Growth of InAs Quantum Dots Using the Strained Superlattices and Their Optical Properties

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ABSTRACT

we have studied the growth of self-assembled quantum dots (QDs) using Stranski-Krastanow growth mode and strain-reducing layers for long-wavelength applications with narrow linewidth in photoluminescence (PL) emission. InAs QDs were grown on the strained superlattices, GaAs(2nm)/$In_xGa_{1-x}As(2nm)_{\times10}$ with x = 0.1, 0.32 and 0.52 and capped with same strained superlattices. Their optical properties related to the integrated PL intensity and peak positions were investigated with different temperature ranging from 11 ~ 325 K.

Keywords: InAs, quantum dots, strained superlattice, Photoluminescence, annealing.

1 INTRODUCTION

The formation of the self-assembled quantum dots (QDs) in largely lattice mismatched systems by the Stranski-Krastanov (SK) mode has attracted much interest in the past several years, because of the possibility of realizing the improved device performance such as promising low threshold current density and high differential gain [1~4]. However, their overall performance in devices has remained inferior to that of the quantum wells (QWs), mainly because the size, shape, and compositional fluctuations that occur in QDs devices result in a large photoluminescence (PL) line width about 50 ~ 80 meV at room temperature [5,6]. To improve the device performance of QDs, the PL linewidth should be decreased to less than that of QWs and the discrete energy level of the QDs should be more than 100 meV in order not to affected by temperature.

The emission wavelength for the conventional InAs QDs grown on GaAs has about 1 μm and is not appropriate for fiber optic communication system [6,7]. Therefore, it has been a strongly interesting subject to obtain the uniform size distribution and the extension in optical emission range available for the GaAs-based optoelectronic devices to 1.3 μm or 1.5 μm with 10 meV in full width at half maximum (FWHM) of the PL peak because of the transparency window of optical fiber [4,8~10].

In the present work, we propose and realize a method to extend to 1.3 μm with significant narrowing of FWHM of PL emission by the growth of InAs QDs by using the newly suggested structure. The optical properties of the high quality InAs QDs on the strained GaAs(2nm)/$In_xGa_{1-x}As(2nm)_{\times10}$ superlattice with different In composition were studied by using PL. The effects of rapid thermal annealing treatments on the self-assembled InAs QDs to achieve more ideal zero-dimensional behavior [11~13] were also investigated with PL measurement.

2 EXPERIMENTS

The samples studied were grown by a Riber 32P molecular beam epitaxy on the (100) semi-insulating GaAs using As_4. After growing a 5000 Å GaAs buffer layer at 560°C, the substrate temperature was lowered to 450°C for the InAs active layer. The 10 period superlattice made of GaAs(2nm)/$In_xGa_{1-x}As$(2nm) was grown above the buffer layer and InAs QDs layer, respectively, with different In mole fraction x = 0.1, 0.32 and 0.52. The GaAs capping layer with thichkness of 25 nm was deposited on the superlattice barrier layer. The rest of the growth and structural conditions for all the samples used in this work were same.

In PL measurement, the Ar^+ laser was used as an excitation source to generate electron-hole pairs and the temperature ranging was from 11 K to 325 K. The luminescence signal was dispersed by 1 m monochromator and detected with a liquid nitrogen cooled Ge detector.

The rapid thermal annealing (RTA) was performed in nitrogen ambient at temperature ranging from 450°C to 850°C for 30 s. Before RTA treatment, the samples cut from the central region of the wafer were capped with bulk GaAs in order for As not to remove from the surface.

3 RESULTS AND DISCUSSIONS

The Fig. 1 shows the PL spectra of the InAs QDs with different In composition, x = 0.1, 0.32 and 0.52 in the strained superlattices at 11 K. From this figure, it is clearly seen that the decrease in the PL peak energy of the InAs QDs by increasing the In composition of the superlattice layer results in the gradual redshift in wavelength. The decrease in the PL intensity with increase in the emission wavelength was observed indicating strain relaxation due to the strained superlattice, while no reduction in PL intensity with increase in In composition in the $In_xGa_{1-x}As$ barrier reported by V. M. Ustinov et al. [14]. The reduction of the transition energy from the QDs could be caused by the intermixing effects between the QDs and the strained superlattices barriers [14,15]. Reduction in the compressive stress and coherent strain effects in the InAs QDs due to the strained superlattices can also play an important role in the redshift of the emission wavelength. We are not sure which process is dominant so far, however, the InAs QDs adopting the strained superlattice show the possibility of being used for the optical communications. In the case of QDs with In mole fraction x = 0.1 of the superlattice, the PL peak energy for the ground state is about 1.124 eV and the excited state is 1.176 eV as shown in Fig. 1. The noticeable point is that this sample has the fairly narrow FWHM with 33 meV in the PL emission, whereas the FWHM of the InAs QDs grown on the GaAs has been reported by 50 ~ 80 meV.

