Growth of defect-free InAs Nanowires using Pd catalyst

H.Y. Xu¹, Y.N. Guo¹, Z.M. Liao¹, J. Zou^{1,2*}, Q. Gao³, H.H.Tan³, and C. Jagadish³

¹ Materials Engineering and ² Centre for Microscopy and Microanalysis, The University of Queensland, St Lucia, 4072, Australia

³ Department of Electronic Materials Engineering, Research School of Physics and Engineering, The Australian National University, Canberra, ACT 0200, Australia

*Corresponding author: j.zou@uq.edu.au

Abstract: To explore the growth mechanism and the effect of non-gold catalysts in growing III-V epitaxial nanowires, InAs nanowires were grown on GaAs(111)B substrates using annealed Pd thin film as catalyst. Through detailed scanning and transmission electron microscopy (SEM/TEM) characterisations, it is found that when the catalyst size is less than 50 nm (from annealing the Pd thin film), defect-free zinc-blende structured epitaxial InAs nanowires are grown along the $\langle 110 \rangle$ directions with four $\{111\}$ side-facets. The common nanowire/catalyst interface is found to be the unusual $\{113\}$ planes of the nanowires.

1 Introduction: In the past decade, significant research efforts have been devoted to the growth of III-V semiconductor nanowires due to its high potential in optoelectronics, sensor and electronic technology [1,2]. Au has been widely used to catalyse the growth of III-V epitaxial nanowires on various substrates, while limited studies have been carried out on the growth of III-V nanowires using non-Au catalysts. In this study, we demonstrate the epitaxial growth of InAs nanowires on GaAs (111)B substrates using Pd as catalyst. The unusual morphological and structural characteristics of InAs nanowires allow the understanding of the effects of Pd catalysts on the growth of III-V nanowires.

2 Experimental Section: A ~ 2 nm thick layer of Pd film was firstly deposited onto GaAs (111)B substrates using an electron-beam evaporator. The InAs nanowires were grown by metal organic chemical vapor deposition using trimethylindium and arsine with flow rates of 1.16×10^{-5} mol/min and 3.35×10^{-5} mol/min, respectively. Prior to the growth,

the Pd coated substrate was annealed in the growth chamber at 600°C for 10 min under arsine ambient to desorb surface contaminants and to agglomerate the Pd thin film into nanoparticles. A growth temperature of 500°C was used due to the higher In/Pd eutectic temperature. The grown InAs nanowires and their corresponding catalysts were investigated by SEM (JEOL 7001F/7800F, both operated at 15 kV) and TEM (Philips F20, operated at 200 kV) to determine their morphological and structural characteristics.

3 Results and Discussion: Figure 1 shows the SEM images of typical nanowires catalysed by the Pd thin film. From Figs. 1A and 1B, the nanowires are not perpendicular to the substrate. To determine their growth direction, the nanowire samples were tilted along the

Fig 1 - SEM images of InAs nanowires grown with Pd catalyst. (A) composite image of the nanowires, (B) side view of the nanowire(s) (C) relationship of projected $\langle 110 \rangle$ and $\langle 112 \rangle$ directions on (111)B substrate. (D) top view of the as-grown nanowire.

Fig 2 – Typical TEM images of nanowires catalysed by Pd thin film. (A) an overview, (B) and (C) bright field image and electron diffraction taken at the tip region of the nanowire viewed along the $[11\bar{2}]$ zone axis. (D) HRTEM image of the nanowire. (E) electron diffraction of the catalyst taken along $[\bar{1}11]$ zone axis.

$\langle 110 \rangle$ axis (refer to Fig. 1C). Figure 1D shows a typical example of a nanowire tilted by 35° to look down the $\langle 110 \rangle$ direction, in which the axial direction of the nanowire is parallel to the electron beam. Geometrically, the growth direction is determined as $\langle 110 \rangle$, and, simultaneously, the diamond-shaped side-facets of the nanowire are determined as the $\{111\}$ planes.

Figure 2 shows TEM investigations of a typical nanowire, where Fig. 2A shows an entire nanowire. To determine the catalyst/nanowire interface, the nanowire specimen was oriented to the direction where the sharp catalyst/nanowire interface is seen (as illustrated in Fig. 2B). Figure 2C is the corresponding electron diffraction and confirms the catalyst/nanowire interface being the un-

usual $\{113\}$ plane. Our extensive TEM investigations confirmed that InAs nanowires are defect free (e.g. lack of spots/streaks in the ED shown as Fig. 2D) and the catalyst is the body-center-cubic structured InPd phase (refer to Fig. 2E). It is believed that our defect-free InAs nanowires benefit from the fact that the growth direction of the nanowire is non- $\langle 111 \rangle$ and the nanowire/catalyst interface is non- $\{111\}$ atomic plane. By changing the interface to $\{113\}$, it is difficult to generate lattice defects in the growth front. Moreover, our InAs nanowires have the low-energy $\{111\}$ side-facets, suggesting that the growth of nanowire is dominated by the energy minimization process of the side facets.

4 Conclusion: By using Pd nanoparticles as catalysts, we have successfully grown defect-free InAs nanowires with unusual growth directions, side-facets and nanowire/catalyst interfaces.

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References

- [1] H. Xu, Y. Wang, Y. Guo, Z. Liao, Q. Gao, N. Jiang, H.H. Tan, C. Jagadish and J. Zou. "High-Density, Defect-Free, and Taper-Restrained Epitaxial GaAs Nanowires Induced from Annealed Au Thin Films", *Cryst. Growth Des.* 12, pp. 2018-2022, 2012
- [2] H. Joyce, J. Wong-Leung, Q. Gao, H.H. Tan and C. Jagadish. "Phase Perfection in Zinc Blende and Wurtzite III-V Nanowires Using Basic Growth Parameters", *Nano Lett.* 10, pp 908-915, 2010.