Extended Abstracts of the 2000 International Conference on Solid State Devices and Materials, Sendai, 2000, pp. 504–505

D-7-4

Lateral Thickness Modulation of InGaAs/GaAs Structures by Selective Area MOVPE

T. Terasawa, F. Nakajima, J. Motohisa and T. Fukui

Research Center for Interface Quantum Electronics (RCIQE), Hokkaido University,
North 13 West 8, Sapporo 060-8628, Japan
Phone: +81-11-706-7172 Fax: +81-11-716-6004 E-mail: terasawa@rciqe.hokudai.ac.jp

1. Introduction

Selective area metalorganic vapor phase epitaxy (SA-MOVPE) is a very promising method for the formation of quantum nano-structures, as well as integrated optical devices. In our previous report, GaAs single electron transistor (SET) having a quantum dot connected with wires through tunneling barriers was successfully formed by SA-MOVPE [1]. For the formation of SET structures by crystal growth, the lateral thickness modulation is important to introduce lateral quantum confinement. In SA-MOVPE, group III atoms diffuse from masked area and sidewall facets to form quantum structures on top of selectively grown layers. Therefore, the mask design and growth conditions are the key issues for the formation of quantum nano-structures. In this paper, we report on the detail investigation of the lateral thickness modulation of InGaAs/GaAs structures depending on the mask design and growth condition.

2. Experimental procedures

Figure 1 shows the mask pattern of the substrate. SiN_x masked (001) GaAs was used as a substrate. Wire-like opening of 1 μm and 3 μm widths connected with a taper region were formed along the [110] direction by electron beam lithography and wet chemical etching. These wire-like opening patterns were periodically formed to the [-110] direction, and the position of the taper part is offset to the [110] direction by 0.5 μm in every pattern. This enabled us to observe the thickness modulation of InGaAs in the [110] direction simultaneously with one cleaved cross section of a wafer. The cross section of the layer structure is shown schematically in Fig. 2. First, a GaAs buffer layer was grown on the masked substrate. Next, a thin $In_{0.22}Ga_{0.78}As$ layer was grown under three different growth conditions. The growth temperatures and the partial pressures of arsine (AsH_3) were 550℃, 6.7×10^{-4}atm (sample A), 600℃, 6.7×10^{-4}atm (sample B), and 600℃, 1.3×10^{-4}atm (sample C), respectively. Finally, a GaAs cap layer was grown. The growth thicknesses of the GaAs buffer, InGaAs, and GaAs cap layers were 400nm, 8nm, and 90nm on a planar substrate, respectively. After the growth, plan views and cleaved cross sections of the epitaxial wafers were observed by high-resolution scanning electron microscope (SEM).

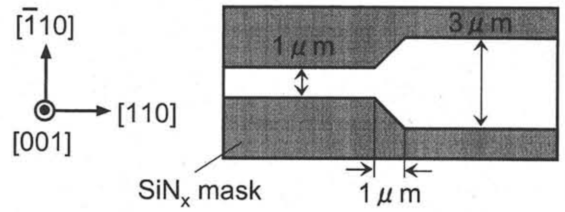

Fig. 1 Schematic illustration of the mask pattern

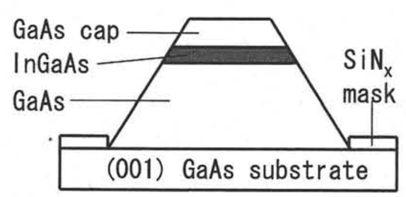

Fig. 2 Schematic cross section of grown structure

3. Results and discussion

Figure 3 shows a plane view SEM image of the sample after the growth. The sidewalls were consisting of {111}B and {011} facets at wire and taper regions, respectively. The growth thicknesses of InGaAs layer versus the positions of cleaved cross sections are plotted in Fig. 4. The vertical axis indicates growth thickness enhancement ratio to that on a planar substrate (8nm). The horizontal axis X represents the position of cleaved cross section, and is defined in Fig. 3. The origin of the X axis corresponds to the narrow end of the taper.

The InGaAs growth thicknesses are enhanced at all the regions. This enhancement is caused by the atom migration mainly from sidewall facets and partly from masked area [2]. Furthermore, it is higher at narrower wire region. This can be readily explained by the fact that the almost same amount of In and Ga atoms migrate from {111}B sidewall facet to the top (001) terrace region, and that their concentration is higher for narrower wire regions. In addition, we can see the transition at the taper region, which strongly depends on the growth condition. That is, in sample A, in which InGaAs layer is grown at 550℃ with AsH_3 partial pressure of 6.7×10^{-4}atm, the transition is abrupt, while thickness modulation becomes gradual for higher temperature or lower AsH_3 partial pressures.

