
SiC/SiO₂ core–shell nanocables formed on the carbon fiber felt
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Abstract

SiC/SiO₂ core–shell nanocables in high yield and high purity were synthesized on carbon fiber felt by a simple thermal evaporation method without the presence of the catalyst. The microstructures and compositions of the samples were studied by SEM, TEM, HRTEM, EDS and SAED. The as-prepared nanocables with diameter of 10–40 nm have a crystalline SiC core and an amorphous shell of SiO₂. This composite nanostructure will provide opportunities for both fundamental research and technological applications in electronic nanodevices.

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1. Introduction

In recent years, nanoscale one-dimensional materials have attracted much attention due to their remarkable physics properties and their great potential for nanoscale electronics and optoelectronics [1]. The SiC/SiO₂ coaxial nanocables were first synthesized by reactive laser ablation in 1998 and have great potential for applications because they have the one-dimensional features of both nanowires and nanotubes in the axial direction and build an ideal semiconductor–insulator heterojunction in the radial direction [2].

Here, we report the fabrication of large quantities SiC/SiO₂ core–shell nanocables on the carbon fiber felt by simple thermal evaporation at 1400 °C. The morphology and the structure of the as-prepared samples have investigated by SEM (LEO 1530 FEG), TEM (JEM-200CX at 160 KV), HRTEM (JEM-2010F at 200 KV) and EDS attached to the HRTEM.

2. Experiment

The react was conducted in a vertical induction furnace including a quartz tube and an inductively heat cylinder. The heated cylinder is made of high-purity graphite and coated with a layer of carbon fiber (also called carbon fiber felt) as the thermoinsulation material. The SiO₂ power was filled in the hollow structure at the upper part of the heated cylinder. After evacuation of system to ~5 × 10⁻¹¹ Torr, pure Ar flow was continuously introduced at a flow rate of 100 sccm. The heated cylinder was heated quickly and maintained at 1400 °C for 10 min under a pressure of 200 Torr.

3. Results and discussion

The discovery was actually made by accident. Our initial attempt was to prepare Si nanowires following the reported method [3-4], in which large-scale Si nanowires can be obtained by thermal evaporation of SiO₂ powder. To our surprise, in addition to the large quantities of Si nanowires were obtained on the inner wall of quartz tube, the carbon fiber
felt was covered by a thick layer of blue fluffy-like products with a thickness of several millimeters. As shown in Fig. 1(b), many mushroom-like lumps grew perpendicularly and separately from the surface of the carbon felt and joined each other at their tip.

The mushroom-like lumps were dispersed from several cross-sections for the SEM observation to investigate their inner structure. Results of SEM observation (Fig. 1(a)) indicated that the whole mushroom-like lump consists of ultra-long wires with diameter of 10–40 nm and the density of wires in the root region is larger than the top region.

Fig. 2 shows a typical XRD spectrum of the as-prepared samples. The diffraction peak positions in the pattern can be indexed to $\beta$-SiC with the cubic structure. The morphology and compositions of the sample were further investigated by TEM and HRTEM. Fig. 3(a) is a low-magnification TEM image of the samples, in which large quantities wires with length up to several tens micrometers and high purity were observed. The HRTEM image (Fig. 3(c)) shows that the wires are core–shell structure with two different parts. Combined with the results of XRD, in situ EDS (Fig. 3(b)) recording on a single nanowire, it can be inferred that the as-prepared samples are nanowires composed of crystalline SiC core coated with a shell of amorphous SiO$_2$. The bright ring in the corresponding SAED pattern (inset in Fig. 3(a)) can be attributed to the crystalline structure in the sample. In Fig. 3(d), the lattice fringes with $d$ spacing of 0.25 nm on the HRTEM image of SiC core correspond to the distance of the $(111)$ plane in $\beta$-SiC. The stacking faults are also visible in the HRTEM image, which is a typical phenomenon in SiC whiskers fabricated by solid-gas reaction of C and SiO$_2$.

It should be noted that metal catalyst particles were found at both ends of the nanowires (Fig. 3(e)).

How did these structures come into being on the carbon fiber felt? To make clear the growth process, the transform of a single short carbon fiber after the reaction was investigated (shown in Fig. 1(c)). As confirmed by SEM observation, the residual carbon fiber was embedded within the blue and loose structures that consisted of large-quantities of nanowires. So, the carbon fiber itself was both the substrate and carbon source for the formation of SiC/SiO$_2$ core–shell nanowires.

Additionally, carbon fiber felt is formed by the weave of many short carbon fibers with diameter about several micrometers. Small diameter and high surface area make the carbon fiber possess of the high reactivity ability with the SiO vapor at high temperature of 1400 °C. The mushroom-like lumps came into being when SiC/SiO$_2$ core–shell nanowires that grown from the many adjacent
short carbon fibers near the surface of the carbon felt joined together. This also can be confirmed by the fact that some not reacted carbon fibers were embedded in the mushroom-like lumps.

Based on all the evidence mentioned above, it can be inferred that the SiC/SiO₂ core–shell nanocables in our experiment were developed through the reaction: C (solid) + 2SiO (gas) → SiC (solid) + SiO₂ (solid). The carbon source was carbon fiber and SiO vapor was generated by thermal evaporation of SiO powder at 1400 °C.

Similar results have been reported in Refs. [6,7]. In these reports, carbon nanotubes were formed on the carbon fiber with the assisted by catalyst in Chemical Vapor Deposition (CVD) process. The yield of the carbon nanotubes was small, and the carbon source was the vapor introduced in the Chemical Vapor Deposition, not the carbon fiber itself.

4. Summary

To sum up, an efficient route has been developed to synthesize coaxial nanocables composed of a crystalline SiC core and an amorphous SiO₂ outer shell. Due to the small diameter and then high reactivity ability, carbon fibers were suitable reactant in the formation of SiC/SiO₂ core–shell nanocables through the solid-gas reaction of C and SiO. The synthesized novel heterostructures are expected to have potential application in nanoscale electronic devices.

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References