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InAsP/InAs/InAsP hetero-nanowires grown via the self-assisted vapor-liquid-solid mode

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The self-assisted vapor-liquid-solid method is an excellent technique to grow high-quality and high-purity semiconductor nanowires. However, up to now there has been no report about the formation of the axial hetero-nanowire via the growth technique. In this study, for the first time, we demonstrate the growth of InAsP and InAs nanowires and their heterostructure nanowires (InAsP/InAs/InAsP) via the self-assisted vapor-liquid-solid mode.

1. Introduction

Semiconductor nanowires (NWs) have been the next-generation build blocks in optoelectronics, sensing, and electronics [1]. The vapor-liquid-solid (VLS) mode has been widely used for the growth of the NWs due to its high controllability and high-crystalline quality. As the catalyst particle material, Gold (Au) is mostly used. However, Au atoms are usually incorporated into the NW as impurity atoms during growth. For III-V semiconductor NWs, to avoid the introduction of the impurity, one can use one of the group III elements as the particle material, which is called the self-catalyzed VLS growth mode [2,3].

The InAsP-based material is a good candidate for nanoelectronic devices due to its excellent electronic and optical properties. InP NWs have been grown via the self-assisted VLS mode and show high controllability including the in-situ modifying of the NW shape [2,4]. For the functional nanostructures, the band-gap engineering is needed and the InAs and the ternary-alloy InAsP NW therefore becomes necessary. However, researchers have concluded that the InAs NW could not be grown via the self-assisted VLS mode [5,6]. Thus, up to now there is no report about the successful growth of InAs and InAsP NWs via the self-assisted VLS mode. In this paper, for the first time, we demonstrate the growth of InAsP and InAs NWs and their hetero-NWs via the self-catalyzed VLS mode.

2. Experiments, results, and discussions

We performed the NW growth in a low-pressure MOVPE system [2]. Indium (In) particles were formed on InP (111) substrate by introducing only TMIn source material at 360 ºC for 5 min. [2]. The temperature was then decreased to the growth temperature (320 ºC) and the growth was initiated by introducing TMIn, TBP, and TBAs materials. The NWs were analyzed using SEM and transmission electron microscopy (TEM) system equipped with an X-ray energy dispersive spectrometer (XEDS).

The first step is to grow the InAsP and InAs NWs via the self-assisted VLS mode. We found out the V/III ratio and the growth temperature has marked effect on the growth behavior. By optimizing the growth parameters (the growth temperature and the V/III ratio), we obtained the growth condition of InAsP and InAs NWs via the self-assisted VLS mode.

We then grew InAsP/InAs/InAsP hetero-NWs with 20 min. growth time for each segment. Figure 1 shows the hetero-NWs grown on the InP(111) substrate. Basically, the NWs are vertically aligned on the substrate, indicating that they were epitaxially grown on the substrate with the <111> direction. At each NW tip, there is a particle [Fig. 1(b)], indicating that the NW was grown via the self-assisted VLS mode.

We dispersed the NWs onto a copper grid and analyzed the NW using the TEM system. The NW has the ZB crystalline structure with stacking faults along the growth direction. We analyzed the composition near the NW tip (Fig. 2). In Fig. 2, there is an InAsP NW with an In particle at the NW tip. Quantitative analysis indicates that the particle is nearly 100% In and the InAsP segment composition is $InAs_{0.745}P_{0.255}$. The result shows that the NW was grown via the self-assisted VLS mode through the In particle.

We further analyzed the composition profile along the NW axial direction (Fig. 3). The result shown in Fig. 3 indicates that the hetero-NW is formed exactly as designed, i.e. InAsP/InAs/InAsP. The In, As, and P profiles in InAsP segments are uniform, while the In and As profiles in InAs segment exhibit increasing tendency along the growth direction. This is because the In source flow rate in the InAs segment growth is higher than that in the InAsP segment growth. The In particle gradually became large and the NW diameter therefore increased with the growth.

About the growth rate, the InAs segment (1.13 nm/s) grew slower than the InAsP segment (1.74-1.98 nm/s), indicating that the addition of P increases the growth rate. The InAsP segment near the In particle (1.74 nm/s) has lower growth rate than the one near the root (1.98 nm/s). Furthermore, the InAsP segment near the In particle shows lower As composition ($InAs_{0.745}P_{0.255}$) than the InAsP segment near the root ($InAs_{0.766}P_{0.234}$). Presumably, this is induced by the different migration length of TBAs and TBP radicals along the NW side faces.

3. Conclusions

We have demonstrated the growth of InAsP and InAs

NWs and their hetero-NWs via the self-assisted VLS mode. The capability of forming the heterostructure NWs via the self-assisted VLS mode enables to grow high-quality and high-purity InAsP-NW-based functional nanostructures. Moreover, the low growth temperature (320 ºC) and no use of Au material make it possible to integrate the InAsP-NW-based devices into the current CMOS process.

