Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp1318-1319

Study on the growth of In-rich InGaAs nanowires by selective-area metal-organic vapor phase epitaxy

Y.Kohashi[1], S.Hara[1,2], and J.Motohisa[1]

[1]Graduate School of Information Science and Technology, Hokkaido University,
[2]Research Center for Integrated Quantum Electronics, Hokkaido University,
West 8, North 14, Sapporo 060-0814, Japan,
Phone: +81-11-706-7173, Fax: +81-11-716-6004, E-mail: kohashi@impulse.ist.hokudai.ac.jp

1. Introduction

Epitaxially grown semiconductor nanowires (NWs) have generated much research interest lately because of their unique potential which is quite suitable for future electronic/photonic devices, such as field-effect transistors (FETs) [1], light emitters, solar cells and so on. In particular, FETs using free-standing NWs can suppress short channel effects and provide effective potential control by adapting surrounding-gate structures. In addition, because NWs are three-dimensional structure with ultra small diameter, it enables us to realize high density integration of III-V compound semiconductors on Si platform [2].

Recently, InGaAs has been studied intensively as one of the promising candidate for a channel material in metal-insulator-semiconductor FETs (MISFETs) [3]. This is because their electron mobility and good interface properties, which allow more effective potential control than other III-V semiconductors. However, these excellent properties are very sensitive to the mole fraction of group III atoms [4], suggesting that controlling their In content and quality are critical issues for the device development to fully utilize their advantages.

We have been reporting on catalyst-free selective-area metal-organic vapor phase epitaxy (SA-MOVPE) of InGaAs NWs with various In-compositions [5,6]. In previous reports, we have shown that the growth dynamics is critically dependent on In-composition. Thus, optimized growth condition will also depend on the In-composition we desire.

In this paper, we report on our detailed study on the SA-MOVPE growth of In-rich InGaAs NWs to explore their growth conditions.

2. Experimental Procedures

Procedure of SA-MOVPE for InGaAs NWs is as follows. After the deposition of 10nm-thick SiO_2 film on InP(111)B substrate by RF sputtering, periodic circular opening pattern of SiO_2 was defined by electron-beam (EB) lithography and wet chemical etching. The opening diameter, d_0, of the pattern was 100nm and opening pitch, i.e. their periods, a, was ranged from 200 to 1000nm. Then, NWs were formed in the low-pressure horizontal MOVPE system, supplying trimethylindium (TMIn), trimethylgallium (TMGa), and 20% arsine (AsH_3) diluted in H_2 as source materials. The partial pressures of TMIn, [TMIn] and TMGa, [TMGa] were 1.63×10^{-6}, 0.70×10^{-6}atm, giving [TMIn] to [TMGa] ratio of 7 : 3, and those of AsH_3, [AsH_3] was ranged from 1.25×10^{-4} to 5×10^{-4}atm, giving V/III ratio of 54 to 214. The growth temperature, T_G, was changed from 590 to 650℃. Growth time, t, was 30min. The height, h, and diameter, d, of NWs were measured by SEM. Alloy composition of NWs was estimated by micro-photoluminescence measurements carried out at 4K.

3. Results and discussions

1. Growth of InGaAs nanowires

Figure 1 shows SEM images of InGaAs NWs grown at different T_G and V/III ratio. Pitch, a, of the mask opening was 1000nm. We could observe highly uniform and non-tapered NWs in each condition, while their diameter, d, and height, h, of NWs critically depended on the growth conditions, as we will discuss below.

2. Growth temperature dependence

Plot of NW height, h, and NW diameter, d, versus reciprocal temperature, $1/T_G$, is shown in Fig. 2(a) for V/III = 107 with a = 1000nm. For a = 200 or 500nm at T_G < 620℃, we found h was lower for narrower a, though we did not discuss in detail in this paper because of their poor uniformity. Here, we observed significant increase of h with decreasing T_G, particularly above 620℃, which was attributable to re-evaporation of InGaAs [7]. On the other hand, d of grown NWs was larger than opening diameter, d_0, particularly at low T_G, which indicates some lateral growth.

