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Photoemission Insight to Filling of Large 1.7 nm-Diameter Single-Walled Carbon Nanotubes with Silver Chloride †

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Abstract: Here, I fill the large 1.7 nm-diameter single-walled carbon nanotubes (SWCNTs) with silver chloride (AgCl). I make the photoemission insight to the filling of SWCNTs. The C1s X-ray photoelectron spectroscopy (XPS) reveals the p-doping of SWCNTs. The Raman spectroscopy data are complementary to the XPS data, and they confirm the strong doping effect of encapsulated silver chloride on SWCNTs.

Keywords: carbon nanotube; silver chloride; photoemission spectroscopy; electronic properties; Raman spectroscopy

1. Introduction

Single-walled carbon nanotubes (SWCNTs) represent a container that can be filled with different substances for various applications. Silver chloride is long used photoactive chemical compound that can be applied in biomedicine. SWCNTs prevent filler from destructions, and the encapsulated substance can at the same time modify properties of carbon nanotubes. There are two methods for investigation of the electronic properties of filled carbon nanotubes, X-ray photoelectron spectroscopy (XPS), and Raman spectroscopy. X-ray photoelectron spectroscopy is a viable tool for characterization of carbon nanotubes [1–19]. It is non-destructive, useful method to reveal the Fermi level shift in filled SWCNTs. The shifts of peaks can be directly attributed to the Fermi level shifts, and work function variations [20]. In our previous work, we studied the small-diameter metallic AgCl-filled SWCNTs [21], and semiconducting AgCl-filled SWCNTs [22]. We observed all differences in varieties of SWCNTs filled with strong filler. The influence of filler on single chiralities with metallic, and semiconducting character was investigated. Here, I fill the large diameter 1.7 nm-diameter SWCNTs with AgCl to make the photoemission insight to filling of SWCNTs. My motivation is the following. Firstly, the filling of large diameter SWCNTs allows encapsulation of more amount of material inside carbon nanotubes. This leads to larger doping effect of filler on SWCNTs. Secondly, these materials were not investigated by photoemission spectroscopy, nor Raman spectroscopy to reveal doping effects. Thirdly, 1.7 nm-diameter SWCNTs are prepared by simple chemical vapour deposition (CVD) method, which allows filling of large amounts of pure SWCNTs by the proposed method, and it opens the way to industrial scale preparation, and applications.

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2. Experimental

I have filled the SWCNTs with AgCl by the following method. I put SWCNTs, and AgCl in a quartz ampoule, pump under vacuum, and seal. The ampoule is heated to temperature that is 100 °C higher than melting point of AgCl ($T_{melting}$(AgCl) = 455 °C). The system is maintained at this temperature for 6 h, and then cooled. The electronic properties of filled SWCNTs are investigated by XPS, and Raman spectroscopy.

3. Results

Here, Figure 1 shows an example of the high resolution transmission electron microscopy (HRTEM) image of AgCl-filled SWCNTs. It is visible that the channels of SWCNTs are filled. In the image, one can observe three individual carbon nanotubes with AgCl inside channels. The structure of crystal can be resolved. The structure of bulk AgCl resembles NaCl structure, Fm3m space group (a = 0.546 nm) [23].

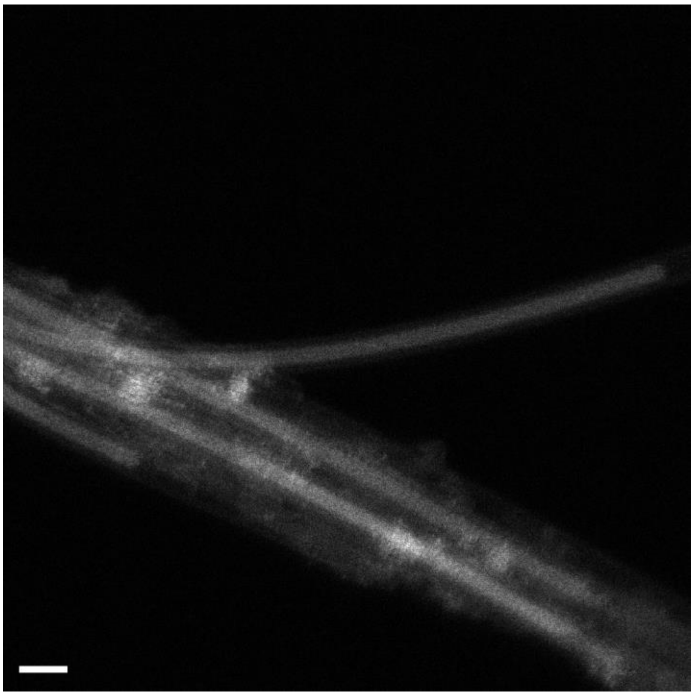

Figure 1. The HRTEM data of AgCl-filled SWCNTs.

In Figure 2, I show the C 1s XPS spectra of pristine SWCNTs, and AgCl-filled carbon nanotubes. The C 1s XPS spectra represent the single peaks. The peak of AgCl-filled SWCNTs is shifted by 0.36 eV to lower binding energies as compared to spectrum of the pristine SWCNTs. The spectrum of filled SWCNTs is broadened in comparison with the one of the pristine SWCNTs. These changes testify about change in the electronic properties of SWCNTs upon filling, and they reveal p-doping of SWCNTs.

