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Controlling the optical properties of self-assembled InAs quantum dots by various annealing treatments

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1. Introduction

The formation of self-assembled quantum dot (QD) structure evolved during the growth of highly lattice-mismatched hetro-epitaxy system has provided the most prominent way for the optoelectronic device applications such as a laser diode and a light emitting diode. Due to the atomic-like joint density of states of a QD system, for example, a QD laser diode is expected to low threshold current density, high thermal stability and high quantum efficiency. However, inspite of these advantages, there have been lots of problems to be solved mainly due to the difficulties in fabricating small QDs at nanometer scale in term of both high quality and uniformity.

Since the emission wavelengths for the conventionally -grown InAs QDs in GaAs matrix were around 1.15 μm at room temperature, controlling the emission wavelength with narrow photoluminescence (PL) linewidth broadening caused by the QD size fluctuation may be necessary for more extensive applications. Generally, the postgrowth thermal treatment has been recently used to tune the emission wavelength with enhanced optical properties of self-assembled QDs[1-3]. Leon et al. and Malik et al. have reported the effect of post-growth annealing, that is, large blueshift in emission peak position of QDs with narrower PL linewidth. However, the effects of the various annealing procedure on the structural and optical properties of QDs have not been fully discussed yet.

In the present work, self-assembled InAs QDs on GaAs subjected to various annealing treatment were investigated by PL. While the PL spectra of the QD samples undergone by one-step annealing treatment at an annealing temperature in the range from 650 to 750 ^{o}C showed the blue-shift with the degradation of PL intensity, the PL intensity of the QD samples annealed by using two- and three-step annealing process during increasing annealing temperature showed significantly higher PL intensity with narrower PL linewidth compared to that of as-grown QDs.

2. Experimental Details

The samples used in the present work were grown by a molecular beam epitaxy with solid sources on semi-insulating (001) GaAs substrate. Before depositing the InAs QDs, the substrate temperature for the growth of 500 nm GaAs buffer was set to 580 ^{o}C and, then, the substrate temperature was lowered to about 460 ^{o}C for the growth of the InAs QD layer. InAs QDs with 2.5 monolayer (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 50 nm GaAs capping layer was grown after the deposition of an InAs QD layer followed by 30 seconds growth interruption time under arsenic-rich condition.

In PL measurement, the He-Ne laser with a wavelength of 632.8 nm was used, as an excitation source to generate electron-hole pairs. The PL signal was dispersed by 1 m monochromator and detected with a PMT.

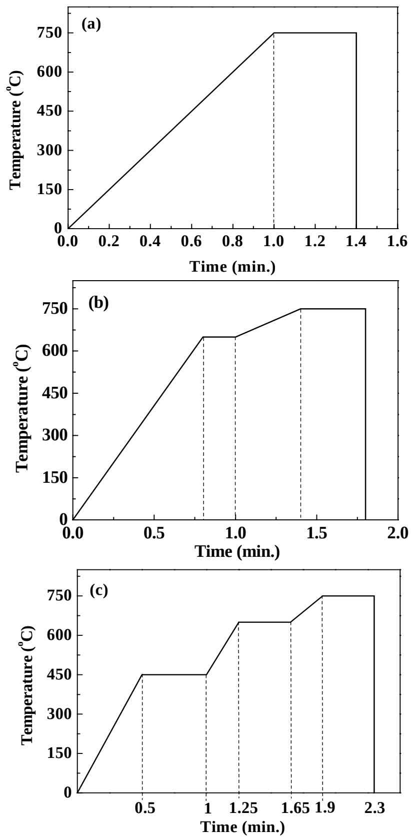

FIG. 1 Rapid thermal annealing process with (a) one-step, (b) two-step, and (c) three-step procedure during increasing annealing temperature.

Rapid thermal annealing (RTA) treatment on the QD samples was performed in nitrogen ambient at an annealing temperature in the range of 300 to 750 ^{o}C, using one-, two-, three-step procedure during increasing the annealing temperature. The schematic illustration for the different annealing step is shown in Fig. 1. The samples were capped by semi-insulating GaAs wafer in order to reduce the arsenic desorption from the sample surface during annealing treatment.