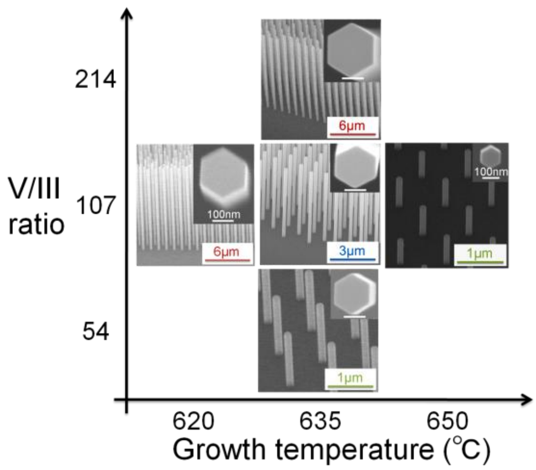

Fig. 1: 45° tilted SEM images of InGaAs NWs grown at different T_G and V/III ratio.Inset shows a top view of the NW. The opening pitch, a, was 1000 nm, respectively. White scale bar : 100nm.

Figure 2(b) shows Ga (In) composition of NWs, plotted as a function of T_G. The alloy composition and their error bars were estimated from PL peak energy position and full width at half maximum (FWHM). Their composition was clearly dependent on T_G, where In-composition increased as T_G decreased. This trend is similar to the case of InGaAs NWs grown under Ga-rich supply condition ([TMIn]:[TMGa] = 8:92) [6]. They argued that, in Ref. [6], this is probably due to the increase of As trimer coverage on (111)B NW top facet [8] with decreasing T_G, resulting that Ga atoms become difficult to incorporate into the NW, compared with In atoms.

3. V/III ratio dependence

Dependence of *h* and *d* on V/III ratio is shown in Figs. 3(a) and 3(b). Here, *h* and *d* are plotted as a function of logarithm of V/III, for each opening-pitch, *a*. Both *h* and *d* increased with increasing V/III. This trend of *h* is contrary to GaAs NWs [9], where higher V/III (AsH_3 partial pressure) leads to increase of As trimer coverage on (111)B [8] and is thought to be resulted in the reduction of growth rate. Rather, it is in accordance with InAs NWs [10]. This suggests that it becomes close to the InAs for In-rich InGaAs NWs and supports an idea for In-composition dependent growth dynamics [7]

Figure 3(c) shows dependence of Ga (In) composition on V/III ratio. Surprisingly, Ga (In) composition is almost constant with the change of V/III, in spite of their length was varied significantly. In addition, this trend was confirmed for each *a*. These results suggest that the influence of V/III variation for NW growth is different from those of T_G.

4. Optimum growth conditions for In-rich InGaAs NWs

To obtain thin NWs with desired length, it is necessary to achieve low radial (lateral) growth rate, while maintaining moderate axial (vertical) growth. Decrease of T_G resulted in an enhancement of axial growth but in a significant increase of *d*. On the other hand, increase of V/III ratio resulted in large enhancement of axial growth and small increase of radial growth. Thus it is considered that optimum growth condition for In-rich InGaAs would be in the slightly high T_G and V/III ratio regime, for instance, 620℃<T_G< 650℃, and V/III>100. For higher-temperature growth, it is noted that In-composition of grown NW is smaller than the ratio of material supply. Therefore, we have to have more TMIn supply to compensate this effect and to achieve desired In-composition in NWs.

