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Proceeding Paper

Lead Halogenide Filled Single-Walled Carbon Nanotubes †

Marianna V. Kharlamova [1,2]

[1] Centre for Advanced Materials Application (CEMEA), Slovak Academy of Sciences, Dúbravská Cesta 5807/9, 845 11 Bratislava, Slovakia; mv.kharlamova@gmail.com or dr.marianna.kharlamova@gmail.com
[2] Moscow Institute of Physics and Technology, 9 Institutskiy per., 141700 Dolgoprudny, Russia
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Abstract: I filled the single-walled carbon nanotubes (SWCNTs) with lead chloride, lead bromide, and lead iodide. The high resolution transmission electron microscopy data proved the filling of SWCNTs. I investigated the electronic properties by Raman spectroscopy, and X-ray photoelectron spectroscopy, and I showed the p-doping of SWCNT.

Keywords: lead halogenide; carbon nanotube; electronic properties; Raman spectroscopy; near edge X-ray absorption fine structure spectroscopy; X-ray photoelectron spectroscopy; optical absorption spectroscopy

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1. Introduction

Single-walled carbon nanotubes (SWCNTs) are filled with metal chalcogenides, metal halogenides, metals, and molecules. Metal halogenides are the largest group of compounds that are introduced inside SWCNTs. I filled many metal halogenides inside SWCNTs [1–11]. Metal halogenides can be electron donors, or electron acceptors. The filling methods of metal halogenides are liquid phase method, and melt method. In this method, the compound is melted, and it is incorporated inside SWCNTs by capillary forces. The SWCNTs filled with metal halogenides can find applications in nanoelectronics, sensors, catalysis, biomedicine, electrochemical energy storage, solar cells, light emission. To apply the filled SWCNTs in these fields, the SWCNTs are investigated by spectroscopic techniques, such as Raman spectroscopy, near edge X-ray absorption fine structure spectroscopy, X-ray photoelectron spectroscopy, and optical absorption spectroscopy. The investigations show that the filled SWCNTs have doping effect on SWCNTs, and the doping effect depends on metal type, halogen type, filling ratio, type of used carbon nanotubes [12–21]. In this work, I fill the SWCNTs with lead halogenides, and I investigate the electronic properties of filled SWCNTs by spectroscopic techniques [22]. The investigations show that the encapsulated lead halogenides cause p-doping of SWCNTs. The doping effect depends on halogen type. It is maximal for lead chloride, and it is minimal for lead bromide. This is caused by the different filling ratios of SWCNTs. Such filled SWCNTs can find applications in various fields, in particular in solar cells.

2. Experimental

The SWCNTs and lead halogenides are put to quartz ampoules, and sealed under vacuum. The heating of system is performed to melt the salt, and to fill it inside SWCNTs. The following cooling causes the crystallization of system. The synthesis is performed at temperatures that are 100 °C higher than the melting point of the compounds ($T_{melting}(PbCl_2)$ = 501 °C, $T_{melting}(PbBr_2)$ = 371 °C, $T_{melting}(PbI_2)$ = 402 °C).

3. Results

The data of high resolution electron microscopy (HRTEM) of filled SWCNTs prove the filling of compounds inside SWCNTs. Figure 1 shows the HRTEM images of lead chloride-filled SWCNTs. In Figure 1a, one can see the bundle of lead chloride-filled SWCNTs. The white contrast lines are observed in the image, which correspond to the filled channels of SWCNTs. Figure 1b shows individual SWCNT filled with lead chloride in the down right part of the image. The individual atoms of salts are visible in the image.

