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Silicon carbide nanowires grown on graphene sheets

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Abstract

Silicon carbide nanowires (SCNs) were synthesized on graphene sheets by a simple heat treatment using a mixture of Si powders and commercial graphene sheets with Fe catalyst addition. A series of analytical techniques were employed to investigate the as-grown SCNs. The SCNs were confirmed to be the cubic β-SiC and grew along their preferred direction perpendicular to (111). Most of the SCNs with the average length of about 10 μm and diameter of 60 nm lay on the graphene sheets. A few SCNs of several micrometers in length show twisted morphology. Solid–liquid–solid (SLS) and vapor–liquid–solid (VLS) mechanisms were proposed which interpret the SCNs' growth process on the graphene sheets and match the nucleation, growth of SCNs very well.

Keywords: Silicon carbide nanowires; Graphene; Growth mechanism

1. Introduction

Silicon carbide, as its wide band gap, high breakout field, high mechanical and thermal properties, and stable under high temperatures, has been widely applied in electronics, optics, and paddles in semiconductor furnaces [1–3]. One-dimensional silicon carbides nanowires (SCNs) are expected to exhibit some unique mechanical, electronic, and optical properties in nano-devices [4]. The promise of SCNs encouraged approaches to the synthesis of this material. Till date, SCNs have been synthesized by several techniques on various substrates [5,6], such as an activated carbon [7,8], carbon black [9,10], carbon fiber [11–16], carbon nanotubes [17–20] and graphite [21–23], including laser ablation [24], chemical vapor deposition (CVD) [25], molten salt synthesis [16,26,27], and thermal evaporation process with metal as a catalyst [28]. However, growth of SCNs on graphene sheets is rarely reported.

Graphene, which owns high carrier mobility [29], high thermal conductivity (5300 W/m K), high elasticity [30] and optical transparency [31], is expected to be the potential functional material applied in the semiconductor industry. The studies on the synthesis of SCNs grown on graphene sheets are of great importance in promoting exploitation of superb graphene composites and novel nano-devices.

In this article, SCNs were synthesized on graphene sheets by a simple heat treatment using a mixture of Si powders and commercial graphene sheets with Fe catalyst addition. The microstructures and the synthesis mechanisms of SCNs were also studied.

2. Experimental

The growth of SCNs on the graphene sheets was carried out by a simple heat-treatment process, in which the mixture of commercial graphene sheets (Ningbo Morsh Technology. Co., Ltd.), Si (micron-sized, purity 99%) powders and Fe (micron-sized, purity 99%) powders was used as the source material. The heat-treatment process was performed at 1573 K under vacuum condition (below 1×10^{-1} Pa). Before the heat treatment, the mixture of graphene,

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Si powders and Fe powders (mass ratio 1:2:3) was milled for 12 h, and then loaded in a graphite crucible and placed in the vacuum induction furnace to synthesize the products. After cooling to room temperature, the extra Fe and Si powders were simply washed and sieved out. Then the graphene sheets with SCNs were cleaned in alcohol, dried and kept in desiccators.

X-ray diffraction (XRD) and Raman spectra test were taken to analyze the phase composition of the reaction products. A Hitachi S-4800 scanning electron microscope (SEM) and a JEM-2100F transmission electron microscope (TEM) were used and an energy dispersive X-ray spectroscopy (EDS) detector was also applied to make further observation of the crystal structure and the growth direction of SCNs on the graphene sheets.

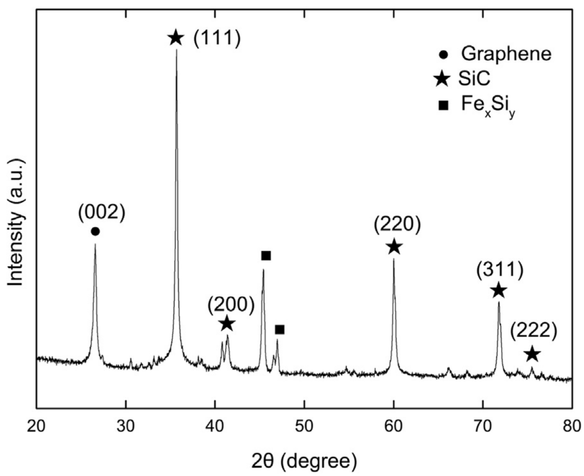

Fig. 1. XRD pattern of the products.

