Direct Formation of GaAs–GaAlAs Quantum-Dot Structures by Droplet Epitaxy

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Abstract. GaAlAs epitaxial layer growth over the GaAs epitaxial microcrystals grown on a sulfur–terminated GaAlAs surface by droplet epitaxy was performed by using MEE process. By using droplet epitaxy and MEE process, we can form GaAs–GaAlAs quantum dots structure directly in an MBE chamber.

1. Introduction

A sulfur(S)–terminated GaAs or GaAlAs surface is recognized providing an inert surface for the foreign atom adhesion caused by an almost filling dangling bond nature[1–3]. Recently, we have observed a three dimensional growth of GaAs epitaxial microcrystals on a sulfur– or selenium–terminated GaAs or GaAlAs surface by sequentially supplying Ga and As molecular beams[4–6]. We termed this method as droplet epitaxy.

For the direct formation of GaAs–GaAlAs quantum dots structure in the MBE chamber, it is necessary to grow a GaAlAs epitaxial layer over the GaAs microcrystals to bury the GaAs microcrystals grown on the GaAlAs surface.

In this paper, we demonstrate a GaAlAs layer growth over the GaAs microcrystals grown on the S–terminated GaAlAs surface by droplet epitaxy.

2. Experimental

The MBE system used in this work was a conventional system (ANELVA–620) with a sample introduction chamber and an electron gun for reflection high–energy diffraction (RHEED) with a primary beam energy of 30 keV. Elemental Ga, Al and As were used as molecular beam source materials. A valved Knudsen cell charged with elemental S was installed in the sample introduction chamber. The background pressure of the sample introduction chamber was 5×10^{-8} Torr.

First, 4000 Å thick GaAs layer was grown on the (001) GaAs substrate at 620°C under a V/III flux ratio of about three. Then, 3000 Å GaAlAs epitaxial layer with Al composition of 30 % was grown at 630°C under the V/III flux ratio of about two on the GaAs layer. The growth rates of GaAs and GaAlAs are about 0.19 ML/s and 0.27 ML/s, respectively. For the S–termination of the (001) GaAlAs, the substrate temperature was decreased to the room temperature. Next, the sample was transferred

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into the sample introduction chamber and exposed to the sulfur vapor which generates a chamber pressure of 1 x 10^{-5} Torr at room temperature for 3 min. The sample was then transferred into the growth chamber again and kept at 400°C for 5 min. The substrate temperature was reduced to 130°C, then Ga and As molecular beams were supplied to the surface sequentially to fabricate GaAs microcrystals. Then GaAlAs overlayer was grown to bury the GaAs microcrystals.

The structures produced on the surfaces of the samples were observed with a field-emission type high-resolution scanning electron microscope(HRSEM).

3. Results and Discussion

Surface morphology and RHEED patterns observed on each stage of growth process on the S-terminated layer are shown in Fig. 1 and Fig. 2, respectively. On the S-terminated GaAlAs epitaxial layer, three dimensional GaAs epitaxial microcrystal growth occurred by the droplet epitaxy. The surface morphology and RHEED pattern of GaAs epitaxial microcrystals grown on the S-terminated $Ga_{0.7}Al_{0.3}As$ surface at the substrate temperature of 130°C are shown in Fig. 1 (a) and Fig. 2 (a). After the deposition of the Ga droplets under Ga molecular beam flux of 3.2 ML/s for the total amount of Ga atoms of 0.3 equivalent GaAs monolayers, As molecular beam with beam equivalent pressure of 2 x 10^{-6} Torr was irradiated subsequently. The Ga droplets changed to the microcrystals surrounded mainly by (111) facets. Base size of GaAs microcrystals is about 100Å x 100Å. The standard deviation of the size

