Optical Characteristics of InAs Quantum Dots Influenced by AlGaAs/GaAs Superlattice Barriers

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ABSTRACT

We investigated the effect of AlGaAs/GaAs superlattice barriers on the optical properties of InAs quantum dots (QDs) by using photoluminescence (PL) spectroscopy. The samples used in the present work were grown by molecular beam epitaxy (MBE) on the (001) semi-insulated GaAs substrates. Five different types of sample structures were designed and grown to investigate the effects of AlGaAs/GaAs superlattice barriers. In order to identify the effect of superlattice barrier, simple GaAs/InAs QD/GaAs structure was also grown as a reference. Based on our experimental results, the AlGaAs/GaAs superlattice barriers can effectively change the emission peak position of InAs QDs without much sacrificing the optical characteristics of QD structures.

Keywords: MBE, Quantum Dot, InAs, Photoluminescence, Superlattice barriers.

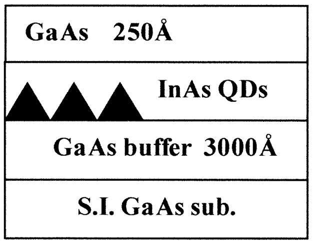
1 INTRODUCTION

The growth of the quantum dots (QDs) by the Stranski-Krastanov mode has been paid much attention in the past few years due to their enormous potentials for the possible device applications [1]. Specially, InAs/GaAs self-assembled QD structures are attracting interest due both to their zero-dimensional properties and the potential they offer in device applications such as ultra-low threshold lasers and memory systems [2,3]. For various applications, manipulation of the energy levels of quantum dos is indispensable. While the study on the shift toward long wavelength of InAs/GaAs QD systems has been performed widely [4,5], less work on the shift to the shorter emission wavelength of InAs QDs has been carried out. In order to get higher ground state energy levels in the QDs, the specific growth processes could be adopted as reported by Lubyshev *et al.* [6]. However, it would be difficult to achieve a high crystalline quality of QD with this method.

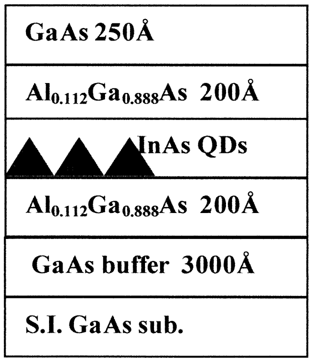
In the present work, we investigated the effects of AlGaAs/GaAs superlattice barriers on the optical properties of InAs QDs in GaAs matrix.

2 EXPERIMENTAL PROCEDURES

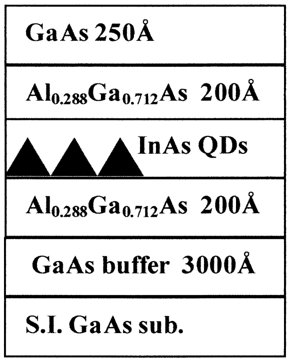
The samples used in the present work were grown by molecular beam epitaxy (MBE). The semi-insulating (001) GaAs wafer was used as a substrate. Five different barrier structures were designed and grown to investigate the effects of AlGaAs/GaAs superlattice barriers on the optical properties of InAs QDs. A simple InAs QD structure was also grown as a reference. The structures are as follows; GaAs/InAs/GaAs(S1: reference sample), GaAs/$Al_{0.112}Ga_{0.888}As$/InAs/$Al_{0.112}Ga_{0.888}As$/GaAs(S2), GaAs/$Al_{0.288}Ga_{0.712}As$/InAs/$Al_{0.288}Ga_{0.712}As$/GaAs(S3), GaAs/ {$Al_{0.112}Ga_{0.888}As$/GaAs}×10 periods /InAs/{GaAs/$Al_{0.112}Ga_{0.888}As$}×10 periods/GaAs(S4) and GaAs/ {$Al_{0.288}Ga_{0.712}As$/GaAs}×10 periods/InAs/{GaAs/$Al_{0.288}Ga_{0.712}As$}×10 periods/GaAs(S5). The schematic diagrams for sample structures are shown in Figure 1.



