Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 808-809

F-7-2

Fabrication of One- or Double- row Aligned Self-organized Quantum Dots by Utilizing SiO_2-patterned Vicinal (001) GaAs Substrates

Hyo Jun Kim, Junichi Motohisa, and Takashi Fukui

Research Center for Integrated Quantum Electronics, Hokkaido University
North 13 West 8, Sapporo 060-8628, Japan
Phone: +81-11-706-7176 Fax: +81-11-716-6004 E-mail: hjkim@rciqe.hokudai.ac.jp

1. Introduction

Self-organized quantum dots (SOQDs) via Stranski-Krastanow growth mode have been demonstrated to be defect free and have high density with three-dimensional quantum confined nature of the electronic spectra [1, 2]. However, when SOQDs are formed on a planar substrate, they are randomly distributed with fluctuations in their size as well as position, which is undesirable for electronic device applications. In this paper, we have studied the formation of $In_{0.8}Ga_{0.2}As$ SOQDs grown on partially SiO_2-patterned vicinal (001) GaAs substrates by selective area metalorganic chemical vapor phase epitaxy (SA-MOVPE). Also, we have studied the interval of multi-step lines on top regions of mesa-shaped GaAs buffer layer which was grown on SiO_2-patterned vicinal GaAs (001) substrates by SA-MOVPE, and investigated the possibility of the interval controllable one- or double-row aligned SOQDs by using SiO_2-patterned vicinal GaAs substrates.

2. Experimental procedures

1°, 2°, and 5° –off GaAs (001) substrates toward $[1\bar{1}0]$ direction coated with 20 nm–thick SiO_2 film was used as a starting material. The whole patterns within 1900 × 1900 μm^2 were consisted of 25 kinds of stripe pattern regions which have different opening layer width (W_0) in range of 300 ~ 540 nm. The selective area was patterned by electron beam lithography and wet chemical etching technique. The growth of GaAs buffer layer and $In_{0.8}Ga_{0.2}As$ SOQDs were performed by low-pressure metalorganic vapor phase epitaxy (LP-MOVPE) working at 76 torr. Purified hydrogen (H_2) was used as a carrier gas. The source materials used were trimethylgallium (TMG) for GaAs buffer layer, trimethylindium (TMI), and triethylgallium (TEG) for SOQDs, and 20 % arsine (AsH_3) in H_2. The partial pressure of the AsH_3 and TMG for GaAs buffer layer were maintained at 2.54 × 10^{-4} and 7.3 × 10^{-6} atm, respectively. The partial pressure of the AsH_3, TEG, and TMI for $In_{0.8}Ga_{0.2}As$ SOQDs were 2.5 × 10^{-5}, 5.0 × 10^{-7}, and 9.1 × 10^{-7} atm, respectively. The growth temperature and growth thickness were 700 ℃ and 200 nm for GaAs buffer layer, and 500 ℃ and 3.0 ML for $In_{0.8}Ga_{0.2}As$ SOQDs, respectively. The surface morphologies were observed by scanning electron microscopy (SEM).

3. Results and Discussion

Figures 1 (a)–(d) show SEM images of the morphologies of $In_{0.8}Ga_{0.2}As$ SOQDs grown on SiO_2-patterned 1°-off (001) GaAs substrate with W_0 of 567 and 633 nm and 2°-off (001) GaAs substrate with W_0 of 546 and 553 nm, respectively. As the GaAs buffer

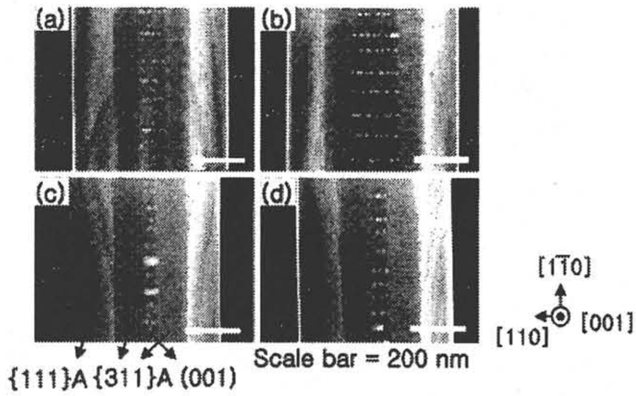

Fig. 1. SEM images of the morphologies of $In_{0.8}Ga_{0.2}As$ SOQDs grown on SiO_2-patterned 1°-off (001) GaAs substrate with W_0 of (a) 566 and (b) 633 nm, and 2°-off (001) GaAs substrate with W_0 of (c) 546 and (d) 553 nm, respectively

layer was grown on opening layer of SiO_2-patterned vicinal (001) GaAs substrates, the formation of GaAs buffer layer was changed to mesa-structure which consists of (001) top facet, {311}A facet surrounding the top region, and {111}A side wall facet. As shown in Figs .1 (a)-(d), the width of {311}A facet of GaAs buffer layer grown on SiO_2-patterned 2°-off (001) GaAs substrate ($W_{\{311\}A}$) is wider than that on 1°-off substrates. In order to explain the dependence of $W_{\{311\}A}$ on misorientation angle of substrate, the schematic diagram for movement of Ga adatoms on GaAs mesa structure was represented in Fig 2 (a). According to Konkar *et al.*'s experimental results, Ga adatoms on side wall having