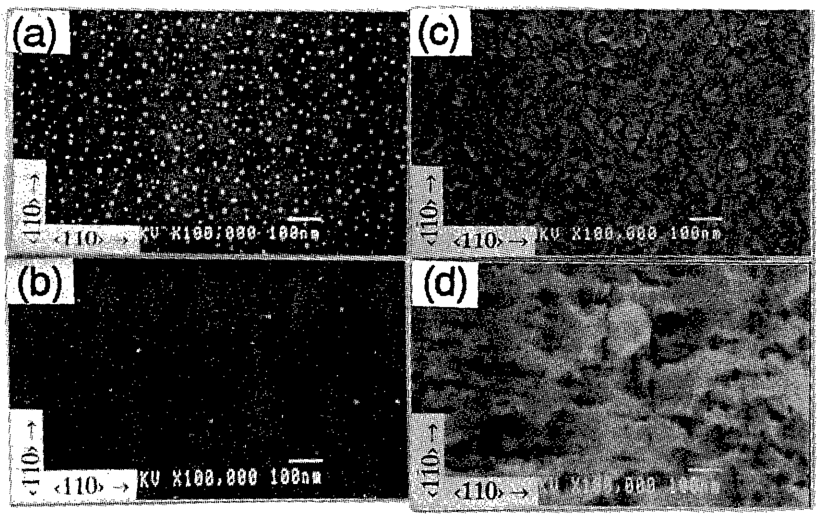

Fig.1.
Surface morphology of the sample after the growth of GaAs epitaxial microcrystals at 130°C by droplet epitaxy (a), after the temperature elevation of sample (a) to 630°C in the arsenic molecular beam (b), after 150Å MEE growth of GaAlAs layer over GaAs epitaxial microcrystals shown (a) at 530°C (c) and after about 1000Å MEE growth of GaAlAs layer over GaAs epitaxial microcrystals shown (a) at 530°C(d).

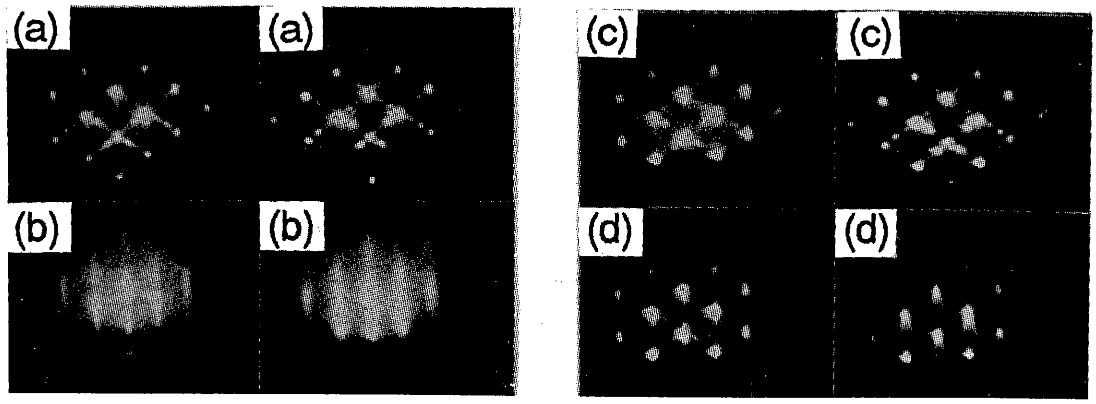

Fig.2.
RHEED patterns observed on each stage of growth process on the S-terminated layer. (a) is a pattern after the growth of GaAs epitaxial microcrystals at 130°C by droplet epitaxy, (b) is a pattern after the temperature elevation of sample (a) to 600°C in arsenic molecular beam, (c) is a pattern after about 150Å MEE growth of GaAlAs layer over GaAs epitaxial microcrystals at 530°C and (d) is a pattern after about 1000Å MEE growth of GaAlAS layer over GaAs epitaxial microcrystals at 530°C. Left column: electron beam along [110]; right column: electron beam along [1$\bar{1}$0].

distribution is about 30% and rather larger than that of the GaAs microcrystals fabricated on the S-terminated GaAs surface[4]. This is caused by the difference of the surface roughness between GaAs and GaAlAs. The density of the GaAs microcrystals is about 10^{11} cm^{-2}. Next, the sample temperature was increased to 630°C in the As molecular beam flux to desorb the sulfur atoms on the GaAlAs surface between GaAs microcrystals and to grow the GaAlAs layer over the GaAs microcrystals by ordinary MBE process. However, the GaAs microcrystals disappeared by this temperature elevation procedure as shown in Fig. 1 (b) and Fig. 2 (b). This is caused by dissociation of As atom from the microcrystals and two dimensional growth of GaAs occurred between residual Ga atoms and impinging As molecular beams. This disappearance occurred at the temperature above 550°C and was inevitable under a high As flux (5 x 10^{-5} Torr). Then we used the MEE process at 530°C to obtain a GaAlAs overlayer. The surface morphology of the samples after about 150Å and 1000Å thick $Ga_{0.7}Al_{0.3}As$ MEE growth over the GaAs microcrystals are shown in Fig. 1 (c) and (d), respectively. The RHEED patterns of the surface after about 150Å and 1000Å thick GaAlAs MEE growth are shown in Fig. 2 (c) and (d), respectively. As the GaAlAs overlayer grew on, the surface became flat with (115) facets. Although the surface is rather rough caused by the covering numerous three dimensional microcrystals, the epitaxial growth of the GaAlAs layer occurred. This means that we can perform a direct formation of GaAs-GaAlAs quantum dots structure in the MBE chamber.

4. Conclusions

The droplet epitaxy is suitable for the direct formation of GaAs–GaAlAs quantum dots structure. The GaAlAs epitaxial layer growth over the GaAs epitaxial microcrystals is performed by using MEE process for burying GaAs microcrystals.

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