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Research Paper

Influence of growth Temperature on the Formation of 10 monolayer-thick InGaAs Quantum dots formed with 5 repetitions of 1 monolayer-thick InAs and 1 monolayer-thick GaAs

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Abstract Effect of growth temperature (T_g) on the structural and optical properties of $In_{0.5}Ga_{0.5}As$ atomic layer epitaxial (ALE) quantum dots (QDs) is investigated in the range of T_g=480-510°C. $In_{0.5}Ga_{0.5}As$ ALE QDs consist of 5 periods of short-period superlattices (SPSs) of 1 monolayer-thick InAs and GaAs. Number of coalescent QDs decreases as T_g increases, and they disappear at T_g=510°C. As T_g increases in the range of 480-495°C, sizes of QDs increase, and densities of QDs decrease due to merge of QDs. On the contrary, although sizes of QDs are maintained at T_g=495-510°C, densities of QDs decrease. This is attributed to the desorption of material-mainly indium-during the growth interruption. This conjecture is supported by the optical properties of the QDs as a function of T_g. As a result, we propose that optimum growth temperature of the QD is 495°C with less repetition of SPSs than 5.

Keyword: Short period superlattices, InGaAs, Quantum dots, PL, AFM

I. Introduction

Self assembled semiconductor quantum dots (QDs) have attracted much attention due to introduction of new physical phenomena and, as a result, improvement of performance in optoelectronic devices such as low threshold current density, high characteristic temperature, and so on. Therefore, many researchers have focused on this topic and developed QD laser diodes (LDs) operated at room temperature [1-4]. We studied $In_{0.5}Ga_{0.5}As$ QDs in GaAs matrix grown by InAs and GaAs short period superlattices (SPSs) as a function of repetition number [5], and found that this technology, so called atomic layer epitaxy, is ideal to make uniform and wetting-layer-free QDs. In this work, we will discuss influence of growth temperature (T_g) on the formation of 10 monolayer-thick $In_{0.5}Ga_{0.5}As$ QDs formed with 5 repetitions of 1 monolayer-thick InAs and 1 monolayer-thick GaAs. As a result we will find that the QD size and the PL-peak wavelength from the QDs are strongly dependent on the growth temperature (T_g), and optimal growth condition for the InGaAs QDs.

II. Experimental Procedure

Figure 1 shows a schematic illustration of a growth structure.

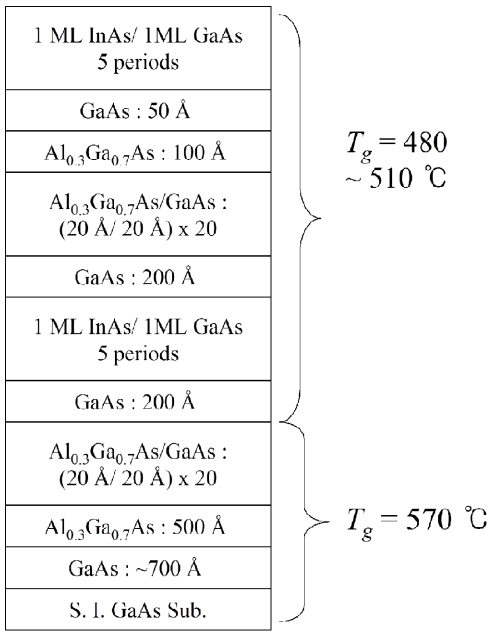

Figure 1. The schematic illustration of a growth structure.

The $In_{0.5}Ga_{0.5}As$ QDs were placed both in the middle of a GaAs matrix and on top of a GaAs layer for optical and structural measurements, respectively. The 10 monolayer-thick $In_{0.5}Ga_{0.5}As$ quantum dots QDs were formed with 5 repetitions of 1 monolayer-thick InAs and 1 monolayer-thick GaAs. During growth of each layer, there is 5 s-long growth interruption. Effect of growth temperature (T_g) on the structural and optical properties of the $In_{0.5}Ga_{0.5}As$ QDs is

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investigated in the range of T_g=480-510°C. Details of growth such as sequence of InAs and GaAs SPS deposition were well described in elsewhere [5]. The information related to densities, heights and widths of the QDs on top of the samples was investigated with atomic force microscopy (AFM). Optical properties of the grown samples were evaluated by photoluminescence (PL) measurements at room-temperature and 10 K. An Ar-ion laser with a wavelength of 514.5 nm was used as an excitation source at the excitation power of 25 mW. A liquid nitrogen cooled InGaAs detector was employed to detect luminescent lights.

