Transactions of the Materials Research Society of Japan 29 [1] 127-129 (2004)

Self-Assembled GaAs/GaSb Quantum Dots by Molecular Beam Epitaxy

Seiki Iwasaki, Takanori Nakai and Koichi Yamaguchi
Department of Electronic Engineering, University of Electro-Communications
1-5-1, Chofugaoka, Chofu, Tokyo 182-8585, Japan
FAX: 81-424-42-5149, E-mail address: iwasaki@crystal.ee.uec.ac.jp

We report self-assembled GaAs/GaSb quantum dots (QDs) by molecular beam epitaxy using a Stranski-Krastanov growth mode. Low growth rate and low Sb pressure conditions enhanced a surface migration of adatoms, and self size-limiting phenomena of lateral dot size were observed. As a result, uniformity in the dot size improved, and an isotropic dot shape was formed. By adjusting the growth temperature of a GaAs capping layer, a narrow photoluminescence linewidth of 65 meV was obtained.

Key words: GaSb, quantum dot, molecular beam epitaxy, Stranski-Krastanov growth mode, Sb pressure

1. INTRODUCTION

Semiconductor quantum dots (QDs) are very attractive structure for optoelectronic device applications such as high efficiency semiconductor lasers [1] as well as for their interesting physical properties based on zero-dimensional (0D) carrier system. Among of their fabrication techniques, self-assemble technique using a Stranski-Krastanov (SK) growth mode is much convenient method. Recently, the SK growth of GaAs/GaSb QDs, exhibiting a type-II band-alignment, has been attempted [2,3]. However, control of their SK growth is difficult because of an exchange of group V elements and large lattice mismatch (7.8 %). In particular, large size fluctuation of GaSb QDs was one of important problems: photoluminescence (PL) linewidth of their QDs revealed about 100 meV. Recently, we have demonstrated highly uniform InAs QDs by molecular beam epitaxy (MBE) via the SK growth mode and have emphasized that an enhanced surface migration of growth species is very important for suppression of size fluctuation [4].

In this paper, we present an improvement of uniformity in GaSb-QD size. In the MBE growth of GaAs/GaSb QDs, low growth rate and low Sb_4 pressure are effective conditions for reducing size fluctuation, and, as a result, narrow PL linewidth of 65 meV was obtained successfully.

2. EXPERIMENT

In this study, samples were grown on semi-insulating GaAs(001) substrates by solid source MBE. After a 200-nm-thick GaAs buffer layer was grown at 590 ℃, the substrate temperature was cooled down to 470 ℃. Then in order to change the GaAs surface for the GaSb one, As_4 irradiation was switched to Sb_4 one (3×10^{-7} - 5×10^{-8} Torr). By the Sb_4 irradiation, reflection high-energy electron-beam diffraction (RHEED) pattern of GaAs-c(4×4) changed into GaSb(1×3) pattern. GaSb QDs were self-formed on the 1-ML-thick GaSb layer at 470 ℃ by SK growth mechanism. The growth mode changed from 2D growth to 3D one at 2.5 ML in coverage: the critical thickness for the dot formation is 2.5 ML including 1-ML-thick GaSb layer formed by the Sb irradiation. After the GaSb growth, a 100-nm-thick GaAs capping layer was grown at 470 ℃.

GaSb QDs without the GaAs capping layer was observed by an atomic force microscopy (AFM). PL properties of capped GaSb QDs were measured at 12 K by using an Ar^+ laser (excitation power density of 3.2 W/cm^2) and an InGaAs photodiode.

3. RESULTS AND DISCUSSION

Figure 1 shows AFM images of GaSb QDs grown at various growth conditions (growth rate: 0.16 ML/s (a), 0.08 ML/s (b) and 0.04 ML/s (c, d) and Sb_4 pressure: 3.0×10^{-7} Torr (a), 2.2×10^{-7} Torr (b), 1.0×10^{-7} Torr (c) and 0.5×10^{-7} Torr (d)). In case of high growth rate and high Sb pressure, the dot density increases, and size fluctuation becomes large. In addition, the dot shape is anisotropy: the lateral size elongates along the $[\bar{1}10]$ direction. As the growth rate and the Sb pressure decrease, uniformity and isotropy of GaSb dots improve. According to the previous report concerning the InAs SK-dot [4], the low growth rate and low As pressure enhanced the surface migration. Although the size of GaSb dots does not increase at low growth rate and the low Sb pressure, the low dot density is attributed to the long surface migration length.

