Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp1275-1276

Lateral GaAs nanowires with triangular and trapezoidal cross-sections grown on (311)B and (001) substrates

Guoqiang Zhang, Kouta Tateno, Hideki Gotoh, and Tetsuomi Sogawa

NTT Basic Research Laboratories, NTT Corporation, 3-1 Morinosato-Wakamiya, Atsugi, Kanagawa 243-0198, Japan
Phone: +81-46-240-2827 E-mail: zhang@will.brl.ntt.co.jp

1. Introduction

Semiconductor nanowires (NWs) have attracted much attention because of their exceptional versatility and wide range of potential applications, from electronics and photonics to biochemistry [1,2]. If NWs are to find photonics applications, a fundamental issue involves understanding and controlling their optical properties. It had been found that these optical characteristics can be effectively tuned by controlling such NW structural parameters as composition [3], diameter [4], and cross-sectional shape [5-7].

Recently, we developed an approach for growing lateral GaAs NWs with a <110> orientation on (311)B substrates in the Au-catalyzed vapor-liquid-solid (VLS) mode. We controlled the size and density of the lateral NWs by using size- and density-selective Au colloidal particles. The sites of the lateral NWs were also controlled by using a Au dot array defined by electron beam lithography [8]. Another research group has demonstrated that lateral NWs can be removed from as-grown substrates and printed on substrates made of different materials [9]. The high controllability of the lateral NWs suggests various potential applications to optical and electrical nanoscale devices. Moreover, we found that the lateral GaAs NWs grew with extremely small diameters (1-5 nm) of less than the exciton Bohr radius. This made the NWs sufficiently small for use in quantum devices. Since theoretical work indicates that the band structure of the quantum NWs depends significantly on the shape of the 2D quantum confinement, i.e., the relative confinement strength in the lateral and vertical directions [4], we can expect to alter the optical characteristics of a lateral NW by changing the cross-sectional shape. The goal of the current work is to control the cross-sectional shapes of the lateral NWs. In this article, we demonstrate that using substrates with different orientations is an effective way to change the cross-sectional shapes of the lateral NWs.

2. Experiments and results

Experiments

Size-selective Au colloidal particles (5, 20, 40 nm) dispersed on GaAs substrates were used to realize GaAs NW growth in the VLS mode. We used GaAs (311)B and (001) substrates to grow lateral NWs. The NW growth was carried out in a low-pressure (76 torr) metalorganic vapor phase epitaxy reactor [3,4,8]. Trimethylgallium (TMGa) was the group III source and AsH_3 was the group V source. The carrier gas was palladium-diffused H_2 with a flow rate of 6.0 *l*/min. The flow rates of TMGa and AsH_3 were 4.4×10^{-6} and 2.0×10^{-4} mol/min, respectively. Before TMGa was supplied, the substrates were annealed at 550 °C in H_2 and AsH_3 ambient. After that, the temperature was reduced to the growth temperature (500 °C), and the TMGa source was introduced to initiate growth.

We analyzed the lateral NWs by atomic force microscopy (AFM, Digital Instruments, operated in the tapping mode). The crystallography of the NWs and NW/substrate interface was analyzed by transmission electron microscopy (TEM, Hitachi, H-9000, operated at 300 kV). Sliced specimens for TEM measurement were prepared by using a focused ion beam system (FIB, SII, SMI-3050SE, operated at 30 kV).

Experimental results and discussion

Figures 1a) and b) show AFM images of lateral NWs grown on GaAs (311)B and (001) substrates, respectively. These NWs are aligned parallel to the <110> direction. We obtained the height of the NWs from the surface near the Au particles from the AFM measurement. Figure 2 shows the NW heights, which were determined by averaging data for 20-30 NWs, as a function of the Au particle size. The lateral NW height increases as the diameter of the Au particles increases. It should be noted that the NWs on (311)B are higher than those on (001).

To figure out the height difference between lateral NWs grown on (311)B and (001) substrates, we characterized the structure of cross-sectional shape by TEM. We obtained two images at different positions along the NW growth direction, i.e., one from the middle part and the other from near the Au particle, as indicated by the white arrows in Fig. 1. The cross-sectional TEM images of the lateral NWs grown on (311)B and (001) substrates are shown in Figs. 3, and 4, respectively. The lateral NW on (311)B has an asymmetric triangular cross-section, as seen in Fig. 3a). In Fig. 3b), a NW segment is clearly observed between the Au particle and the underlying layer. Moreover, the NW is faceted by {111}B on the left side and {001} on the right side, as indicated in the figure. In contrast, Fig. 4a) shows that the lateral NW on (001) has a symmetric trapezoidal cross-section. A {001} facet appears at the top of the lateral NW. Figure 4b) shows that the lateral NW is symmetrically faceted on both sides by identical facets.

The above results indicate that the cross-sectional shape of the lateral NW changed from triangular to trapezoidal when the substrate was changed from (311)B to

(001). The fundamental reason for this transition is that the system minimizes the surface energy of the lateral NW. This is achieved by reconstructing the side facet structure, which normally consists of facets with relatively low surface energies such as {111}B and {001}. When grown on (311)B, the lateral NW has {111}B and {001} facets instead of a (311)B facet because the (311)B facet has a relatively high surface energy. When grown on (001), the lateral NW has a top {001} facet because of its low surface energy [11]. Although {111}B has the lowest surface energy, the side facets of the lateral NWs grown on (001) are not {111}B, but {115} B or other high-index facets. This may be induced by the facet transition in the lateral NW. A similar phenomenon has been observed with SiGe islands self-assembled on a Si substrate [10].

