NanoMaterials Group

Summer student projects 2018

The NanoMaterials Group (NMG), headed by Prof. Esko I. Kauppinen, is among the top aerosol technology laboratories in the world and offers a unique environment for strong interdisciplinary research and a proven track record of productive cooperation.

We offer summer projects related to **the conductive and transparent thin film based on single-walled carbon nanotube**. The projects include the following topics.

- Carbon nanotube synthesis in FC-CVD reactors (experimental, optimization)
- Better and novel applications with patterned carbon nanotube films (experimental, modelling)
- Relationship between carbon nanotube film morphology and conductivity (modelling, characterisation)

1. **Carbon nanotube synthesis in FC-CVD reactors (experimental, optimization)**

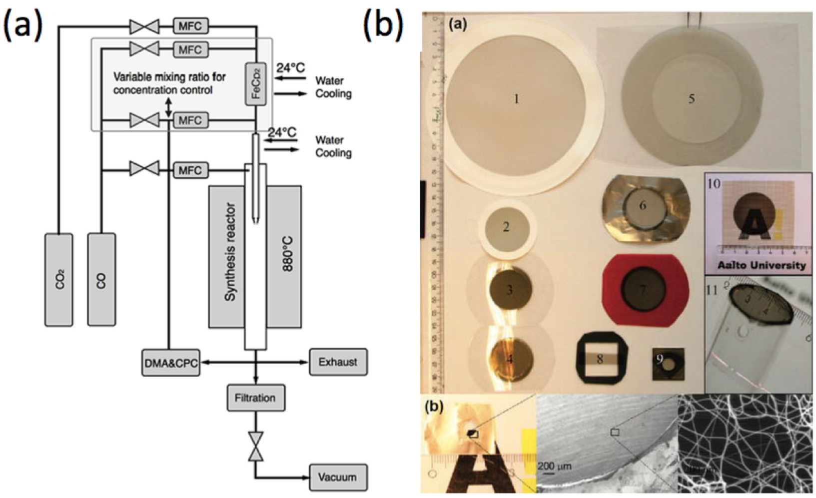

Fig 1. CNT film fabrication from FCCVD. (a) Schematic of SWCNT formation with dry vacuum filtration based on the CO FCCVD system. (b) SWCNT films on various substrates.

Recently, the demand for transparent conducting films has surged due to the expansion of the commercial market for optoelectronic devices such as liquid-crystal displays, touch panels, photovoltaics, and organic light-emitting diodes. Because of their high stretchability, mechanical flexibility and excellent optoelectronic properties, the thin carbon nanotube (CNT) films as a novel transparent conducting material, has attracted tremendous attention, especially in the flexible. electronics. Floating catalyst chemical vapour deposition (FCCVD), an important method used for CNT growth in both fundamental science and industrialized production, can directly fabricate CNT films (Fig. 1a).(*1*) For FCCVD, the catalyst particles and CNTs are suspended in gas phase as an aerosol throughout the entire CNT formation process. The aerosol can be directly deposed into the CNT film with dry vacuum filtration or thermophoretic technique (Fig. 1b). The performance and yield of CNT film are related to CNT synthesis which depends on catalyst composition, catalyst size, carbon source, temperature, and gas-phase chemistry -- the five principal parameters for FCCVD. We are going to study and optimize these synthesis conductions to improve the conductivity and yield of CNT film.(*2*)

2. Better and novel applications with patterned carbon nanotube films (experimental, modelling)

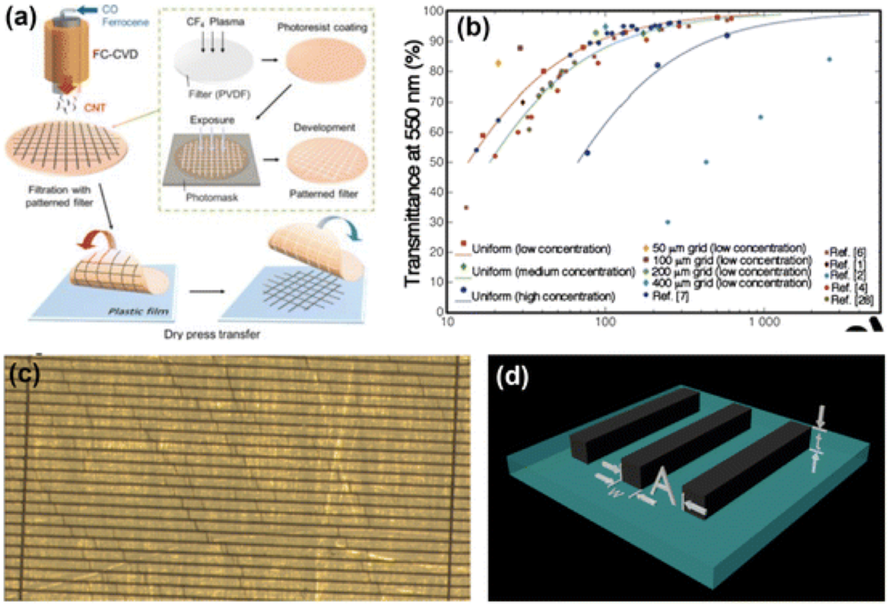

Fig 2. Patterned carbon nanotube films. (a) Fabrication steps for patterned film utilizing patterned filters. (b) Comparison of sheet resistance between patterned and uniform carbon nanotube films. (c) optical image of patterned carbon nanotube films with rectangular geometry. (d) Structural parameters of the rectangular pattern geometry.