Figure 2 shows the GaSb coverage dependence of the dot size (a, b) and the dot density (c). The GaSb dots were prepared under low growth rate (0.04 ML/s) and the low Sb pressure (0.5×10^{-7} Torr). The lateral size and dot density tend to saturate at more than about 3 ML. In case of the InAs SK dot, self size-limiting phenomena due to facet formation have been observed [5]. In this experiment, the stable facet did not appear clearly. Additonally, the size limiting effect of the dot height was not observed, as shown in Fig. 2(b). Therefore, it is possible that the saturation of the lateral size is caused by the strain at the island edge: an incorporation of adatoms is suppressed at the island edge [6]. On the contrary, the active incorporation occurs at the top of the dot because of the lattice relaxation at the top, and, as a result, the dot height increases with an increase in the coverage.

Figure 3 shows the substrate temperature dependence of the average dot size (a), standard deviation (b) and the dot density (c). The GaSb coverage was 4.5 ML. As the substrate temperature increases, the dot size increases and the dot density deceases. An enhancement of the surface migration is expected for the high substrate temperature during the GaSb growth, if reevaporation of adatoms is not active. The long surface migration is favorable for suppression of the size fluctuation. Indeed, the standard deviation reduces with increase in the substrate temperature. Here, in order to keep high dot density and uniformity in the dot size, the substrate temperature of 470 ℃ was selected.

From above results, it is concluded that the proper growth conditions of GaSb SK-dots are low growth rate of 0.04 ML/s, low Sb pressure of 0.5×10^{-7} Torr and substrate temperature of 470 ℃. Size distributions of GaSb SK-dots grown under the above condition are shown in figure 4. The GaSb coverage was 5 ML. For this sample, the dot density was 8.9×10^{-9} cm^{-2}, and, the standard deviations were 9.2 % for the lateral size and

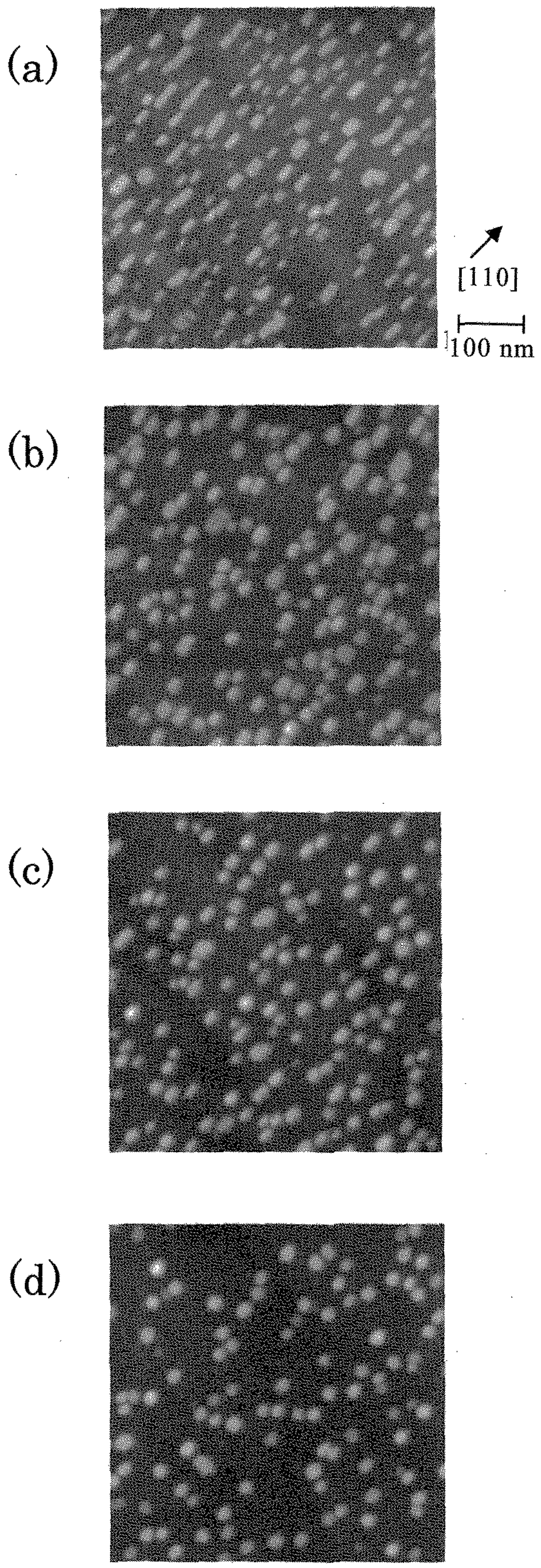

Fig. 1. AFM images of GaSb quantum dots (growth rate: 0.16 ML/s (a), 0.08 ML/s (b) and 0.04 ML/s (c, d) and Sb_4 pressure: 3.0×10^{-7} Torr (a), 2.2×10^{-7} Torr (b), 1.0×10^{-7} Torr (c) and 0.5×10^{-7} Torr (d)).

