Comparison of self-assisted VLS GaAs nanowires grown by MBE on Si (111) and GaAs (111)B substrates

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Abstract In this work GaAs nanowires were grown by self-assisted growth method with completely identical growth parameters, such as growth temperature, growth time, Ga and As flux, on GaAs (111)B and Si (111) substrates using Molecular Beam Epitaxy (MBE). All samples were then characterized by Scanning Electron Microscope (SEM), Energy-dispersive X-ray spectroscopy (EDX), and X-ray Diffraction (XRD). The results from both substrates were compared in order to understand the effect of substrate type on nanowires.

1. Introduction

Nanowire growth method has been an interesting topic recently due to gaining popularity of using nanowires in electrical and optical applications [1][2][3]. First nanowire growth method was proposed by Wagner and Ellis in 1964 [4]. Their Au-assisted Vapor Liquid Solid (VLS) method utilizes Au droplets as seed particles to grow nanowires. This growth method is very well-known and convenient however it comes up with a problem of gold contamination which can cause negative effects to electrical and optical properties of nanowires. To eliminate the problems from Au contamination, Fontcuberta proposed self-assisted VLS method in 2008 [5]. Instead of Au, this method utilizes an element metal which is the composition of nanowire as seed particles, and ultra-thin SiO₂ layer deposited on substrate surface improves growth rate of nanowires by a reasonable margin. This has been one of the most developed technique to grow the compound semiconductor nanowires up to date. However as good as it may look, this method still possesses some crucial problems such as occurrence of parasitic growth on SiO₂ layer [6], and tilted or non-directional growth nanowires caused by non-uniformity thickness of SiO₂ layer [7]. All these issues prevent it from being an ideal nanowire growth method. Thus, we came up with the idea to grow GaAs nanowires directly on GaAs substrate. Since our method does not need Au and SiO₂ layer in the process, we believe that all previous problems can be overcome.

2. Experimental procedures

GaAs nanowires were carried out in COMPACT-21 Molecular Beam Epitaxy (MBE) system on n-doped GaAs (111) and Si (111) substrates. All substrates were free from any surface or chemical treatment and only prepared by degassing in pre-heat chamber at 400°C for 1 hours to get rid of the humidity and some contamination on surface before loaded into growth chamber. After loaded into the growth chamber, substrate temperature was ramped up to growth temperature of 450°C and remained constant for the whole process. To form seed particles for growth initiation, Ga
droplets were deposited with constant flux pressure of \(1.6 \times 10^{-6}\) Torr for 40 seconds. Substrates were then exposed with Ga and As at flux pressure of \(1.6 \times 10^{-6}\) and \(8 \times 10^{-6}\) Torr respectively to grow nanowires. Growth process continued for 30 minutes before Ga supply was cut off to terminate the process. After growth finished, substrate temperature was ramped down to 240ºC before As\(_4\) supply was cut off to prevent damage of GaAs surface. After growth process finished, the samples were unloaded from MBE system and cut into pieces for characterization and analysis. The fabrication process of this experiment is displayed in Fig. 1.

3. Results and discussions

(1) Surface morphology

SEM images of the surface morphology at \(\times 30,000\) magnification show vast difference between nanowires grown on GaAs (111) and on Si (111) substrates as shown in Fig. 2. On GaAs (111), nearly all nanowires grew vertically with only few tilted nanowires, no parasitic growth or bulk structure exists on substrate. While on Si (111) substrate, tilted nanowires and parasitic growth are clearly visible. This may result from non-uniformity thickness of SiO\(_2\) layer which required to perform GaAs nanowire growth on Si substrate [8].

(2) Growth rate, density, vertical yield, and elemental composition

As clearly seen in Fig. 3, the average growth rate of nanowires grown on Si(111) is almost 3 times of nanowires grown on GaAs (111) substrate. This might result from lower sticking coefficient of Ga on SiO\(_2\) surface that caused Ga atoms to have higher diffusion length and higher tendency to reach seed particles than on GaAs substrate [9]. However the nanowires on GaAs (111) substrate are much superior in density and vertical yield. The growth rate of nanowires correlates with density, shorter nanowires are likely to grow with higher density than longer ones and vice versa due to mass conservation [10]. For vertical yield, since our Si (111) substrate was completely free of any surface treatment, substrate surface was normally covered with native SiO\(_2\) layer. As
discussion in previous topic, non-uniformity thickness of the native SiO$_2$ layer can lead to tilted nanowires and parasitic growth [6]. Ga/As ratio is similar for nanowires grown on both substrates. This suggests that nanowires are GaAs nanowires with nearly stoichiometric composition.

Fig.3 Chart of growth rate, density, vertical yield, and Ga/As ratio of nanowires grown on GaAs (111) substrate compared to grown on Si (111) substrate

(3) Crystal structure

XRD result of nanowires grown on GaAs (111) substrate shows the highest peak at 27.4° which corresponds to Zincblende (ZB) GaAs (111) structure. There is shoulder peak at 26.5° to 27.0°, this probably represent Wurtzite (WZ) GaAs structure. This implies that nanowires grown on GaAs (111) substrate have mixed structure of ZB and WZ GaAs.

For Si (111) substrate sample, the main peak at 28.6° is likely to result from Si (111) substrate. Shoulder peak exists at around the same position as ZB GaAs (111) peak. A slight peak shift and broad FWHM is likely to result from defects in crystal structure. There is no WZ GaAs peak exists for Si (111) substrate.

Fig.4 XRD scans of nanowire samples grown on GaAs (111) and Si (111) substrates
4. Conclusion

We succeeded in the growth of GaAs nanowires by self-assisted method on GaAs (111) and Si (111) substrates. The nanowire growth on both substrates shows the different properties. GaAs nanowires were grown on GaAs (111) possess higher density, and excellent vertical yield. While on Si (111), the nanowires were grown with higher growth rate, however there are many parasitic islands existing on substrate. XRD results show that nanowire sample grown using Si (111) substrate seem to be dominated with ZB GaAs structure whereas mixed structures of WZ and ZB GaAs are found on GaAs (111) substrate.

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