The change of the lateral thickness modulation is mainly explained by the difference of the diffusion length on (001) surfaces, as shown in Fig.5. In addition, we should take into account the difference of the net diffusion from sidewall facets. For the wire regions having {111}B sidewall facets, no overgrowth was observed on {111}B facets in the growth condition investigated here. On the other hand, the overgrowth on the {011} facets was observed and its amount depends on the growth condition; for lower temperature and higher AsH_3 partial pressure, the amount is larger. Note that the diffusion length on sidewall facets is sufficiently longer than the width of the facets in all the growth conditions. This means that the growth species supplied by the diffusion from {011} facets depend critically on the growth condition. It is generally expected that the profile on the (001) surface becomes steeper for less supply from the sidewalls. Therefore, abrupt transition of thickness at the taper region for sample A is also due to the suppression of supply of growth species from {011} sidewall facets.

In our SET structures studied previously, we proposed that quantum dots were formed by the lateral thickness modulation of GaAs layer along the channel and the depletion layer from sidewalls [1]. Our present results clearly demonstrate the presence of such thickness modulation. Our results also indicates that the lateral thickness modulation along the X direction (along the channel) becomes more abrupt if one suppresses the diffusion at (001) surface and the supply of growth species from sidewall facets at the transition region. Therefore, abrupt change in the lateral thickness can be achieved by reducing the growth temperature and the design of the mask pattern which utilizes the different nature of {111}B, {011} and {111}A sidewall facets and its dependence on the growth conditions, and SA-MOVPE is useful for the fabrication of quantum structures having strong lateral quantum confinement.

4. Summary

We investigated the lateral thickness modulation of InGaAs/GaAs structures in SA-MOVPE. The results indicate that the thickness modulation of InGaAs layer takes place for the mask pattern on the taper region, and it critically depends on the growth condition. It is possible to achieve abrupt change of the lateral thickness by the optimization of the growth conditions for the fabrication of quantum structures, such as SETs, with strong quantum confinement.

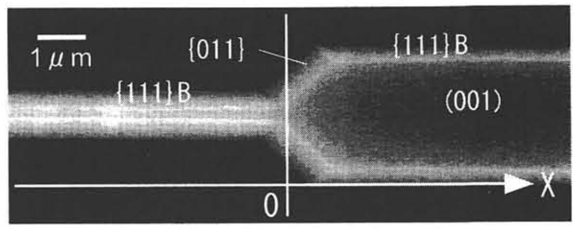

Fig. 3 a plane view SEM image of the sample after the growth

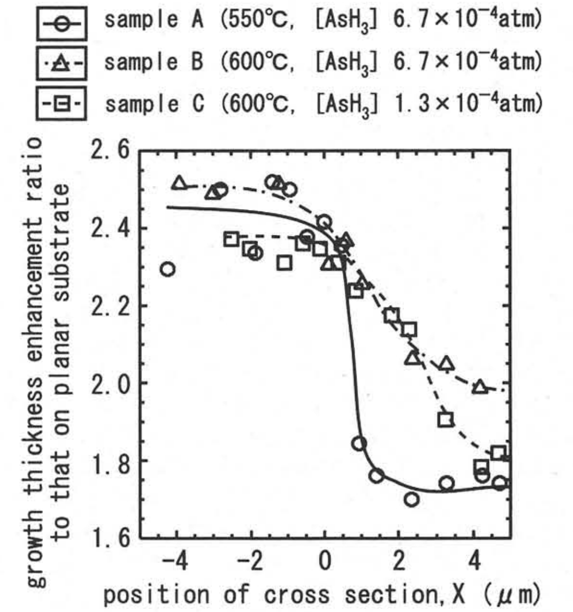

Fig. 4 The growth thickness of InGaAs layer versus the position of cleaved cross section

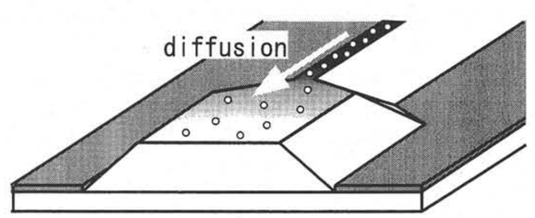

Fig. 5 Schematic illustration of the diffusion of surface migrating atoms on (001) terrace

References

[1] K. Kumakura, J. Motohisa, T. Fukui, Physica E 2 (1998) p. 809

[2] Y. Arituka, T. Umeda, J. Motohisa, T. Fukui, Mat. Res. Soc. Symp. Proc. 570 (1999) p. 97.