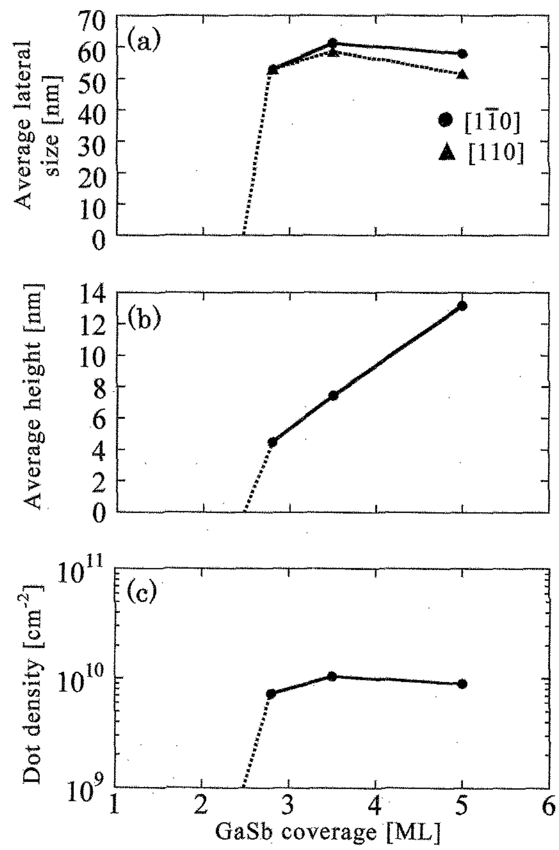

Fig. 2. Average lateral size (a), average height (b) and density (c) of GaSb dots as a function of GaSb coverage.

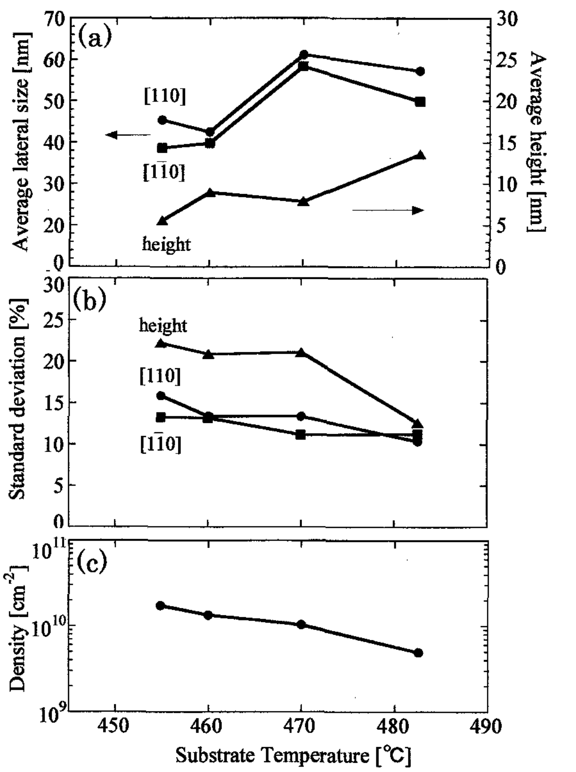

Fig. 3. Average lateral size (a), standard deviation (b) and density (c) of GaSb dots as a function of substrate temperature.

