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# Photoreflectance and Photoluminescence Study of Direct-and Indirect-Gap Band Lineups of GaAsP/GaP Strained Quantum Wells

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We study the direct- and indirect-gap band lineups of GaAsP/GaP strained quantum wells by the combination of photoreflectance (PR) and photoluminescence (PL) spectroscopy. From the comparison between the transition energies obtained by the PR measurements and those calculated based on the envelope function approximation including the effect of the spin-orbit split-off bands, the conduction band offset ratio is estimated to be $0.60 \pm 0.04$ at the $\Gamma$ point. This leads to a type-I band lineup at the $X$ point, where the conduction band offset ratio is $0.44 \pm 0.06$. The PL results are in good agreement qualitatively and quantitatively with this band lineup.

## 1. Introduction

The $GaAs_{1-x}P_x$ strained-layer system has been one of the most intensively studied strained-layer systems since Osbourn proposed the concept of strained-layer superlattices (SLS).[1] In the $GaAs/GaAs_{1-x}P_x$ strained-layer heterostructures, the band lineup has been revealed to be of type-I by several studies.[2-4] On the other hand, in the $GaAs_{1-x}P_x/GaP$ strained-layer heterostructures, the band lineup is considered to change from type-I to type-II depending on the strain configuration. For example, Gourley and Biefeld[5] reported that the band lineup at the $X$ point is of type-II in a GaAsP/GaP SLS grown on a GaAsP layer of average composition of SLS. On the contrary, Hara *et al.*[6] and Pistol *et al.*[7] pointed out that the band lineup at the $X$ point is of type-I in the case of the $GaAs_{1-x}P_x/GaP$ strained quantum wells (QWs) grown on GaP(100) substrates. Although the strain dependence of the band offset may cause this discrepancy, it has not been clarified yet.

In the present work, we study the direct- and indirect-gap band lineups of $GaAs_{1-x}P_x/GaP$ strained QWs grown on GaP(100) substrates using photoreflectance (PR) and photoluminescence (PL) spectroscopy. In the $GaAs_{1-x}P_x/GaP$ strained QW, the coupling between the light-hole and spin-orbit split-off (SO) bands cannot be ignored because of both the small SO energy ($\Delta_0 \sim 0.1$ eV) and the strain effect. Taking the SO coupling into account, in this study, we have determined more accurately the band offset at the $\Gamma$ point than previous work,[6] where the analysis was simply based on the energy difference between 1e–1hh and 1e–1lh transitions and the SO coupling was ignored.

## 2. Experimental

The samples used in this study were grown on GaP(100) substrates by metalorganic vapor phase epitaxy (MOVPE).[6] The strained QW structures consist of 5 periods of $GaAs_{1-x}P_x$ wells and GaP barriers. The phosphorus content $x$ in the well layer was chosen to be about 0.8. The well width was varied from 30 to 90 Å. The sample structure was determined accurately using double-crystal x-ray diffraction. PR and PL measurements were carried out at 80 K and 6 K in a closed cycle cryostat, respectively. The 325 nm line of a He-Cd laser was used as an excitation source for PR and PL measurements.

### 3. Results and Discussion

The 80 K PR spectrum of a $GaAs_{1-x}P_x/GaP$ strained QW structure is shown in Fig. 1. The well width and the phosphorus content in the well layer were 63 Å and 0.83, respectively. The optical transitions related to the QW levels at the $\Gamma$ point are clearly observed. The transitions in the GaP layer, $E_0$ and $E_0 + \Delta_0$, are also seen. In order to derive the optical transition energies from the PR spectra, first-derivative Lorentzian functions[8] were fitted to the experimental data.

