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Growth of high quality, epitaxial InSb nanowires

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Abstract

The growth of InSb nanowires on an InSb(1 1 1) substrate in a closed system is described. A high density InSb nanowires was grown by the use of InSb substrates in a torch sealed quartz tube at a temperature of 400 °C, using a 60 nm size gold colloid catalyst. The typical diameter of the InSb nanowires was 80–200 nm and they consisted of nearly equal atomic percent of In and Sb. Transmission electron microscopy showed the wires to be single crystal, with a growth direction of ⟨1 1 0⟩.

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1. Introduction

Indium antimonide (InSb) (melting point~525 °C) is a narrow bandgap semiconductor, well known for its highest bulk electron mobility, smallest effective mass, and largest *g* factor among binary III–V materials [1]. It therefore has potential electronic applications in high-speed devices [2,3] magnetoresistors [4], and has been used previously as magnetic sensors [5], and infrared (IR) detectors [6]. It also has a large Bohr exciton radius of ~60 nm [7,8], consequently making 1–D InSb nanowires an attractive semiconductor for quantum effect studies. Despite its interesting properties, a limited amount of work has been reported on the growth of InSb nanowire, most likely due to the difficulty of growth of this material. Previously, nanowire growth using asbestos [9], and anodized alumina membranes (AAM)[10–12] has been reported. In the growth using AAM, direct current [10] and pulsed [11,12] electrodepositions were used to synthesize polycrystalline and single crystalline InSb nanowires, respectively. The crystallinity of the asbestos-grown InSb nanowires, on the other hand, has not been reported, and is not known to our knowledge. In this work, we report on the synthesis and characterization of single crystalline InSb nanowires that were grown epitaxially on InSb(1 1 1) substrate using Au as the metal catalyst. No templates or toxic gases were used, and our growth system, which is capable of producing high quality and dense InSb nanowires, is much simpler and cheaper than any other nanowire growth methods employed thus far.

2. Experimental procedure

The InSb nanowires were grown inside a sealed quartz tube (10 mm in diameter) in an open tube furnace (10.16 cm in diameter). The growth procedure used here was similar to the procedure used to grow InAs nanowires. [13,14] The native oxide on the InSb substrates was removed by chemical etching in HCl:H_2O (1:10). Using Poly-L Lysine, 60 nm sized gold nanoparticles (Ted Pella, Inc.) were placed on the InSb(1 1 1) substrate. No other gold nanoparticle sizes were used. The gold coated InSb substrate (nanowire growth substrate) and a bare InSb substrate (In and Sb source) were then immediately placed inside a quartz tube, evacuated to 30 mTorr using a mechanical pump and sealed with a torch. During the growth of the nanowires, the furnace temperature was first raised to 585 °C and once

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the temperature was stabilized, the quartz tube (with the InSb substrates inside) was inserted into the furnace. The tube was positioned in such a way that the InSb source substrate was at 540 °C, while the nanowire growth substrate was at 400 °C. The quartz tube was annealed for a specific time period, which corresponds to the nanowire growth time. Once the annealing was finished, the quartz tube was immediately removed from the hot furnace (while the furnace was still at 585 °C) and cooled under running tap water. The grown nanowires were analyzed using a LEO SUPRA 55 scanning electron microscope (SEM), JEOL 4000EX high resolution transmission electron microscope (HRTEM) working at 400 keV, and HF2000 transmission electron microscope working at 200 keV with X-ray energy dispersive spectroscopy (EDS) attached. The InSb substrate with the nanowires was sonicated in a methanol solution, followed by dropping of the solution onto a TEM holey copper grid.

3. Results and discussions

The nanowire growth results are discussed below. The SEM image of the nanowires grown for 30 min is shown in Fig. 1. As can be seen, the nanowires were found to grow predominantly at a set angle to the InSb(1 1 1) substrate, with typical length of about 1 μm. The scale bar is 300 nm. The region near the base of the nanowires can be seen covered with irregularly shaped deposits. Fig. 2 shows an SEM image of the dense nanowires grown at the same temperature, but for a longer growth time of 50 min. The scale bar is 10 μm. The length of the nanowires was several micrometers. The typical diameter of the nanowires grown using this method was about 80∼200 nm.As expected from using the Au nanoparticles as the metal catalyst during the nanowire growth, all the nanowires were found with nanoparticles at the tip.

