Encapsulation of $MoTe_2$ nanoribbons inside carbon nanotubes

Shivani Shukla,[1,2] Yusuke Nakanishi,[2] and Hisanori Shinohara[3]

[1]*Department of Materials Science and Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*

[2]*Nakatani RIES: Research and International Experience for Students Fellowship in Japan, USA*

[3]*Department of Chemistry & Institute for Advanced Research, Nagoya University, Nagoya, Japan*

Previous research has shown that the physical properties of bulk crystalline materials can vary greatly as the material is transformed from 3D-bulk to 2D-sheets or nanotubes, and finally to 1D-nanoribbons. Specifically, bulk graphite is conductive, as is single-layer graphene, but carbon nanotubes conduct electricity differently depending on chirality. Finally, graphene nanoribbons are semiconducting. A different pattern has been observed in transition metal dichalcogenide (TMD) nanoribbons, such as molybdenum disulfide. It is important to further study this interesting physical phenomenon in other TMDs and crystals, to uncover novel physics and eventually apply each nanomaterial optimally in future devices. Research has shown that high-yield synthesis of MoS_2 nanoribbons via encapsulation inside CNTs is difficult to achieve. In this study, we have successfully encapsulated $MoTe_2$ nanoribbons and tellurium nanowires inside CNTs via sublimation.

Encapsulation of Te nanowires and $MoTe_2$ nanoribbons inside carbon nanotubes

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[1]*Department of Materials Science and Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*
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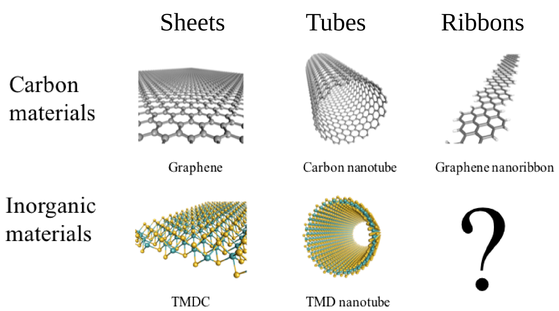
Background



- Physical properties of bulk crystalline materials vary greatly with dimensionality.
- Research on novel 2D materials has revealed this phenomenon:
  - *[Graphite]* Bulk graphite is conductive, as is single-layer graphene. Carbon nanotubes conduct electricity differently depending on chirality, and graphene nanoribbons are semiconducting.
  - *[Molybdenum disulfide]* Bulk MoS_2, a transition metal dichalcogenide (TMD), is a semiconductor, but the electrical properties of MoS_2 nanoribbons depend on chirality. High-yield synthesis of MoS_2 nanoribbons via encapsulation inside CNTs is difficult to achieve via sublimation.
  - ***[Molybdenum ditelluride]*** Bulk molybdenum ditelluride, also a TMD semiconductor, contains a higher bond strength than MoS_2. High-yield synthesis of $MoTe_2$ was attempted too see if higher bond strength could facilitate encapsulation

Research Question

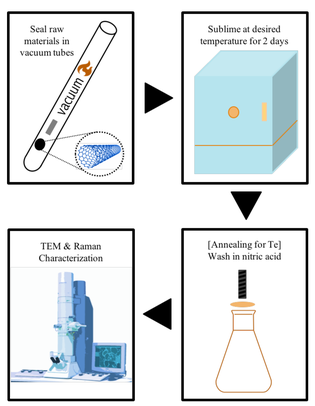
- Encapsulation of materials inside carbon nanotubes (CNTs) is an active field of research.
- Sublimation is most common method; *selectivity of certain kinds of CNTs for certain TMDs and metals is not yet clear.*
- 1-Dimensional TMD nanoribbons or metal nanowires could reveal *novel physical properties*
- If high-yield synthesis is achieved, extraction and application to future electronics
- Successfully encapsulated $MoTe_2$ nanoribbons and tellurium nanowires inside CNTs via sublimation.

