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Self-alignment of self-assembled InAs quantum dots

Sung Ui Hong*, Jin Soo Kim, Jin Hong Lee, Ho-Sang Kwack, Won-Seok Han, Dae Kon Oh

Basic Research Laboratory, Electronics and Telecommunications Research Institute, 161 Gajeong-Dong, Yuseong-Gu, Daejeon, 305-350, Korea

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Abstract

The lateral self-alignment properties of self-assembled InAs quantum dots (QDs) on a conventional GaAs (1 0 0) substrate by molecular beam epitaxy were investigated. The shape and optical properties of QDs were investigated by atomic force microscopy, transmission electron microscope, and photoluminescence (PL). Attempts were made to grow InAs-QDs using the In-interruption growth technique, in which the In flux was periodically interrupted. QDs grown without using the In-interruption growth technique were grown randomly on all regions. On the other hand, in the case of QDs grown using the In-interruption growth technique, QDs were self-aligned at the boundary between bright and dark regions, the PL intensity was increased and the PL peak position of QDs were red-shifted to 1300 nm. This represent a new technique for growing self-aligned QDs because no extra processing such as electron-beam lithography, V-grooves and surface modification by scanning tunneling microscopy is needed, and aligned QDs can be grown in situ on conventional GaAs substrates.

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Keywords: A1. In-interruption; A1. Self-alignment; A3. MBE; A3. Quantum dot; B1. InAs

1. Introduction

Numerous studies have been reported concerning self-assembled semiconductor quantum dots (QDs) grown by Stranski–Krastanove growth mode, since it enabled the development of new device applications such as laser diodes, photodetectors and electronic devices [1–3]. In particular, the ordering of semiconductor QDs offers new functions for QD-based devices that include single-electron transistors or highly parallel computing architectures. The vertical alignment between QDs has been much studied already [4,5], while the lateral alignment of QDs has been much less studied. So far, various attempts have made to achieve the lateral alignment of QDs. Aligned QDs have been prepared using patterned substrates by electron-beam lithography, V-grooves and surface modification using scanning tunneling microscopy [6–11]. When these techniques are used, problems related to interruption in the growth run and the need for additional processing are encountered. Beside on these techniques, it was reported that aligned QDs could be grown in situ on vicinal GaAs substrates [12]. To the best of our knowledge, there were few reports relating to the in situ growth of self-aligned QDs on more conventional GaAs (1 0 0) substrate.

In our investigation, we demonstrate the lateral self-alignment of InAs-QDs on a more conventional GaAs (1 0 0) substrate using the In-interruption growth technique. In addition, the optical properties of the QDs were improved. This technique was used only during the actual growth of the QDs.

2. Experiment

A RIBER MBE45 molecular beam epitaxy system was employed to grow the InAs-QDs. The substrates were conventional semi-insulating GaAs (1 0 0) wafers. The substrates were cleaned in situ in the main chamber to remove native oxides on the GaAs substrate by a heat treatment at 580 °C for a period of 15 min. A 300 nm GaAs

*Corresponding author. Tel.: +82 42 860 5121; fax: +82 42 860 6248.
E-mail address: hse61924@etri.re.kr (S.U. Hong).

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buffer layer was grown at 580 °C and InAs-QDs were then grown at 480 °C. The Ga, In, and As fluxes were 1.75×10^{-7}, 7.2×10^{-8}, and 5.0×10^{-6} Torr, respectively. The surface properties of the QD samples were monitored by reflection high-energy electron diffraction during growth. After growth, atomic force microscope (AFM), transmission electron microscope (TEM), and photoluminescence (PL) were employed to observe the surface morphologies and optical properties.

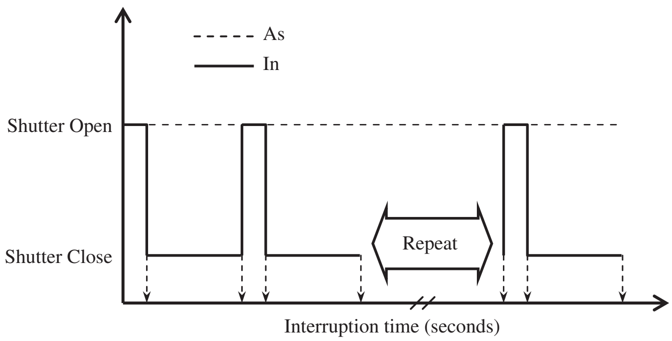

Fig. 1. Schematic illustration of the In-interruption growth technique. Under an As shutter in the always opened state, an In shutter was opened for 1 s and then closed for 9, 19 and 29 s. This sequence was repeated 30 times during the growth of InAs-QDs.

