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# Influence of capping layer on the properties of MOVPE-grown InAs/GaAs quantum dots

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ABSTRACT

During the capping process of InAs/GaAs quantum dots (QDs), the redistribution of In atoms decreases the height of QDs and changes their shape. These changes can be influenced not only by the composition of the covering strain reducing layer but also by the growth parameters of layers covering QDs. We have studied the effect of GaAs capping layer growth rate on the QD properties. It was found that a higher GaAs capping layer growth rate enhances the surfactant behavior of In atoms and diminishes the alloying effect in QD surrounding material. Higher capping layer growth rate can also decrease the dissolution of In atoms from QDs. The capping layer growth rate has stronger effect on the ground state photoluminescence (PL) maximum energy, when InGaAs strain reducing layer is not present in the structure.



## 1. Introduction

Growth conditions of InAs/GaAs quantum dot (QD) layers determine such parameters as density, homogeneity and original size of QDs. However, during the capping process, the redistribution of In atoms takes place and the strain field surrounding QDs is also changed. The changes in the size and shape of QDs induced by their overgrowth influence the QD photoluminescence (PL) properties. The strain field can be influenced by the composition and the thickness of the covering layers grown above QDs. The redistribution of In atoms, which decreases the height of QDs and changes their shape, can be influenced by the composition of the overgrowing layers and also by their growth parameters like thickness, growth temperature and growth rate.

Processes which take place during overgrowth of QDs by GaAs layer, InGaAs strain reducing layer (SRL), and combination of InGaAs SRL and GaAs layer are described in Refs. [1–3]. In this work, we study the influence of GaAs capping layer growth rate on the properties of QDs. Properties of QDs overgrown by InGaAs SRL and without SRL are compared.

## 2. Experimental procedure

QD structures were prepared by LP MOVPE in AIXTRON 200 with non-rotating susceptor on SI (1 0 0) GaAs substrates using Stranski–Krastanow growth mode. InAs, GaAs and $In_{0.23}Ga_{0.77}As$ layers were grown at 490 °C using TMIn, TMGa and $AsH_3$ as precursors. The amount of deposited InAs is estimated to be 2.1 ML. InAs was grown using V/III ratio about 150. The growth interruption after the InAs layer deposition needed for QD formation was 15 s. GaAs capping layer was grown on top of all structures, and waiting time between SRL and this cap was 10 s. Details are described in Ref. [1].

Reflectance anisotropy spectroscopy (RAS) in-situ measurement using EpiRAS 200 TT (LayTec) monitors the formation and development of InAs QDs, as well as InGaAs and GaAs growth [4]. PL of QDs was excited by semiconductor laser (670 nm) with 10 W cm$^{-2}$ excitation power density. PL was detected by a Ge detector using standard lock-in technique. All PL measurements were performed at room temperature. Atomic force microscopy (AFM) images were obtained by Veeco Dimension 3100 equipment operated in tapping mode with simultaneous detection of the phase signal. The tip radius was ~10 nm.

We have grown two groups of samples (see Table 1). Group 1 consists of three samples with the same structure: InAs/GaAs QDs

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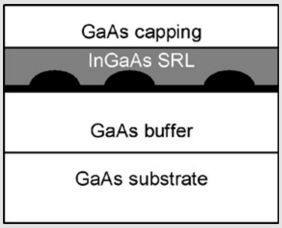
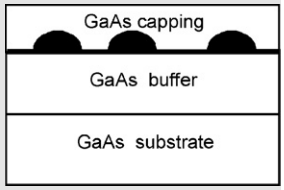
**Table 1**
Two different groups of QD samples with and without InGaAs SRL prepared at different GaAs capping layer growth rate

| GaAs capping layer growth rate ($ML\,s^{-1}$) | Group 1 | Group 2 |
|---|---|---|
| |   |   |
| 0.21 | A1 | A2 |
| 0.64 | B1 | B2 |
| 1.9 | C1 | C2 |

covered by 5 nm $In_{0.23}Ga_{0.77}As$ SRL and followed by 7.5 nm GaAs capping layer. Samples A1, B1 and C1 differ from each other only by the GaAs capping layer growth rate as can be found in Table 1. Group 2 sample structure is similar to Group 1, but the InGaAs SRL is missing here.

## 3. Results and discussion

The PL spectra measured at excitation density $10\,W\,cm^{-2}$ have typically two main peaks, which belong to the ground state and the first excited state PL transitions (Fig. 1). The fine structure of PL spectra at about 0.9 eV is caused by the water vapor absorption. For the samples in Group 1, the PL maximum red shift of 60 meV was achieved only by increasing the growth rate (from 0.21 to $1.9\,ML\,s^{-1}$) of the GaAs capping layer on the top of the structure (Fig. 1a). The smaller distance between two lowest PL maxima for sample with lower GaAs capping growth rate suggests that the aspect ratio (height to lateral dimension ratio) of QDs is lower or the QD base is more elongated [5]. The growth rate of GaAs capping layer probably affects the final shape of QDs.