Materials

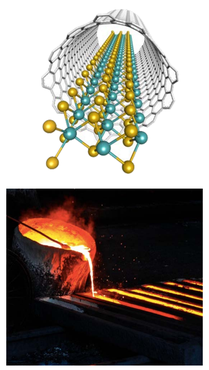
- Encapsulation of $MoTe_2$ nanoribbons inside EC 1.5 (DIPS) CNTs was attempted using a mixture of pure Te and 2H $MoTe_2$
- Encapsulation of 1T' $MoTe_2$ and pure Te was attempted using SO (arc discharge) CNTs
- Both CNTs had target diameter of 1.5nm, with EC 1.5 having a broader range

Synthesis

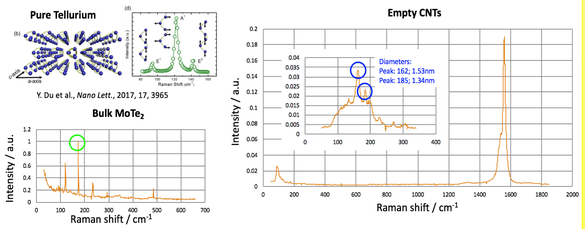
The Sublimation Process



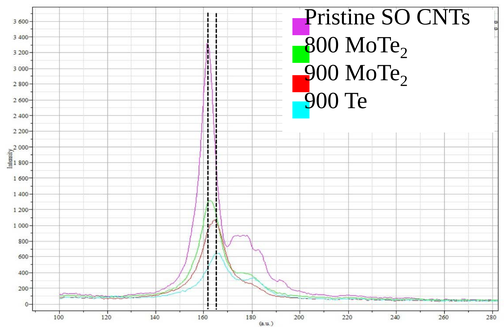
Encapsulation of materials inside CNTs similar to molds used in metalworking.



Raw Materials Characterization

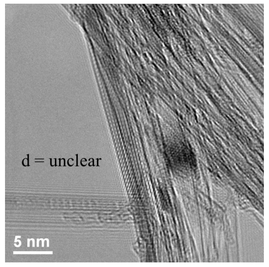


Raman spectra of SO CNTs

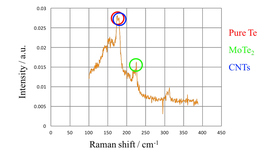


Encapsulation @ EC 1.5 CNTs

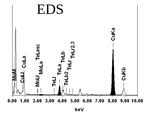
700: low-yield Te encapsulation



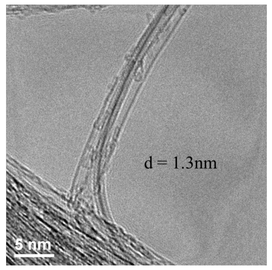
Typical Raman Spectra for EC 1.5 Samples



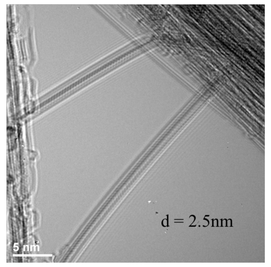
EDS

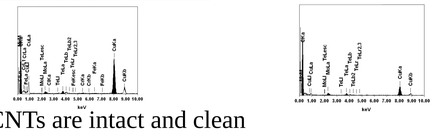


800: low-yield $MoTe_2$ encapsulation



1000: high-yield $MoTe_2$ encapsulation

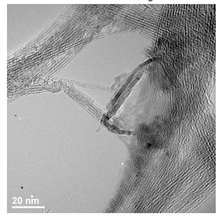




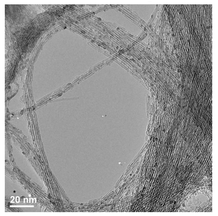
- CNTs are intact and clean
- Diameter range: 1.3-2.5nm
- Encapsulated materials identified using Raman spectroscopy and EDS

Encapsulation @ SO CNTs

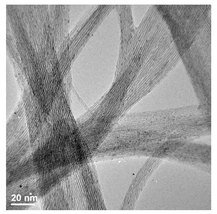
800°C + $MoTe_2$



900°C + $MoTe_2$



900°C + Te



- CNTs are empty; $MoTe_2$ CNTs are broken
- Raman spectra (left) reveal 1.5nm diameters
- Shift in peaks of 900 samples may be due to low-yield encapsulation

Discussion

- [Broken SO CNTs] $MoTe_2$ 1T' crystal structure is unstable at room temperature. This could have led to formation of oxides before vacuum sealing. At high temperatures, crystal transition caused oxygen to evaporate, damaging CNTs
- [Encapsulation in EC 1.5 only] EC 1.5 encapsulated nanotubes tended to have diameters around 2nm. Since SO CNTs are higher quality, smaller range in diameter.
- Possible selectivity for EC 1.5 over SO or 2H over 1T' crystal structures

Future work

- Obtain quantitative diameter distribution for encapsulated EC 1.5 CNTs
- Experiment with EC 2.0 CNTs
- Synthesize nanoribbons using 2H $MoTe_2$
- HRTEM images of nanowires and nanoribbons

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