PS-8-01

Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp1137-1138

Molecular Beam Epitaxial Growth of Dense GaAs/GaNAs Core-Multishell Nanowires on Silicon and SOI

Mitsuki Yukimune, Ryo Fujiwara, and Fumitaro Ishikawa

Ehime Univ
3, Bunkyo-cho, Matsuyama
Ehime 790-8577, Japan
Phone: +81-89-927-9765 E-mail: ishikawa@ee.ehime-u.ac.jp

Abstract

We grow GaAs/GaNAs/GaAs core-multishell nanowires with their density in the order of 10^8cm^{-2} by molecular beam epitaxy (MBE). The MBE is equipped with water cooled shroud, resulting in non-efficient adsorption of As vapor in the MBE growth chamber. Nanowires were grown by plasma-assisted molecular beam epitaxy using constituent Ga-induced vapor-liquid-solid growth on Si(111) substrates and silicon(111) on insulating (SOI) substrate. Probably due to the scattered As within the MBE growth chamber, As impinges on the substrate induces nanowires having non-controlled directions as well as large nanowire density. On the other hand, the structure of each nanowires are precisely controlled and showing clear formation of core-multishell structure.

1. Introduction

III-V semiconductor nanowires (NWs) are promising as building blocks in nanoelectronics and nanophotonics. Dilute nitride GaNAs are materials of physical and technological interest due to the tunability of their lattice constant and band gap. The incorporation of a few percent of nitrogen into GaAs leads to an anomalous reduction of the band gap, which makes this material suitable for applications in near infrared regime light emitters and solar cells [1]. We have recently reported high-quality GaNAs nanowires with 0.5% of N enabling lasing up to 150 K [2]. Such efficient optical characteristics at the near infrared regime should be suitable for solar light absorber, which should be applicable to photovoltaics and/or photosynthesis[3,4]. To enhance the ability for those applications, the volume nanowire is essential. The larger the area and density, the output of those device get larger. Also, to reduce the loss of the current flow, the usage of silicon on insulating (SOI) substrate is preferable for variety of device applications. In this report, we show large density GaAs/GaNAs nanowires gowth on Si and SOI substrate.

2. Experiments

The investigated samples were simultaneously grown on phosphorous-doped n-type Si(111) and SOI substrates in a plasma-assisted molecular beam epitaxy (MBE) system equipped with a water-cooled shroud. [5,6] A conventional solid-source effusion cell was used for supply of Ga, and an As-valved cracker cell was operated in the As_4 mode. Nitrogen was supplied by an electron cyclotron resonance plasma source. The surfaces of the epi-ready Si or SOI substrates were not treated prior to the NW growth. The substrate surface was thus covered with a thin native oxide with a typical thickness of several nanometers. The GaAs NWs core was then formed by vapor-liquid-solid growth assisted by constituent Ga seed particles when Ga and As flux were supplied on the Si substrate.. We grew GaAs/GaNAs/GaAs core-multishell samples by varying the flux of N atoms using the following procedure. The beam equivalent pressure (BEP) of As was adjusted to 4×10^{-3} Pa throughout the growth. The Ga supply was set to match a planar growth rate of 1 ML/s on GaAs(001) before the growth. The V/III BEP ratio was 37 at these conditions. The GaAs core growth was initiated by opening the Ga shutter under an As overpressure and the GaAs core was grown for 30 min at 580 °C. By introducing a growth interruption, the catalyst Ga became crystallized. The Ga flux was reduced to 0.5 ML during the crystallization. Subsequently, the lateral growth became dominant, which was expected to form the wire shells. The first GaAs shell was grown for 20 min, followed by the second growth interruption. During the interruption, the growth temperature was reduced to 500 °C and the nitrogen plasma was ignited. We then grew the GaAs shell for 5 min, the GaNAs shell for 30 min by opening the shutter of the plasma source, and the outermost GaAs shell for 30 min. The nanowire consequently formed a GaAs/GaNAs/GaAs core-multishell structure. The concentration of nitrogen in the GaNAs layer was estimated to be about 3%.

3. Results and Discussions

Figure 1 (a) show the plan-view scanning electron microscope (SEM) images of the NWs. We observe the clear formation of NWs. As seen in the figure, NWs exist over the area having their density in the order of 10^8cm^{-2}. The direction of the wires are not regular. Figure 1 (b) shows an enlarged image of Fig. 1(a). Those NWs typically have a length of 5-6 μm and an average diameter of approximately 350 nm. On the substrate, we also observe areas dominantly having NWs of vertical alignment. Figure 3 (c) shows 30^{o}-tilted SEM image of the NWs on the identical Si substrate for the area dominantly having vertical alignment. As seen in the image, on the are, most of the NWs have vertical alignment. The area without the existence of NWs coule be due to initial substrate condition having some unexpected contamination, or a result of scratch at the handling of the samples. Note that we observe NWs having non-vertical alignment as seen in Fig. 1 (a) and (b) for most of the area on the substrate. Also, we have never achieved this dense NWs density until we employ water cooled shroud, as previously we have used liquid nitrogen-cooling system. As vapor does not efficiently adsorbed on the shroud when we use the water cooling system, hence in that case, As-dominated growth chamber pressure is preserved even though As pressure was terminated by closing valve of As valved cracker cell. Probably, the scattered As species impinge on the substrate surface, which would enhance the nucleation and development of the NWs for arbitrary directions.

