Structure Controlled Synthesis of Single-Walled Carbon Nanotubes Using Solution Based Catalyst Deposition

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Because of its excellent electrical, optical, mechanical and physical properties, single-walled carbon nanotube (SWCNT) has been considered for many applications. We would like to exploit the unique electronic properties of SWCNTs that arise from their structural parameters such as diameter and chirality. Unfortunately, the large-scale synthesis of SWCNTs with predetermined diameter and chirality is a major challenge because of their structure dependence. We address this problem by studying the scalable tailored structure controlled synthesis of SWCNTs through thermal chemical vapor deposition (CVD). Our process uses ethylene the carbon source in the presence of water. By varying the concentration of Fe catalyst, we synthesized SWCNT array film with different thickness ranging from the nanometer to the millimeter scale. We also demonstrate a simple process to control the diameter of SWCNTs. The results from this study can be used to apply for nano-scale-electronic devices, mechanical application, etc.

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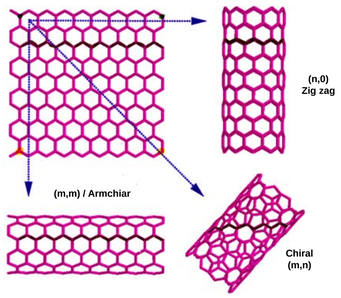
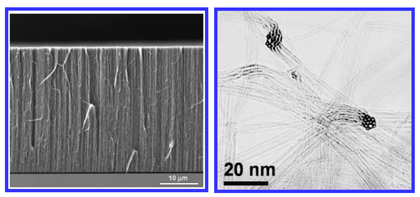
What Is Carbon Nanotube (CNT) ?

- CNT is formed by rolling up a graphene sheet characterized by its chirality. Many properties are chirality dependent.



M. Meyyappan, *Carbon Nanotubes: Science and Applications*, CRC Press, (2004) p.5



SEM (left) and TEM (right) image of vertically-aligned single-walled CNT (VA-SWCNT) array.

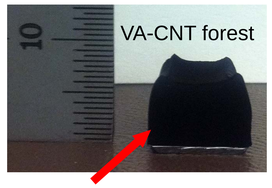
E. Einarsson et al., *Carbon* **46** (2008) 923.
R. Xiang et al., *J. Nanosci. Nanotech.* **10** (2010), 103901.

Why is structure control needed?

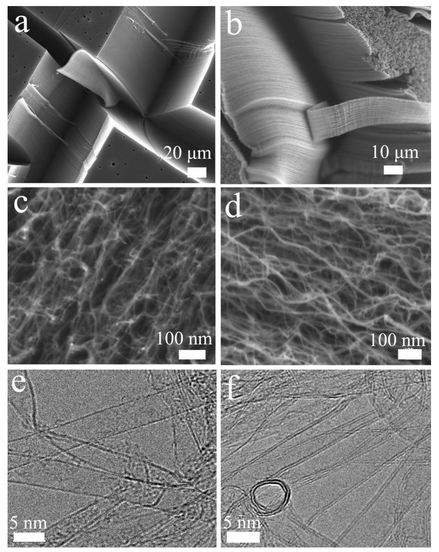
- Producing uniform structure with nearly homogenous properties.
- Inducing to many more potential applications such as mechanical and electrical properties.

Vertically-Aligned Carbon Nanotubes (VA-CNTs)

Photographs of millimeter scale VA-CNT forest grown by water-assisted ethylene CVD.

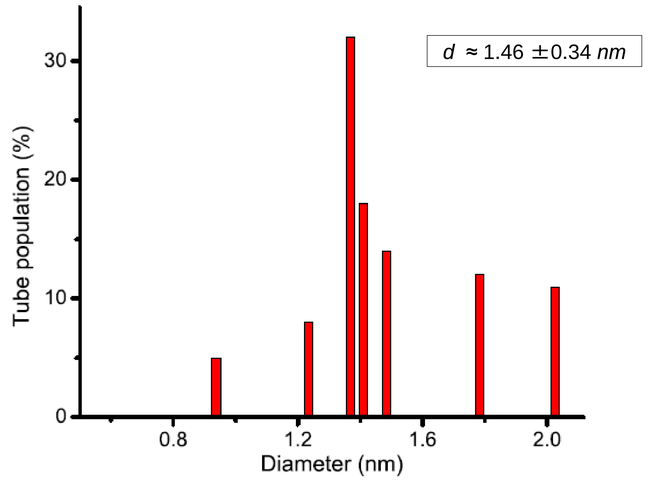


VA-CNT forest (~1 cm (1.4 mm/h)



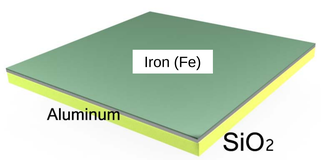
SEM micrographs of CNT forest (a-d) show dense morphology of CNTs and well aligned along tubes, and the tube diameter investigated by TEM images (e,f) indicates few-walled CNTs with diameter control.

