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Proceeding Paper

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 large 1.7 nm diameter single-walled carbon nanotubes (SWCNTs) with silver chloride (AgCl). I present photoemission insights into the filling of SWCNTs. 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

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1. Introduction

Single-walled carbon nanotubes (SWCNTs) represent a container that can be filled with different substances for various applications. Silver chloride has long been used as a photoactive chemical compound that can be applied in biomedicine. SWCNTs prevent filler from destruction, and the encapsulated substance can at the same time modify the properties of carbon nanotubes. There are two methods for investigating the electronic properties of filled carbon nanotubes: X-ray photoelectron spectroscopy (XPS) and Raman spectroscopy. X-ray photoelectron spectroscopy is a viable tool for the characterization of carbon nanotubes [1–19]. It is a non-destructive, useful method to reveal the Fermi level shift in filled SWCNTs. The shifts in the peaks can be directly attributed to the Fermi level shifts and work function variations [20]. In our previous work, we studied 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 a metallic and semiconducting character was investigated. In this study, I filled large 1.7 nm diameter SWCNTs with AgCl to make photoemission insights into the filling of SWCNTs. My motivation is the following. Firstly, the filling of large-diameter SWCNTs allows for the encapsulation of a greater amount of material inside carbon nanotubes. This leads to a 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 via a simple chemical vapour deposition (CVD) method which allows the filling of large amounts of pure SWCNTs with the proposed method, and it opens the way to industrial-scale preparation and applications.

2. Experimental Section

I filled SWCNTs with AgCl using the following method. I put SWCNTs and AgCl in a quartz ampoule, pumped them under vacuum, and sealed them. The ampoule was heated to a temperature that was 100 °C higher than melting point of AgCl ($T_{melting}$(AgCl) = 455 °C).

The system was maintained at this temperature for 6 h, and then cooled. The electronic properties of filled SWCNTs were investigated using XPS and Raman spectroscopy.

3. Results

Here, Figure 1 shows an example of a 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 the channels. The structure of the crystal can be seen. The structure of bulk AgCl resembles a NaCl structure Fm3m space group (a = 0.546 nm) [23].

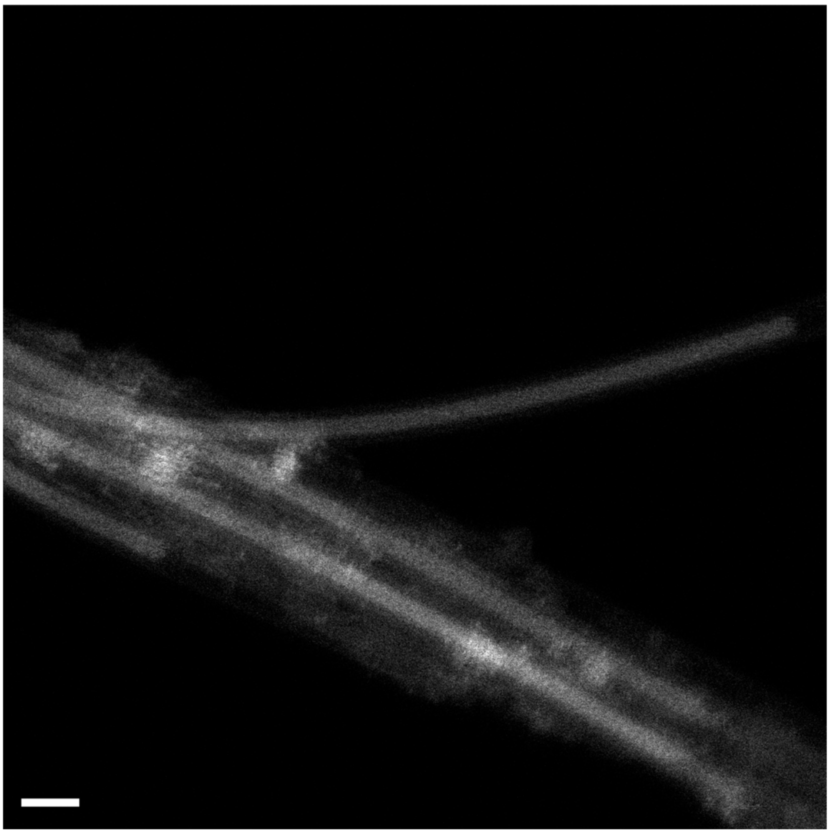

Figure 1. The HRTEM data of AgCl-filled SWCNTs.