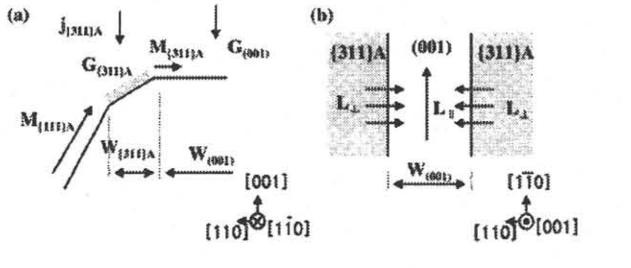

Fig. 2 The schematic diagram for movement of Ga adatoms on (a) GaAs mesa structure and (b) (001) top facet.

higher nucleation density moved easily to top (001) facet than bottom region by synergistic surface migration [3]. Therefore, the growth rate GaAs in crystal phase on {311}A facet ($G_{\{311\}A}$) disregarding desorption and surface migration toward bottom site of mesa can be represented [4];

$$G_{\{311\}A} = j_{\{311\}A} + M_{\{111\}A} - M_{\{311\}A} \qquad (1)$$

where $j_{\{311\}A}$, $M_{\{111\}A}$, and $M_{\{311\}A}$ mean net flow of incidence per unit {311}A surface area, the surface migration of Ga adatoms from {111}A to {311}A facet per area, and the surface migration of Ga adatoms from {311}A to (001) facet per area, respectively. Q. Gong et al. suggested that $W_{\{311\}A}$ depend on ratio of $G_{\{311\}A}$ to the growth rate of surrounded facets [5]. The kink density in [110] direction of {311}A facet is high, whereas that of {111}A and (001) facets are 0. As the misorientaion angle in $[1\bar{1}0]$ direction of substrate is higher, the step density of facets on mesa is increased, and incorporation probabilities of Ga adatoms to the step sites from the adjacent terrace sites (θ_{step}) is increased [6]. This θ_{step} in $[1\bar{1}0]$ direction on mesa gives strongly catalystic effect to kink density in [110] direction of {311}A facet than that of {111}A and (001) facets. Therefore, as the misorientation angle is higher, the surface migration of Ga adatoms from {311}A to top region is more obstructed, and $G_{\{311\}A}$ and $M_{\{311\}A}$ in Eq. (1) are increased and decreased, respectively. The bunching effect of GaAs buffer layer on (001) top facet is originated from the surface migration length of Ga adatom in parallel direction to misorientation direction ($L_{\parallel}$ in Fig. 2 (b)) [6]. Also, it is obstructed by the surface migration length in perpenicular direction to the misorientaion direction ($L_{\perp}$ in Fig. 2(b)), which is more increased as $W_{(001)}$ is narrower [3]. Therefore, SOQDs were preferentially grown on step site on (001) facet affected by the bunching effect which depend on the misorientation angle and $W_{(001)}$. In order to reduce $W_{(001)}$ region having indefinite interval of SOQDs which are undesirable for electronic device applications, we have applied same growth condition to SiO_2-patterned 5°-off (001) GaAs substrate having higher multi-atomic steps. Figures 3 (a) and (b) show SEM images of the morphologies of $In_{0.8}Ga_{0.2}As$ SOQDs grown on SiO_2-patterned 5°-off (001) GaAs substrates with W_0 of 640 and 667 nm, respectively. The interval in $[1\bar{1}0]$ direction of one-row aligned SOQDs in Fig. 3(a) is accordance with that of double-row aligned SOQDs in Fig. 3(b), and the region with indefinite interval on (001) facet was not observed because $L_{\perp}$ is almost reached to 0.

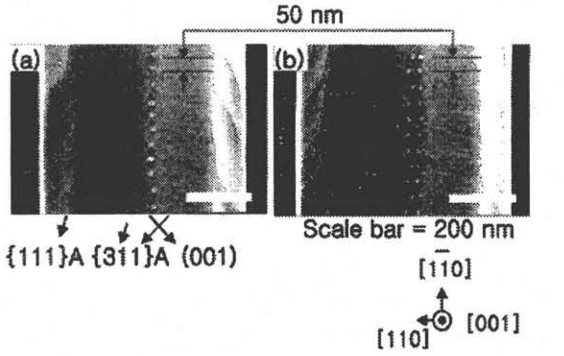

Fig. 3. SEM images of the morphologies of $In_{0.8}Ga_{0.2}As$ SOQDs grown on SiO_2-patterned 5°-off (001) GaAs substrate with W_0 of (a) 640 and (b) 667 nm, respectively.

4. Conclusions

One- or double-row aligned SOQDs with define interval was successfully fabricated by utilizing SiO_2-patterned 5°-off (001) GaAs substrate. These results suggest that the selective growth technique of SOQDs by utilizing SiO_2-patterned vicinal substrates hold promise for applications in nanoelectronic devices, such as single electron tunneling transistors.

References

[1] S. K. Jung, S. W. Hwang, B. H. Choi, S. I. Kim, J. H. Park, Y. Kim, E. K. Kim, S. K. Min, Appl. Phys. Lett. **74**, 714 (1999)

[2] F. Heinrichsdoff, M. H. Mao, N. Kirstaedier, A. Krostaedier, A. Krost, D. Bimberg, A. O. Kosogov, and P. Werner, Appl. Phys. Lett. **71**, 22 (1997)

[3] A. Konkar, A. Madhukar, and P. Chen, Appl. Phys. Lett. **72**, 220 (1998).

[4] M. Othsuka and S. Miyazawa, J. Cryst. Growth **95**, 55 (1989).

[5] Q. Gong, R. Nötzel, H. –P. Schönherr, and K. H. Ploog, Appl. Phys. Lett. **77**, 3538 (2000)

[6] H. J. Kim, Y. J. Park, E. K. Kim, and T. W. Kim, J. Cryst. Growth **223**, 450 (2001).