Modification of Material Parameters for InGaAs/InAlAs Quantum Wells
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1. Introduction
Semiconductor optical modulators and switches based on phase modulation such as Mach-Zehnder (MZ) modulators are becoming more and more important in optical fiber communications. For high-performance optical modulators and switches based on phase modulation, we have developed five-layer asymmetric coupled quantum wells (FACQWs) [1-3].
In our research on the InGaAs/InAlAs FACQW for 1.55 μm wavelength, we theoretically calculated absorption coefficient spectra of InGaAs/InAlAs quantum wells (QWs) using frequently used material parameters in some references. But we found that experimental data are slightly different from the calculated. To estimate the electrorefractive index change of InGaAs/InAlAs QWs more accurately, material parameters such as energy band gap, effective masses must be modified.
In this paper, we discuss material parameters for InGaAs/InAlAs QWs comparing experimental and calculated data. Using the modified material parameters, we succeeded in obtaining the calculated absorption coefficient spectra more consistent with the experimental.

2. Modification of Material Parameters
For the calculation of absorption coefficient spectra, we used the k·p perturbation theory with a 4 x 4 Luttinger-Kohn Hamiltonian[4,5] and The effects of excitons were calculated using the non-variational approach [6] and the effect of valence band non-parabolicity was taken into account. To compare the calculated results with the experiments, we grown some InGaAs/InAlAs QWs lattice-matched to an InP substrate using metal-organic vapor phase epitaxy (MOVPE). The material parameters we investigated are the bandgap energy (Eg), the electron and hole effective masses (me, mh, mh). We also considered deteriorated abruptness in heterointerfaces.

2.1. Bandgap Energy of InAlGa1-xAs
Equation (1) [7] is the expression of Eg for the InAlGa1-xAs used in our calculation. It is slightly different from the experimental data which were obtained from photoluminescence (PL) of several InAlGaAs bulk crystals measured at room temperature. We modified the coefficients in Eq. (1) as summarized in Table 1.

\[ E_g = a_0 + a_1 x + a_2 (1 - x - y) + a_3 x^2 + a_4 (1 - x - y)^2 + a_5 x (1 - x - y) - a_6 x y (1 - x - y) \] (1)

2.2. Abruptness of InGaAs/InAlAs Heterointerfaces
Figure 2 (a) shows a line profile of Ga luminescence from the InGaAs/InAlAs FACQW with high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM). The designed structure of the FACQW is shown in Fig. 2 (b). As shown in Fig. 2(a), some deteriorations of abruptness occurs in the heterointerfaces. In our calculation, we assumed that the Ga composition profile is expressed as Eq.(2) using the normal distribution function.

\[ f(x) = \frac{1}{\sqrt{2\pi\sigma}} \exp\left(-\frac{x^2}{2\sigma^2}\right) \] (2)

2.3. Effective Masses
The effective mass of a heavy hole (mhh) and the effective mass of a light hole (mlh) are expressed in eq. (3)

\[ m_{hh} = \frac{m_0}{\gamma_1 - 2\gamma_2}, \quad m_{lh} = \frac{m_0}{\gamma_1 + 2\gamma_2} \] (3)

where \( m_0 \) is the mass of a free electron and \( \gamma_1, \gamma_2 \) are the Luttinger parameters.

Table 1. Coefficients of eq.(1)

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<th>a0</th>
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Fig. 1. Experimental and calculated bandgap energy of InAlxGa1-xAs lattice-matched to InP.

(a) Fig.2. (a) Line profile of Ga luminescence of InGaAs/InAlAs FACQW measured using HAADF-STEM and (b) a potential profile of InGaAs/InAlAs FACQW.
3. Modified Absorption Coefficient Spectra

Figure 3(a) shows the calculated absorption coefficient spectra using the parameters in Ref.[7] and the modified ones. A photocurrent spectrum of an InGaAs/InAlAs rectangular QW (well width 5 nm) measured at room temperature is shown in Fig.3(b). The spectrum calculated using the modified parameters agrees well with the experimental result. In the case of the 10-nm thick InGaAs QW, we also obtained the spectrum agreed well with the experiments.

Figure 4 (a) shows the absorption coefficient spectra of a symmetric coupled QW under the applied voltages, and it shows the typical quantum confined Stark effect (QCSE). The QW is composed of 4.4-nm InGaAs well layers and a 0.88-nm InAlAs barrier layer. The absorption coefficient spectra calculated using the modified parameters in Fig.4(b) agrees well with Fig. 4 (a).

4. Conclusions

We discussed the material parameters of InGaAs/InAlAs QWs. Comparing the experimental and the calculated data, we successfully obtained more appropriate material parameters for predicting photocurrent spectra of InGaAs/InAlAs QWs. The modified parameters are quite useful for InGaAs/InAlAs QW optical devices such as optical modulators and switches.

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References