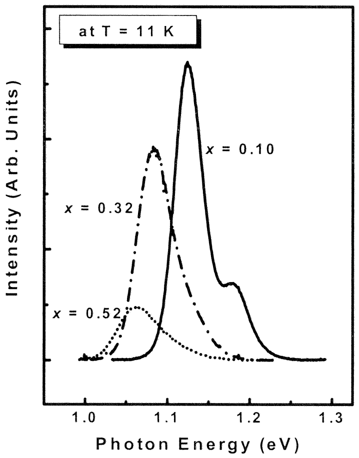

Figure 1 : PL spectra of the InAs QDs with different In composition, x = 0.1, 0.32 and 0.52 in the strained superlattices at 11 K.

The Fig. 2 and 3 show the temperature dependence in emission wavelength of the ground state and excited state of InAs QDs on $GaAs(2nm)/In_xGa_{1-x}As(2nm)_{\times10}$ superlattice with x = 0.1, 0.32 and 0.52 measured by varying temperature, respectively. With increase in temperature, the emission wavelength is shifted toward long-wavelength and the temperature dependence of the ground state and excited state in PL peak shows the almost same trend. While the PL peaks were not observed from high In composition, x = 0.32 and 0.52, the PL peak for x = 0.1 was measured at room temperature. This is attributed to being poor quality of the QDs caused by enhancing the known In segregation effect with respect to increase in In content of the large lattice mismatched epitaxy. Even though the PL peak at room temperature can not be seen from the QDs with x = 0.52 due to the crystalline problems by In segregation, this QDs structure has potential application for 1.3 µm in PL emission. This very important result strongly suggests that inserting the InAs QDs into an

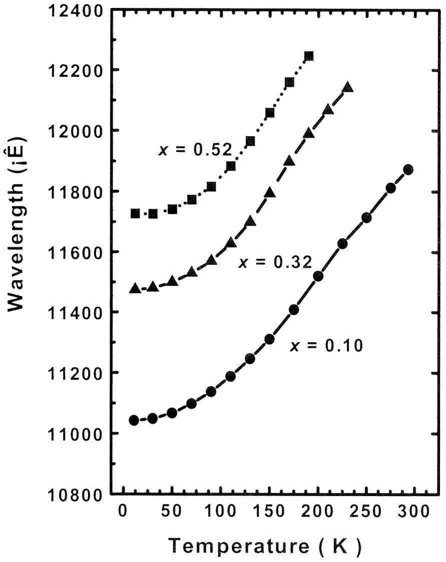

Figure 2 : The temperature dependence of emission wavelength of the ground states x = 0.1, 0.32 and 0.52.

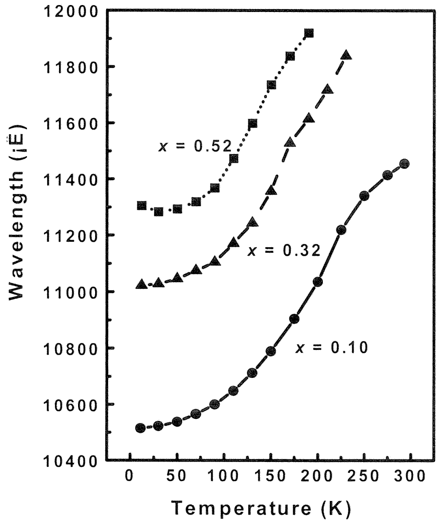

Figure 3 : The temperature dependence of emission wavelength of the excited states x = 0.1, 0.32 and 0.52.

external strained superlattice has shown to extend the long-wavelength limit of the emission from the structures grown on the same strained superlattice to 1.3 μm at room temperature.

