Observation Of The Light-Hole Quantum Dots In A Strained GaAs Quantum Well

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Abstract. We observed a light-hole-to-electron transition of strain-induced quantum dots (SIQDs) in a strongly strained GaAs quantum well (QW). Circularly-polarized luminescence excitation spectroscopy showed a pronounced counter-circularly polarized component below the heavy-hole exciton transition in the QW. This special feature can be explained by the existence of the light-hole-to-electron transition at this energy level. On the other hand, a very high co-circular polarization (=0.8) was obtained near the lowest transition of SIQD.

INTRODUCTION

Semiconductor quantum dots (QDs) have properties of artificial atoms characterized by the discrete energy levels with angular momenta and are of interest for new optoelectronic devices such as QDs laser, elements for the quantum computer, and charge-storage devices. The strain-induced quantum dots (SIQDs) have been known as a new kind of the quantum dots. The advantages of the SIQDs are homogeneous size distribution in the growth direction, no defect at the interface and harmonic-oscillator-type lateral confinement potentials in the QW. It is expected that both the heavy-hole (HH) and the light-hole (LH) have individual lateral confinement potentials in the QW. However, all the reports on SIQDs discussed only HH transitions so far [1, 2]. The LH transitions in the SIQDs have not been observed yet. We believe this paper describes the first observation of the LH transitions in the SIQDs.

SAMPLES AND EXPERIMENTAL

The samples we studied were grown by metal organic vapor-phase-epitaxy on semi-insulating GaAs (001) substrates. A single GaAs/Al$_{0.3}$Ga$_{0.7}$As QW 4.0nm thick was grown. A well is made at 7.0nm in depth from the surface. Island-like InP stressors were grown on the surface of the sample which induce strain into the GaAs QW. The QDs are formed under the stressors in the GaAs QW. The islands were 90nm wide and 20nm high. The areal density of the islands was $3 \times 10^9 \text{cm}^{-2}$.

Circularly-polarized photoluminescence excitation (PLE) spectra were measured at 10K by using a circularly-polarized tunable cw Ti:sapphire laser as an excitation source. Because HH and LH have different selection rules for optical transitions [3], optical transitions for HH and LH can be assigned by using circularly polarized laser as an excitation light source. Here, we use the notation (σ_+, σ_+) to describe the "co-circular" polarization. The former and the latter indicate the circular polarization of the excitation light and the detection light, respectively. We also use the notation (σ_+, σ_-) to describe the "counter-circular" polarization. The Degree-of-polarization is defined as $(I_+ - I_-)/(I_+ + I_-)$, where I_+ is the intensity in the (σ_+, σ_+) configuration and I_- is the intensity in the (σ_+, σ_-) configuration.

RESULTS AND DISCUSSION

Figure 1 shows a PL and PLE and degree-of-polarization spectra of the sample A. We can see three excited states of the QDs. They have nearly equal energy intervals. A very high positive value of degree-of-polarization was obtained to be 0.8 around 1.62eV and around 1.64eV a pronounced dip of the
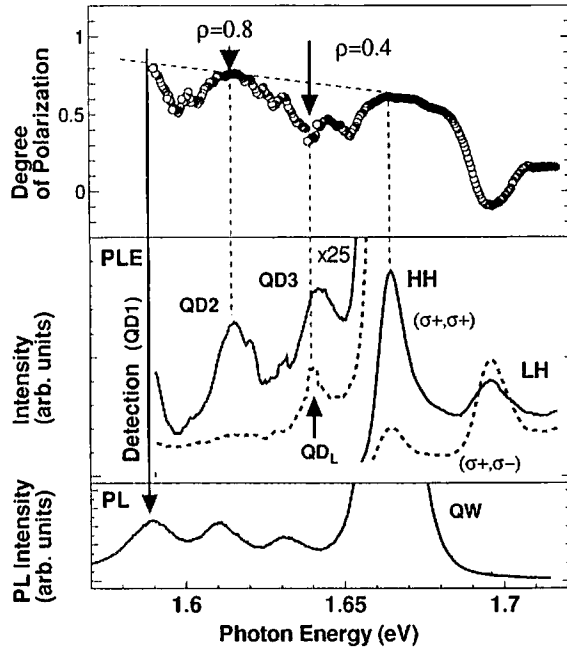
FIGURE 1. Bottom panel: Photoluminescence (PL) spectrum. Middle: Circularly-polarized photoluminescence excitation (PLE) spectra at co-circular (solid line) and counter-circular (dotted line) configurations. Top: Degree of polarization of the PLE spectra.

