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Selective Formation of Self-Organized InAs QDs on Patterned GaAs Substrates by Molecular Beam Epitaxy

Akio Ueta[1], Kouichi Akahane[1], Sinichiro Gozu[1], Naokatsu Yamamoto[1] and Naoki Ohtani[2]

[1]National Institute of Information and Communications Technology
4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan
Phone: +81-42-3275324 E-mail: ueta@nict.go.jp
[2]Doushisya-University
1-3, Tatara-Miyakodani, Kyotanabe-shi, Kyoto 610-0321, Japan

1. Introduction

Quantum dots (QDs) are of great interest for novel optical device applications such as lasers [1,2] and single photon emitters. [3,4] Most of the studies on QDs have been on self-organized QDs such as InAs on GaAs. [4-7] However, the self-organized QDs formed randomly on surfaces. The random QDs formation might induce low reliability of optical devices, especially single photon emitters. The control of positions of the QDs is an important issue to obtain high reliability of the optical devices. In this work, we studied the position control of the self-organized InAs QDs on patterned GaAs substrates. The InAs QDs are suitable materials toward the development of the optical devices in optical fiber communication systems at wavelength region of 1.3 and 1.55 μm. [1-7]

2. Experimental

Self-organized InAs QDs were grown on (001) GaAs substrates by molecular beam epitaxy (MBE). Patterned GaAs substrates were fabricated by focus ion beam (FIB) system. Growth temperatures of InAs and GaAs buffer layers were set at 500ºC and 560ºC, respectively. The InAs QDs were grown by periodic supply epitaxy. [8] Periodic supply epitaxy is the growth induced using an alternative supply of In or As and enhances migration lengths of the atoms. The supply times of In and As cells were fixed at 5 s and 10 s with 2 s interruptions. The beam flux of In and As cells were 1.0 x 10^{-7} and 1.0 x 10^{-5} Torr, respectively. The amount of InAs was 0.1 ML/s. The structural properties of the QDs were characterized by atomic force microscopy (AFM). Optical properties were characterized by photoluminescence (PL) measurements by a 532-nm YAG laser at room temperature (RT).

3. Results and discussions

Figure 1 shows an atomic force microscopy (AFM) image of self-organized InAs QDs on the (001) GaAs surface. The total deposited amount of InAs was 4.0 ML (8 cycles). The QD formation was clearly observed as shown in Fig. 1, and the density of the InAs QDs was 3.7 x 10^9 cm^{-2}. The density of the InAs QDs grown by periodic supply epitaxy was lower than InAs QDs by conventional growth mode, which supplied In and As cells at the same time. The InAs QDs grown conventionally had a density of about 3.0 x 10^{10} cm^{-2}. Figure 2 shows a PL spectrum from the InAs QDs by periodic supply epitaxy. Strong emissions from the InAs QDs were observed even at RT. This result indicates that the InAs QDs grown by periodic supply epitaxy might have high crystalline quality.

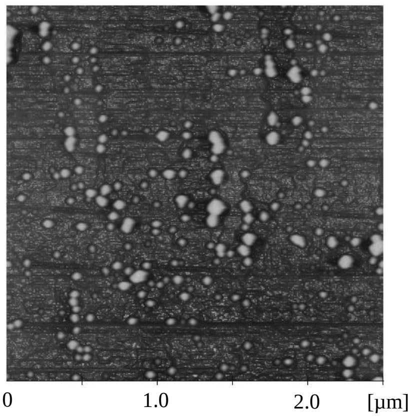

Fig. 1 AFM image of self-assembled InAs QDs on the (001) GaAs surface.

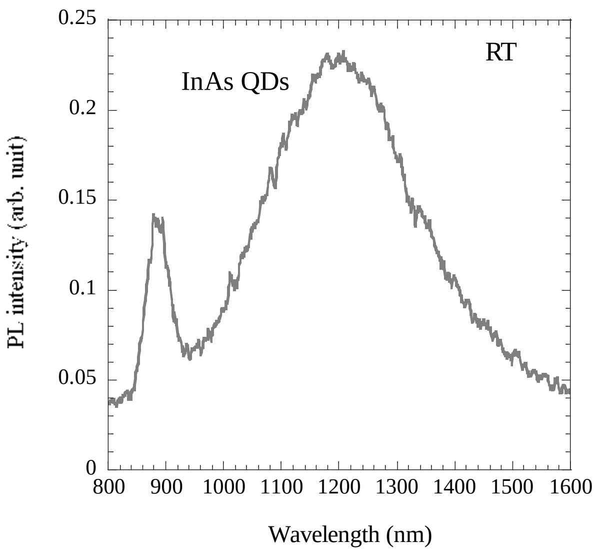

Fig. 2 PL spectrum from the InAs QDs grown by periodic supply epitaxy. Strong emissions from the InAs QDs were observed even at RT.

