Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 94-95

E-1-3

Selective MBE Growth of GaAs Hexagonal Nano-wire Networks on (111)B Patterned Substrates

Souichi Yoshida, Isao Tamai, Taketomo Sato 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
Phone: +81-11-706-7171 E-mail: souichi@rciqe.hokudai.ac.jp

1. Introduction

Recently, intensive research efforts have been made for realization of high-density large-scale quantum integrated circuits (Q-LSIs) based on semiconductor quantum nano-devices. For example, the binary decision diagram (BDD) quantum circuit approach proposed by our group [1] is one of the most realistic approaches for high density Q-LSIs. Key-points here are how to control the size and position of basic quantum wires (QWRs) and quantum dots (QDs) as well as how to combine these structures into circuit networks with high integration density.

Among the various formation techniques, selective MBE/MOVPE growth using patterned substructures is one of the promising techniques to fabricate quantum structures with high position-and size controllability [2-4].

The purpose of this paper is to investigate feasibility of forming GaAs/AlGaAs close-packed hexagonal nano-wire networks by selective MBE growth on pre-patterned GaAs (111)B substrates. Our previous work [3,4] has been done on the conventional (001) substrates where wire width and height tend to become different depending on the wire direction. On (111)B substrates, formation of networks having three-fold symmetry may become feasible.

2. Experimental

Figures 1(a) and (b) show substrate patterns used for selective growth experiments. As the basic wire direction to form a hexagon, three equivalent <-1-12> orientations were chosen, since they possess three-fold symmetry with a rotation angle of 120° on (111)B plane.

Basic feasibility of growth of <-1-12> oriented QWRs was first investigated using a pattern for straight wires shown in **Fig. 1(a)**. After optimization of growth conditions, hexagonal nano-wire networks were fabricated on the pattern shown in **Fig. 1(b)**. These patterns were prepared on semi-insulating (111)B GaAs substrates by photo-lithography and H_3PO_4-based chemical etching.

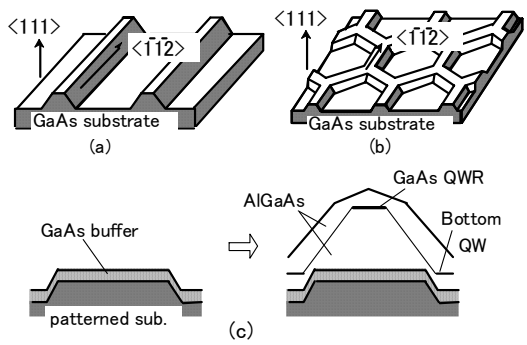

Fig.1 Patterned substrates for (a) straight nano-wires and (b) hexagonal networks. (c) Selective growth sequence.

The growth sequence is shown in **Fig. 1(c)**. It is similar to our selective growth process of <-110>-oriented GaAs QWRs on (001) substrates [4]. After a thermal cleaning in the MBE chamber for native oxide removal, a GaAs buffer layer was first grown on mesa patterned substrates. Then, self-organized QWR growth was attempted by supplying $Al_{0.3}Ga_{0.7}As$/GaAs/ $Al_{0.3}Ga_{0.7}As$ sandwiched layers.

3. Results and Discussion

Growth of straight nano -wires in <-1-12> direction

Figure 2 shows the cross-sectional SEM image of GaAs nano-wire grown on <-1-12>-oriented straight mesa-patterns. The mesa formed by wet chemical etching consisted of a top (111)B facet and side (3-11) facets. Subsequent growth of a GaAs buffer layer followed the substrate pattern. Further supply of a thick AlGaAs layer formed the same AlGaAs mesa structure with a reduced top width. Then, GaAs nano-wire was selectively formed on the narrow top facet of AlGaAs mesa, leading to formation of an entirely embedded QWR after supply of a top AlGaAs layer as shown in **Fig. 2**. Quantum wells (QWs) were also formed on the bottom of the mesa.

Figure 3 plots the measured values of the width of GaAs nano-wires as a function of AlGaAs supply thickness, t_{AlGaAs}. Here, the wire width, w, is normalized by the top width, w_0, of the initial mesa pattern. As expected, the wire width decreased linearly as t_{AlGaAs} increased. Furthermore, it was found that the slope of the plot changes with the substrate temperature, T_{sub}, being similar to the case of <-110>-oriented wires formed on (001) substrates [4]. This is probably due to the difference in

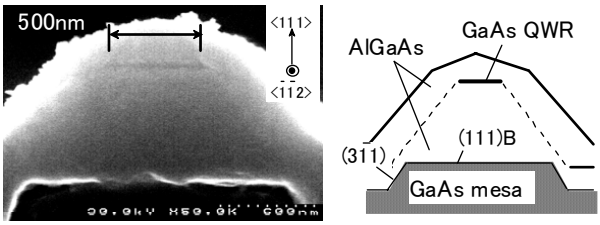

Fig.2 Cross-sectional SEM image of <-1-12>-oriented GaAs nano-wire.

