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Effect of GaAs(1 0 0) 2° surface misorientation on the formation and optical properties of MOCVD grown InAs quantum dots

S. Liang [a,*], H.L. Zhu [a], X.L. Ye [b], W. Wang [a]

[a] National Research Center of Optoelectronic Technology, Institute of Semiconductors, The Chinese Academy of Science, Beijing 100083, PR China
[b] Key Laboratory of Semiconductor Materials Science, Institute of Semiconductors, The Chinese Academy of Science, Beijing 100083, PR China

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Abstract

The influence of GaAs(1 0 0) 2° substrate misorientation on the formation and optical properties of InAs quantum dots (QDs) has been studied in compare with dots on exact GaAs(1 0 0) substrates. It is shown that, while QDs on exact substrates have only one dominant size, dots on misoriented substrates are formed in lines with a clear bimodal size distribution. Room temperature photoluminescence measurements show that QDs on misoriented substrates have narrower FWHM, longer emission wavelength and much larger PL intensity relative to those of dots on exact substrates. However, our rapid thermal annealing (RTA) experiments indicate that annealing shows a stronger effect on dots with misoriented substrates by greatly accelerating the degradation of material quality.

Keywords: Photoluminescence; Quantum dots; Indium arsenide

1. Introduction

There has been considerable interest in the fabrication of S-K mode InAs/GaAs quantum dots (QDs) due to their δ-like density of states and the possibility of extending their emission beyond 1.3 μm [1,2]. Impressive properties of QD devices have been demonstrated, such as low threshold current [3], low chirp [4] and high characteristic temperature [5]. To fully utilize their superior electronic and optical properties, spatial ordering of QDs is desired. A certain degree of lateral order of InAs QDs can be achieved by using GaAs(1 0 0) misoriented substrates [6,7]. In such case, the self-aligned QDs are formed along the multiatomic step edges on GaAs(1 0 0) misoriented surface. By now, a few works about the optical properties of QDs on misoriented substrates have been reported. It is shown that the misorientation of the substrates led to a decrease of the FWHM of PL lines and a blueshift of the emission wavelength [8].

InAs/GaAs QDs are usually gown at relatively low temperature. However, it is essential that the temperature be increased to obtain high-quality cladding layer and cap layer for device use. Therefore, many studies have been concentrated on the effect of high temperature annealing on QDs [9–13]. It has been shown that thermal annealing can lead to a strong narrowing of photoluminescence (PL) linewidth, a large blueshift in the intersubband transition energy, and a great reduction in intersublevel spacing energies, which are generally attributed to the In–Ga interdiffusion between InAs QDs and the GaAs matrix. In spite of the many works about the annealing effect on QDs, no such research focused on dots grown on a misoriented substrate has been reported.

In this work, we discuss the effect of 2° substrate misorientation on the formation and optical properties of InAs QDs. On misoriented substrates, the QDs are found to be formed in lines with a clear bimodal size distribution. Room temperature photoluminescence (PL) measurements show that, besides a narrower FWHM, QDs on misoriented substrates also have a longer emission wavelength and a much larger PL intensity compared with those of dots on exact substrates, which is favored for device use. However, our rapid thermal annealing (RTA) experiments indicate that, compared with dots

* Corresponding author.
E-mail address: liangsong@red.semi.ac.cn (S. Liang).

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on exact substrates, annealing shows a stronger effect on dots with misoriented substrates by greatly accelerating the degradation of material quality.

2. Experimental procedure

All samples are grown via a horizontal low-pressure MOCVD reactor (AIXTRON-200) at a total pressure of 60 mbar, with Pd-diffused H_2 as carrier gas. Trimethylgallium (TMGa), trimethylindium (TMIn), arsine (AsH3) are used as source materials. The substrates used are HB grown n-GaAs with a Si dope concentration of $1.7 \times 10^{18}\,cm^{-3}$. For comparison, we prepared two sets of samples with difference in only their substrates which are (1 0 0) exact and (1 0 0) 2° misoriented to (1 1 0) substrates, respectively.

Prior to the growth, the substrates, which are loaded simultaneously side by side, are preannealed at 700 °C for 3 min in arsine flow for deoxidation. Then a 200 nm GaAs buffer layer is grown at 600 °C with a growth rate of 1 ML/s and V–III ratio of 25. Under this growth condition, a step flow growth mode is found for the buffer layer on the exact substrate and multiatomic steps are formed on the misoriented substrate. The detail step-bunching mechanism has already been reported [14]. The QDs are formed by depositing at 507 °C with a nominal InAs layer thickness of 1.7 ML/s. The growth rate and V–III ratio is 0.032 ML/s and 5, respectively. After a growth interruption (GI) of 20 s under arsine flow, a 30 nm GaAs cap layer is started with a growth rate of 0.3 ML/s and V–III ratio of 25.

