

ated to be 600 ± 50 meV. Katnani and Margaritondo[7] carried out photoemission spectroscopy and derived 630 ± 150 meV for GaAs/GaP heterojunction. For comparison between our result and other studies, intrinsic band offset must be estimated. Assuming that the valence band offset varies linearly with the phosphorus composition, we obtain ΔE_v = 380 ± 70 meV for GaAs/GaP heterojunction. This value is rather smaller than that of other studies. There are several reasons for this disagreement. One is that the coupling between light-hole- and spin-orbit-states was not included in the calculation of Gourley and Biefeld, as pointed out by Pearsall *et al.*[10] Another reason is that the photoemission measurements were not made on directly the heterojunction between GaAs and GaP.

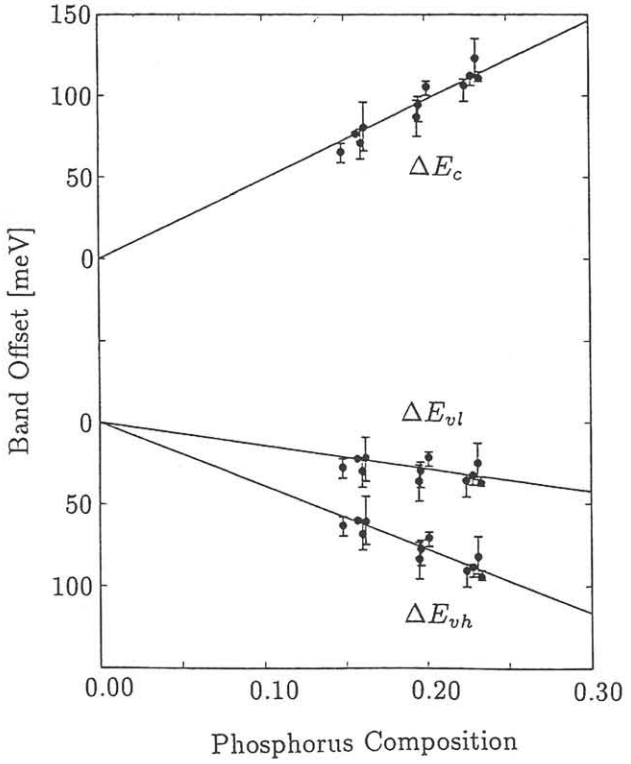

Fig. 3

Conduction- and valence-band offsets at the heterojunction in GaAs/GaAsP strained-barrier quantum well as a function of phosphorus composition.

On the other hand, Zhang *et al*[5] studied the band offset of GaAs/GaAsP "strained-well" quantum well structures using photoluminescence and reflectance spectroscopy. From this result, intrinsic valence band offset is estimated to be 390 meV. This is in good agreement with our result.

4. Conclusion

We have studied the band offsets at the heterointerface of GaAs/GaAsP SBQW structures using PR spectroscopy. The band offsets are found to be almost linearly dependent on the phosphorus composition in the range of $x \leq 0.23$. In addition, it was found that the conduction band offset ratio $Q_c = 0.57 \pm 0.05$.

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