For controlling positions of the InAs QDs, the InAs QDs growth on patterned GaAs substrates was studied. The patterned GaAs substrates were etched by FIB. The pattern fabricated was stripes with 400-nm pitch. A width and a depth of each line were 300 nm and 50 nm, respectively. These lines are parallel to the [-110] direction. Figures 3 (a) and (b) show an AFM image and a schematic drawing of the patterned GaAs substrate after the growth of 300-nm-thick GaAs. A clear saw-like structure was formed with smooth A-facets. A height difference between the peak and the valley was about 22 nm. Figures 4 (a) and (b) show an AFM image and a schematic drawing after the growth of the 4.0-ML InAs. The InAs QDs was selectively formed on the A-facets. No InAs QD formation on small (001) planes between the facets was observed. This result was caused that In atoms on the small (001) planes migrated to the A-facets, and the QD formation might be enhanced on the A-facets. We also studied stripe patterns, which are parallel to the [110] direction. However, no clear selective QD formation was observed. These results indicated that patterned substrates with (001) surfaces and A-facets could allow controls of positions of the InAs QDs.

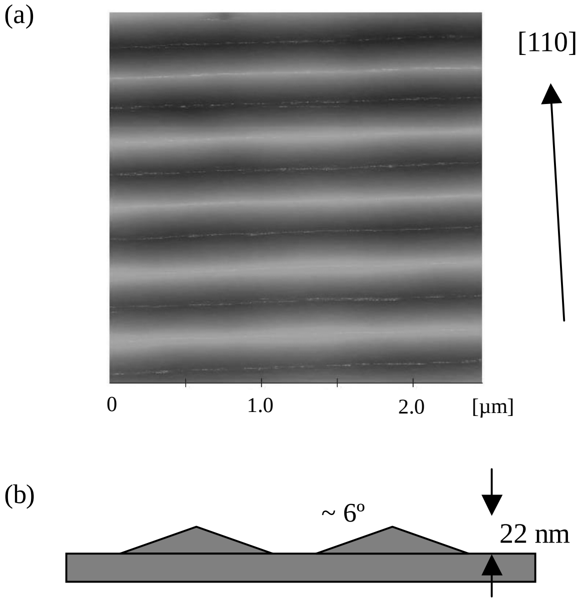

Fig. 3 AFM image (a) and a schematic drawing (b) of the patterned GaAs substrates after the growth of 300-nm-thick GaAs.

4. Conclusions

Self-organized InAs QDs on patterned GaAs substrates were studied. To enhance migrations of atoms, the InAs QDs were grown by periodic supply epitaxy. In the case of the InAs growth on stripe patterns, which are parallel to the [-110] direction, the InAs QDs were selectively formed on A-facets. This will indicate that In atoms migrated to the A-facets and QD formation on the A-facets was enhanced. Further study of this work may reveal possibilities to control of exact positions of the InAs QDs.

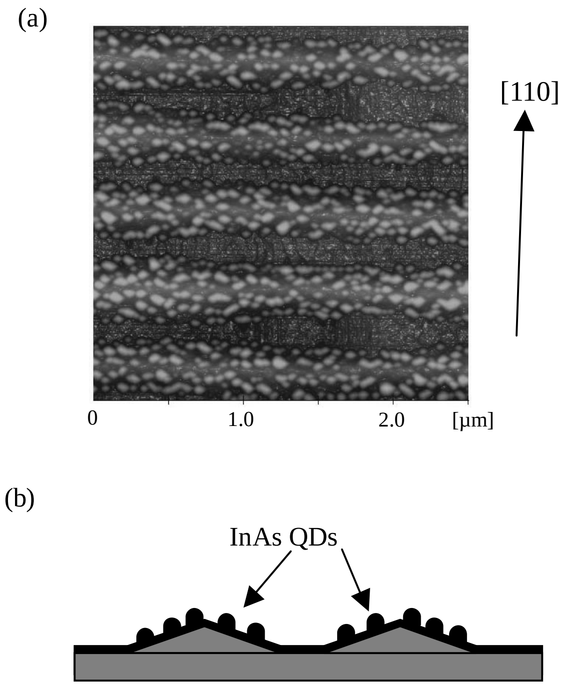

Fig. 4 AFM image (a) and a schematic drawing (b) of the patterned GaAs substrates after the growth of the 4.0-ML InAs.

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