HOKKAIDO UNIVERSITY

Title	Selective MBE Growth of GaAs Ridge Quantum Wire Arrays on Patterned (001) Substrates and Its Growth Mechanism
Author(s)	Sato, Taketomo; Tamai, Isao; Hasegawa, Hideki
Citation	Institute of Physics conference series, 174, 145-148
Issue Date	2003
Doc URL	http://hdl.handle.net/2115/8386
Rights	copyright (C) 2003 IOP Publishing Ltd.
Type	proceedings (author version)
File Information	TSATO45.PDF

Instructions for use

Hokkaido University Collection of Scholarly and Academic Papers : HUSCAP

Selective MBE Growth of GaAs Ridge Quantum Wire Arrays on Patterned (001) Substrates and Its Growth Mechanism

Taketomo Sato, Isao Tamai and Hideki Hasegawa

Research Center for Integrated Quantum Electronics (RCIQE) and
Graduate School of Electronics and Information Engineering,
Hokkaido University, North 13, West 8, Sapporo, 060-8628, Japan

Abstract. The selective MBE growth of the <-110>-oriented GaAs ridge QWRs were made in a basis of the proper understanding of growth mechanism on pre-patterned (001) substrates. The arrow-head shaped GaAs wire was selectively formed on the top (113)A facets of GaAs ridge structure utilizing the enhanced growth selectivity against to side (111)A facets. The wire width could be kinetically controlled by the growth process.

1. Introduction

Recently, intensive research efforts have been made on semiconductor quantum devices such as single electron transistors (SETs) and quantum wire transistors (QWR-Trs). For realization of such quantum devices, it is necessary to form the high quality and highly uniform quantum structures in the size- and position-controlled fashion.

Among various approaches to from quantum structures, selective MBE/MOVPE growth on pre-patterned substrates is one of the promising techniques for formation of position- and size-controlled arrays of III-V quantum wires (QWRs) and quantum dots (QDs) [1-5]. However, growth on non-planar substrates is complicated due to simultaneous involvement of various high-index facets and related kinetic processes. Proper understanding of the growth mechanism is, thus, inevitable for precise control the feature size.

In this paper, <-110>-oriented GaAs/AlGaAs ridge QWR arrays were successfully fabricated on (001) patterned substrate by selective MBE growth technique for the first time. In a basis of the proper understanding for the formation mechanism, it was realized to precisely control the wire size of present GaAs ridge wire.

2. Experimental

As the templates for selective MBE growth, a patterned substrate shown in **Fig. 1(a)** was used for the formation of GaAs ridge QWRs. The array of <-110>-orientated mesa stripes with (111)A side facets was formed on semi-insulating (001) GaAs substrates by electron-beam (EB) lithography and wet chemical etching.

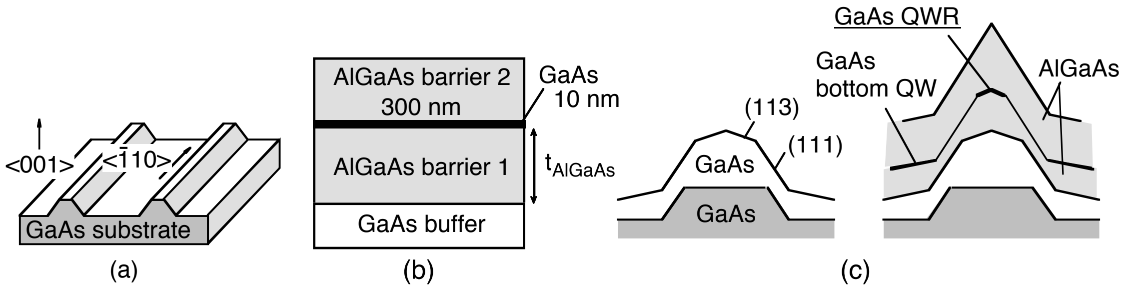

Figure 1. (a) Substrate, (b) material supply in this sutdy and (c) growth sequence.

As pre-growth treatments, organic cleaning and light wet chemical etching were applied in the atmosphere. Then, thermal cleaning under As pressure was done just before the growth in order to remove native oxides in MBE chamber.

Typical material supply and growth sequence are shown in **Fig. 1(b) and (c)**, respectively. After thermal cleaning in the MBE chamber, GaAs buffer layer was first grown on the patterned substrate. This led to the formation of GaAs ridge structures defined by two (113) facets. Then, attempts of self-organized QWR growth were made by supplying $Al_{0.3}Ga_{0.7}As$/GaAs/$Al_{0.3}Ga_{0.7}As$ on the ridge structure. It is similar to that which we use for growth of InP-based ridge QWRs [3]. Growth rate of AlGaAs layer and V/III flux ratio were kept to be 500 nm/hour and 30, respectively, when grown on a flat (001) surface. Samples were grown at various substrate temperature in rage from 600°C to 680°C.