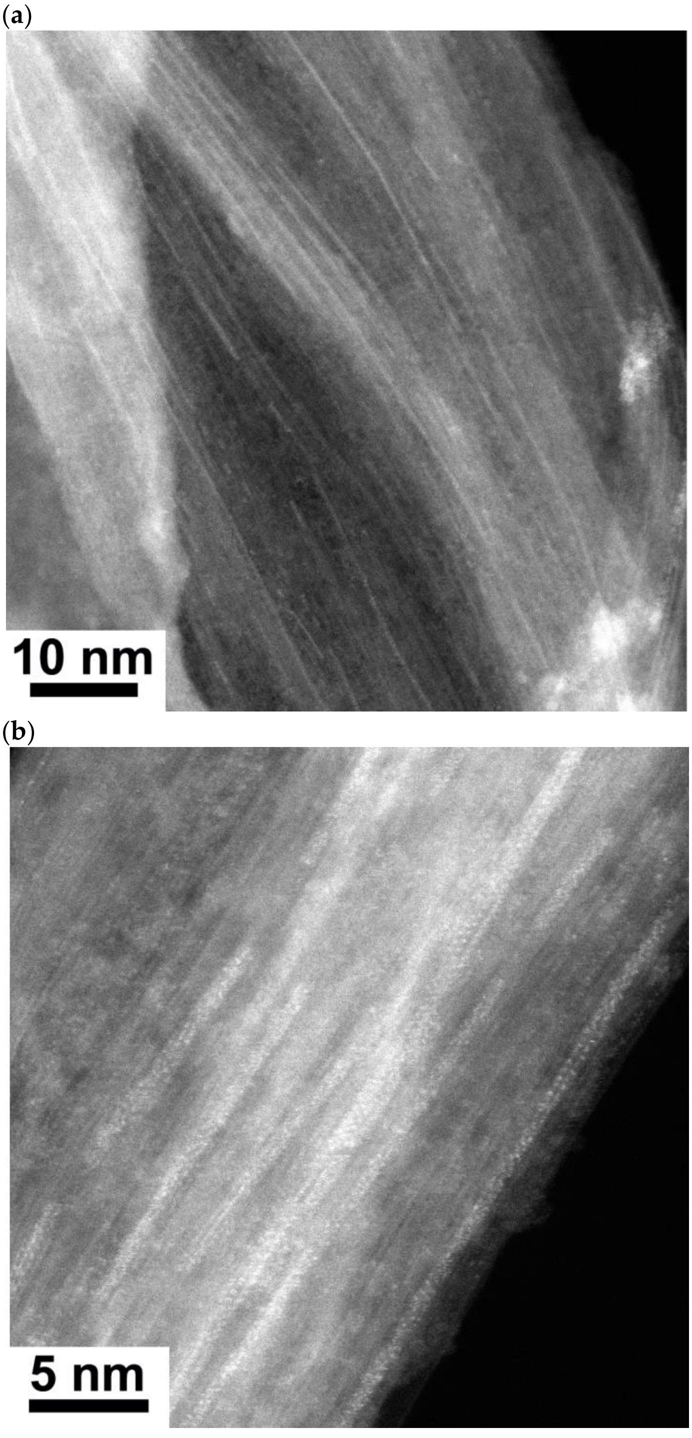

Figure 1. The HRTEM image of bundle of lead chloride-filled SWCNTs (**a**), the image showing individual lead chloride-filled SWCNT (**b**).

Figure 2 shows the HRTEM image of lead iodide-filled SWCNTs. Two filled SWCNTs are visible in the image. The atoms of salts are clearly recognized inside SWCNTs. They are visible as white dots. Three columns of atoms are observed within the walls of carbon nanotubes. The distances between three columns of atoms are equal.

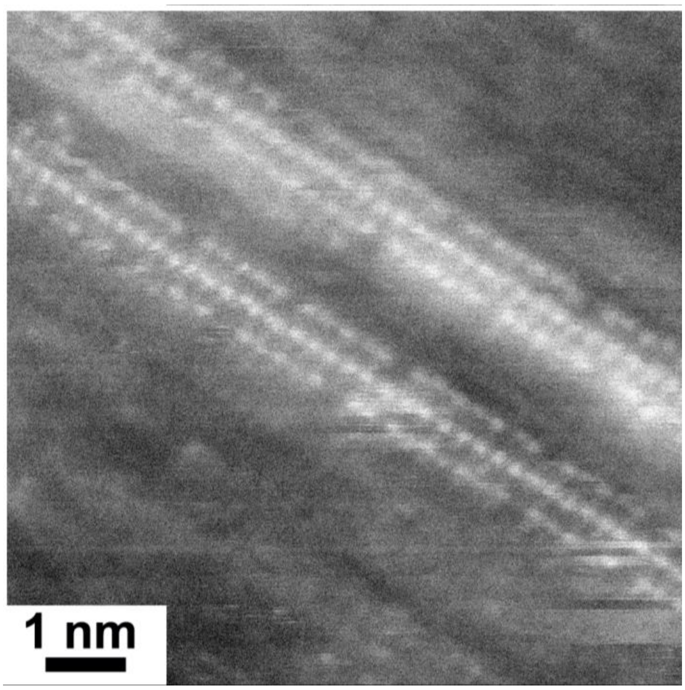

Figure 2. The HRTEM image showing two individual lead iodide-filled SWCNTs.

The investigations of lead halogenide-filled SWCNTs by spectroscopic techniques, such as Raman spectroscopy, and X-ray photoelectron spectroscopy showed that the introduced salts have p-doping effect on the carbon nanotubes. The effect is different for different lead halogenides. Lead chloride has the maximal doping effect on SWCNTs, whereas lead bromide has the smallest doping effect on the carbon nanotubes.

4. Conclusions

In this work, I filled the SWCNTs with lead halogenides. The HRTEM data proved the filling of compounds in the interior cavities of SWCNTs. The electronic properties were analyzed by Raman spectroscopy, and X-ray photoelectron spectroscopy. The p-doping of carbon nanotubes was confirmed.

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