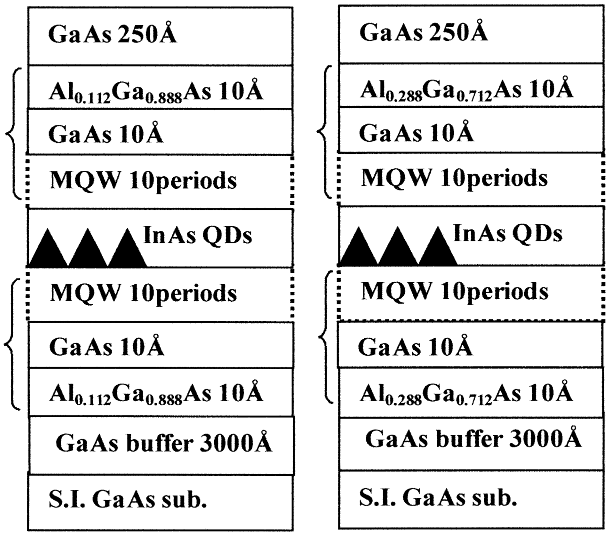
(a) GaAs/InAs/GaAs (S1: reference sample)



(b) GaAs/$Al_{0.112}Ga_{0.888}As$/InAs/$Al_{0.112}Ga_{0.888}As$/GaAs(S2)



(c)GaAs/$Al_{0.288}Ga_{0.712}As$/InAs/$Al_{0.288}Ga_{0.712}As$/GaAs(S3)



(d) S4 (e) S5

Figure 1. The schematic band diagram for sample Structures.

The growth rate of GaAs and AlGaAs is 803.1 nm/h and 1123.3 nm/h based on the reflection high-energy electron diffraction (RHEED) oscillations. Before depositing the InAs QDs, the substrate temperature for the growth of GaAs buffer and AlGaAs/GaAs superlattice barrier was set to 580°C and, then, the substrate temperature was lowered to about 460°C for the growth of InAs QDs layer. InAs QDs with 3 ML were grown at a rate of 0.07 ML/s and the formation of InAs QDs was verified by the observation of the 2D-3D transition monitored by *in situ* RHEED pattern after 1.7 ML. An undoped 25 nm GaAs capping layer was grown after InAs QDs deposition followed by 30 s growth interruption time under As-rich condition. To investigate the effects of different superlattice barriers, photoluminescence (PL) measurements were conducted. In PL measurement, the Argon ion laser with wavelength of 514.5 nm was used as an excitation source to generate electron-hole pairs. The samples were loaded into the helium closed circuit refrigerator for low temperature PL measurements. The luminescent signal was recorded by the liquid nitrogen cooled Ge detector.

3 RESULTS AND DISCUSSIONS

The photoluminescence spectra recorded from the InAs QD reference sample (Sample S1) are shown in Figure 2. As can be seen in the figure, ground state energy transition was found at the 1.067 eV and saturated at about 13 mW/cm^2. The full width at half maximum (FWHM) of the peak was found to be 52 meV. This relatively narrow peak width is an evidence of the high crystalline quality of our QD sample. A second peak appeared at 1.143eV, which may be attributed to the transition involving the |001> hole state as described by Grundmann *et al.* [7]. The peak separation between the first and second peaks is found to be 76meV. The FWHM of the second peak was measures as 60meV. The third transition peak was observed at 1.209 eV and the FWHM was 72meV. Figure 3 shows the fitting curve with three Gaussians for the spectrum recorded with excitation energy density of 300mW/cm^2. Two excited states showed larger inhomogeneous broadening than the ground state energy transition. From these results, it may be concluded that the transitions between the only electron ground state and various confined hole states were clearly identified [7] in our Sample S1. No excited electron states exist in our Sample S1due to small size of QD.

In case of the sample S2, 3000Å thick GaAs buffer layer was grown on the semi-insulating GaAs wafer and 200Å thick-$Al_{0.112}Ga_{0.888}As$ layer was grown on top of it. The thin GaAs wetting layer was grown before InAs QD layer was grown on it. Then, the InAs QD layer was covered with a monolayer of GaAs. The 200Å thick-$Al_{0.112}Ga_{0.888}As$ layer was grown on top of it. Finally, 200Å thick-GaAs cap layer was grown to cover the AlGaAs layer. The sample S3 had the same structure as the sample S2 except the composition of aluminum content in AlGaAs layer. The $Al_{0.288}Ga_{0.712}As$ was adopted in the sample S3. The sample S4 and S5 also possess the same structures. However, the AlGaAs layer was replaced with 10 periods of GaAs/AlGaAs layer. The thickness of 1 period was 20 Å.

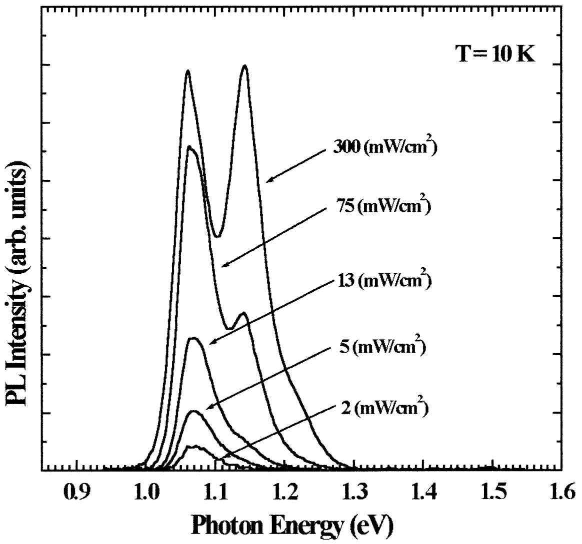


Figure 2. Photoluminescence Spectra for the reference sample S1 of InAs QDs with different excitation density given in mW/cm^2 at 10K.