Diameter Analysis

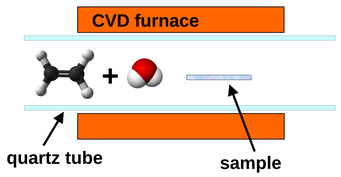


- Diameter range: 0.937 – 2.027 *nm*
- Mean diameter: 1.368 *nm* (Population: 32%)
- Major 3 diameters: 1.368, 1.411 and 1.485 *nm* (64%)
- Not only large scale production of CNTs, but also structure and diameter control

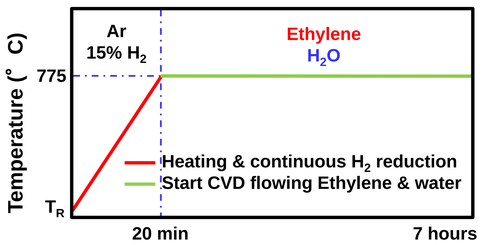
Catalyst Deposition & Synthesis



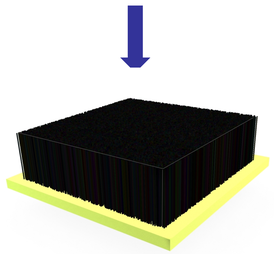
1.5 nm Fe prepared by sputtering on 10 nm Al deposited on SiO_2/Si substrate.



Water-assisted CVD process using ethylene as a carbon source.

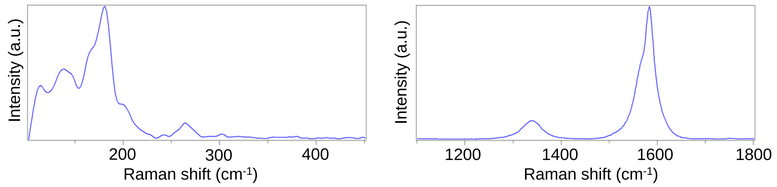


Profile of reduction conditions of Fe catalyst through water-assisted CVD.



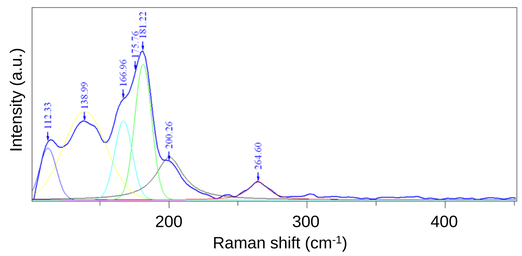
Model of millimeter scale VA-CNT forest after CVD process.

Heterogenous Diameter by Raman



- The G-band (1590 cm^{-1}) shows the sample synthesized is CNTs.
- The RBM region (100-400 cm^{-1}) indicates the presence of SWCNTs.
- The peaks at 145 and 180 cm^{-1} indicate the SWCNT growth in perpendicular to the substrate.

Y. Murakami et al., *Phys. Rev.* B **71** (2005) 085403.



The curve fitting of possible peaks in RBM region using Gaussian and Lorentzian function with the error less than 9 x 10^{-3} % as shows different sizes of diameter of SWCNTs in the sample.

Summary

- Millimeter scale VA-CNT forest can be achieved by water assistance (~1 cm).
- Water and aluminum can promote large scale growth.
- Aluminum layer was used to restrict the aggregation Fe catalyst, resulting in diameter control of few-walled CNT.

Further Works

- To achieve large scale high purity SWCNT forest.
- Further applications such as gas sensor, reinforce formation, H_2 storage, *etc*.

References

1. M. Meyyappan, *Carbon Nanotubes: Science and Applications*, CRC Press, (2004) p.5.
2. E. Einarsson et al., *Carbon* **46** (2008) 923.
3. R. Xiang et al., *J. Nanosci. Nanotech.* **10** (2010), 103901.
4. Y. Murakami et al., *Phys. Rev.* B **71** (2005) 085403.

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