III. Results and Discussion

Dependence of structural properties of the $In_{0.5}Ga_{0.5}As$ QDs in GaAs matrix on T_g measured by AFM is illustrated in Fig. 2. Coalescence of QDs is found in the 480 and 495°C-gown sample. Number of the coalescent QDs decreases as T_g increases, and they disappear at T_g=510°C (see Fig. 2). Strong alignment of the QDs along [1-10] occurs in the QDs grown at T_g=510°C. As T_g increases in the range of T_g=480-495°C, sizes of the QDs increase, and densities of QDs decrease due to merge of the QDs (see Fig. 3). On the contrary, although sizes of the QDs are maintained at T_g=495-510°C, densities of the QDs decrease. This is attributed to the desorption of material-mainly indium-during growth interruption. This conjecture is supported by the optical properties of QDs as a function of T_g. As shown in Fig. 4, PL-peak wavelength is red-shifted due to size-effect at T_g=480-495°C. However, it is blue-shifted at T_g=495-510°C. Considering size of QDs grown at T_g=495-510°C is similar, blue-shift in PL peak wavelength is attributed to material desorption-mainly indium. 480°C-grown QDs do not show 300 K-PL due to large number of coalescence QDs, and line-width of QDs

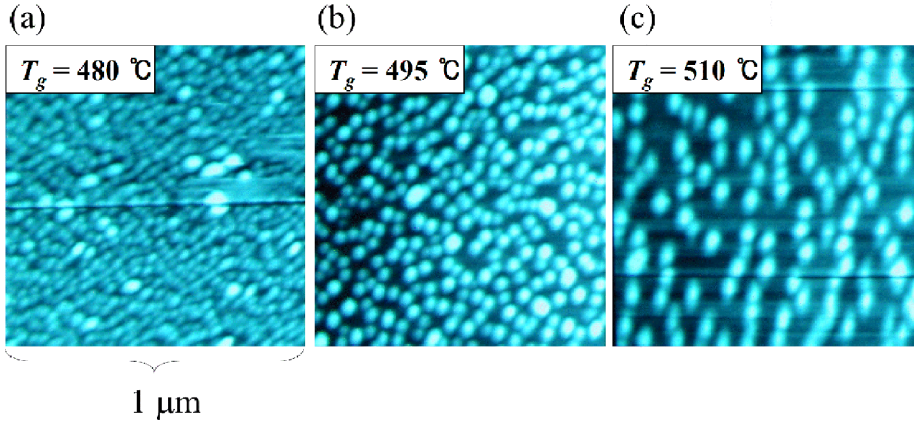

Figure 2. 1 μm×1 μm area AFM images of $In_{0.5}Ga_{0.5}As$ ALE QDs on top of the structure in the growth temperature (T_g) range of (a) 480, (b) 495, and (c) 510°C.