References

[1] Q.-T. Do *et al.*, IEEE Elect. Dev. Lett. **28** (2007) 682
[2] T.Tanaka *et al.*, APEX. **3** (2010) 025003
[3] Y.Xuan *et al.*, IEEE Elect. Dev. Lett. **29** (2008) 294
[4] H.H. Wieder *et al.*, J. Vac. Sci. Technol. *B*, **20** (2002) 1759
[5] T.Sato *et al.*, JCG. **310** (2008) 5111
[6] M.Yoshimura *et al.*, JJAP. **49** (2010) 04DH08
[7] Y.Kohashi *et al.*, presented at ISCS 2011 (2011)
[8] T.Nishida *et al.*, JJAP. **34** (1995) 6326
[9] J.Noborisaka *et al.*, APL. **86** (2005) 213102
[10] K.Tomioka *et al.*, JCG. **298** (2007) 644

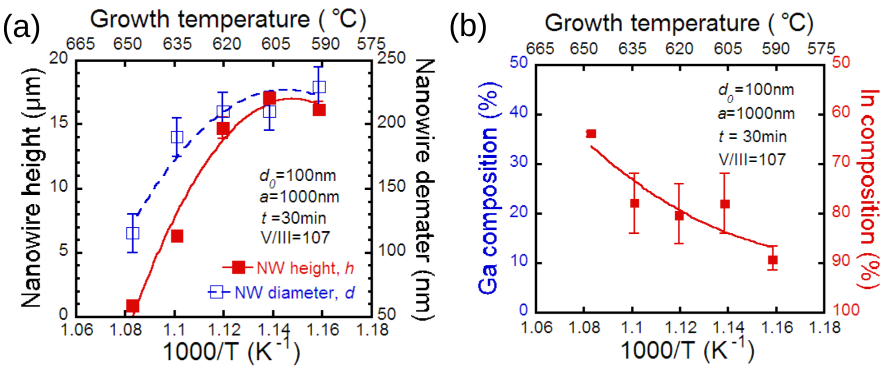

Fig. 2: Temperature dependence of nanowire (a) height, *h*, and diameter, *d*, and (b) composition. The error bar in (a) shows maximum & minimum and in (b) shows FWHM, respectively.

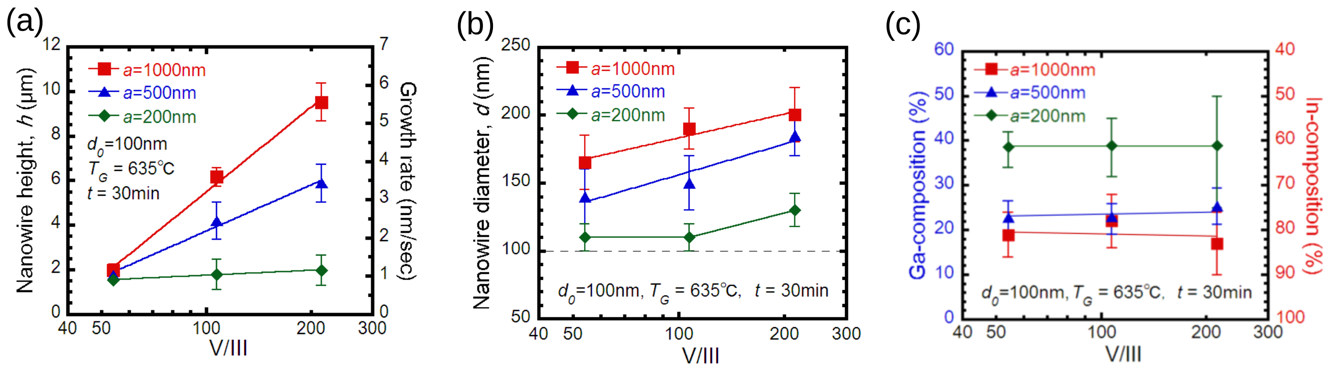

Fig. 3: V/III ratio dependence of nanowire (a) height, *h*, (b) diameter, *d*, and (c) composition. The dashed line of inset (b) shows d_0. The error bar in (a),(b) shows maximum & minimum and in (c) shows FWHM, respectively.