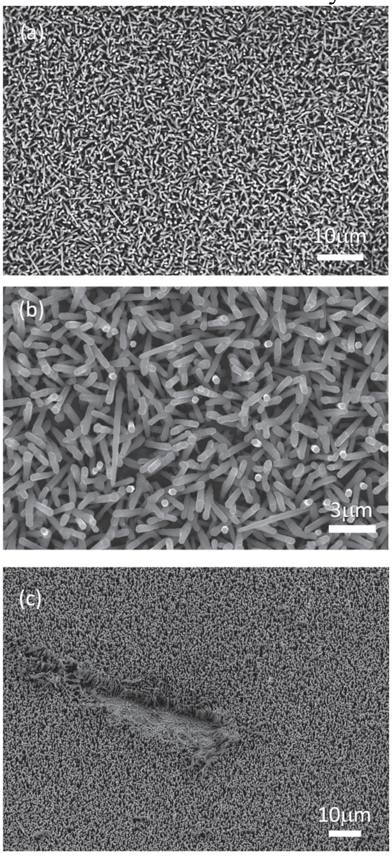

Fig. 1 (a) Plan-view SEM images of nanowires grown on Si substrate, (b) its enlarged image, (c) 30^{o}-tilted SEM image of the nanowires for the area dominantly having vertical alignment on Si substrate.

Fig. 2 shows cross-sectional transmission electron microscope image of nanowires grown on Si. We can observe hexagonal structure having three layered core-multishell structure, corresponding to the intended GaAs/GaNAs/GaAs structure. Hence, individual the NWs observed in Fig. 1(a)-(c) have the observed core-multishell structures.

Fig. 3 (a) is plan-view SEM image of the NWs grown on SOI substrate, and (b) is its enlarged image. The sample was simultaneously grown with the sample shown in Figs. 1 and 2. We confirmed the formation of the NWs, its structure seems to have like a flower seems to be formed by the development of arbitral wires from a cores. The diameter of the wires are about 350 nm, mostly identical with the samples grown on Si, suggesting the formation of the core-multishell NWs shown in Fig. 2. Consequently, we obtained intended dense NWs on both the Si and SOI substrate.

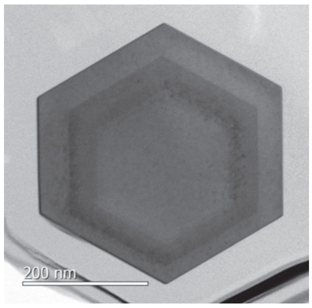

Fig. 1 (a) Cross-sectional transmission electron microscope images of the nanowire grown on Si.

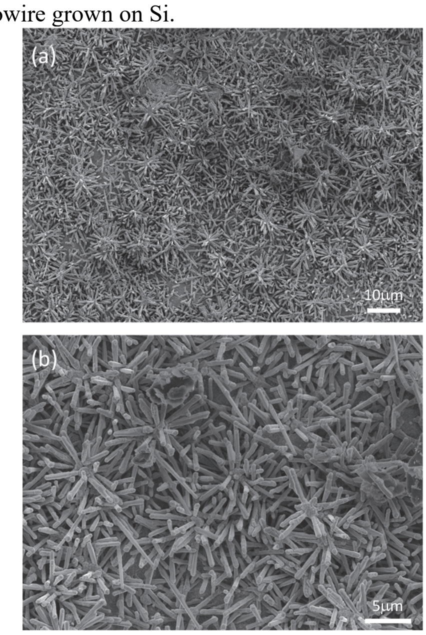

Fig. 3 (a) plan-view SEM image of the NWs grown on SOI substrate, and (b) its enlarged image.

4. Conclusions

We grow GaAs/GaNAs/GaAs core-multishell NWs with their density in the order of $10^{8}cm^{-2}$ by MBE equipped with water cooled shroud. NWs can be formed on Si(111) substrates and SOI substrates. Probably due to the scattered As within the MBE growth chamber, As impinges on the substrate, inducing nanowires having arbitraly directions as well as large nanowire density.

Acknowledgements

We gratefully acknowledge the funding support from KAKENHI (No. 16H05970) from Japan Society of Promotion of Science.

References

[1] Ed. F. Ishikawa and I. A. Buyanova, Novel Compound Semiconductor Nanowires: Materials, Devices and Applications, 2017.

[2] S. Chen, M. Jansson, J. E. Stehr, Y. Huang, F. Ishikawa, W. M. Chen, I. A. Buyanova, Nano Lett. 17 (2017) 1775.

[3] J. A. Czaban, D. A. Thompson, R. R. LaPierre, Nano Lett. 9 (2009) 148.

[4] C. Liu, N. P. Dasgupta, P. Yang, Chem. Mater. 26 (2014) 415.

[5] Y. Araki, M. Yamaguchi, and F. Ishikawa, Nanotechnology 24, (2013) 065601.