environmental sciences proceedings

MDPI

Proceeding Paper

Growth of Inner Carbon Nanotubes inside Cobaltocene-Filled Single-Walled Carbon Nanotubes †

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† Presented at the 6th International Electronic Conference on Atmospheric Sciences, 15-30 October 2023. Available online: https://ecas2023.sciforum.net

Abstract: In this work, the single-walled carbon nanotubes (SWCNTs) were filled with cobaltocene. The growth properties of individual chirality nanotubes were studied with Raman spectroscopy. It was shown that the larger nanotubes grow slower. The growth of inner nanotubes becomes faster with increasing annealing temperature. This results are of high importance as they stimulate research on carbon nanotubes, and bring ideas from laboratories in factories.

Keywords: Raman spectroscopy, growth properties, cobaltocene

1. Introduction

Filling of single-walled carbon nanotubes (SWCNTs) is important for applications [1-4]. Metallocenes is promising filler material as they modify the chemical, and physical properties of SWCNTs. Metallocenes inside SWCNTs represent a unique system for the growth of inner carbon nanotubes. The electronic properties of filled SWCNTs are also modified [5, 6]. In this work, I have filled the SWCNTs with cobaltocene, and I investigated the growth of inner carbon nanotubes. Raman spectroscopy allowed me to trace the process of growth with the high precision. The growth of inner SWCNTs with chiralities of (13,1), (12, 3), and (11, 1) was detected. The chirality-specific growth curves of SWCNTs were obtained at different temperatures to compare kinetics.

2. Experiments

I performed the filling of SWCNTs with cobaltocene in gas phase. The filling was performed in glass ampoule at low temperature (~59°C). The filled SWCNTs were annealed at different temperatures to investigate kinetics. This system is very interesting for investigation of these properties as it gives a clean environment for high precise study of growth of SWCNTs.

3. Results

Figure 1 shows the growth curves of inner nanotubes inside cobaltocene-filled SWCNTs at temperatures of 540 ◦C (a), 560 ◦C (b), 580 ◦C (c), 600 ◦C (d), 620 ◦C (e) and 640 ◦C (f). With these lots of data, it is visible that the larger nanotubes grow slower. The growth of inner nanotubes becomes faster with increasing the annealing temperature. This is because kinetics of growth of inner SWCNTs depends on their chirality. Here, I present the chirality-specific kinetics, which is important knowledge for applications. For

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

example, this will allow decreasing the growth temperature of SWCNTs to make the preparation processes easier, simpler, and a low-cost. It should be noted that the growth kinetics of SWCNTs in this system should be investigated with different conditions, i.e. precursor types, which lead to new results, and important information on synthesis protocols is implemented in industry. The kinetics experiment is time-consuming, but the established fundamental dependencies, and trends lead to quick modernization of preparation processes. I expect that this data is involved in factory process developments soon.