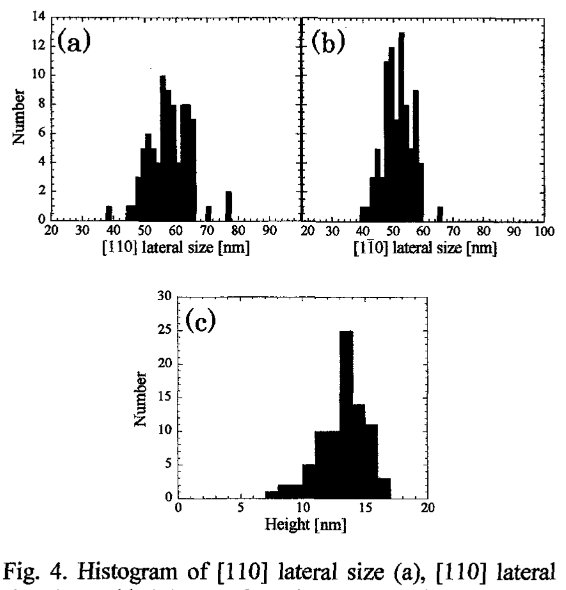

Fig. 4. Histogram of [110] lateral size (a), [110] lateral size (b), and height (c) of GaSb dots: growth temperature 0.04 ML/s, Sb_4 pressure 5×10^{-8} Torr.

14 % for the height. After their GaSb dots were embedded in the GaAs layer, PL properties were measured as follows.

Figure 5 shows PL spectra obtained from GaSb QDs as a function of the growth temperature of the GaAs capping layer (490 ℃ (a), 470 ℃ (b) and 450 ℃ (c)). It is found that PL peak wavelength reveals blue shift as

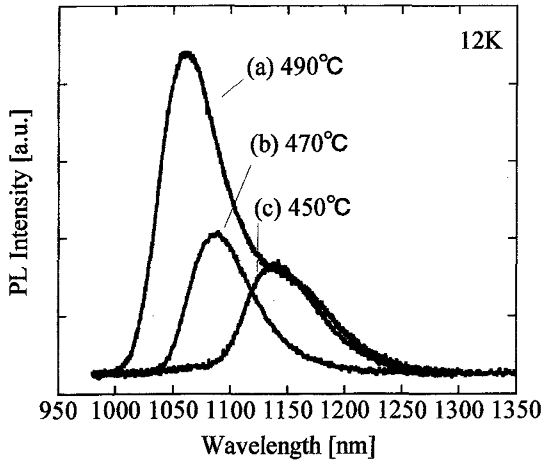

Fig. 5. PL spectrum (12 K) of 4 ML GaSb QDs (Growth temperature of GaAs capping layer: 490 ℃ (a), 470 ℃ (b) and 450 ℃ (c)).

the growth temperature increases. In case of the 490 ℃ growth (a), the RHEED pattern changed from spot pattern into streak one during the growth interruption between the SK growth and the capping growth. Therefore, the blue shift is attributed to the change of the QD structure into QW-like structure. For the growth at 470 ℃ (b) or 450 ℃ (c), the RHHED spot pattern was kept until the embedding in the GaAs capping layer. Thereby, it is predicted that the blue shift for the 470 ℃ growth is caused by a size reducing of GaSb QDs. Here it should note a narrow PL linewidth of 65 meV for the 470 ℃ growth.

4. CONCLUSION

Self-assembled GaAs/GaSb QDs were grown by the MBE growth under low growth rate and low Sb pressure. These growth conditions improved uniformity in the dot size and provided an isotropic shape of the dot. Suppression of the size fluctuation is attributed to the size limiting effect, which is induced by the enhanced surface migration. By adjusting the growth condition, we could obtain the narrow PL linewidth of 65 meV.

5. ACKNOWLEDGEMENT

This work was partially supported by a Grant-in-Aid Scientific Research from the Ministry of Education, Science, Sports and Culture of Japan.

6. REFERENCES

[1] Y.Arakawa and H.Sasaki, Appl. Phys. Lett. 40(1982) 939.

[2] F.Hatami, M.Grundman, N.N.Ledentsov, F.Heinrichsdorff, R.Heitz, J.Bohrer, D.Bimberg, S.S.Ruvimov, P.Werner, V.M.Ustinov, P.S.Kop'ev and Zh.I.Alferov, Phys. Rev. B57, (1998) 4635.

[3] K.Suzuki, R.A.Hogg and Y.Arakawa, J. Appl. Phys. 85 (1999) 8349.

[4] K.Yamaguchi, T.Kaizu, K.Yujobo and Y.Saito, J. Cryst. Growth 237-239, (2001) 1301.

[5] T.Kaizu and K.Yamaguchi, Jpn. J. Appl. Phys. 40 (2001) 1885-1887.

[6] Barabasi. A. L., Appl. Phys. Lett. 79(1997) 2565.

(Received October 12, 2003; Accepted December 2, 2003)