自己集合法によるハイブリッドナノワイヤ・ナノ微粒子ナノ構造

Self-assembled hybrid nanowire-nanoparticle nanostructures

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Semiconductor nanowires offer the possibility of enhancing the degree of freedom for 3D integration. Metallic nanoparticles have shown promising applications in plasmonic, nanowire synthesis, etc. The combination of semiconductor nanowires with metallic nanoparticles in self-assemble way may open up new opportunities for novel applications in optoelectronics and nanostructure synthesis. Here we report self-assembled hybrid nanowire-nanoparticle 3D nanostructures with aligned indium and bismuth nanoparticles on nanowire side (112) faces.

We synthesized the InP nanowires in a metalorganic vapor phase epitaxy (MOVPE) system in the self-catalyzed vapor-liquid-solid (VLS) mode [1-4]. Indium particles were formed by self-aggregation of indium atoms resulting from decomposition of TMIn material absorbed on the surface [1,2]. We grew InP nanowires with different shapes under varied flow rate of source materials (TMIn and TBP) (Fig. 1). We usually grew InP nanowires with a uniform diameter (Fig. 1a). We have also developed an in-situ diameter tuning technique by modulating V/III ratio for varied nanowire shapes [3] (Figs. 1a, 1b). To form indium particle on the nanowire side faces, we supplied only indium source material (TMIn) after the InP nanowire growth for 5 min. at 320 °C. Because indium nanoparticles can be formed at the same condition on InP (111)B substrate, we expect that indium nanoparticles can also be formed on the nanowire side faces under the similar condition by self-aggregation process.

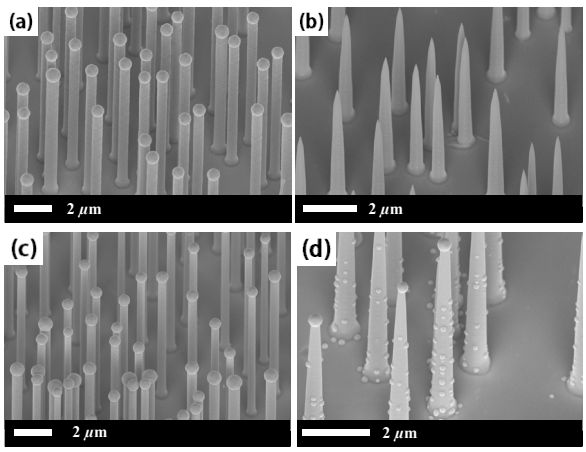

Fig. 1. SEM images (tilt: 38º) of (a) and (b) InP nanowires with uniform diameter and tapering shape. (c) and (d) SEM images (tilt: 38º) of InP nanowires with additional 5 min. supply of TMIn material at 320 °C.

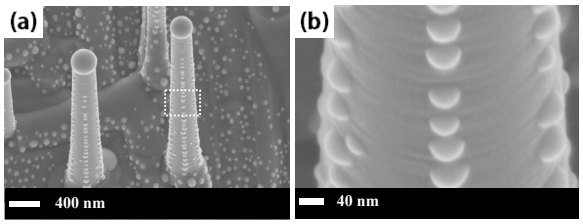

Fig. 2. SEM images (tilt: 38º) of (a) InP nanowires with Bi nanoparticles aligned on the side faces and (b) enlarged view of the area shown in (a). There are Bi nanoparticles aligned on side (112) faces.

For the nanowires with a uniform diameter, there is no indium nanoparticle formed on the side face (Fig. 1c). This indicates that indium atoms absorbed on the side face directly desorb or migrate along the nanowire side and eventually join the nanoparticle at the tip. However, there are indium nanoparticles formed on the side face for the nanowires with a tapering shape (Fig. 1d). This is induced by the macrosteps formed on the tapering nanowire sides. In contrast to the smooth side face of the nanowire with a uniform diameter, the aggregation of indium atoms absorbed on the side face into nanoparticles can take place more easily on a rough surface with macrosteps.

Most likely, this is a common phenomenon dominated by the diffusion and aggregation process of metallic atoms on the nanowire sides. We performed the similar experiment using bismuth source material (TMBi). Under the similar condition, the migration length of Bi atoms is much shorter than that of indium atoms. The nanoparticle spacing should be proportional to the migration length on the side face. Figure 2 shows that there are Bi nanoparticles aligned on the side (112) faces. This has been also confirmed by TEM measurement. As predicted, the Bi nanoparticle spacing is much shorter than that of indium nanoparticle (Figs. 1d and 2b).

In conclusion, we have developed a self-assembled approach for hybrid nanowire-nanoparticle nanostructures by using nanowires with a tapering shape. Indium nanoparticles can be preferentially aligned into an 1D array on the side (112) face. We further show that the synthesis approach is also applicable to other materials like Bi. This work opens up new opportunities for development of novel applications by combing metallic nanoparticle and semiconductor nanowires.

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References: [1] Zhang, et al. Appl. Phys. Express **5** (2012) 055201 [2] Zhang, et al. ACS Nano **9** (2015) 10580. [3] Zhang, et al. Nanotechnology **29** (2018) 155202. [4] Zhang et al., Sci. Adv. **5** (2019) eaat8896.