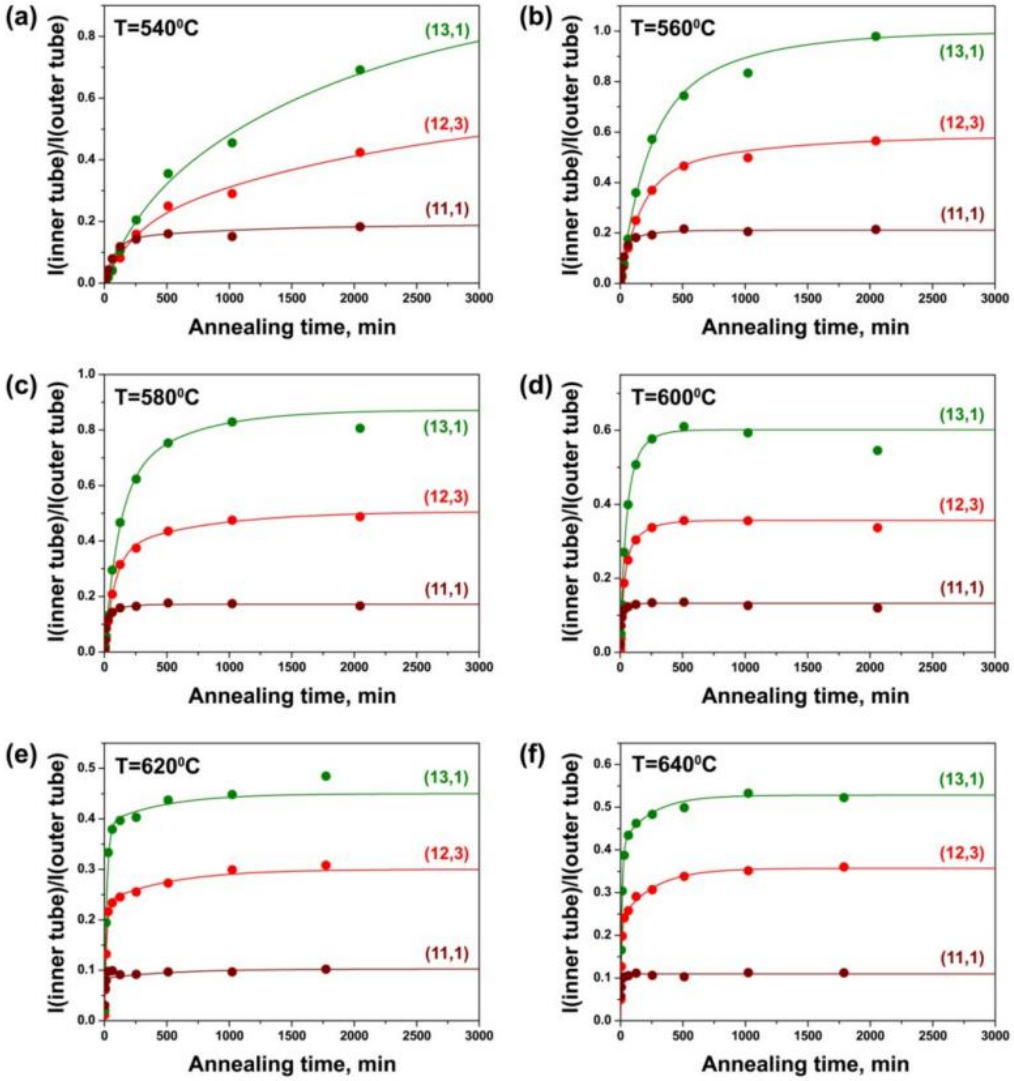

Figure 1. The growth curves of inner nanotubes inside cobaltocene-filled SWCNTs at temperatures of 540 ◦C (a), 560 ◦C (b), 580 ◦C (c), 600 ◦C (d), 620 ◦C (e) and 640 ◦C (f) [2].

4. Conclusions

In this work, the growth properties of individual chirality nanotubes were studied. It was shown that the larger nanotubes grow slower. The growth of inner nanotubes become faster with increasing the annealing temperature. High importance of this data is caused by necessity of driving force for researchers to study. With these materials obtained, research on carbon nanotubes is going faster.

Author Contributions: The manuscript is written solely by Marianna V. Kharlamova.

Funding: These studies were partly performed during the implementation of the project Building-up Centre for advanced materials application of the Slovak Academy of Sciences, ITMS project code 313021T081 supported by Research & Innovation Operational Programme funded by the ERDF.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.
Data Availability Statement: The data are available on request of Marianna V. Kharlamova.

Acknowledgments: Marianna V. Kharlamova thanks Christian Kramberger-Kaplan (University of Vienna, Vienna, Austria).

Conflicts of Interest: The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Kharlamova, M.V.; Kramberger, C. Applications of Filled Single-Walled Carbon Nanotubes: Progress, Challenges, and Perspectives. Nanomaterials 2021, 11, 2863
2. Kharlamova, M.V.; Kramberger, C. Metal Cluster Size-Dependent Activation Energies of Growth of Single-Chirality Single-Walled Carbon Nanotubes inside Metallocene-Filled Single-Walled Carbon Nanotubes. *Nanomaterials* 2021, *11*, 2649
3. Kharlamova, M.V.; Kramberger, C. Spectroscopy of filled single-walled carbon nanotubes. Nanomaterials 2022, 12, 42
4. Kharlamova, M.V. Advances in tailoring the electronic properties of single-walled carbon nanotubes, Progress in Materials Science, 2016, 77, 125-211
5. Kharlamova, M.V. Electronic properties of pristine and modified single-walled carbon nanotubes, Physics – Uspekhi, 2013, 56(11), 1047-1073
6. Kharlamova, M.V.; Kramberger, C. Metallocene-filled single-walled carbon nanotube hybrids, Nanomaterials, 2023, 13, 77