Four types of samples were grown using the In-interruption growth technique in this study. For the first type sample, 2.7 mololayers of InAs-QDs were grown in a pure GaAs matrix for 30 s and this sample is denoted as the Ref. The second, third and fourth type of samples were grown using the following growth technique. The In flux was interrupted by a closed In shutter during QD growth. The shutter of the In source was opened for 1 s and then closed for 9, 19 and 29 s. This growth sequence was repeated 30 times during the growth of InAs-QDs in a pure GaAs matrix. The samples grown with In-interruption times of 9, 19 and 29 s are denoted as QD1, QD2 and QD3, respectively. For each sample, the total amount of In contributing to the growth was the same but total growth time was varied during the InAs growth. A schematic of the

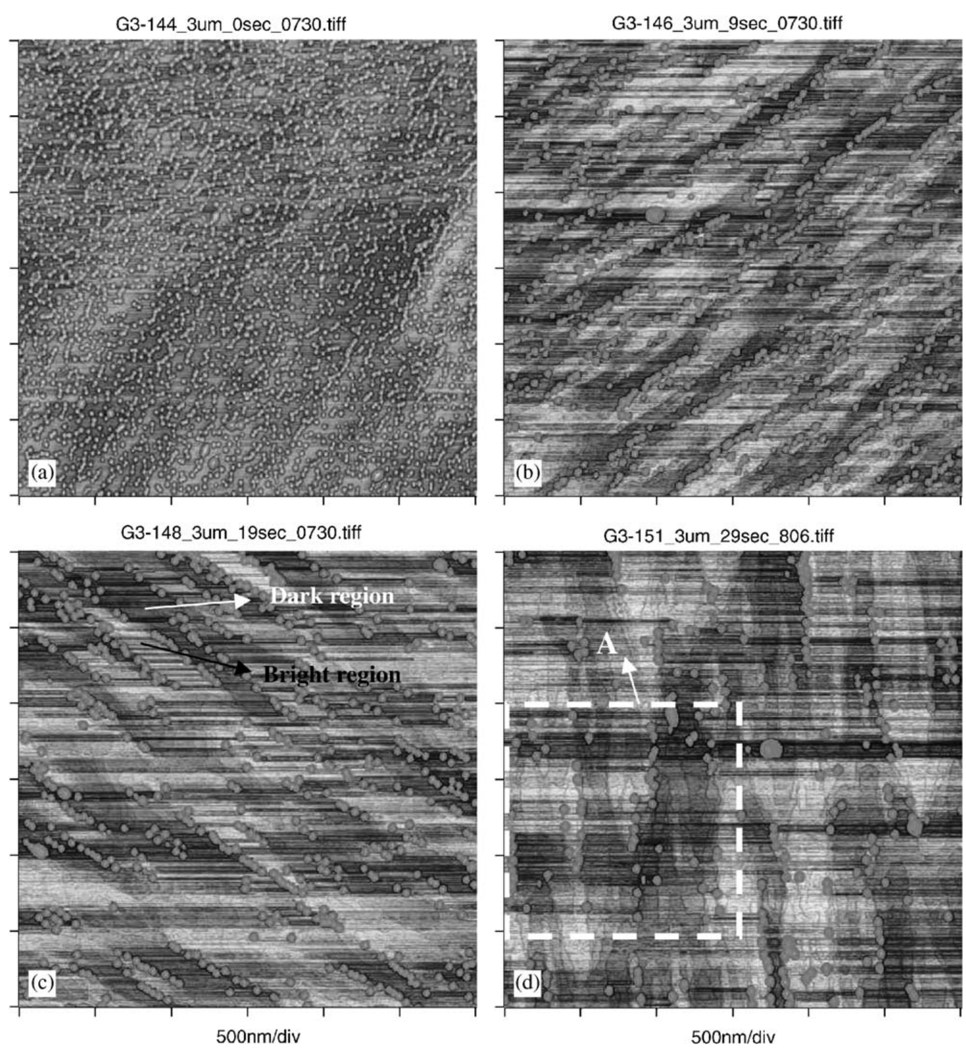

Fig. 2. AFM images (3000 nm × 3000 nm scale) of InAs-QDs. (a) In-interruption time of 0 s for the Ref, (b) In-interruption time of 9 s for the QD1 sample, (c) In-interruption time of 19 s for the QD2 sample and (d) In-interruption time of 29 s for the QD3 sample.