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Bismuth Chalcogenide-Filled Single-Walled Carbon Nanotubes †

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Abstract: In this work, bismuth selenide, and bismuth telluride were filled inside SWCNTs. High resolution transmission electron microscopy confirmed the filling of SWCNTs. The chemical properties of filled SWCNTs were investigated by Raman spectroscopy, photoemission spectroscopy, and optical absorption spectroscopy. The investigations lead to conclusion that the introduced substances do not have influence on the electronic properties of SWCNTs.

Keywords: bismuth chalcogenide; carbon nanotube; electronic properties; atomic structure

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1. Introduction

The filling of single-walled carbon nanotubes (SWCNTs) opens doors to applications of carbon nanotubes in nanoelectronics, catalysis, sensors, spintronics, thermoelectric power generation, light emission, solar cells, biomedicine [1–4]. The SWCNTs can be filled with inorganic substances, simple substances, and molecules [5]. Depending on chemical properties of filler, the properties of SWCNTs are tuned for required tasks. Introduced inorganic substances are metal halogenides, metal chalcogenides. Simple substances are nonmetals, metals. Molecules are metallocenes, metal acetylacetonates [6]. The introduced molecules can decompose inside SWCNTs with the formation of metal catalysts that catalyze the growth of SWCNTs. There are also other chemical reactions in channels of carbon nanotubes [5].

In this work, I filled the SWCNTs with bismuth selenide (Bi_2Se_3), and bismuth telluride (Bi_2Te_3). The filling was performed by the melt method. The SWCNTs were mixed with metal chalcogenide in a quartz ampoule, and sealed under vacuum. Then the ampoule was heated to temperature exciding the melting point of bismuth chalcogenides. The chemical properties of filled SWCNTs were investigated by Raman spectroscopy, photoemission spectroscopy, and optical absorption spectroscopy. The detailed analysis of chemical properties of filled SWCNTs lead to conclusion that the introduced substances do not have influence on the electronic properties of SWCNTs, except of small influence on single chirality species.

2. Experimental

The SWCNTs were pre-opened in dry air for 30 min at 500 °C. The SWCNTs were mixed with powder of bismuth selenide, or bismuth telluride. The mixture was put into quartz ampoule, which was sealed under vacuum. The ampoule was heated to the temperature, which exceeded the melting point of compound by 100 °C ($T_{synthesis}$ (Bi_2Se_3) = 806 °C, $T_{synthesis}$ (Bi_2Te_3) = 686 °C). The ampoule was cooled slowly with rates of 0.1–1 °C/min to form good atomic-thick crystals inside SWCNTs.

3. Results

The microstructure of filled SWCNTs was studied by high resolution transmission electron microscopy (HRTEM). Figures 1 and 2 show the microphotos of bismuth selenide, and bismuth telluride-filled SWCNTs. These photos demonstrate the microstructure of crystals inside SWCNTs. The channels of SWCNTs are filled. The crystals of filler are recognized inside SWCNTs.

