DIRECT SYNTHESIS OF NANOCABLES OF SINGLE-WALLED CARBON NANOTUBES SHEATHED WITH AMORPHOUS SILICA

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Abstract

Coaxial nanocables of single-walled carbon nanotubes (SWNTs) sheathed with amorphous silica were synthesized by using an arc discharge method. The as-obtained nanocables were characterized by TEM, SEM and laser Raman. It was found that the nanocalbes are usually tens of microns in length and about 50 nm in diameter, and each of the cylinder-shaped nanocabels contains one to several SWNTs at the center part. The growth mechanism of the nanocables is proposed. These SWNT/amorphous silica nanocables may have potential applications in field effect transistors and other related nanodevices.

Introduction

With rapid development on the micromation and integration of electronic devices, bottom-up organization technique and related materials are attracting increasing research interest [Huang Y, Baughman RH]. Quasi-one-dimensional hetero-nanostructures are considered to be important building blocks for the construction of nanodevices [Wu Y]. Nanocables that made up of coaxial metallic or semi-conducting core and an insulating sheath layer have been studied intensively due to their unique structural characteristics and interesting physical and chemical properties. Various nanocables containing Si, SiC, ZnO, CdS, ZnS, TiO_2, Ge, Ag, and carbon nanotubes have been reported. Among them, carbon nanotube-based nanocables showed superior integrated properties of good stability, easy manipulation, and selectivity in transportation features, and therefore have been studied intensively [Seeger T, Whitsitt EA, Fu L]. The reported carbon nanotube-based nanocables were mainly prepared by dispersing the carbon nanotubes evenly in the sheath layer precursor solution firstly, and then obtain the nanocables via certain chemical or thermal treatments. Multi-walled carbon nanotube (MWNT)-based nanocables have been prepared effectively [Seeger T, Fu L, Zhang XT]. Since SWNTs are more difficult to be dispersed than for MWNTs, alternative method is needed for preparing SWNT-based nanocables. Liu [Fu Q] and Zhou [Liu XL] et al. synthesized isolated SWNTs in substrate and then obtained SWNT-based nanocables by depositing sheath layer precursors on them selectively. However, the SWNT-based nanocables thus obtained were deposited on the substrate, which makes it difficult in manipulating the nanostructure. Moreover, the chemical process involved during the sheath layer deposition may also bring defects to the nanotubes, and hence influence the electric transportation property of the nanocables.

In this study, we propose to prepare nanocables of SWNT sheathed with amorphous silica directly by an arc discharge method, which showed advantages of simple synthesis process and little structural damage to the SWNTs. The microstructure of the as-obtained nanocables is characterized, and the growth mechanism of the nanocables is discussed.

Experimental

The nanocables were synthesized in an arc discharge furnace. The cathode is a graphite rod with a diameter of 10 mm, while a mixture of silicon powder, graphite powder, iron catalyst, and FeS growth promoter was cold pressed to a cylinder-shaped serving as the anode (20 mm in diameter). Hydrogen gas was employed as the buffer gas, and small amount of water was placed inside the chamber to provide vapor. The as-prepared samples were characterized by using TEM, SEM, and laser Raman.

Results and discussion

The as-prepared products are thin film-like or filament-like substance that is gray in color. SEM observation (Fig. 1) showed that they were composed of numerous entangled fibers with mean diameter of about 50 nm and length of several to tens of microns. TEM observations (Fig. 2) revealed that the fibers are coaxial cable-like nanostructure. The core of the cable is made up of one to several

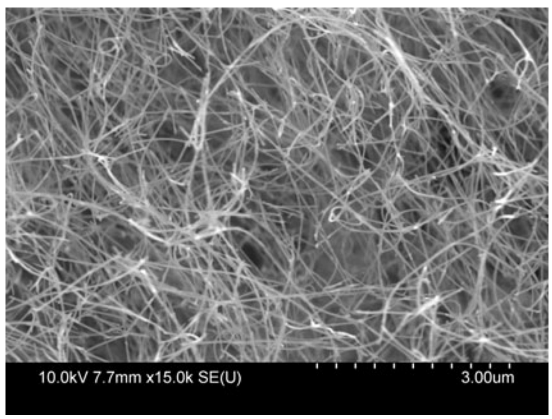

Fig. 1 SEM image of the as-prepared nanocables

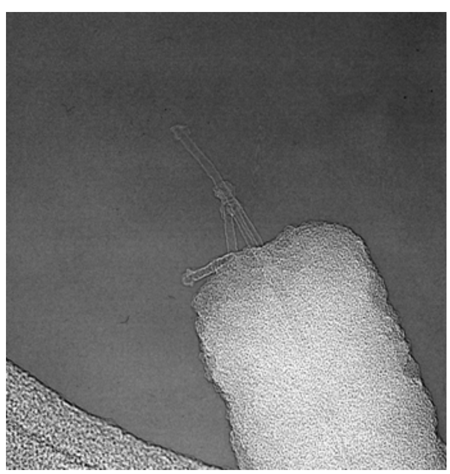

Fig.2 TEM image of an as-prepared nanocable

nanotubes, while the sheath layer of the cable is amorphous. EDS analysis showed that the sheath layer contains mainly silicon and oxygen with atomic ratios in the range of 1:1 to 1:2. Distinct RBM peaks of SWNTs were observed in the Laser Raman spectra of the nanocables, indicating that the nanotubes located at the center part of the nanocables are SWNTs. Therefore, the coaxial nanocables are SWNTs sheathed with amorphous silica.

The growth process of the nanocables are proposed as follows: (1) raw materials of graphite, silicon, and catalyst powders were vaporized under high temperature of around 4000K brought by the electric arc; (2) SWNTs start to form aided by the catalysts; (3) silicon was oxidized by water vapor as following: $Si + xH_2O \longrightarrow SiO_x + xH_2$; (4) amorphous silica deposited on the SWNTs forming nanocables, and this process is energetically favorable since the total surface energy can be reduced; (5) the growth of the nanocables ceased when they were transported to low temperature range. Therefore, the structure and composition of the nanocables are controllable by tuning C/Si ratio, concentration of water vapor, and the temperature gradient in the chamber etc.

With a semi-conducting SWNT core and an insulating amorphous silica sheath layer, the nanocable can be used for fabricating field effect transistors. Since the diameter, length, and composition of the nanocables are controllable, various features of the nanocable-based field effect transistor are expected to be tuned. In depth studies are underway.

Summary

We have developed a hydrogen arc discharge technique for preparing nanocables of SWNTs sheathed with amorphous silica directly. The nanocables are about 50 nm in diameter and several to tens of microns in length. Each cable may contain one to several SWNTs at the center part with amorphous silica wrapped coaxially. A growth mechanism of the nanocables is proposed. The structural characteristics of the nanocables, such as diameter, length, and chemical composition etc. are expected to be controlled by tuning experimental parameters. These nanocables can be used for fabricating high efficiency field effect transistors.

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