3. Results and discussion

Figure 2 shows the PL spectra of QD samples subjected to one-step annealing treatment measured at 14 K. The emission peak position is blue-shifted with increasing the annealing temperature due to the change in the structural properties of a QD such as the composition and shape, thus changing the optical properties. The change in the QD properties can be largely attributed to the interdiffusion at the interface between a QD and GaAs barrier. For the PL spectrum obtained from the QD sample annealed at 750 ^{o}C for 30 seconds, the emission linewidth broadening is 44 meV, while the PL for the QD samples annealed at 650, and 700 ^{o}C have the linewidth broadening of 78 and 71 meV, respectively.

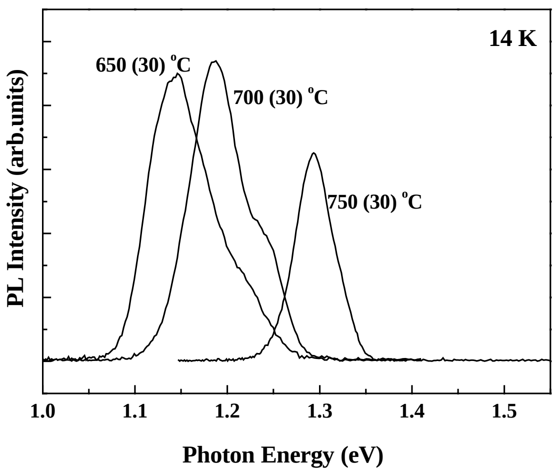

FIG. 2 Low temperature PL spectra of QD samples subjected to one-step annealing treatment. The notation for annealing temperature in this figure, for example, 650 (30) ^{o}C indicates that the QD sample was annealed at 650 ^{o}C for 30 seconds.

Figure 3 shows the PL spectra of the QD samples, in which two- and three-step procedure during increasing the annealing temperature were used for RTA treatment. The PL peak position for QD samples is strongly dependent on the final annealing temperature similar to the one-step annealing treatment as shown in Fig. 2, however, the PL intensity is drastically increased more than 10 times larger than that of as-grown sample. Also, the PL linewidth of the QD samples using the multiple annealing process become significantly narrower than the as-grown sample. For PL obtained from QD sample successively annealed at 650 and 750 ^{o}C, the PL linewidth is 34 meV, which is more than 1.5 times smaller than the as-grown sample.

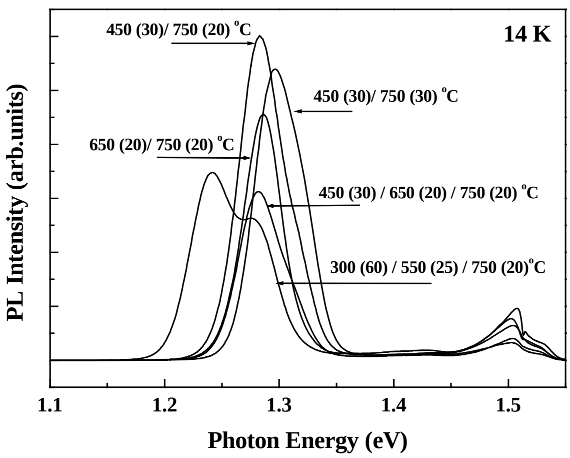

FIG. 3 Low temperature PL spectra of QD samples subjected to two- and three-step annealing treatment.

4. Conclusions

Optical properties of self-assembled InAs QDs such as the emission peak position, PL intensity, and linewidth broadening were controlled by using various annealing process. The PL of the QD samples annealed at multi-step annealing treatment showed the enhanced PL intensity with relatively narrower PL linewidth compared to those of as-grown sample and those of QD sample subjected to one-step annealing treatment. These results indicate that the structural and optical properties can be systematically manipulated by various annealing process.

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