Application of Band Theory to Experimental Eigen-State Energies of $In_{0.53}Ga_{0.47}As$ Quantum Wells Lattice-Matched to InP

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Abstract-**Nonparabolic subband structure of In-GaAs/InAlAs multi-quantum wells was studied theoretically and experimentally. Electron eigen-energies fit very well with our experiments in a wide energy range of 0.5 eV in the multi-quantum wells.**

I. INTRODUCTION

Nonparabolic subband structure of InGaAs/InAlAs multi-quantum wells (MQWs) was studied theoretically and experimentally. In this paper, we report that nonparabolic effective masses of electrons and band offset of InAlAs barriers were experimentally deduced from eigen-states of conduction subbands confined within the two-dimensional InGaAs quantum layers. An effective mass equation was solved in a finite well potential, self-consistently with Coulombic charges in the wells and the barriers. As the dispersion relations for electron, light hole and hole subbands were obtained using the envelope function approximation taking into account band nonparabolicity, we propose a simple way to design of the light detectors.

II. EXPERIMENTAL

Specimen including the $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ MQWs grown by MBE on each (100) surface of n-type InP substrates. Undoped MQWs V720, V706, V748 and U10 were in succession to an n-InAlAs buffer layer on the n-type InP substrate. The widths of the InGaAs quantum wells were 5, 9.4 and 20 nm for each specimen. Numbers of quantum wells were 33, 25, 10 and 16, respectively. Width of the InAlAs barriers was commonly 10 nm. A heavily-doped p-InGaAs layer was on this MQW structure , which was as an electrode. Photocurrent spectra were measured were about such a p-i-n junction. Other two specimens, M10L and M10H, have modulation-doped quantume wells, which are higher and lower doping concentoration. Numbers of quantum wells and barriers were 10 and 10, respectively. About other specimens not having the electrode, transmission spectra were measured.
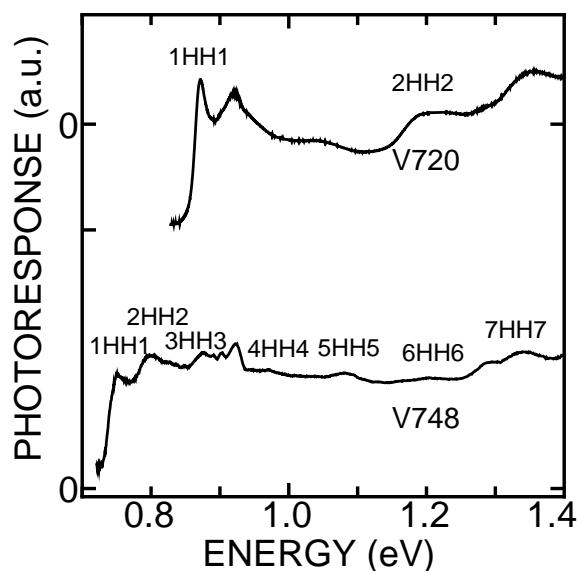
III. RESULTS AND DISCUSSION

Fig. 1 Photocurrent spectra of the V720 and V748.

Photocurrent spectra of the V720 and V748 were measured in no bias voltage at room temperature, as shown in Fig. 1. The spectra were normalized by wavelength dependence of detectors [1,2]. Step-like structures accentuated by exciton peaks were started after each big edge between 0.7 and 0.9 eV. Types of interband transitions, which were assigned from the spectral structures, were labeled by using the notation $nxHl$, where n and l were principal quantum numbers of the conduction and valence subbands and x=H or x=L indicate heavy hole (HH) or light hole (LH) subband. Major peaks corresponded to allowed transitions having same quantum numbers ($n = l$). Peaks for the interband transitions caused by the HH between the conduction subband and the valence subband were bigger than the

ones caused by the LH. Peaks of the V720 were correspond to quantum number 1, 2. Peaks of the V748 were correspond to quantum number between 1 and 7.