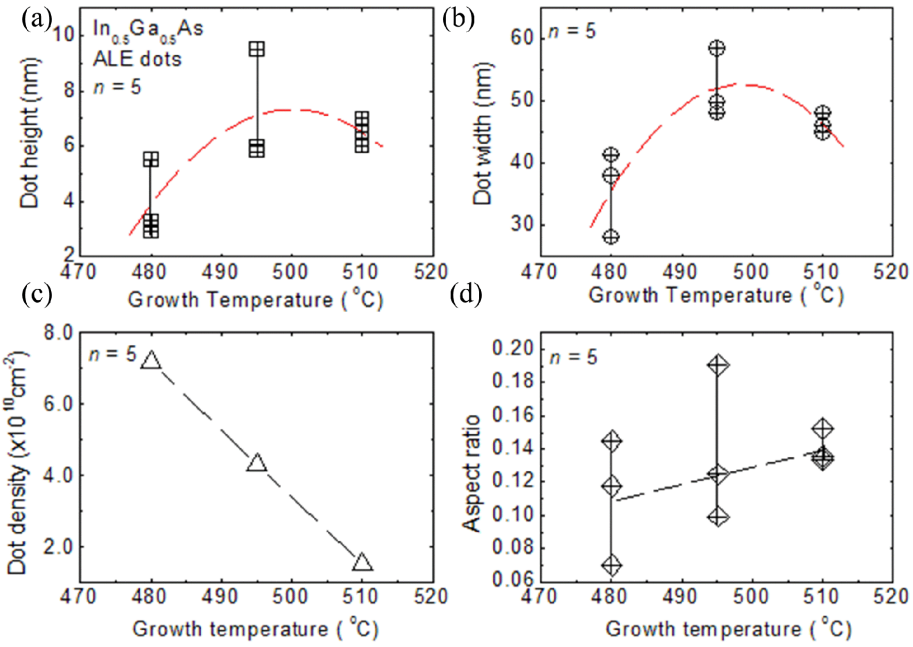

Figure 3. (a) Measured dot heights, (b) dot widths, (c) dot densities, and (d) aspect ratios of the $In_{0.5}Ga_{0.5}As$ ALE QDs in the growth temperature (T_g) range of 480, 495, and 510°C.

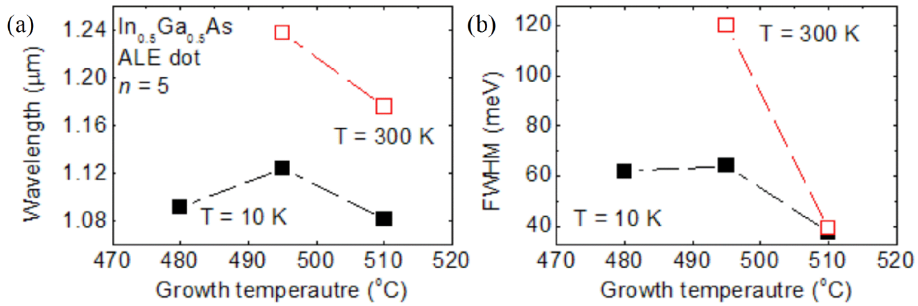

Figure 4. (a) 10 K- and 300 K-PL peak wavelengths (b) and PL linewidths of the $In_{0.5}Ga_{0.5}As$ ALE QDs in the growth temperature (T_g) range of 480, 495, and 510°C. A 300 K-PL spectrum for the 480°C-grown sample is not measured due to low signal intensity from it.

are broadened due to larger size distribution caused by merging of the QDs in the range of at T_g=480-495°C.

Considering all the 510°C-grown InGaAs QDs have strong alignment [1-10] and rather elliptical shapes for all repetitions of InAs and GaAs SPSs [5], we can consider relation between alignment of the QDs and indium desorption, because no alignment is shown in the QDs and the shapes of the QDs are circular in AFM shape at T_g<510°C. That is, at T_g=510°C, indium atoms move on surface quickly or longer before formation of the QDs and, finally, are partially desorbed on the surface. During this process, movement of gallium atoms is enhanced with the help of quickly moving indium atoms; as a result, gallium atoms have a chance to be located preferable direction of [1-1 0]. It is noteworthy that direction of oval defect over (0 0 1) surface is [1-10] [6].

If we consider these QDs as an active medium for the optical devices, we should avoid desorption process, because we cannot hope good reproducibility with this hardly-controllable process. Therefore, 495°C is the optimum growth temperature of the $In_{0.5}Ga_{0.5}As$ ALE QDs, and less repetition is necessary to remove coalescent QDs.

IV. Conclusions

We reported dependence of the structural and optical properties of the 10 monolayer-thick $In_{0.5}Ga_{0.5}As$ QDs formed with 5 repetitions of 1 monolayer-thick InAs and 1 monolayer-thick GaAs on growth temperature (T_g) in the range of T_g=480-510°C. Coalescent QDs disappear at T_g= 510°C, and blue-shift in PL peak of 510°C-grown QDs is attributed to desorption of indium during growth interruption. As a result, we propose that optimum growth temperature of the QD is 495°C with less repetition of SPS than 5.

Acknowledgments

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