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Growth of SiC Nanowires on Different Planes of 4H-SiC Substrates

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Abstract. Growth of SiC nanowires (NWs) on monocrystalline 4H-SiC substrates was conducted to investigate a possibility of NW alignment and polytype control. The growth directions of the NWs on the top surfaces and the vertical sidewalls of 4H-SiC mesas having different crystallographic orientations were investigated. The majority of the NWs crystallize in the 3C polytype with the ⟨111⟩ growth axis. Six orientations of the 3C ⟨111⟩ NWs axis with respect to the substrate were obtained simultaneously when growing on the (0001) plane. In contrast, no more than two NW axis orientations coexisted when growing on a particular mesa sidewall. Growth on a particular {10-10} plane resulted in only one NW axis orientation, giving well-aligned NWs.

Introduction

Silicon carbide nanowires (NWs) are extensively investigated because of the wide band gap of this material, high breakdown strength and radiation resistance, high mechanical strength and thermal conductivity [1]. Impressive chemical stability and biocompatibility of SiC [2] make SiC NWs very promising for biomedical and gas sensors [3,4]. Chemical vapor deposition (CVD) is one the most popular growth techniques for SiC NWs [5-7]. Various substrates were used for SiC NW synthesis, including SiO_2 [7], graphite [9-12], and poly-SiC [5]. Use of polycrystalline or amorphous substrates normally results in a disordered growth of 3C-SiC NWs. The axes of the 3C NWs are typically oriented along ⟨111⟩ [7,11], and less frequently along ⟨110⟩, ⟨100⟩, and ⟨112⟩ [6] directions. When growing on substrates other than monocrystalline SiC, other polytypes were occasionally obtained, including 6H [5,9,10], 2H [5,8], 15R [5,12], and 4H [12,13]. Monocrystalline 4H and 6H-SiC have also been investigated to achieve NWs having the same polytype as the of the substrate by the epitaxial growth mechanism [14-16].

In this work, growth on (0001) top surfaces and on differently oriented walls of 4H-SiC mesas is investigated in order to obtain well-aligned SiC NWs.

Experimental

SiC nanowires were grown on different surfaces of mesas formed by RIE on the top of monocrystalline 4H-SiC wafers. The growth was conducted by CVD using the vapor-liquid-solid (VLS) mechanism. Growth was conducted in a hot-wall CVD reactor at 150 Torr with H_2 carrier gas and $SiCl_4$ and CH_3Cl as the silicon and carbon sources, respectively. The vapor-phase catalyst delivery mechanism with NiSi source was employed [17]. This approach was found the most efficient to provide sufficiently rare NWs growing by epitaxial mechanism, which is convenient for investigating NWs orientations with respect to the substrate. The NWs were characterized by

Nomarski optical microscopy, scanning electron microscopy (SEM), X-ray Diffraction (XRD), electron diffraction and imaging in a transmission electron microscope (TEM), and electron-back-scatter-diffraction (EBSD).

Results and Discussion

Several preferential orientations for the NW axis with respect to the crystallographic orientation of the 4H-SiC substrates were established when growing on (0001) surfaces [16]. A majority of the NWs crystallize in the 3C polytype with the ⟨111⟩ growth axis (Fig.1a). They grew at 20° with respect to the substrate *c*-plane (Fig.2b and Fig.3) and exhibited high densities of stacking faults (SF) on those {111} planes that are parallel to the substrate *c*-planes (Fig.2b). Projections of these NWs on the c-plane formed six directions at the azimuth angles of 60° with respect to each other (Fig.2a). Consequently the NW projections on the (0001) plane point along one of the six equivalent ⟨10-10⟩ crystallographic directions (Fig.6a).

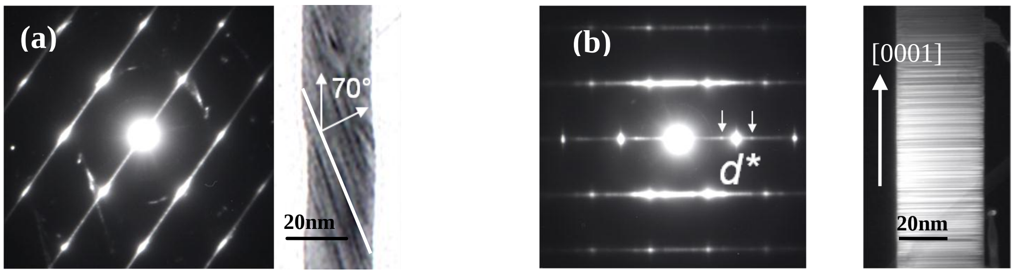

Fig. 1. SAEDs with corresponding high-resolution TEM images of (a) a NW with the growth axis at 70° to the [0001] direction of the substrate and (b) a NW having the fault planes orthogonal to the NW axis. SAED in (a) displays a 3C NW with a high density of {111} stacking faults. SAED in (b) reveals the 4H polytype with a strong stacking disorder as manifested in superlattice reflections at ¼d* indicated with arrows.