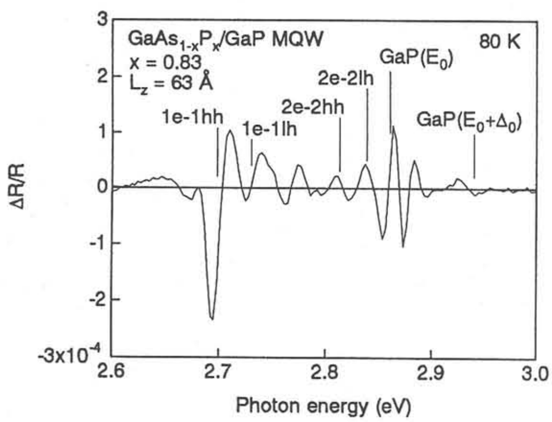


Fig. 1 80K photoreflectance spectrum of a GaAsP/GaP strained quantum well structure. The transitions related to the quantum well levels at the $\Gamma$ point are clearly observed.

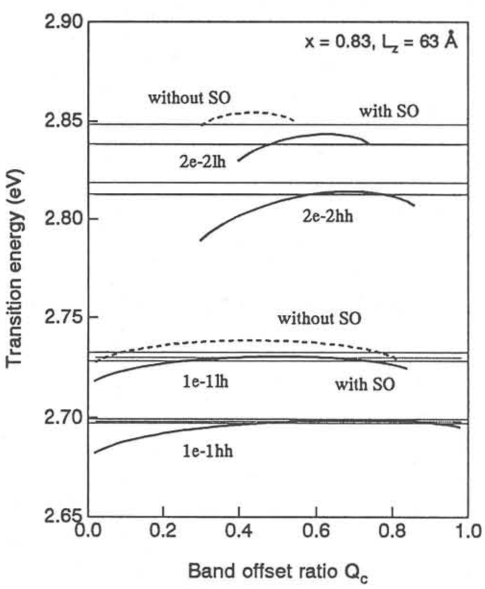


Fig. 2 Comparison between the experimental and calculated transition energies in the GaAsP/GaP strained quantum well. Solid and dashed curved indicate the transition energies calculated with and without the effect of the spin-orbit split-off bands, respectively.

Figure 2 shows the comparison between the experimental and calculated transition energies. Horizontal lines shows the transition energies obtained from the PR measurements. Solid and dashed curves indicate the transition energies calculated with and without the SO coupling, respectively. As can be seen from this figure, when the SO coupling is ignored, the calculated lh transition energies do not agree with the experimental ones. From the similar analysis for several samples, the conduction band offset ratio $Q_c$ $(= \Delta E_c/(\Delta E_c + \Delta E_{vh}))$ at the $\Gamma$ point is estimated to be $0.60 \pm 0.04$. Here $\Delta E_c$ and $\Delta E_{vh}$ are conduction band and heavy-hole valence band offset, respectively. This result leads to a type-I band lineup with $Q_c = 0.44 \pm 0.06$ at the X point. This is confirmed qualitatively and quantitatively by the PL measurements.

The PL spectrum of a $GaAs_{1-x}P_x/GaP$ strained QW structure is shown in Fig. 3. The peaks labeled LA, TA, TO and NP correspond to the LA, TA and TO phonon assisted transitions and a no-phonon transition, respectively. The energy differences between the NP transition and the phonon assisted transitions agree well with the phonon energy at the $X$ point obtained by neutron scattering.[9] This shows that the transitions observed by the PL measurements are the indirect-gap transitions at the $X$ point.

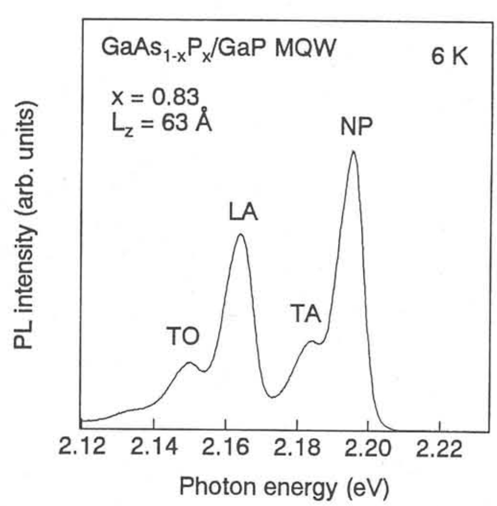


Fig. 3 Photoluminescence spectrum of a GaAsP/GaP strained quantum well structure. The peaks labeled LA, TA, TO and NP correspond to the LA, TA and TO phonon assisted transitions and a no-phonon transition, respectively.