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 compared to the spectrum of the pristine SWCNTs. The spectrum of the filled SWCNTs is broadened in comparison with that of the pristine SWCNTs. These changes confirm the change in the electronic properties of SWCNTs upon filling, and they reveal the p-doping of 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 the G-band. In the RBM-band, there are modifications in the band profile which were caused by alterations in the peak intensities. In the G-band, there are shifts in the 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, leading to a shift in the whole spectrum by about 10 cm^{-1}. This corresponds to the p-doping of SWCNTs by AgCl, and these results confirm the photoemission spectroscopy data.

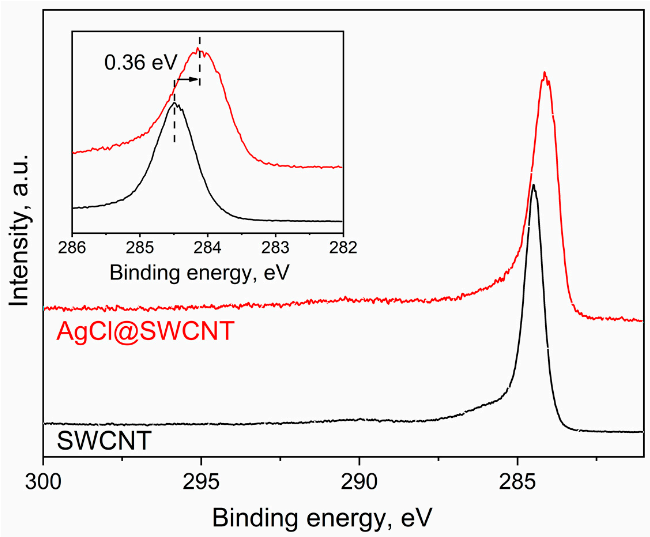

Figure 2. The C 1s XPS spectra of the pristine 1.7 nm diameter SWCNTs and AgCl-filled SWCNTs.

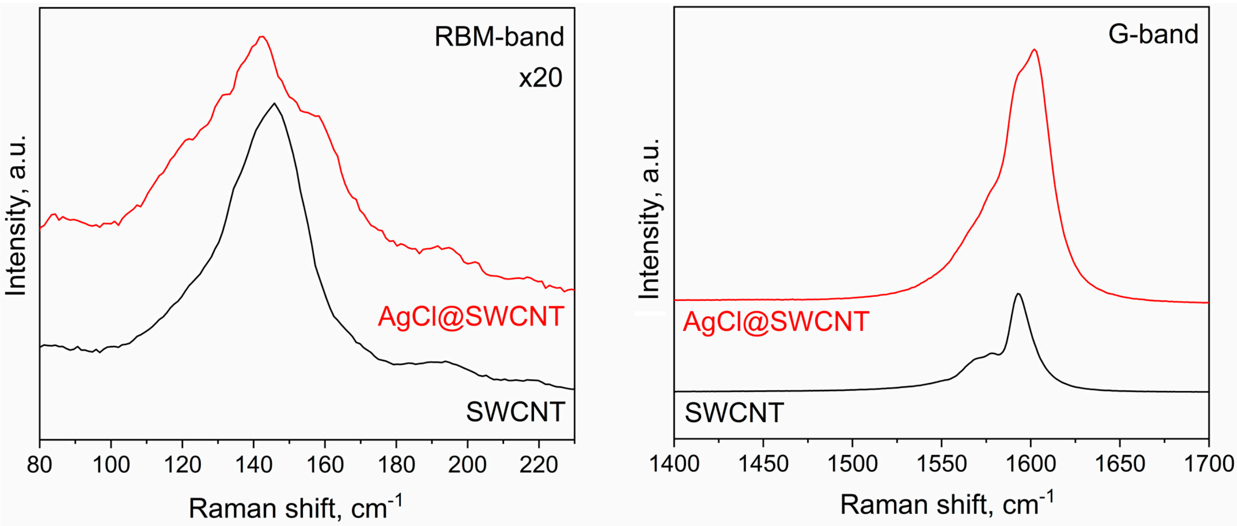

Figure 3. The RBM and G-bands of Raman spectra of the pristine 1.7 nm diameter SWCNTs and AgCl-filled SWCNTs.

4. Conclusions

In this work, I filled SWCNTs with AgCl, and I made photoemission insights into the filling of SWCNTs with AgCl. It was revealed that AgCl has a p-doping effect on SWCNTs. The proposed filling method allows for filling SWCNTs synthesized by an industrial CVD method simply and quickly. It opens up possibilities for industrial applications of filled SWCNTs.

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Conflicts of Interest: The author declares no conflict of interest.

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