FIGURE 2. Schematic drawing of the potential energy in GaAs QW and SIQDs.

degree-of-polarization is observed. At the bottom of the dip around 1.64eV, it is 0.4. On the other hand, the degree-of-polarization of 0.6 was observed at the HH exciton in the QW. These features, considerable changes of the degree-of-polarization in the PLE spectra of the sample, can be explained by considering that QD_L is the lowest LH-to-electron transition in SIQDs and that QD1, QD2, and QD3 are the HH-to-electron transitions in SIQDs. Equal energy intervals of 27.0meV among QD1, QD2, and QD3 and highly positive circular polarization show that QD1, QD2, and QD3 are the HH-to-electron transitions in SIQDs.

The additional two-dimensional confinement appears in the QW region below the stressor and SIQDs are formed. Figure 2 shows the energy deformation of the electron, HH, and LH levels in the QW described by two deformation potentials; a hydrostatic deformation potential (δE_{hy}) and a shear deformation potential (δE_{sh}) [4,5]. The energy interval between the QW and QD was obtained to be 74.9meV from Fig.1, which corresponds to $(2/3)\delta E_{hy} + (1/3)\delta E_{hy} - (1/2)\delta E_{sh} - (\hbar\omega_e + \hbar\omega_h)$, as is displayed in Fig.2. A ratio $\delta E_{hy}/\delta E_{sh}$ in GaAs is known to be 2.18 [5]. From these relations, the confinement potentials of the electron, HH, and LH are
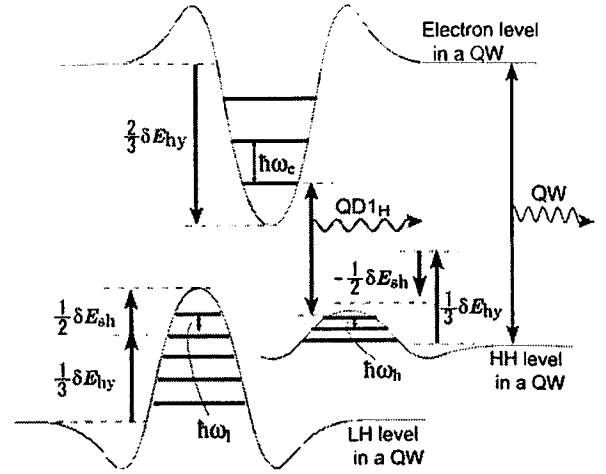
obtained to be 89.9meV, 14.0meV, and 75.8meV, respectively. The lateral effective mass of the SIQDs of the electron (m_e), HH (m_h), and LH (m_l) are $0.067m_0$, $0.111m_0$, and $0.203m_0$, respectively. Here, the m_0 shows the rest mass of the electron. By using the relation between parabolic potential confinement and the deformation potentials for each carrier, and the energy interval between QD1 and QD2 (27.0meV), we obtained the quantum energy interval for electron, HH, and LH: $\hbar\ \omega_e$ =20.2meV, $\hbar\ \omega_h$ =6.7meV, $\hbar\ \omega_l$ =11.5meV. The calculated quantum states of the HH-to-electron transitions were in good agreement with the experimental observation, while the calculated 3rd quantum state of the LH-to-electron transition was shifted from the observed QD_L by 10meV. Since the QD_L around 1.64eV forms a remarkable peak in the counter-circular PLE spectrum, we believe the dip in the same energy to come from the LH-to-electron transition.

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