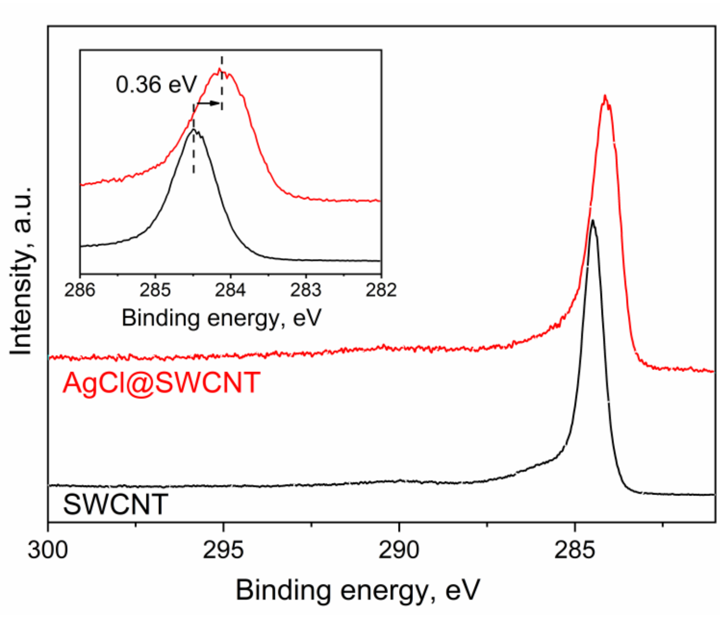

Figure 2. The C 1s XPS spectra of the pristine 1.7 nm-diameter SWCNTs, and AgCl-filled SWCNTs.

In Figure 3, I show the Raman spectroscopy data of AgCl-filled SWCNTs in comparison with the data of the pristine carbon nanotubes. These data are complementary to the photoemission spectroscopy data. The Raman spectrum of filled SWCNTs has differences in radial breathing mode (RBM), and G-band. In RBM-band, there are modifications of band profile, which are caused by alterations of peak intensities. In G-band, there are shifts of peaks. The Breit-Wigner-Fano G_{BWF}, peak of tangential contribution G_{TO}, and peak of longitudinal contribution G_{LO} are shifted to higher frequencies, and it leads to shift of whole spectrum by about 10 cm^{-1}. This corresponds to p-doping of SWCNTs by AgCl, and these results confirm the photoemission spectroscopy data.

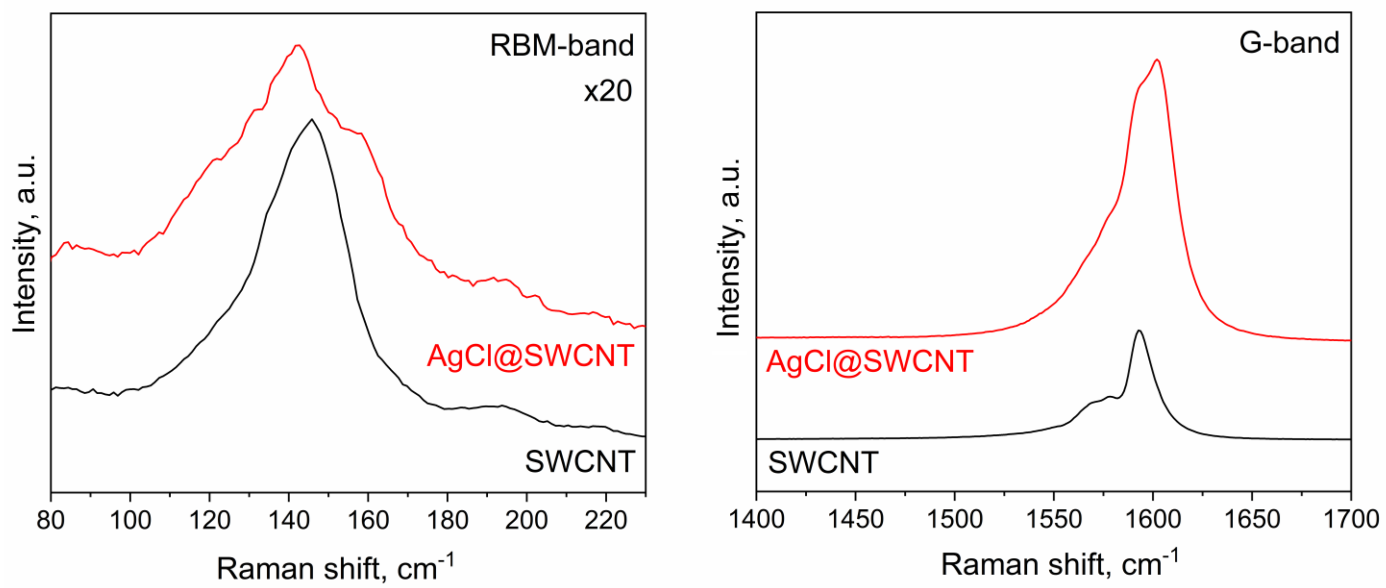

Figure 3. The RBM and G-bands of Raman spectra of the pristine 1.7 nm-diameter SWCNTs, and AgCl-filled SWCNTs.

4. Conclusions

In this work, I filled the SWCNTs with AgCl, and I made the photoemission insight to filling of SWCNTs with AgCl. It was revealed that AgCl has p-doping effect on SWCNTs. The proposed filling method allows filling SWCNTs synthesized by industrial CVD method simply, and quickly. It opens ways to industrial applications of filled SWCNTs.

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Conflicts of Interest: The authors declare no conflict of interest.

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