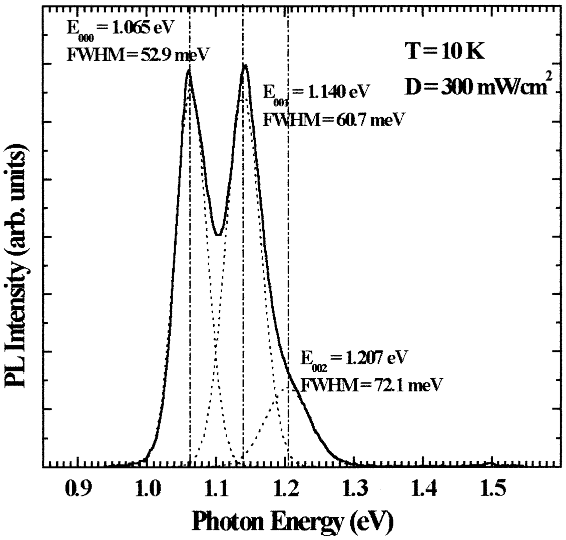


Figure 3. Three Gaussian fit curve to the 300mW/cm^2 spectrum.

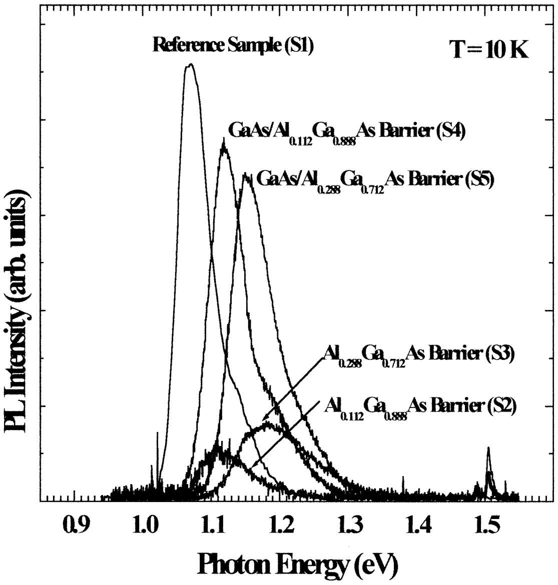


Figure 4. PL spectra for the InAs QDs samples with different superlattice barriers measured at 10K.

Figure 4 shows the PL spectra measured at 10 K for samples from S1 to S5. 20mW/cm^2 of excitation energy was applied. As can be seen in the figure, all samples with AlGaAs barrier and superlattice were blue-shifted. When we compare the PL peak of Sample S2 with S3, as the aluminum content of AlGaAs layer is increased from 0.112 to 0.288, the PL peak position was shifted toward to the higher energy. The amounts of shifts were found to be 33 and 123 meV with respect to the peak position of the Sample S1, respectively. However, unfortunately, the peak intensities were drastically reduced comparing with that of the sample S1. The FWHM of the PL peaks of the Sample S2 and S3 were found to be 80 and 140 meV, respectively. The broadening of the peak is attributed to the defects involved in AlGaAs barrier layer.

On the other hand, in the case of Samples S4 and S5, the blue shifts were also achieved. The amounts of shifts were almost similar to the previous cases and found to be 31 and 112 meV with respect to the peak position of the Sample S1, respectively. However, the peak intensities are comparable with that of Sample S1. Furthermore, the FWHM of Samples S4 and S5 showed almost comparable values with that of the Sample S1. The FWHMs of the Sample 4 and 5 was found to be 53meV and 56 meV, respectively. Therefore, by applying the superlattice structure instead of a single layer of AlGaAs barrier, it was possible to achieve blue shift without scarificing high quality of InAs QD. The energy level shift could be explained by the energy level modification due to high potential barrier [8].

4 CONCLUSION

We have investigated the effect of AlGaAs/GaAs superlattice barriers on the optical properties of InAs quantum dots (QDs) by using photoluminescence (PL) spectroscopy. Based on the low temperature PL intensity and FWHMs results, GaAs/AlGaAs superlattice barrier was the effective method to make an energy modification of InAs QDs. The FWHMs of the Sample 4 and 5 was found to be 53meV and 56 meV, respectively. Based on our experimental results, the AlGaAs/GaAs superlattice barriers can effectively change the emission peak position of InAs QDs without much sacrificing the optical characteristics of QD structures.

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