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Lattice Deformation and Ga Diffusion Concerning InAs Self-Assembled Quantum Dots on GaAs(100) as a Function of Growth Interruption Time

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1. Introduction

InAs self-assembled quantum dots (SAQDs) have been challenged to be used for potential optoelectronic devices. For device fabrication reproducibility, growth process of InAs SAQDs is of vital importance. In our previous report [1], an accurate value of InAs coverage was determined and diffusion of Ga atoms into InAs QDs was observed by using Rutherford backscattering. Moreover, our study [2] revealed that the amount of diffused Ga for samples by 60 s growth interruption strongly depended on the InAs coverage. For QDs by InAs coverages less than 1.7 monolayer (ML), the diffusion was hardly observed. On the other hand, the diffusion was clearly observed when InAs coverage was 1.7 ML or larger. However, it remains an unsettled question whether Ga diffusion occurred during InAs layer deposition or during growth interruption of 60 s. The influence of the diffusion on the lattice deformation is important to describe a conclusive picture of the self-assembled growth process. In this article, we investigated the crystallographic structure of InAs QDs by 1.8ML coverage on the growth interruption time, $\tau_{interrupt}$, to 180 s.

2. Experiments

All samples contained a single InAs layer, and were grown by molecular-beam epitaxy (MBE). A 400nm-thick GaAs with the growth rate of 800nm/h, a 100nm-thick $Al_{0.3}Ga_{0.7}As$, and 44nm-thick GaAs were first deposited at 620℃. Subsequently, 1.8 ML of InAs was grown at 510℃. After the growth of InAs layer, growth was interrupted from 0 to 180 s. InAs coverage was estimated by the growth rate of the order of 0.1 ML/s. After the growth interruption, 20nm-thick GaAs layer was grown at 510 ℃. After increasing growth temperature to 600℃, 80nm-thick GaAs, 100nm-thick $Al_{0.3}Ga_{0.7}As$, and 50nm-thick GaAs were grown.

In order to characterize the crystallographic structure, we performed ion channeling observed by particle induced x-ray emission (PIXE).

The channeling experiments were carried out by 1.00 MeV H^+ ions for $\tau_{interrupt}$ of 0, 15, 30 and 60 s and by 2.28 MeV He^+ ions for $\tau_{interrupt}$ of 60, 90 and 180 s.

In order to evaluate lattice deformation, we introduced the normalized minimum yield, χ_{min}, which is defined as a ratio of aligned yields to random yields. In general, the larger χ_{min} suggests the higher lattice deformation which was defined as a lateral displacement from a GaAs host lattice.

3. Results

Figure 1 shows χ_{min}'s (In, Ga) and photoluminescence (PL) peak wavelength as a function of the growth interruption time (0 to 60 s). From Fig.1, two different mechanisms of Ga diffusion into QDs were suggested because Ga deformation resulted from the Ga diffusion to form InGaAs dots [2]. In order to investigate the Ga diffusion beyond 60 s, we performed PIXE/channeling experiments for the samples having $\tau_{interrupt}$ of 60 to 180 s. Figure 2 shows the χ_{min}'s and PL peak wavelength as a function of the growth interruption time (60 to 180 s). From Figs.1 and 2, lattice deformation of In increased with $\tau_{interrupt}$ from 0 to 90 s. In particular, the deformation drastically increased from 0 to 15 s. Also, a strong correlation between the deformation and PL redshift was found. This suggests that the size of the dots increased during the growth interruption. Deformation of Ga decreased when $\tau_{interrupt}$ was changed from 0 (non-interruption) to 30 s, and increased from 30 to 90 s. Beyond 90 s, deformation of Ga kept constant, and deformation of In didn't change significantly.

4. Discussion

If the diffusion occurred before or during growth interruption, the diffusion cannot decrease with increased $\tau_{interrupt}$. Therefore, we attributed the decrease from 0 to 30 s to the Ga diffusion after the growth interruption. Previously, in the coverage-dependence of Ga diffusion [2], we observed that the Ga diffusion was suppressed for larger dots probably because lattice constant of upper part of InAs

QDs becomes closer to that of bulk InAs. The decreased Ga diffusion from 0 to 30 s can be attributed to this size dependence.

The diffusion from 30 to 90 s, slightly increased and thus is considered to have occurred during the growth interruption. Although the size of the QDs was not fully saturated from 30 to 90 s, Ga diffusion increased during this period. The size effect was supposed to be not so large as that for 0-30 s.

Beyond 90 s, the Ga deformation and time evolution of the redshift reached saturation. Thus, the Ga diffusion and also the size of InAs QDs got fully saturated.

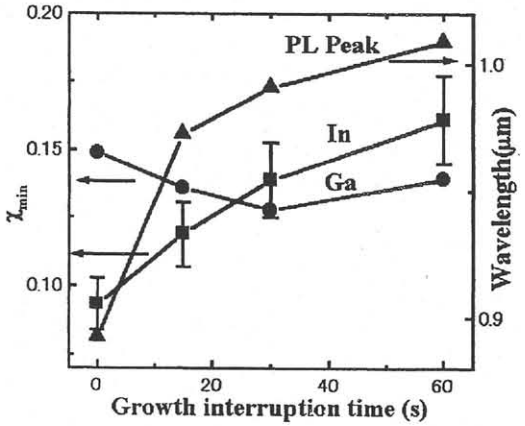

Fig. 1. The lattice deformation (χ_{min}'s) and PL peak as a function of the growth interruption time (0 to 60 s)

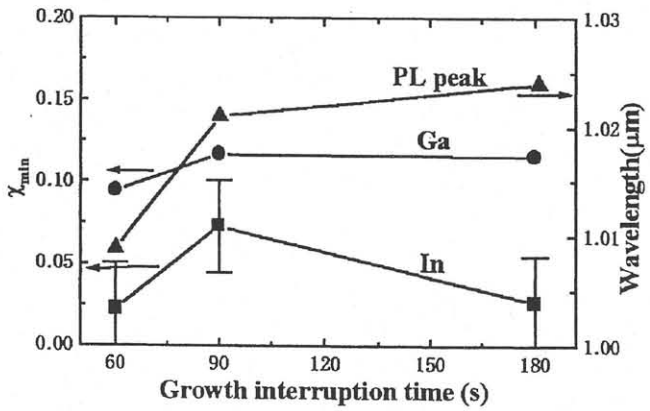

Fig. 2. The lattice deformation (χ_{min}'s) and PL peak as a function of the growth interruption time (60 to 180 s)

5. Summary

In summary, we investigated the Ga diffusion into InAs SAQDs as a function of the growth interruption time (0 to 180 s) by using PIXE/ion channeling. A strong correlation between the deformation of In and redshft of PL peak was found. This indicates size of dots increased during growth interruption. The deformation of Ga of the sample was reduced when growth interruption time was changed from 0 to 30 s, and increased from 30 to 90 s, and reached saturation at about 90 s, which is explained by the Ga diffusion into QDs. From these results, two modes of Ga diffusion into InAs SAQDs were identified. The Ga diffusion from 0 to 30 s was concluded to have occurred after the growth interruption, and was interpreted as the size dependent diffusion. The Ga diffusion from 30 to 90 s was explained as time-enhanced diffusion. No further Ga diffusion was observed beyond 90 s.

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