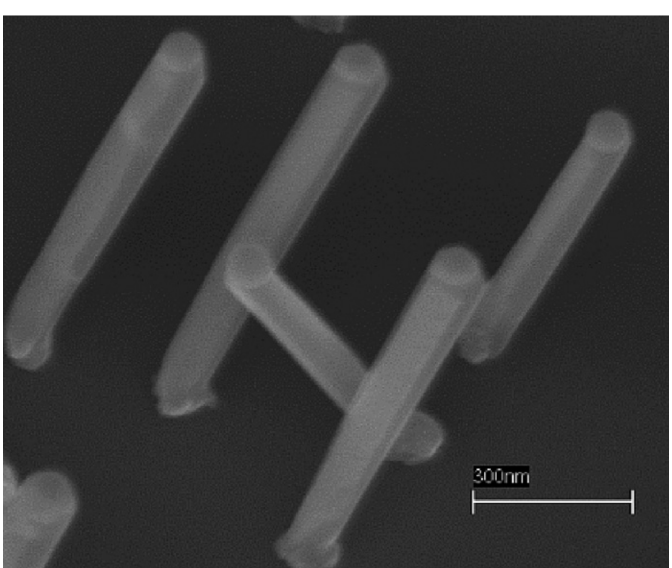

Fig. 1. 60 nm grown for 30 mins. Scale bar is 300 nm.

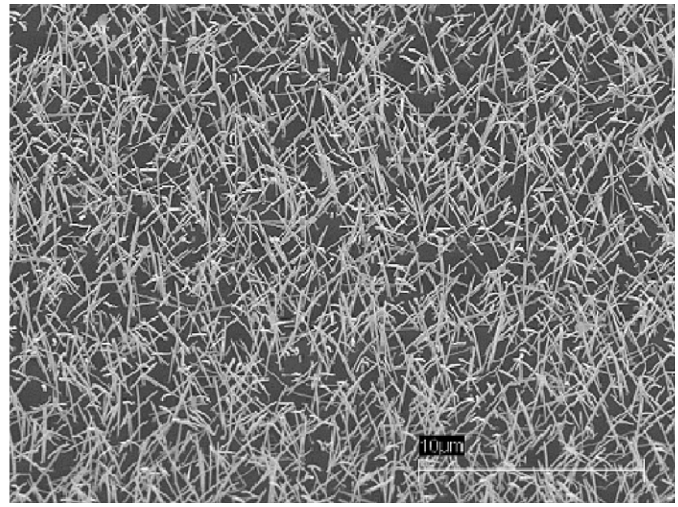

Fig. 2. InSb nanowires grown for 50 mins. The scale bar is 10 μm.

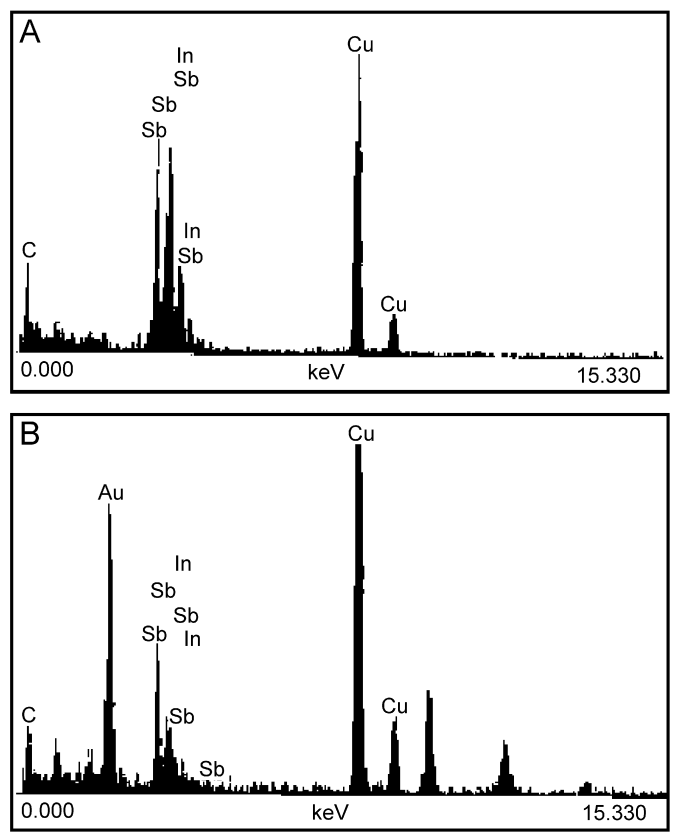

Fig. 3. EDS analysis on the body (A) and tip (B) of the nanowire.

