Band offset of GaAs/In0.48Ga0.52P measured under hydrostatic pressure

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Low-temperature photoluminescence spectra of an In0.48Ga0.52P alloy and a p-type GaAs/In0.48Ga0.52P multiple quantum well, both grown by molecular beam epitaxy, have been obtained under hydrostatic pressures from 0 to 6 GPa. The zero-pressure extrapolation of the InGaP(ν) to GaAs(Γ) transitions yields a 0.40 ± 0.02 valence-band offset, and hence only a small, 0.06 ± 0.02 eV, conduction-band offset. These offset values are in agreement with measured values of the confinement energy versus well width.

Quantum well structures of GaAs and (InGa)P alloys provide alternatives to the GaAs/(AlGa)As system. They have been attractive because of the larger band-gap energy and the possibility that strain-layer superlattice structures can be grown. However, the band offset of this system has been controversial. A theoretical value of the conduction-band offset AE, = 0.16 eV was obtained by Harrison for a GaAs/In0.49Ga0.51P interface. Shubnikov–de Haas measurements have implied AE, = 0.39 eV, capacitance-voltage profiling of GaAs/(InGa)P heterojunctions have given ΔE, = 0.24 eV3 and 0.19 eV,4 and deep level transient spectroscopy5 has led to ΔE, = 0.20 eV. Recently, however, Kobayashi et al.6 investigated the current-voltage characteristics of a metalorganic chemical vapor deposition InGaP/GaAs heterojunction bipolar transistor and concluded that ΔE, was ~ 30 meV. No other determinations of the band offsets for this system have been reported, to our knowledge.

Hydrostatic pressure has been a powerful tool for studying band structures of semiconductors. Recently, Venkateswaran et al.7 and Wolford et al.8 used photoluminescence spectroscopy at high hydrostatic pressures to determine the band offset of GaAs/AlGaAs quantum wells. It is the most direct method known. The purpose of this letter is to report the first such measurement of the band offset of GaAs/InGaP quantum wells, enabling us to discriminate between the earlier, discordant results.

The samples were grown by gas-source molecular beam epitaxy (MBE) on a (100) semi-insulating GaAs substrate at 520 °C.9 The multiple quantum well (MQW) consisted of a 600 nm InGaP buffer layer, a 20-period well with each containing a 5.9 nm layer of GaAs and 23.7 nm layer of In0.49Ga0.51P, capped with a 45 nm GaAs layer. The composition parameter, x, was determined from x-ray diffraction to be 0.48 ± 0.01. Lattice mismatch is less than 0.1%. Based on the photoluminescence described below, the InGaP was a disordered alloy. The MQW was uniformly doped p type with Be to a concentration of 5 × 1016 cm⁻³. The bulk sample was grown by the same techniques, but was not intentionally doped. It was in the form of a 2.64 μm layer on a GaAs substrate and was weakly n type with n ~ 10¹⁶ cm⁻³.

The samples were compressed separately in a minia-
where \( E_v \) and \( E_c \) approximately cancel in the InGaP and GaAs components. Thus, the valence-band offset is modified by the correction due to \( E_{1hh} \) 15 meV and \( E_A = 28 \) meV to:

\[
\Delta E_v = (0.40 \pm 0.02) \text{ eV}.
\]

The conduction-band offset can be determined in a straightforward way from this:

\[
\Delta E_c = E_g(\text{InGaP}) - E_g(\text{GaAs}) - \Delta E_v
\]

\[
= (0.06 \pm 0.02) \text{ eV}.
\]

Therefore, \( Q_c \) and \( Q_v \) the fractional offsets take the values 0.13 \( \pm \) 0.04 and 0.87 \( \pm \) 0.04.

A consistency check on the large valence-band offset can be made by examination of confinement energy as a function of well thickness. Figure 3 shows the total confinement energy, \( E_{1hh} + E_{1le} \) previously deduced by PL from a series of quantum wells of varying thickness in a single sample. 17 The calculated thickness dependence of confinement energy for several reported values of \( \Delta E_v \) and \( \Delta E_c \) is shown for comparison. Effective masses of \( m_e = 0.11 m_0 \) and \( m_h = 0.46 m_0 \) were used for InGaP. 18 Larger ratios of \( \Delta E_v \) to total offset require thinner wells to yield the same \( E_{1hh} + E_{1le} \) since the heavy hole mass term \( E_{1hh} \) increases slowly and becomes more dominant. The experimental data clearly agrees better with the calculations where the major portion of the band offset is in the valence band.

The pressure coefficients for all the PL peaks are listed in Table I. The coefficients for the GaAs(\( X \)-\( \Gamma \)) and InGaP(\( X \)-to-GaAs(\( \Gamma \)) transitions are \(- (20 \pm 3) \text{ meV/GPa} \) and \(- (30 \pm 3) \text{ meV/GPa} \), respectively. The higher value of the latter is somewhat unusual. It may be due to residual stress or to a small shift of the band offset with pressure. It is noted that the extrapolation of the transition energies to \( P = 0 \) in the present work estimates the offset

| TABLE I. Photoluminescence zero pressure energies and pressure coefficients at 25 K. |
|---------------------------------|-----------------|-----------------|
| GaAs/InGaP MQW (MBE 144) | InGaP Alloy (MBE 299) |
| \( E_v^0 \) (eV) | 1.510 \( \pm \) 0.003 | 1.970 \( \pm \) 0.002 |
| \( E_c^0 \) (eV) | 1.93 \( \pm \) 0.01 | 2.26 \( \pm \) 0.02 |
| \( E_{1hh} \) (eV) | 1.511 \( \pm \) 0.002 | 1.85 \( \pm \) 0.01 |
| \( E_{1le} \) (eV) | 0.019 | 0.015 |
| \( E_A \) (eV) | 0.028 | |
| \( dE_v/dP \) (meV/GPa) | 93 \( \pm \) 2 | 84 \( \pm \) 2 |
| \( dE_c/dP \) (meV/GPa) | \(- (20 \pm 3)\) | \(- (20 \pm 2)\) |
| \( dE_{1hh}/dP \) (meV/GPa) | \(- (30 \pm 3)\) |
| Crossover pressure (GPa) | 15 GaAs (\( X \)-\( \Gamma \)) | 7.6 InGaP (\( X \)-\( \Gamma \)) |

![FIG. 3. Variation of quantum confinement energy for MQWs of varying well thickness. The open circles are the experimental results from Ref. 17, and the lines are the results of calculations with various values of the band offsets: dashed line—present result; curve 1—Kobayashi et al. (see Ref. 6); curve 2—Harrison (see Ref. 1), curve 3—Watanabe et al. (see Ref. 4); curve 4—Biswas et al. (see Ref. 5); curve 5—Rao et al. (see Ref. 3); curve 6—Kodama et al. (see Ref. 2).](image)
at zero pressure, where this quantity is of technological interest. Uncertainty in the slope of $E_\text{g}$, as seen in Fig. 1, makes only a small difference in the zero pressure intercept.

In conclusion, photoluminescence spectroscopy was performed on a MBE-grown In$_{0.48}$Ga$_{0.52}$P alloy and a GaAs/In$_{0.48}$Ga$_{0.52}$P superlattice at 25 K under hydrostatic pressures. The observation of transitions associated with $X$ states in bulk InGaP, and both PL components of the GaAs/InGaP MQW, enables a straightforward extrapolation of the band energy separations, so that the band offset of the GaAs/InGaP quantum wells studied can be determined directly. Only 13% of the total band offset is found to occur in the conduction band.

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