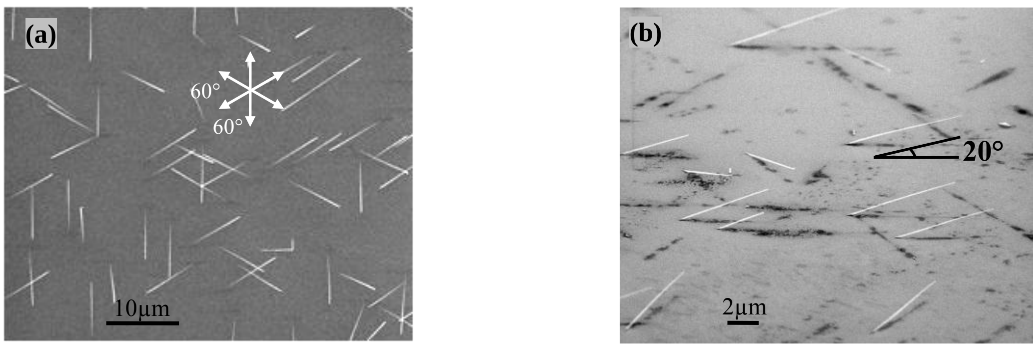

Fig. 2 SEM images of (a) top and (b) tilted views of sparse NWs grown using NiSi catalyst at 1150°C.

The second NW type featured the 4H structure albeit with a strong stacking disorder (Fig.1b). The SAED patterns exhibit discernable maxima at ¼d* indicated using arrows, where d* is a reciprocal of the *c*-layer spacing for hexagonal SiC. The stacking faults in these NWs were perpendicular to the [0001] nanowire axes (inset in Fig.1b).

Most of the NWs grown on vertical side-walls of the 4H-SiC mesas were of 3C polytype (see Refs.16,18 for more details on

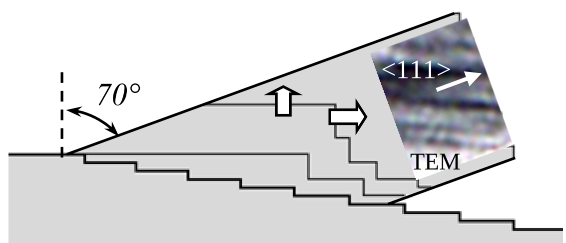

Fig. 3 Diagram of the NW growth at 70° with respect to the *c*-axis of the substrate. The inset shows the TEM image of a 3C NW with SF parallel to the basal plane of the substrate.

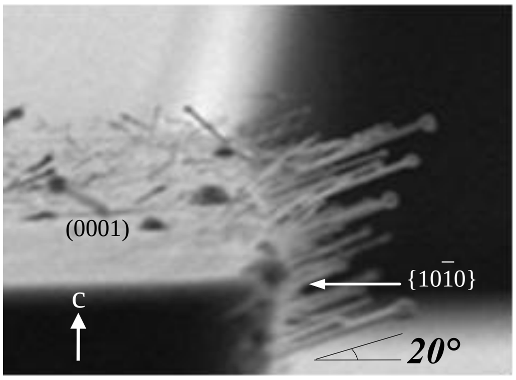

Fig. 4 A tilted view illustrating NW growth on the vertical sidewalls at the 20° angle with respect to the basal plane (c-plane) of the 4H-SiC substrate. Note that the *20°* is the real angle rather than the angle visible from this tilted view.