AFM images of samples A1, B1 and C1 from Group 1 capped by GaAs capping layer prepared with different growth rates are compared in Fig. 2. The covered boat-like-shape QDs with a height up to 3 nm and big objects (not QDs) with holes in the middle can be recognized in all images. The elongated smaller islands are believed to be formed by InGaAs around QDs during the covering process of QDs in accordance with Refs. [2,3,6].

Two processes are responsible for the formation of elongated islands during QD overgrowth: first, dissolution of In atoms from the top of QDs and second, incorporation of these In atoms into the capping layer. Dissolution of QDs predominantly diminishes the height of QDs and so causes the blue shift of QD PL maxima. The incorporation of In atoms into the capping layer takes place predominantly in the vicinity of QDs. The strain field drives this process and boat-like-shape InGaAs islands are formed around InAs QDs. Their elongation into $[\bar{1}10]$ direction is caused by anisotropical lateral growth rate. These islands increase the effective size of QDs and decrease the potential barrier and strain in QDs. These effects cause the red shift of ground state PL maximum. The alloying of InAs and GaAs in these islands with their elongation also decrease the energy separation of the ground state and the first excited state PL transitions.

Both processes depend on the growth rate of the GaAs capping layer. The height of capped QDs measured on Group 1 samples is shown in Fig. 3. This measurement confirms that increasing GaAs capping growth rate decreases dissolution of In atoms from QDs and in consequence causes increase of the final QD heights.

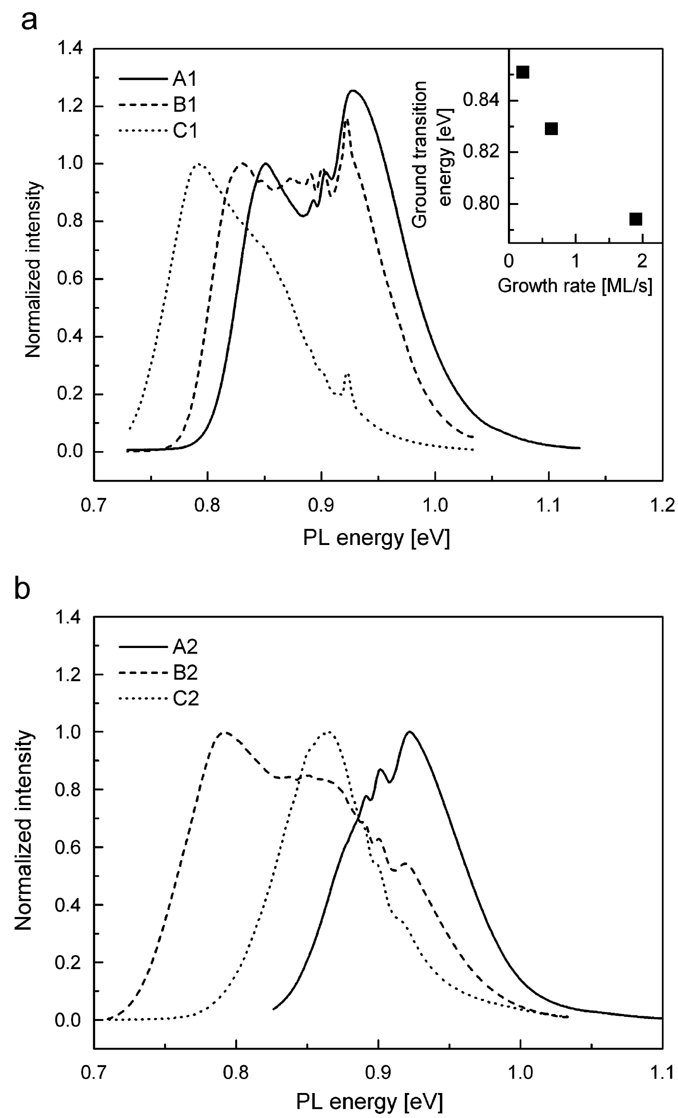



**Fig. 1.** Normalized (with respect to the lowest energy PL transition) PL spectra of QD structures with different growth rate of GaAs capping layer: (a) Group 1, with SRL-A1, B1 and C1, in the inset the dependence of the QD ground transition energy on the growth rate is shown and (b) Group 2 samples without SRL A2, B2 and C2.

Information about the In incorporation process can be obtained from in-situ RAS measurement during and after the growth of GaAs capping layer. Time-resolved RAS measurements at 4.2 eV were used for monitoring of QD growth since the RAS signal at this energy was found to be most sensitive to QD formation process [7]. RAS measurements taken during the growth of Group 1 samples A1, B1 and C1 are compared in Fig. 4a. It can be noticed that during the growth of the capping layer the RAS signal at 4.2 eV is higher for samples with higher growth rates and it stays at these values even when the epitaxial growth is finished. This can be a sign of surfactant behavior of In atoms on epitaxial surface. To prove this hypothesis, the whole reflectance anisotropy spectra of the Group 1 samples were taken after the growth from their surface at their growth condition: temperature and $AsH_3$ partial pressure (Fig. 5a).

The difference in the surface reconstructions is evident. The surface of the sample A1 (with the lowest GaAs growth rate) has dominantly the GaAs $c(4\times4)$ reconstruction with only negligible feature at 2.6 eV—a sign of low concentration of In atoms present on the sample surface. Surprisingly, the surface reconstruction of