3. Results and discussion

3.1. Fabrication of <-110>-oriented GaAs ridge QWR

Figure 2 (a) shows the cross-sectional SEM image of the sample grown at 640°C. The stain etching using an alkali solution was applied on craved surface where GaAs was selectively dissolved into a solution. After the stain etching, the self-organized formation of GaAs QWR became clearly visible on the cross-sectional surface. The wire structure is very different from the <110>-oriented case [2]. Namely, subsequent supply of AlGaAs/GaAs/AlGaAs materials resulted in self-organized formation of arrow-head shaped nano-wire on the top (113) facets of GaAs ridge structure, as schematically shown in **Fig. 2(b)**. Furthermore, two boundary planes separating (111)/(113) growth region also became visible within the AlGaAs layer after the stain etching.

The results of photo-luminescence (PL) and cathodo-luminescence (CL) measurements on GaAs ridge QWR were shown in **Fig. 3(a) and (b)**, respectively. The wire width of the measured QWR sample was 40 nm. As shown in **Fig. 3(a)**, two sharp peaks were observed at 1.52 eV (peak

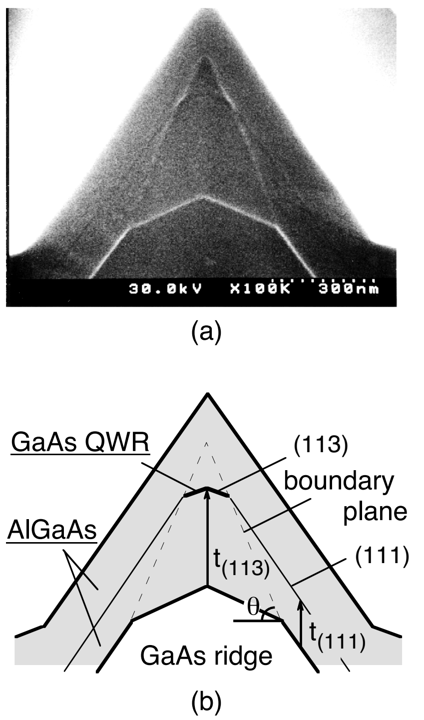

Figure 2. (a) Cross-sectional SEM image of GaAs QWR and (b) schematic.

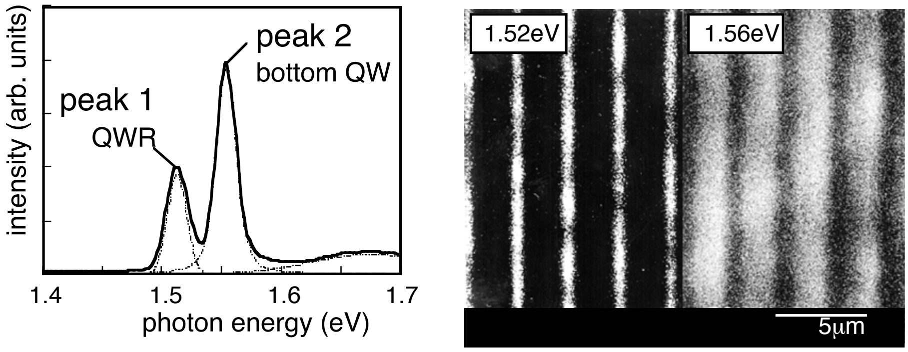

Figure 3. (a) PL spectra and (b) monochromatic CL images of top surface obtained from <-110> GaAs QWR at 30K.

1) and 1.56 eV (peak 2). From the spatially resolved monochromatic CL measurements shown in **Fig. 3(b)**, it was found that peak 1 and peak 2 came, respectively, from top QWR and bottom quantum well (QW) region. The quantum wire peak 1 had a narrow full width a half-maximum (FWHM) of 20 meV. From the results of PL and CL measurements, it was found that the spatially uniform GaAs wire was formed on the pre-patterned substrate by the selective MBE growth technique.

3.2. Formation mechanism and size controllability of QWR

In order to realize the precise control of QWR size, well understanding of the growth mechanism on a patterned substrate is quite necessary. The angle of the boundary plane formed within AlGaAs layer is one of the important parameter to control the QWR size, because the wire width is defined by the two boundary planes, as schematically shown in **Fig. 2(b)**. From the SEM observation shown in **Fig. 2(a)**, two boundary planes kept a constant angle throughout entire growth.

Figure 4 shows the plot of the measured boundary angle, θ, with respect to (001) plane as a function of growth temperature, T_{sub}. Rather surprisingly, any attempts to correlate these boundary planes with a particular high index facet failed. In fact, the value of θ was found to depend strongly on the growth temperature, T_{sub}, as shown in **Fig. 4**.

Growth selectivity on the GaAs ridge structure having two (113) and (111) facets was also investigated by changing substrate temperature. **Figure 5** shows the plots of measured growth thickness defined as $t_{(113)}$ and $t_{(111)}$ in **Fig. 2(b)** versus various growth temperature, T_{sub}. The plotted data were normalized by the thickness on (001) plane, $t_{(001)}$. As the temperature increased, the growth thickness on (113) facets increased, while that on (111) facets decreased. This is due to the difference in migration and atom incorporation rate between on (113) and (111). Thus, the growth selectivity on (113) facets against to (111) facets was enhanced at higher growth temperature, as schematically illustrated in insets of **Fig. 5**.

