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Growth of InAs quantum dots on vicinal GaAs (1 0 0) substrates by metalorganic chemical vapor deposition and their optical properties

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Abstract

The growth of InAs quantum dots on vicinal GaAs (1 0 0) substrates was systematically studied using low-pressure metalorganic chemical vapor deposition (MOCVD). The dots showed a clear bimodal size distribution on vicinal substrates. The way of evolution of this bimodal size distribution was studied as a function of growth temperature, InAs layer thickness and InAs deposition rate. The optical properties of dots grown on vicinal substrates were also studied by photoluminescence (PL). It was found that, compared with dots on exact substrates, dots on vicinal substrates had better optical properties such as a narrower PL line width, a longer emission wavelength, and a larger PL intensity.

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1. Introduction

Self-assembled quantum dots (QDs) are promising to improve the performance of laser devices due to their δ-like density of states [1]. There have been considerable interests in the fabrication of self-assembled InAs/GaAs QDs due to their potential of extending emission wavelength of GaAs-based devices to the important optical-fiber communication wavelengths of 1.3 and 1.55 μm [2–4]. While InAs/GaAs QD lasers grown by molecular beam expitaxy (MBE) have been shown to possess impressive characteristics such as low threshold current [5] and high characteristic temperature [6], QDs grown by metalorganic chemical vapor deposition (MOCVD) progress slowly. Though QD devices grown by MOCVD have practical advantages in terms of high growth rate in volume production and application to distributed feed back lasers, only a few long-wavelength lasers have been demonstrated so far. It is relatively difficult to obtain long-wavelength MOCVD grown QDs with good material quality due to the defects formed with increasing strain and the complicated surface environment [4].

It has been shown that, by using vicinal substrates, lines of QDs were formed [3] with certain degree of space ordering, which is desired for fully utilizing QD's superior properties. In such a case, the self-aligned QDs are formed along the multiatomic step edges on GaAs (1 0 0) vicinal surface. Studies showed that the misorientation of the substrates led to a decrease of the FWHM of photoluminescence (PL) lines and a blueshift of the emission wavelength [7].

In this paper, we studied the influence of different growth conditions on the formation of InAs QDs on

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vicinal GaAs (1 0 0) substrates using low-pressure MOCVD. Their optical properties were also studied in compare with dots on exact substrates.

2. Experimental details

All the samples were grown on vicinal GaAs (1 0 0) substrates with a Si-dope concentration of $1.7 \times 10^{18}\,cm^{-3}$ (2° tilted toward (1 1 0)) by low-pressure MOCVD, using trimethylgallium (TMGa), trimethylindium (TMIn) and arsine (AsH_3) as source materials. Prior to the growth, the substrates were preannealed at 700 °C for 3 min in arsine flow for deoxidation. Then a 200 nm GaAs buffer layer was grown at 600 °C with a growth rate (G_r) of 1 ML/s and V–III ratio of 25. Under this growth condition, multiatomic steps were formed on the vicinal substrates [8]. The QDs were grown subsequently with InAs coverage varying between 0.9 and 2.4 ML, growth temperature ranging from 500 to 535 °C, and growth rate varying from 0.01 to 0.09 ML/s. After the QD formation, a 20 s growth interruption (GI) was introduced with arsine flow and then the QDs were either cooled down to room temperature (RT) rapidly for morphology study or capped with a final 30 nm GaAs layer for PL study. The growth temperature of the GaAs cap layer was the same with that of the QDs. To extend the emission wavelength of QDs, an $In_{0.15}Ga_{0.85}As$ strain reduce layer (SRL) grown at the same temperature used for QDs was inserted between the QDs and the GaAs cap layer. A Nanoscope Dimension 3100 AFM with a tapping mode in air were used to study of QD morphology and to correlate the evolution of size distribution with growth conditions. The PL measurements were 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 were detected with a Fourier transform infrared spectrometer operating with an InGaAs photodetector.

3. Results and discussion

3.1. Growth and structural studies of QDs

Fig. 1 shows the AFM images of QDs on vicinal GaAs (1 0 0) substrates grown at different temperatures with G_r of 0.034 ML/s, InAs coverage of 1.7 ML, and V–III of 5. Fig 1(a), (b), and (c) correspond to temperatures of 507, 520, and 535 °C, respectively. A typical QD height histogram obtained from Fig. 1(a) is shown in Fig. 1(d). As can be seen from the figures, QDs were formed in lines with a degree of space ordering and exhibited a clear bimodal size distribution with two size groups of large and small dots. The formation of dots in lines is due to QDs

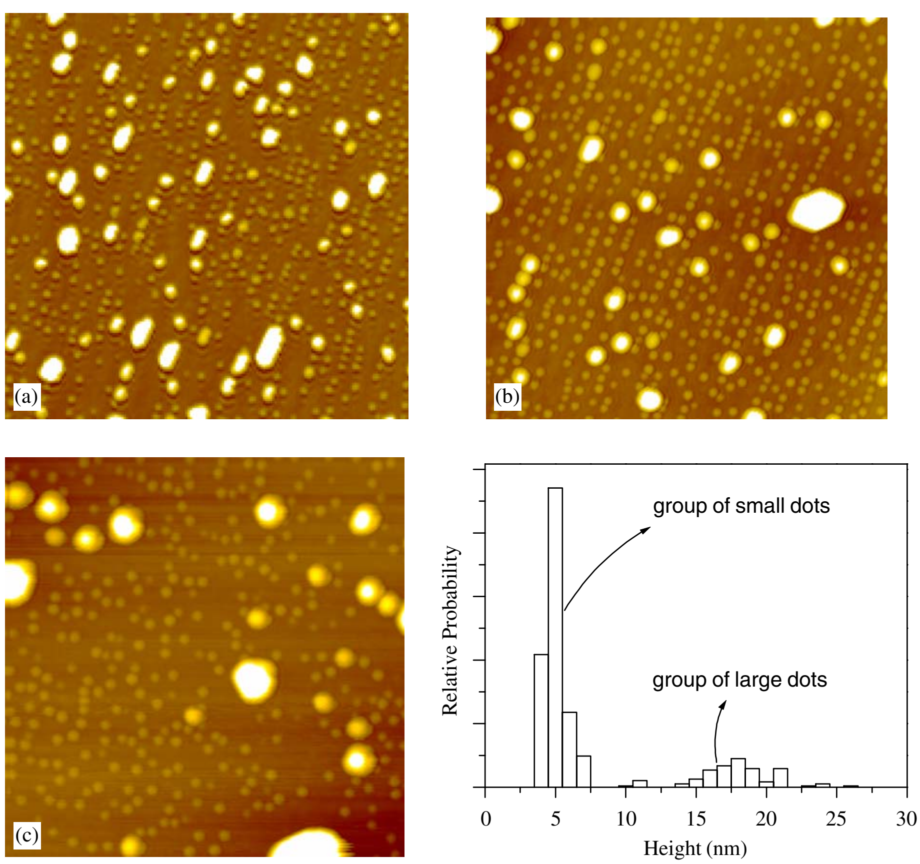

Fig. 1. AFM images showing the effect of growth temperature. (a) $T = 507\,°C$, (b) $T = 520\,°C$, and (c) $T = 535\,°C$. All samples are formed by 1.7 MLs of InAs and $G_r = 0.034$ ML/s and V–III ratio = 5. (d) A typical height histogram obtained from (a). The scan size is 1 μm × 1 μm.