Transmission spectra of the U10 (UNDOPED) M10L (LOW DOPED) and M10 (HIGH DOPED) were measured at 120 K. Spectral structures gave the existence of two-dimensional confined states, as shown in Fig.2. Optical allowed transitions having a quantum number, 1, were masked by Fermi edge.
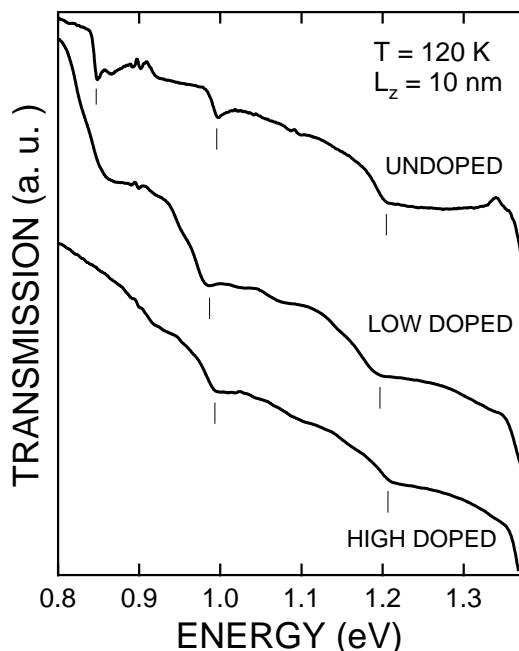

Fig. 2 Interband transmission spectra.

An effective mass equation was solved in a finite well potential, self-consistently with Coulombic charges in the wells and the barriers. The effective masses of the conduction subbands were estimated in fitting experimental transition energies to the equation. Using a assumption that electron effective mass is 0.041 m_0 at bottom of a conduction quantum well as much as one of bulk at the conduction bandedge and varies smoothly toward higher energy, the energy dependence of the effective mass was sufficiently considered even as small eigen-energy at small quantum-number [2,3]. After fitting experimental transition energies to the envelope function model, nonparabolicity of the electron effective mass explicitly was determined as a function of energy in a direction normal to quantum well layers.

We adopted band-offsets of valence and conduction bands were 0.22 eV and 0.52 eV and HH and LH effective masses of mHH=0.38 m_0 and mLH=0.051 m_0, where m_0 was the electron mass in vacuum. The estimated effective masses of the specimens were 0.04 m_0 to 0.07 m_0 up to 0.5 eV, as $m_e^*(E[eV]) = 0.041 m_0 \times (1 + 2.2 \cdot E - 1.4 \cdot E^2)$ in Fig. 3. These estimated effective masses agreed with the p-i-n and the modulation-doped MQWs structures. Electron eigen-energies were calculated
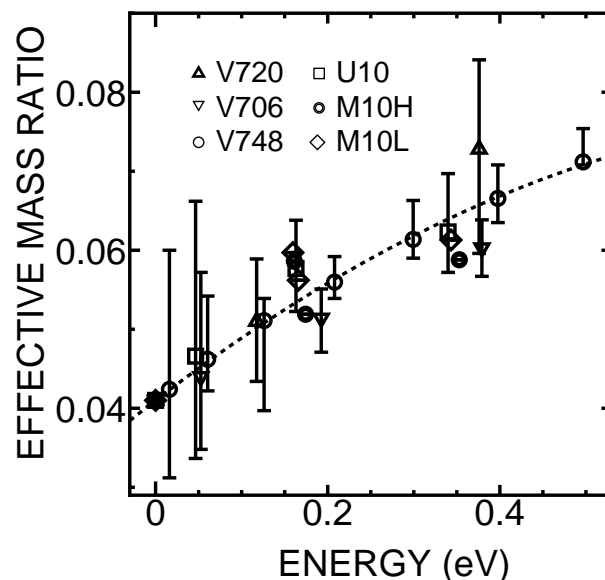

Fig. 3 Estimated effective mass ratio

with Yamada model [4] in QWs based on Bastard's analysis [5] and Kane's three-level band theory. The energy dispersion relation is calculated using the envelope function approximation where all eight bands are taken into account. Applying the boundary conditions at the heterointerface, one finds the dispersion relations for InGaAs/InAlAs QWs.

IV. CONCLUSION

In conclusion, An effective mass equation was solved in a finite well potential, self-consistently with Coulombic charges in the wells and the barriers. Applying bulk band theory of narrow-gap semiconductor to the MQWs, eigen-states of conduction electrons were theoretically deduced. And electron eigen-energies fit very well with our experiments in a wide energy range of 0.5 eV.

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