3. Conclusions

In conclusion, the cross-sectional shape of lateral NWs can be varied by using substrates with different orientations. Lateral NWs with triangular and trapezoidal cross-sections were grown on (311)B and (001) substrates.

Acknowledgements

We thank Dr. Hiroki Hibino of NTT BRL for support with the AFM measurement and Dr. Toshitsugu Mitate of NTT Advanced Technology Corporation for his technical assistance with the TEM measurement.

References

[1] L. Samuelson, Mater. Today **6** (2003) 22.
[2] Y. Li, et al., Mater. Today **9** (2008) 18.
[3] K. Tateno, et al., Nano Lett. **8** (2008) 3645.
[4] G. Zhang et al., Appl. Phys. Lett. **95** (2009) 123104.
[5] H. Ando, et al., J. Appl. Phys. **74** (1993) 6383.
[6] X. Wang, et al., J. Cryst. Growth **213** (2000) 19.
[7] T. Sogawa, et al., Appl. Phys. Lett. **67** (1995) 1087.
[8] G. Zhang, et al., Nanotechnology **21** (2010) 095607.
[9] S. A. Fortuna, Nano Lett. **8** (2008) 4421.
[10] R. S. Williams, Accts. Chem. Res. **32** (1999) 425.
[11] N. Chetty, Phys. Rev. B **45** (1992) 6074.

Figures and captions

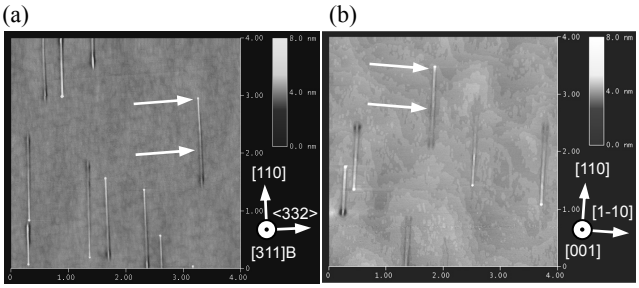

Fig. 1 AFM images of lateral GaAs NWs grown on (a) (311)B and (b) (001) substrates using 5-nm-diameter Au particles.

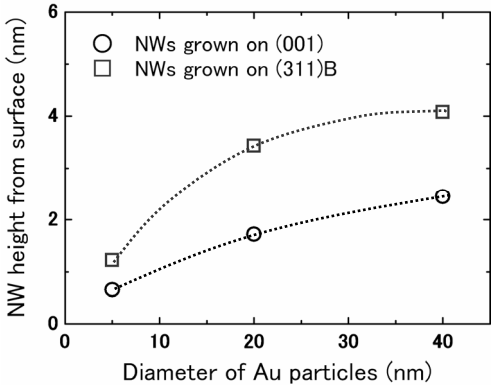

Fig. 2 NW height as a function of the diameter of Au colloid particles for lateral NWs grown on (311)B and (001) substrates.

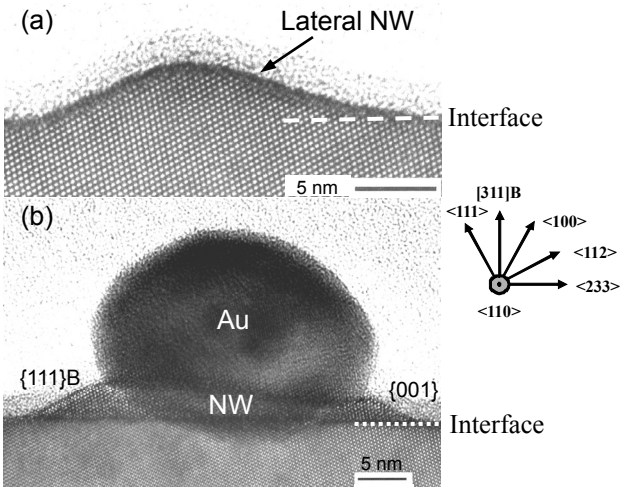

Fig. 3 TEM images of lateral GaAs NWs grown on a (311)B substrate near (a) the center and (b) a Au particle.

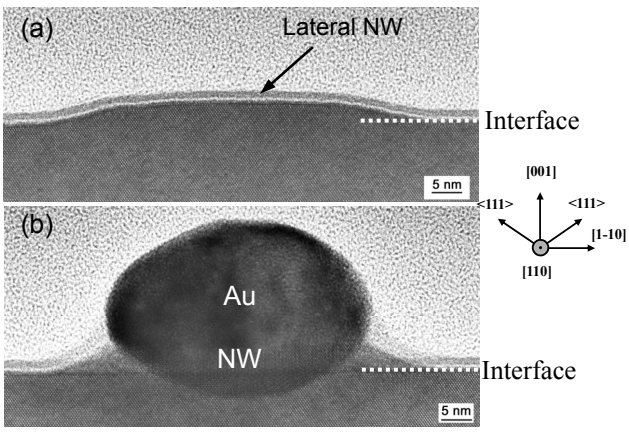

Fig. 4 TEM images of lateral GaAs NWs grown on (001) substrate near (a) the center and (b) a Au particle.