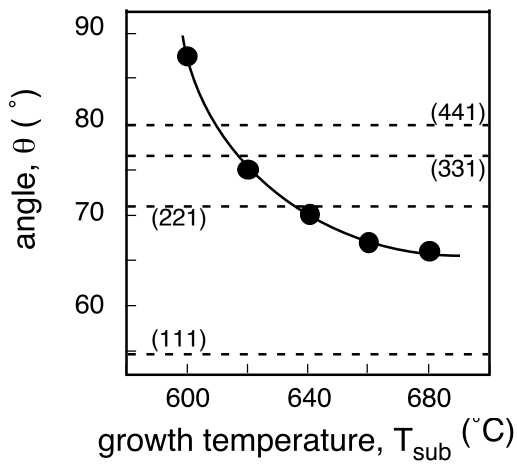

Figure 4. θ vs. growth temperature, T_{sub}.

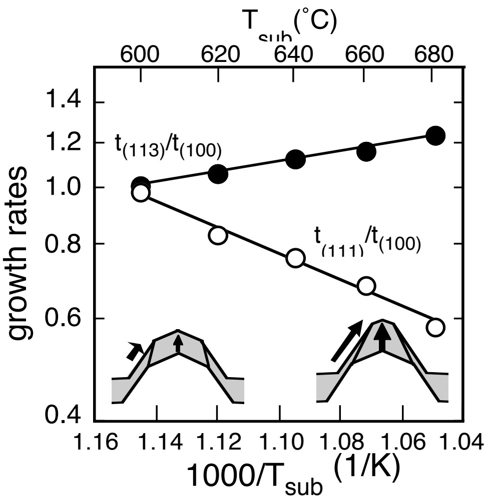

Figure 5. Vertical growth rates on (113) and (111) facets.

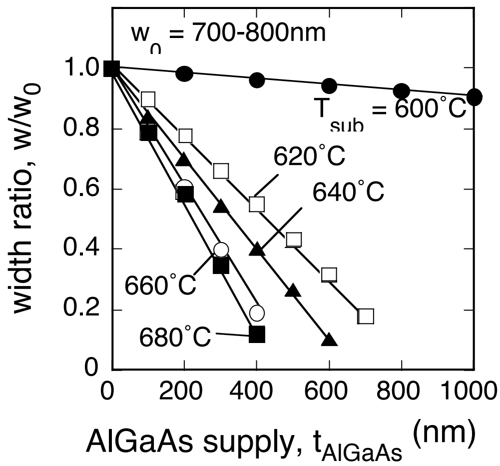

Figure 6. QWR width vs. AlGaAs supply thickness.

Furthermore, temperature-dependent differences in migration rate and the atom incorporation rate lead to a Ga-rich thicker region on (113) facet, and a less Ga-rich thinner region on (111) facet at higher temperatures. Due to slight composition difference, the boundary becomes visible by stain etching for cross-sectional SEM observations shown in **Fig. 2(a)**. Thus, it has been concluded that evolution of the boundary planes is the result of difference in the migration and the atom incorporation rates between (113) and (111) facets.

The size controllability of the present QWR was shown in **Fig. 6** as a function of the AlGaAs supply thickness just prior to the growth of GaAs wire. As expected, the wire width, w, changed linearly with the AlGaAs supply thickness, t_{AlGaAs}, where w_0 denotes the initial GaAs ridge width prior to AlGaAs supply. At high growth temperature, the wire width rapidly decreased as the AlGaAs supply thickness increased, due to the reduction of boundary angle. From these results, it was found that the size of the present QWR can be kinetically controlled by the growth process.

4. Conclusion

In this study, the selective MBE growth of the <-110>-oriented GaAs ridge QWRs were made on pre-patterned (001) substrates for the first time in a basis of the proper understanding of growth process.

(1) From SEM, PL and CL measurements, it was found that the arrow-head shaped GaAs wire was selectively formed on the top (113) facets of GaAs ridge structure with good size uniformity.

(2) The wire width of present GaAs QWR could be kinetically controlled utilizing the difference in migration rate and the atom incorporation rate between top (113) facets and side (111) facets of GaAs ridge structure.

References

[1] Kapon E, Hwang D M and Bhat R: Phys. Rev. Lett., 63 (1989) 430.

[2] Koshiba S, Noge H, Ichinose H, Akiyama H, Nakamura Y, Inoshita T, Someya T, Wada K, Shimizu A and Sakaki H: Solid-State Electronics, 37 (1994) 729.

[3] Fujikura H and Hasegawa H: J. Electron. Mater., 25 (1996) 619.

[4] Wang X L, Ogura M and Matsuhata H: Appl. Phys. Lett., 66 (1995) 1506.

[5] Sato T, Tamai I and Hasegawa H: presented at ISCS 2001.