The SEM measurements were performed using a XL30-FEG microscope at 20 kV. A Nanoscope Dimension 3100 SPM system with a tapping mode in air was used for AFM measurements. Under the cover of 100 nm SiO_2, the QDs samples with cap layer are subjected to RTA in nitrogen ambient at temperatures ranging from 650 to 800 °C for 40 s. Before PL measurement, the SiO_2 films are removed using HF solution. The PL measurements are carried out in closed-cycle He cryostat under the excitation of 514.5 nm line of Ar^+ laser focused onto a 0.5 mm^2 spot. The luminescence spectra are detected with a Fourier transform infrared spectrometer operating with an InGaAs photo detector.

3. Results and discussion

Fig. 1a and c show the SEM images of surface InAs QDs grown on misoriented GaAs(1 0 0) and exact GaAs(1 0 0), with the corresponding size histogram shown in Fig. 1b and d, respectively. As can be seen from Fig. 1, while dots on exact substrate show only one dominant size, QDs on misoriented GaAs are formed in lines and show a clear bimodal size distribution with two groups of large and small dots. The density of the large and small QDs are 0.91×10^{10} and $4.05 \times 10\,cm^{-2}$, respectively, with a total of $4.96 \times 10^{10}\,cm^{-2}$, greater than that of dots on exact substrate, which is $1.21 \times 10^{10}\,cm^{-2}$. The formation of dots in lines is due to QDs preferably nucleate along the multiatomic step edges on misoriented substrate [6], as shown clearly in the inset of Fig. 1a. The higher QD density is resulted from smaller critical nuclei for stable island growth when dots nucleate on the steps [7]. The bimodal size distribution of QDs on misoriented surface can be related to the reduced surface diffusion during MOCVD growth. The small QDs are not in thermal equilibrium and will subsequently develop into the energetically favorable large QDs. However, on the misoriented substrates, migration of adatoms on the surface is prohibited due

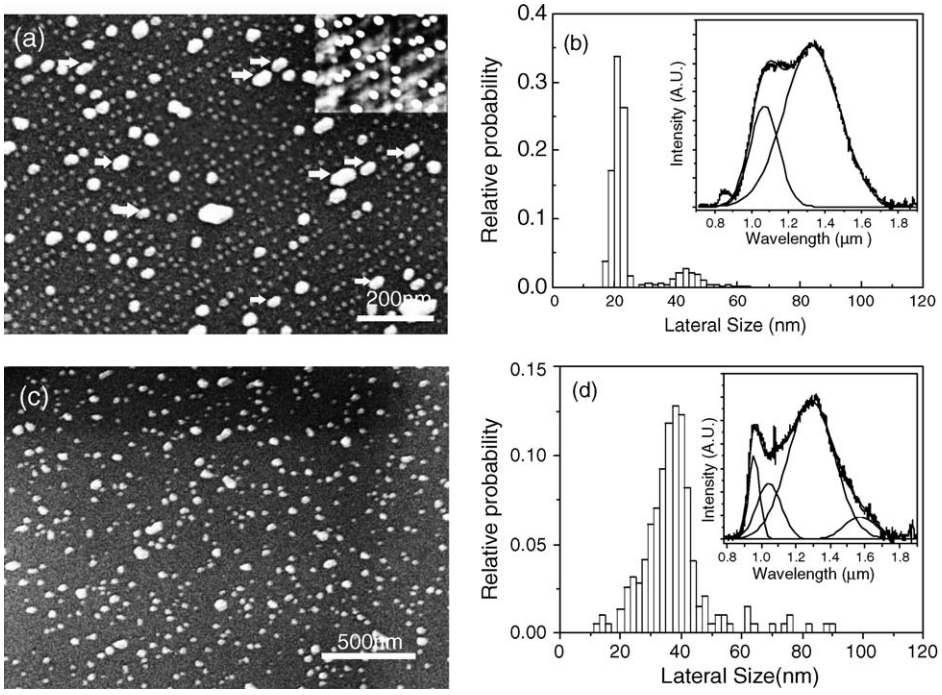

Fig. 1. SEM image of QDs on misoriented GaAs(1 0 0) (a) and exact GaAs(1 0 0) (c), with corresponding size histogram shown in (b) and (d), respectively. Inset of (b) and (d) show the 77K PL spectra of surface dots on corresponding substrates. Inset of (a) shows a 300 nm × 250 nm AFM image.