Other than usual film manufacturing, deposition of patterned films is another critical step of FCCVD for relevant final products such as touch panels and displays. Compared to the 2D CNT Network, such patterning of CNT films can also overcome the trade-off between transmittance and conductivity in TCFs.(*3*) Patterned films are not uniformly transparent but may still meet many of the application requirements, as long as the features of the pattern are thin enough to not be recognized by the naked eye. Instead of vanishing, the transmittance of patterned film approaches (1 – W/A) as the pattern becomes thicker, where W is the CNT grid width and A is the grid pitch. Therefore, factors limiting the conductivity are the quality of the CNTs and how thick the grid can be. Based on FCCVD, the record-breaking performance of 69 Ω/□ at 97% transmittance of patterned film has been reported.(*4*) However, the conductivity of even state-of-the-art CNT films must still be improved to meet industrial requirements for certain applications. For example, transparent electrodes for photovoltaic devices require high transmittance above 90% and conductivity of R below 10 Ω/□ for efficient energy harvesting. In order to achieve this goal, the collection process, pattern structure, grid thickness, and doping techniques will be further studied for patterned CNT films.

3. Relationship between carbon nanotube film morphology and conductivity (modelling, characterisation)

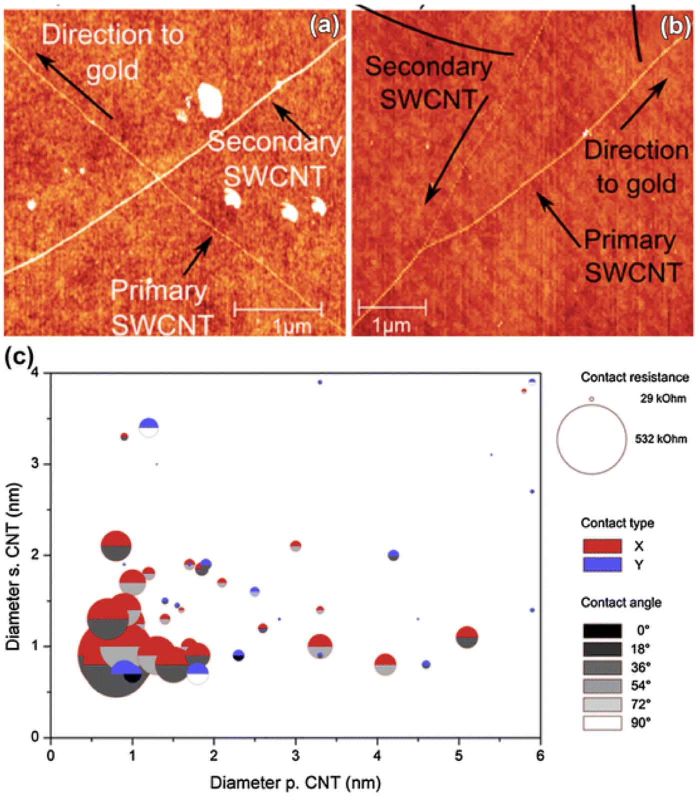

Fig. 3 Morphologies and contact resistances of SWCNT intermolecular junctions. (a, b) AFM images of X and Y junctions, two main SWNT intermolecular junctions. (c) Contact resistance of X and Y junctions versus diameters of primary and secondary CNTs and their intersection angles. Y junctions have lower resistance than X junctions for given structural parameters, with minimum value of 29 kΩ. The contact resistance of both junctions is inversely proportional to the diameters of the CNT branches.

Based on theoretical and experimental results,(*4*, *5*) the optoelectronic properties of SWNT films are related to the morphology of CNT and bundle, including length, diameter, orientation, junction type, etc. Since the contact resistance between individual SWNTs or bundles is orders of magnitude higher than the resistance along a tube, highly resistive junctions limit the electrical conductivity of SWNT films obtained from FCCVD as well as other methods. We are going to model the relationship between the network morphology and the film conductivity. Especially, the effect of network morphology on junction resistance will be further studied in theory and experiment (Fig. 3).(*6*) According to the model, the network morphology will be optimized during the CNT synthesis and with the post-treatment methods, to improve the film conductivity.

References

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4. A. Kaskela *et al.*, Highly individual SWCNTs for high performance thin film electronics. *Carbon N. Y.* **103**, 228–234 (2016).
5. A. Kaskela, K. Mustonen, P. Laiho, Y. Ohno, E. I. Kauppinen, Toward the Limits of Uniformity of Mixed Metallicity SWCNT TFT Arrays with Spark-Synthesized and Surface-Density-Controlled Nanotube Networks. *ACS Appl. Mater. Interfaces*. **7**, 28134–28141 (2015).
6. A. Znidarsic *et al.*, Spatially Resolved Transport Properties of Pristine and Doped Single-Walled Carbon Nanotube Networks. *J. Phys. Chem. C*. **117**, 13324–13330 (2013).

Hint for the application

We would like to know what you are interested in, which topic you most want to investigate in and tell us something about why you choose it.

For more information on our research in general, check out the group website or contact nan.wei@aalto.fi, qiang.zhang@aalto.fi, esko.kauppinen@aalto.fi.

We welcome any ideas and discussions!