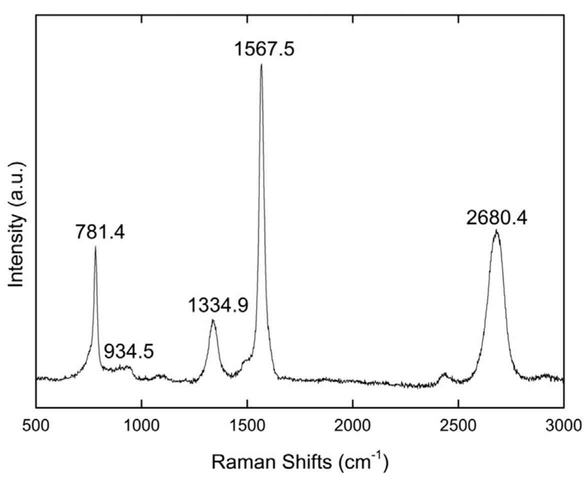

Fig. 2. Raman spectrum of the products.

3. Results and discussion

3.1. Microstructure of composites

Fig. 1 shows the XRD pattern of the products. Four β-SiC peaks at 35.70°, 41.38°, 60.02° and 71.80° were observed, which are diffractions from SiC (111), (200), (220) and (311) planes respectively, indicating the formation of β-SiC (JCPDS card no. 29-1129). Two peaks at 45.41° and 46.97° are attributed to the Fe–Si compound, which is very important for the growth of SCNs, and the growth mechanism will be discussed below in detail.

Further information on the nature of the SCNs grown on the graphene sheets is provided by the Raman spectra in Fig. 2. The Raman spectra were collected with a Renishaw Raman microscope (532 nm laser excitation wavelength). The peaks at 1334.9, 1567.5, and 2680.4 cm^{-1} have been attributed to the vibration mode of inter-icosahedra C–C bonds. Peaks at 781.4 and 934.5 cm^{-1} shift towards the lower wavenumber than the two peaks corresponding to the optical phonon mode of β-SiC, which includes the transverse optical phonon mode (796 cm^{-1}) and longitudinal optical phonon mode (972 cm^{-1}) [32], indicating the different crystalline structures from the SiC nanostructure materials.

Fig. 3(a) shows a typical SEM image of the products revealing that nanowires are densely grown on the graphene sheets. Most of the SCNs lay on graphene sheets with the average length of about 10 μm and diameter of 60 nm. The magnified interface image of the SCNs/graphene from Fig. 3(b) indicates that the SCNs and

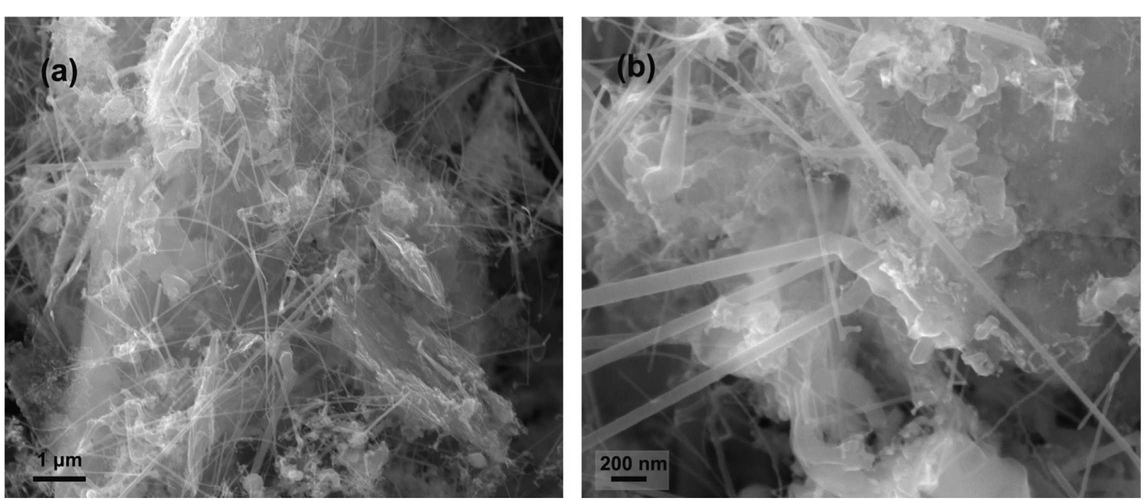

Fig. 3. SEM pictures of the SCNs grown on graphene sheets: (a) low-magnification SEM image of the SCNs grown on graphene sheets and (b) high-magnification SEM image of the SCNs/graphene interface.