Three-dimensional AlGaAs nano-heterostructures using both VLS and MOVPE growth mode

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1. Introduction

The fabrication of nano-sized structures is attractive from the viewpoints of fundamental physics and technological applications [1]. Vapor-liquid-solid (VLS) growth is a well-known method for growing semiconductor nanowires. Heterostructures and p-n junctions have already been demonstrated, which may lead to the use of VLS-grown nanowires in electrical and optical nano-devices. Recently, we have reported AlGaAs-buried nanowires that show improved photoluminescence characteristics compared with bare nanowires [2]. For the VLS growth mode, the growth occurs only at the Au particles, which act as catalysts, towards the [111]B direction. For the metalorganic vapor phase epitaxy (MOVPE) growth mode, the growth occurs over the entire surface. Combining these two modes, we can make three-dimensional (3D) nano-heterostructures. One of the features of this technique is that they can be made in situ by the bottom-up approach, that is, only by changing the growth temperature and source flow rates. Figure 1 shows illustrations of cross-sections of the 3D nano-heterostructures obtained using this technique. The 3D structure shapes that can be obtained with this technique are limited, but the technique is very easy. In addition, there are no damage-causing or air-exposure processes, so good crystal quality is expected. Below, we show several 3D nano-heterostructures and discuss some of their features.

2. Experimental

The VLS and MOVPE growth modes were carried out in a low-pressure MOVPE reactor. Trimethyl-gallium and trimethyl-aluminum were the group-III sources, and AsH_3 was the group-V source. GaAs(311)B substrates were used in this study. After the GaAs substrates were cleaned by slight wet etching, Au was evaporated in a vacuum system. The Au thickness was less than one monolayer. Au particles formed during the wire growth when the temperature was raised to 700 ˚C in the AsH_3/H_2 gas. The wires were grown at low temperature (400-500 ˚C) under the VLS mode and the buried growth was performed at high temperature (600-700 ˚C) under the MOVPE mode. The structure of the wires was examined by scanning electron microscopy (SEM) and transmission electron microscopy (TEM).

3. Results and Discussions

Figure 2(a) shows the GaAs/AlAs wires buried with $Al_{0.3}Ga_{0.7}As$. First, 250-nm GaAs wires were grown at 470 ˚C, and then 120-nm AlAs wires were grown at 540 ˚C. AlAs was grown at the higher temperature so that it would cover the GaAs wires, which is why the inner wire structure can scarcely be seen in this figure. Finally, $Al_{0.3}Ga_{0.7}As$ was grown in the MOVPE mode at 700 ˚C. The rod structures are similar to each other, which is reflected by the growth feature of GaAs nanowires. The Au particles are at the top of the rods so that they are always on the surface even in the MOVPE mode. By using this feature, the 3D structures in Fig. 1(b) may be possible by repeating growth in VLS and MOVPE modes.

Figure 2(b) shows the repeated GaAs/AlAs nanowires buried with repeated GaAs/AlAs layers. GaAs/AlAs wires were grown at 470 ˚C, and GaAs/AlAs burying layers were grown at 700 ˚C. Because of the high contrast between GaAs and AlAs materials, the growth process can be clearly seen in this figure. For VLS-grown nanowires, three blurry white spots are seen in the cross-sectional image, which occurred due to the heterostructures. The shapes of the rod structures are not smooth enough. This is because AlAs does not well diffuse compared with GaAs.

Here, the burying layers are not thick enough to get flat surfaces. A critical problem here is twin formation in nanowires [3], which causes many defects in the burying layers. As a result, the surface morphology is degraded. So it is considered that the application may be limited to using individual rod structures unless a technique for growing single crystal can be found.

4. Conclusion

Using both the VLS and MOVPE growth modes, we have successfully grown 3D nano-heterostructures. Smooth and well-shaped structures are possible, but twin formation in nanowires is a problem in obtaining flat surfaces with good morphology.

References

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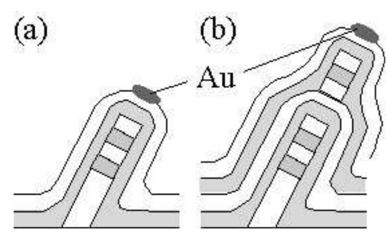

Fig. 1. Illustrations of 3D nano-heterostructure cross sections. (a) One process and (b) two processes of VLS and MOVPE growth modes.

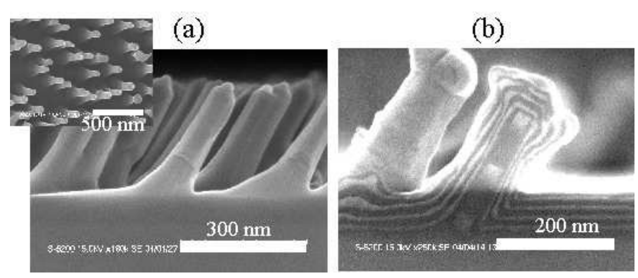

Fig. 2. SEM images of 3D nano-heterostructure cross sections. (a) AlGaAs buried structures (inset is top view) and (b) repeated GaAs/AlAs buried structures.