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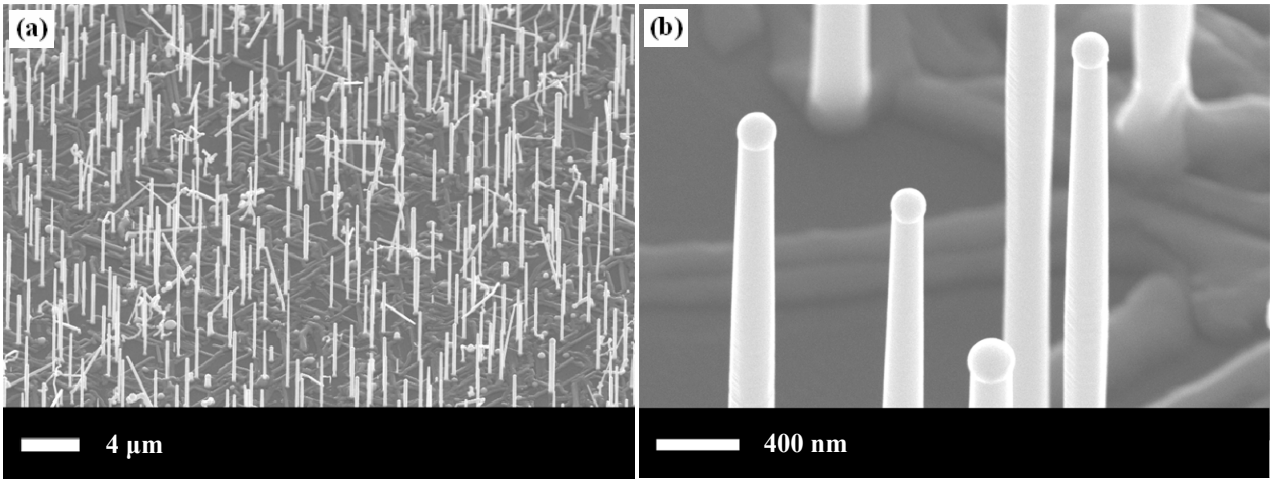

Fig. 1. (a) Low and (b) high magnification side-view (tilt: 38º) SEM image of InAsP/InAs/InAsP axial-hetero-NWs grown on the InP (111) substrate. Particles at the NW tip are visible from (b).

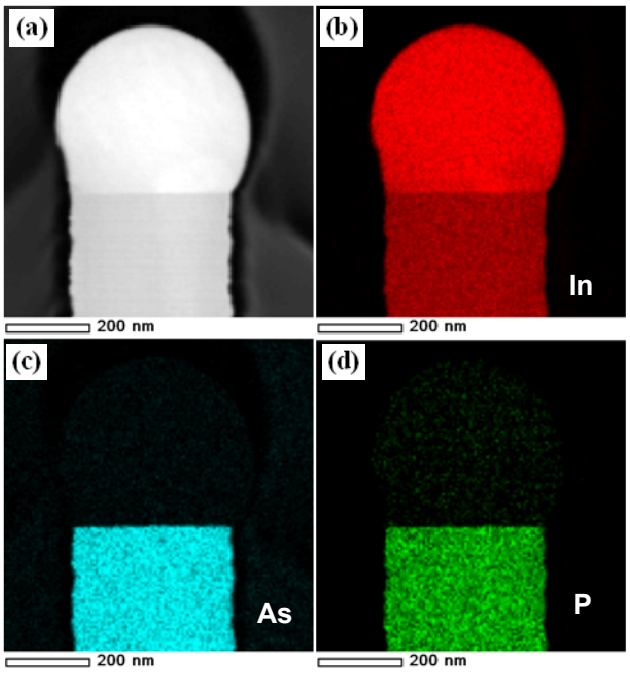

Fig. 2. (a) HAADF-STEM image of the NW tip. (b), (c), and (d) Elemental mapping of In, As, and P, respectively. The NW composition is InAsP and the particle is In.

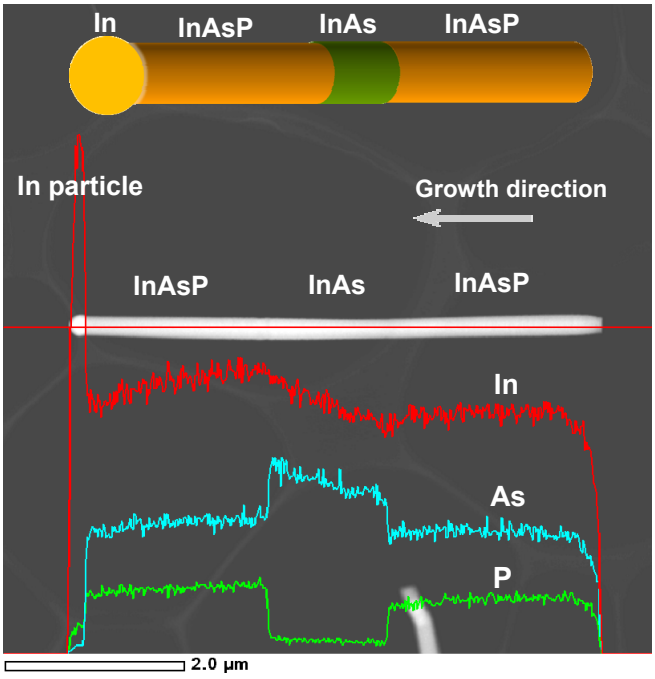

Fig. 3. Compositional line scan of the hetero-NW along the axial direction. The inset is the HAADF-STEM image of the measured NW. The schematic illustration in the upper side shows the structure of the NW.