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Self-induced InAs nanowires grown on natural-oxide-covered Si(111) by molecular-beam epitaxy

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1. Introduction

Semiconductor nanowires (NWs) have currently become one of the most investigated topics in both fundamental physics and novel applications due to their unique one-dimensional properties and great potential for high performance nano-devices [1,2]. Among the III–V NWs, InAs has attracted much attention because of its narrow gap and high electron mobility characteristics for electronic and optoelectronic applications, especially when integrated on silicon or silicide [3-6]. The growth of InAs NWs on Si substrates via the vapor–liquid–solid (VLS) method was recently demonstrated as one of the most promising routes [7-10]. Although catalysts can initiate the growth, they cause several disadvantages, such as incorporating into semiconductors and degrading of crystalline quality. Except the VLS procedure, another mature way to produce InAs NWs is so-called selective-area epitaxy (SAE) by using the substrate underlying a artificially deposited, especially prepatterned SiO_x layer to restrict the epitaxial growth inside the openings [11-14]. This method enable formation of NWs without using foreign catalysts and obtaining of pure crystal with flat-top facet, but it needs a complicated process prior to growth.

In this letter, we attempt a simple method to grow self-induced InAs NWs on natural-oxide-covered Si(111) substrates by molecular-beam epitaxy (MBE), neither using catalysts nor template masks, and investigate the surface morphology of grown samples and structural characteristic of InAs NWs by utilizing scanning electron microscopy (SEM) and high-resolution transmission electron microscopy (HR-TEM), respectively.

2. Experimental Methods

The growth procedure was carried out in a solid source MBE system (V80 MARKI). First of all, the natural-oxide-covered Si(111) wafers were ultrasonicly cleaned by acetone, ethanol and deionized water successively, and then loaded into the MBE growth chamber. After annealed for 15 min at 700°C to remove any contaminants, SiO_x -coverd substrates were subsequently cooled down to growth temperatures in the range of 450-650°C. Nanowires growths were performed for 45 min using the As_4 flux (beam equivalent pressure) of 5.2×10^{-6} mbar, corresponding to a nominal V/III flux ratio of 25.

3. Results and discussion

Surface morphology

We utilized SEM to study the surface morphology of prepared samples. Representative SEM micrographs of InAs NWs on SiO_x/Si(111) substrates are shown in figure 1 for the growth temperature of 600°C. Fig. 1(a) is the cross-view image. It clearly reveals that InAs NWs are directly formed on the natural-oxide-covered Si(111) wafer with random growth direction. The average diameter and length are statistically 70nm and 800nm, respectively. It is noted that the natural SiO_x layer is composed of granular amorphous silicon oxide and the thickness of the layer is almost 100nm. In previous studies, III–V NWs prefer to grow following the (111)B direction of the substrate [12-15], and for the growth on SiO_x-coated substrates, vertical aligned nanowires usually occurred under the condition that the SiO_x mask could not be too thick, basically with the thickness below 30nm in various experimental work [13-17]. In this work, random orientations of nanowires is probably related to the thicker natural SiO_x layer and the existence of residual native oxsides on exposed Si substrates. Fig. 1(b) is the top-view image of the same sample. This image and its magnified area (inset) visibly show that the nucleation of most nanowires arises from the nanometer-sized opening of the substrate surface.

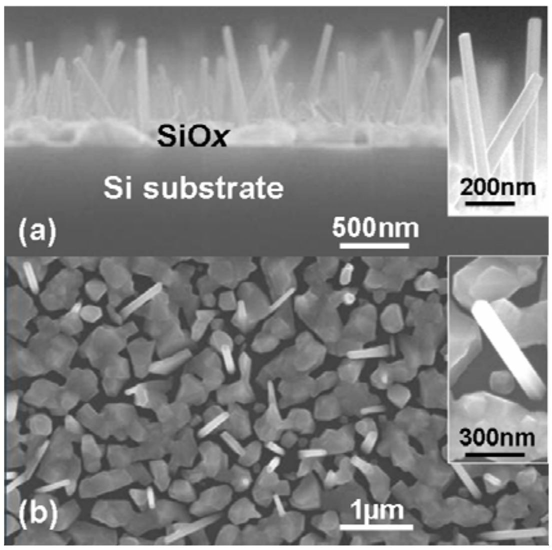

Fig. 1 SEM images of InAs NWs grown on a SiO_x/Si(111) substrate. (a) Cross-view image. (b) Top-view image.

Structural characterization

The structural characterization of grown InAs NWs are examined by TEM. The cross-sectional TEM images of a typical nanowire extracted from the substrate are shown in figure 2. Fig. 2(a) shows the bright-field low-magnification micrograph of a single InAs nanowire. It can be seen that the length of the nanowire is slightly more than 1μm, while the diameter is approximatively 60nm and uniform along its entire length. The dark-field image of the same nanowire is shown in Fig. 2(b). It presents the dark contrasts mainly result from stacking faults perpendicular to the growth direction. Fig. 2(c) shows the HR-TEM image of the same nanowire near the top region. The growth direction is indicated by the arrow. This image reveals that the InAs nanowire is composed of both zincblende and wurtzite structures, and the lattice defect contains the stacking of the atomic layer, typically rotational twins with 2 to 6 MLs periods. The similar crystal structure of InAs nanowires was reported in quite a number of experimental studies [10, 13, 14, 18-20]. An atomically abrupt interface at the top of the nanowire without In droplet is also imaged, indicating a catalyst-free growth mechanism. The TEM results suggest the necessary further work to obtain pure crystal phase within the same nanowire.

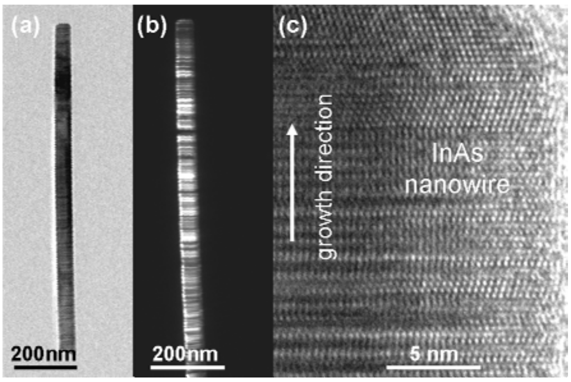

Fig. 2 Cross-section TEM images of a representative InAs nanowire. (a) The bright-field TEM image. (b) The dark-field TEM image. (c) The HR-TEM image near the top region.

3. Conclusions

Self-induced InAs NWs were grown on natural-oxide-covered Si(111) by molecular beam epitaxy with no catalysts. The morphology characterization reveals that InAs NWs with random orientations originate from the nanometer-sized opening of the substrate surface. The crystal structurure of InAs NWs is composed of both zincblende and wurtzite structures, as well as the stacking of the atomic layer. Our result may provide a convenient way to fabricate InAs NWs on natural-oxide-covered Si substrates by MBE.

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