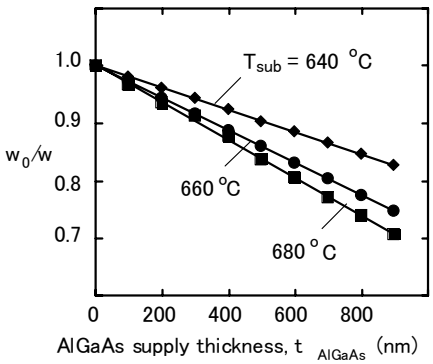

Fig.3 Plot of wire width vs. AlGaAs supply thickness.

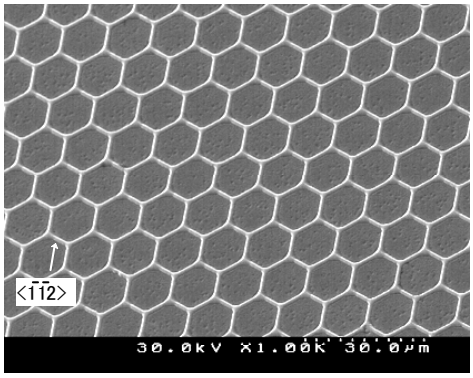

Fig.4 Top view of hexagonal nano-wire network formed by selective MBE growth.

migration and atom incorporation rates between on (111)B and (3-11) facets, where the growth rate on (111)B plane is much larger than that on side (3-11) facets.

Fabrication and characterization of hexagonal nano-wire networks

Figure 4 shows a plan-view SEM image of the hexagonal nano-wire network selectively grown on the patterned substrate shown in **Fig. 1(b)**. From the detailed AFM measurements, it was found that growth at relatively high values of T_{sub} around 700°C with a low As pressure gave the most uniform surface morphology with a rms roughness of 2.3 nm. These growth conditions are different from those for growth on (001) substrates.

In order to clarify the optical properties of hexagonal nano-wire networks, PL and CL measurements were performed. **Figure 5** shows the PL spectra obtained from the sample grown at T_{sub}=700°C. Two sharp emissions were observed at 1.65 eV and 1.69 eV in addition to a broad emission around 1.85 eV coming from the AlGaAs barrier layer The full width at half-maximum (FWHM) of observed two sharp peaks were about 30meV, indicating the formation of uniform quantum structures over a large area by the present selective growth technique.

From detail CL measurements shown in **Figures. 6(a) and (b)**, PL peaks observed at 1.69 eV and 1.65 eV were assigned to emission from the top QWRs and from the bottom QWs, respectively. Furthermore, <-1-12>- oriented

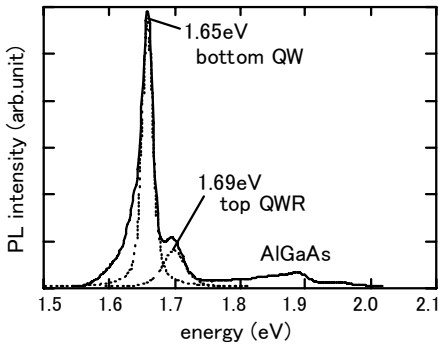

Fig.5 PL spectra from hexagonal nano-wire network.

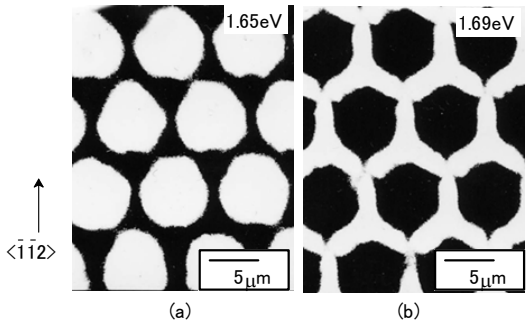

Fig.6 Monochromatic CL images of hexagonal nano-wire network measured at (a) 1.65eV and (b) 1.69eV.

wires were spatially connected. These results indicate that the present technique is promising to form the hexagonal nano-wire network for BDD based Q-LSIs.

4. Conclusion

High quality <-1-12>-oriented QWRs could be selectively grown on (111)B GaAs substrates. The width of QWR could be precisely controlled by the supply thickness of AlGaAs barrier layer and the initial pattern size. GaAs hexagonal nano-wire networks having three fold symmetry were successfully fabricated on patterned (111)B substrates using selective MBE growth. The result indicates that the present technique is promising to form the close-packed hexagonal nano-wire networks with smooth wire connections.

Acknowledgement

The work reported here is supported in part by 21st Century COE Project on "Meme-Media Technology Approach to the R&D of Next-Generation Information Technologies" from Japanese Government.

References

[1] S. Kasai and H. Hasegawa, IEEE Electron Device Letters 23. 446 (2002)

[2] S. Koshiba et al, Solid-State Electronics 37. 729 (1994)

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

[4] T. Sato, I. Tamai and H. Hasegawa, presented at ISCS 2002, to appear in IOP Conf. Ser. (2003)