EDS analysis was performed on the body, as well as on the tip of the nanowire and the results are shown in Fig. 3(A) and (B), respectively. The quantitative analysis on the body of the nanowire, shown in Fig. 3(A), indicates approximately 50:50 (In:Sb) at% ratio, confirming the nanowires to be InSb. Based on this analysis technique, no Au was detected in the nanowire body. The copper line is due to the TEM copper grid. The quantitative EDS analysis on the nanoparticle found at the nanowire tip, shown in Fig. 3(B),

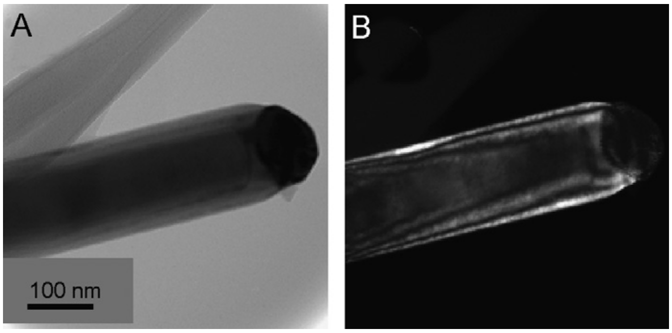

Fig. 4. Bright (A) and dark field (B) TEM images of the grown InSb nanowires. The structure seen in the dark field image is due to thickness fringes. The scale bar is 100 nm.

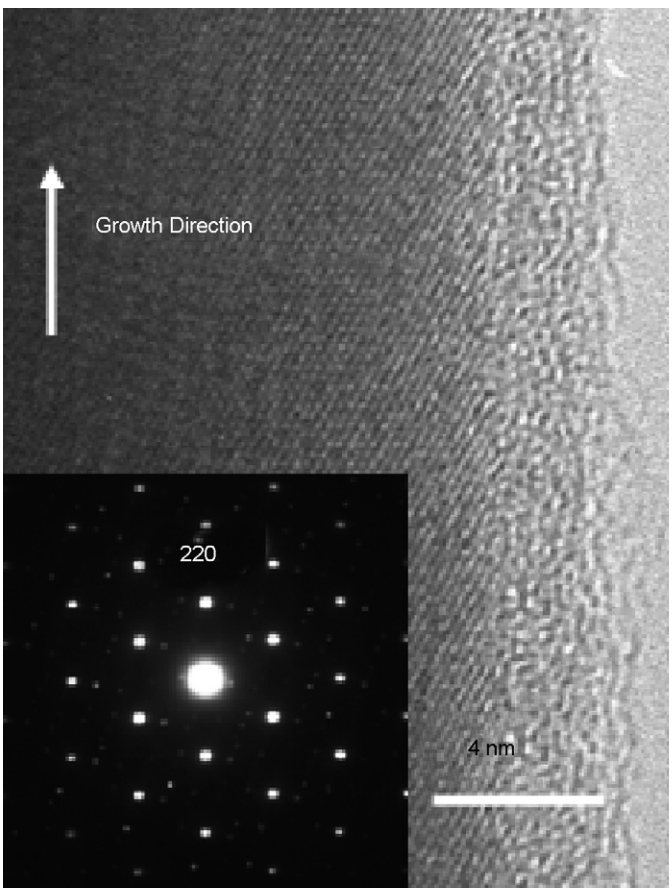

Fig. 5. HRTEM image of the nanowire. The scale bar is 4 nm.

indicated the presence of all constituents (at% ratio In(50):Sb(9.6):Au(40.4)), with a relatively small amount of Sb. The existence of a metallic alloy nanoparticle at the tip suggests that the growth likely occurred by the well known vapor-liquid-solid (VLS) growth mechanism [15], but it should be noted that the In-Sb-Au ternary phase diagram is not only complex, but sufficient literature results for this system are lacking. Thus, it is not possible to determine the eutectic point for this ternary system and thus it is not possible to unambiguously assign VLS as the growth mechanism at this point.

In Fig. 4 (A) and (B), bright-field and dark-field TEM images of an InSb nanowire are shown, respectively, revealing the nanowire structure to be a single crystal free of extended defects. In Fig. 5, the HRTEM image of the InSb nanowire is shown (the scale bar is 4 nm). The selective area diffraction micrograph shows the nanowire to be a single crystal with the growth direction of $\langle 110 \rangle$. At ambient pressure and temperature, InSb is a zinc-blende crystal structure with a lattice constant of 6.48 Å. Our lattice spacing measured was 6.46 Å, confirming the nanowire to be zinc-blende InSb, similar to what is expected in the bulk. The HRTEM image also showed an amorphous sheath covering the InSb single crystal, which we believe is due to post-growth room temperature oxidation. It should be noted that some regions of the nanowires exhibited weak diffracted intensities in addition to those associated with zinc-blende. The origin of these weak reflections is being investigated and will be reported separately.

4. Conclusions

In this paper, we present results on the growth of high quality InSb nanowires grown in a simple closed quartz tube configuration using only InSb substrates. Using 60 nm sized Au nanoparticles, the grown nanowires were found to be a single crystal with a typical diameter of 80–200 nm. The InSb nanowires were also found to grow in a high density with a growth direction along $\langle 1\,1\,0 \rangle$. These results indicate not only the simplicity of this growth technique, but also demonstrate that high quality, epitaxial single crystal InSb nanowires can be grown in high densities on InSb substrates.

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