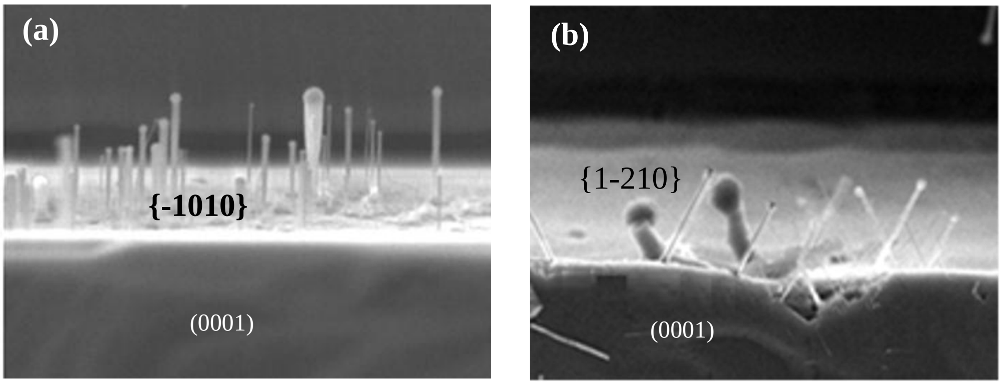

Fig. 5 NWs grown on the SiC mesa vertical sidewalls corresponding to: (a) {-1010} planes, and (b) {-12-10} planes.

characterization of the NW arrays by XRD as well as individual NWs by electron-back-scatter-diffraction). They followed the same crystallographic orientations of 20° with respect to the substrate *c*-plane (Fig.4) and had their projections on the c-plane at 60° with respect to each other.

As a result, well-aligned (all parallel) NWs grew on {-1010} planes (Fig.5a), while NWs with two distinct crystallographic orientations grew on {1-210} planes (Fig.5b). The diagram in Fig.6 shows the top and side views of NWs growing on the top surface and the vertical sidewalls.

When 3C NWs having [111] axis grow at 70° angle with respect to the c-axis, it results in the [-111] NW plane to be parallel to the basal plane of the substrate. In addition, the {112} and {110} planes in 3C NWs are parallel to {10-10} and {11-20} planes of the 4H substrate, respectively**.** It is suggested that this orientation relationship yields the best lattice match between 3C NWs and the 4H substrate when growing on (0001) plane. The results of the NW crystal lattice allignment presented in this work correlate with the epitaxial relationships for the growth of 3C-SiC inclusions on 4H-SiC or intentionally induced nucleation of 3C on hexagonal SiC surfaces [19].

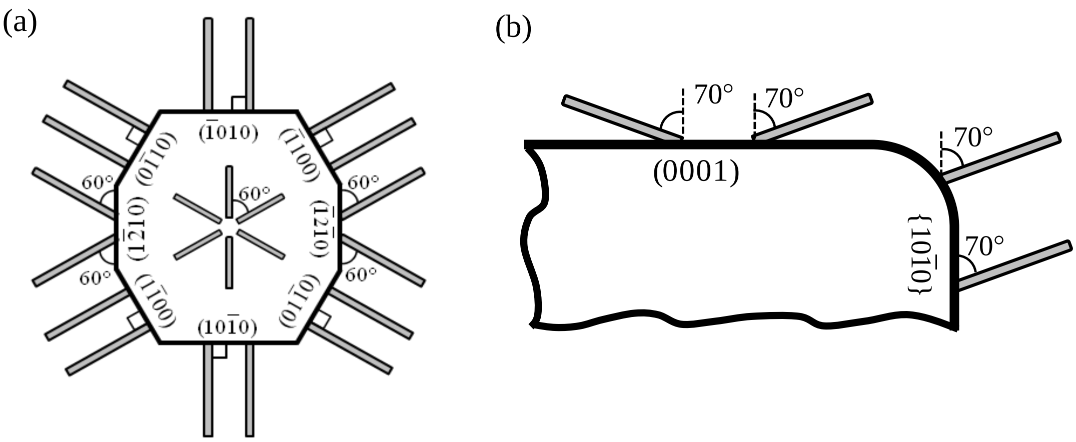

Fig. 6 A schematics representation of the orientations of the <111> 3C NWs growth axes: (a) the top view showing the azimuth orientation of the growth direction, (b) a side view demonstrating the growth angle of the NWs with respect to the c-axis.

Summary

Epitaxial growth mode for 3C-SiC NWs on the (0001) growth surface and the vertical sidewalls of 4H-SiC mesas ensures that NWs axis is aligned along one of six crystallographic orientations with respect to the substrate, with 20° angle with the c-plane and the projections on the (0001) plane aligned along one of the six equivalent ⟨10-10⟩ crystallographic directions. This provided an opportunity to grow all-parallel NWs by selecting one of the {-1010} planes. A possibility of achieving reliable polytype reproducibility and controlled NW growth of predominantly 4H polytype will be further investigated.

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