Selective MBE Growth of High-Density Hexagonal Nanowire Networks on Pre-Patterned GaAs (001) and (111)B Substrates

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Recently, intensive research efforts have been made on high-density and large-scale integration of semiconductor quantum devices to realize future quantum LSIs (Q-LSIs). Selective MBE growth is one of the most promising techniques to form size- and position-controlled III-V nano-structures required to realize such LSIs. The purpose of this study is to attempt to grow high-density hexagonal quantum wire (QWR) networks on GaAs (001) and (111)B substrates on the basis of proper understanding of the evolution mechanism of the QWR cross-section. Such networks will be useful for implementation of the hexagonal binary decision diagram (BDD) Q-LSI architecture [1,2].

The initial patterns and material supply are shown in **Figs. 1(a)** and **(b)**, respectively. As the wire directions to form a hexagon, <-110>- and <510>-orientations were chosen for (001) substrates, and three equivalent <-1-12>-orientations were chosen for (111)B substrate.

First, selective growth conditions were optimized, using straight mesa-patterns. **Figures 2(a) and (b)** show the cross-sectional SEM images of <-110>- and <-1-12>-oriented straight nanowires. Cleavage followed by stain etching revealed that GaAs nanowires were selectively formed on the top of AlGaAs ridges with lateral sizes smaller than the initial mesa width. By repeated wire growth experiments, existence of two facet boundary planes (FBPs) separating the region grown on the top facet and those grown on the side facets was recognized within AlGaAs layers. These FBPs determine the position and lateral width of the QWR for all the wire directions studied.

Figures 3(a) and (b) summarize the measured wire width normalized by the initial mesa width for <-110>- and <-1-12>-oriented wires as a function of the supply thickness, t_{AlGaAs}, of AlGaAs layer defined in **Fig. 1(b)**. The width decreased with increase of t_{AlGaAs}, whose rates were larger at higher T_{sub}. Growth simulation combined with measurements on each facet indicated that cross-sectional structure of QWR is determined kinetically by facet-dependent atom migration and incorporation processes. As shown in **Figs. 3 (a) and (b)**, theoretical lines obtained by simulation reproduced the experiment very well.

Then, attempts to grow hexagonal networks were made. SEM images taken after QWR growth on (001) and (111)B hexagonal patterns with a hexagon density of 3.2×10^8 cm^{-2} are shown in **Fig. 4(a)**. Good surface morphology with rms value of 2.0 nm was obtained on both substrates. **Figure 4(b)** shows the results of PL and CL measurements on the sample grown on thee (111)B substrate. The spatial resolved CL image showed that the QWRs were smoothly connected with the confinement energy of 1.63 eV. These results indicate that the present process is suitable for the formation of high-density quantum nano-structures. Further increase of hexagon density seems to be feasible by pattern size reduction and growth optimization.

[1] S. Kasai and H. Hasegawa: IEEE EDL, 23 (2002) 446.
[2] H. Hasegawa: Proc. of ECS 2001 / 6th International Symposium on Quantum Confinement 19, (2001) 189.

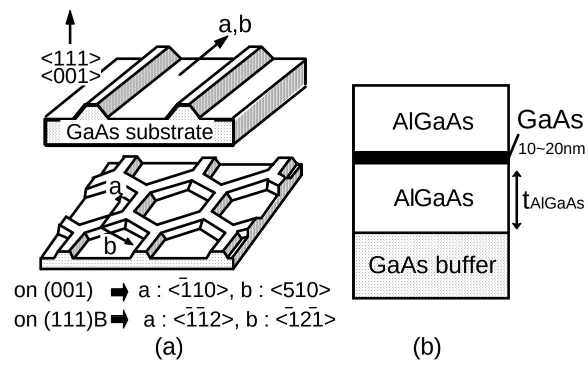

Fig. 1 (a) Patterned substrates and **(b)** material supply used in this study.

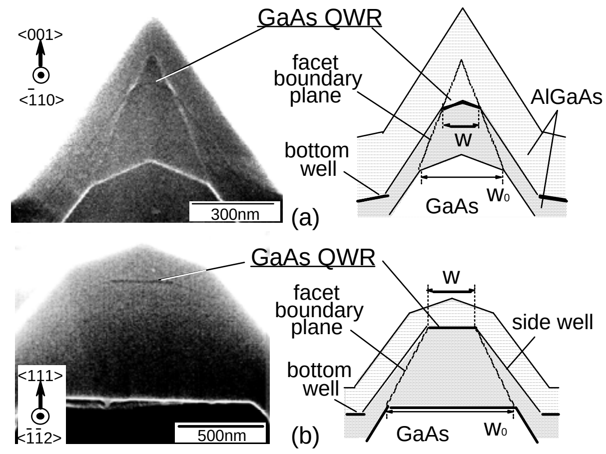

Fig. 2 Cross-sectional SEM image of **(a)** <-110>-oriented QWR grown on (001) substrate and **(b)** <-1-12>-oriented GaAs QWR grown on (111)B substrate.

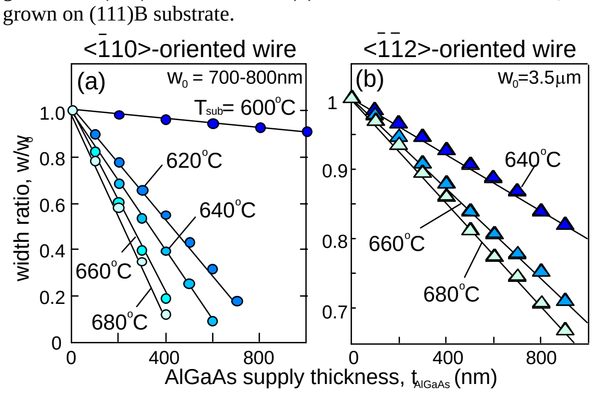

Fig. 3 Wire width ratio vs. t_{AlGaAs} for **(a)** <-110>- and **(b)** <-1-12>-oriented wires.

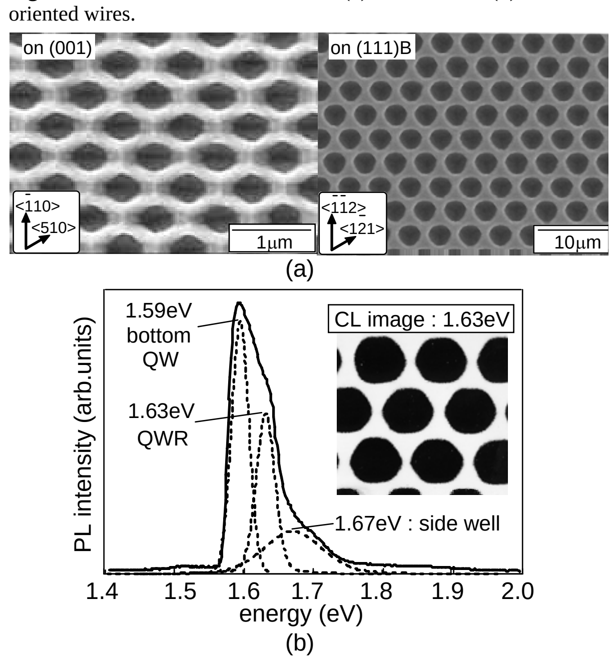

Fig. 4 (a) SEM images of hexaganal networks and **(b)** PL spectra with monochromatic CL image obtained on (111)B samples.