Figure 4 and 5 (filled squares) shows the PL spectra obtained from sample with x = 0.1 annealed at different temperature, where the PL spectra represented by as-grown is for the unannealed sample. The annealing treatment results in a blueshift in the emission energy with increasing temperature. This blueshift in the PL spectrum can be explained by interdiffusion of the In and Ga atom at the interface between the QDs and GaAs(2nm)/In$_x$Ga$_{1-x}$As(2nm)$_{\times 10}$ superlattice barriers leading to a change in the size and the composition of the QDs during annealing [14,15]. While there is an increase in the integrated PL intensity for the annealing temperature up to 800°C, a large decrease in the intensity is observed at higher annealing temperature. The increase in PL intensity up to 800°C is regarded as the reduction of the non-radiative recombination center and the decrease in the intensity above 800°C indicates the degradation of material quality and the destruction of the self-assembled QDs. Those results are in good agreement with those reported by S. J. Xu [11], however, the FWHM shows the different results as shown in Fig. 5 (filled circles). The FWHM of the PL increases up to 700°C and decreases above this temperature while those of the S. J. Xu decrease by increasing annealing temperature. Those differences could be explained by the growth temperature of the QDs, that is, the QDs used in this work were grown at 450 °C lower than that of the S.J. Xu case, 560 °C.

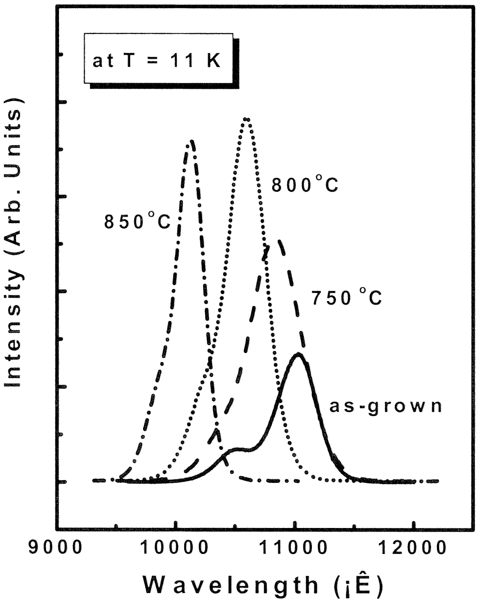

Figure 4 :11 K PL spectra obtained from the samples as-grown and annealed at different temperatures.

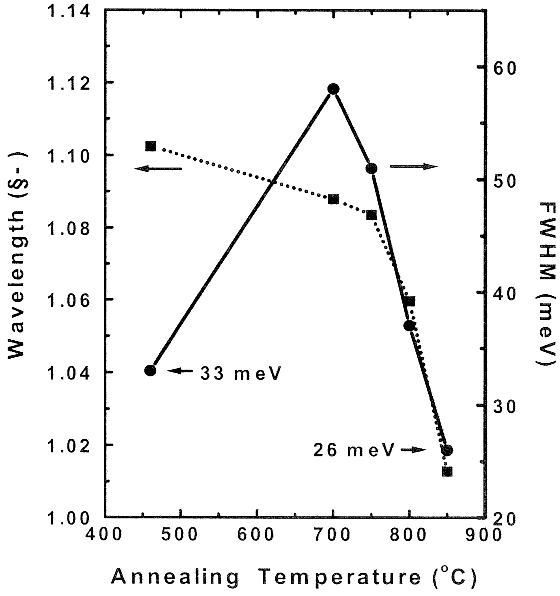

Figure 5 : The emission wavelength and FWHM of the PL as a function of annealing temperatures.

4 CONCLUSIONS

We have studied the possibility that the InAs QDs grown on the strained superlattice, GaAs(2nm)/In$_x$Ga$_{1-x}$As(2nm)$_{\times 10}$ and capped by the same strained superlattice can be used to obtain the extension of emission wavelength to 1.3 μm with narrow FWHM for the application of the optical fiber communication. The luminescence peak position of InAs QDs was redshifted and the intensity of the emission peak became reduced by increasing the indium composition of the superlattice layer. And the structure with In mole fraction x = 0.1 of the superlattice also showed the 33 meV in FWHM. There is large blueshift in emission wavelength resulted from thermal annealing of the InAs QDs and the significant narrowing of FWHM. From the results, we showed the possibility that this newly proposed structure could be used for the fiber optic communication.

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