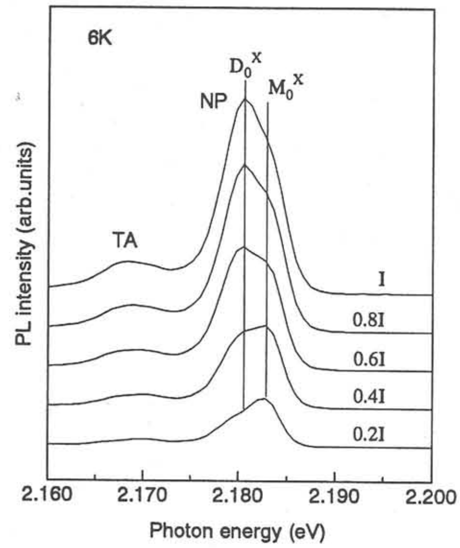


Fig. 4 Excitation power dependence of the photoluminescence spectrum of the GaAsP/GaP strained quantum well.

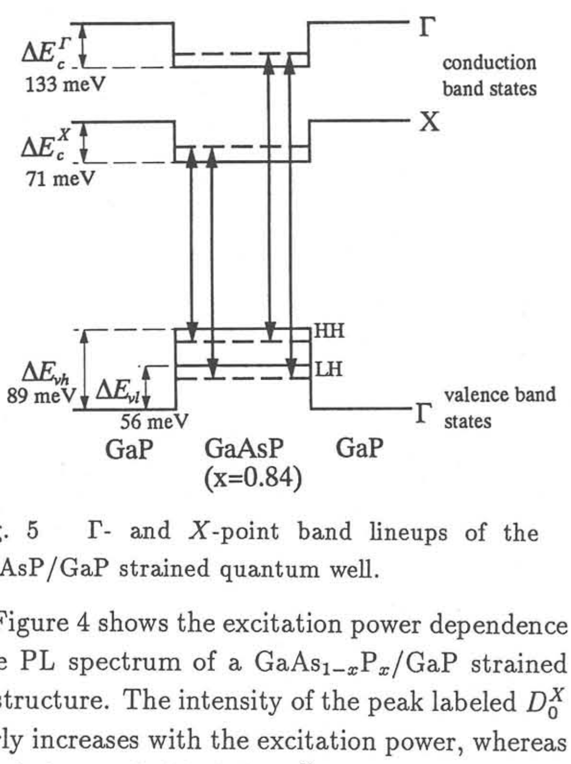


Fig. 5 $\Gamma$- and $X$-point band lineups of the GaAsP/GaP strained quantum well.

Figure 4 shows the excitation power dependence of the PL spectrum of a $GaAs_{1-x}P_x/GaP$ strained QW structure. The intensity of the peak labeled $D_0^X$ linearly increases with the excitation power, whereas that of the peak labeled $M_0^X$ saturates, which is characteristic of the PL from bulk GaAsP alloys.[10] Therefore, the observed PL is deduced to come from the GaAsP layer, which indicates that the indirect-gap band lineup is of type-I. We have also calculated the PL transition energies in the $GaAs_{1-x}P_x/GaP$ strained QW structures assuming the conduction band offset ratio $Q_c = 0.44$ at the $X$ point. This calculation can explain well the PL transition energies. As a result, we have determined the $\Gamma$- and $X$-point band lineups of the $GaAs_{1-x}P_x/GaP$ strained QW structure, as shown in Fig. 5.

## 4. Conclusion

Direct- and indirect-gap band lineups of the $GaAs_{1-x}P_x/GaP$ strained QW structures were investigated by the combination of PR and PL spectroscopy. The conduction band offset ratio at the $\Gamma$ point is found to be $0.60 \pm 0.04$ from PR measurements. From this result, it is deduced that the band lineup at the $X$ point is of type-I and that the conduction band offset ratio is $0.44 \pm 0.06$. This is in excellent agreement qualitatively and quantitatively with the PL results.

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