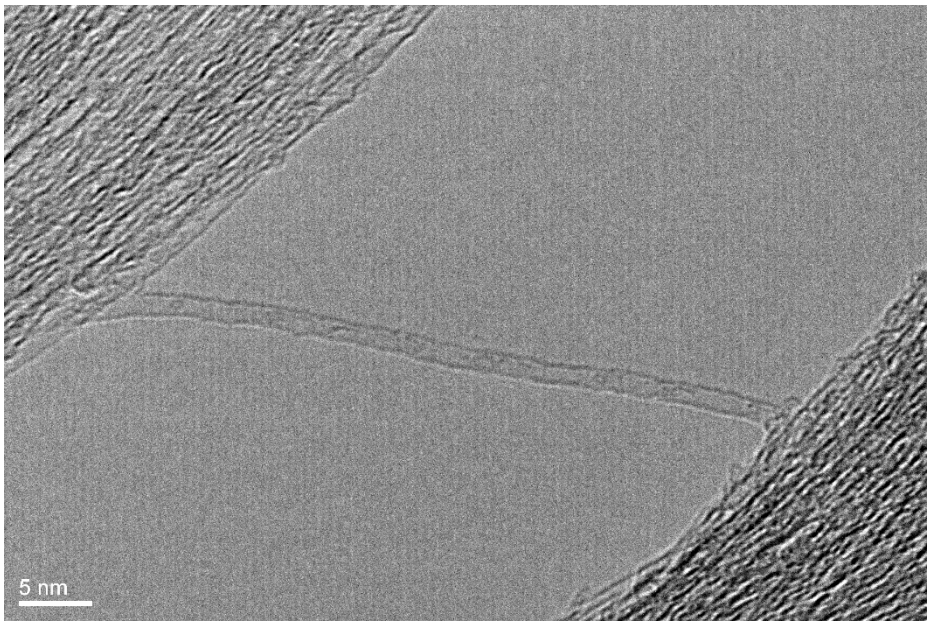

Figure 1. The HRTEM image of bismuth selenide-filled SWCNTs.

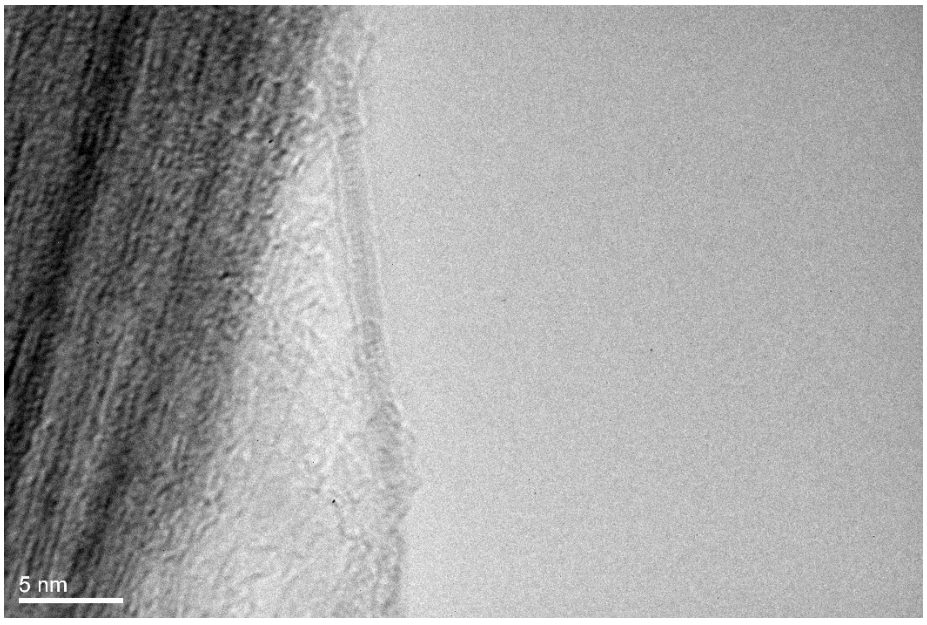

Figure 2. The HRTEM image of bismuth telluride-filled SWCNTs.

The Raman spectroscopy allows investigating the vibronic, and electronic properties of filled SWCNTs. Raman spectra of bismuth selenide, and bismuth telluride-filled SWCNTs show only small changes in comparison with the pristine nanotubes. These small changes concern only several single chirality species.

Photoemission spectroscopy (X-ray photoelectron spectroscopy (XPS), ultraviolet photoelectron spectroscopy (UPS)) allows investigating the Fermi level shift of SWCNTs

upon filling. The shift of C 1s XPS peak corresponds to equal shift of π-peak in the UPS spectrum of filled SWCNTs. In the case of bismuth chalcogenide-filled SWCNTs, there are no noticeable shifts of peaks in C 1s XPS spectrum.

The optical absorption spectroscopy (OAS) allows investigating the charge transfer in the filled SWCNTs. In bismuth chalcogenide-filled SWCNTs, there are no noticeable changes in the OAS spectra in comparison with the pristine SWCNTs.

4. Conclusions

The experimental data testify that bismuth selenide, and bismuth telluride do not have significant influence on the electronic properties of SWCNTs. This is confirmed by HR TEM, Raman spectroscopy, photoemission spectroscopy, and OAS. These findings allow studying in detail the crystal structure of encapsulated compounds, which is the object of our work.

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