



# Growth and Applications of Vertically Aligned Large-diameter Double-walled Carbon Nanotube Arrays

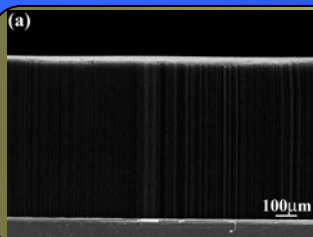


Lijie Ci, Robert Vajtai, Pulickel. M. Ajayan

Department of Materials Science and Engineering, Rensselaer Polytechnic Institute, Troy NY 12180, USA

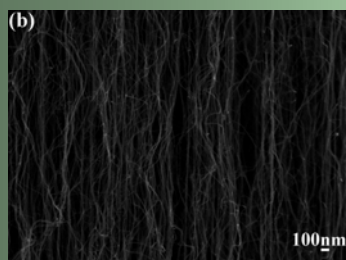
Department of Mechanical Engineering and Materials Science, Rice University, Houston TX 77005, USA

We have selectively synthesized ultra-low density ( $0.015 \pm 0.002 \text{ g/cm}^3$ ) double-walled carbon nanotube (DWNT) arrays. The low mass density is due to the large diameter and low site density of DWNTs in the arrays. The diameter of the as-grown DWNTs varies from 4.5 nm to 14.8 nm with a mean value of 7.9 nm. The role of the thickness of Fe catalyst layer is evaluated for the selective growth of large-diameter DWNTs. Our DWNT arrays have promising applications in areas such as solar absorbers, super-hydrophobic surfaces. (Ci et al. JPCA 2007)

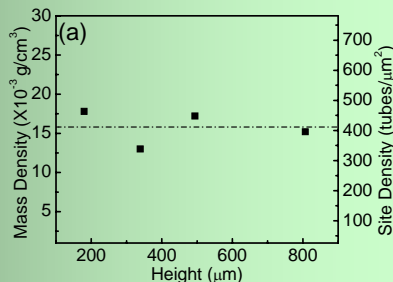


### Growth process:

Vertically aligned DWNT films were prepared by a water-assisted chemical vapor deposition process. 10 nm thick Al and 1-5 nm Fe layer were deposited by E-beam thermal evaporator. Ethylene and Ar/15vol% $\text{H}_2$  were used as gas source. Carbon nanotube growth temperature was 750-800 °C. (SEM of a nanotube sample)



High resolution SEM image of aligned nanotubes

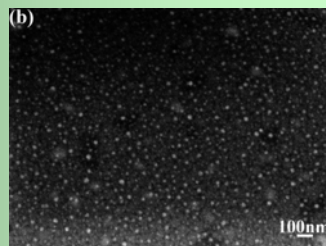


Mass density (left Y-axis) and site density (right Y-axis) of DWNT arrays at different height

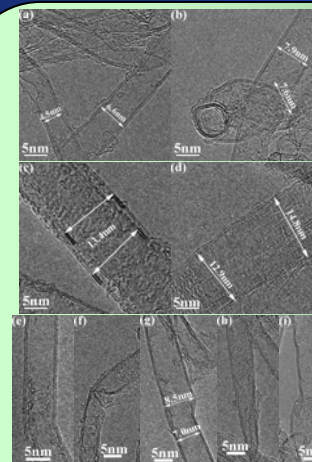
Mass density:  $0.015 \pm 0.002 \text{ g/cm}^3$   
Site density:  $411 \pm 56 \text{ tubes}/\mu\text{m}^2$   
Tube-tube spacing:  $\sim 50 \text{ nm}$   
Nanotube volume filling fraction: 1.5%~2.0%

Individual DWNT density was Modeled by Nanotube Modeler:

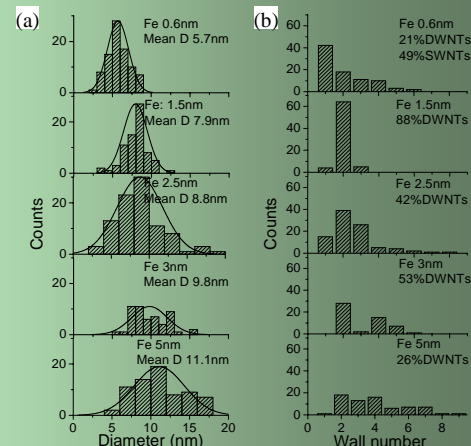
Density of 7.9 nm DWNT:  $0.784 \text{ g/cm}^3$   
Density of 3.7 nm DWNT:  $1.647 \text{ g/cm}^3$



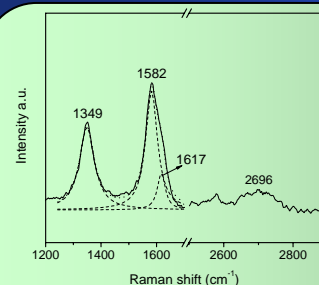
Distribution of nano-sized catalyst particles



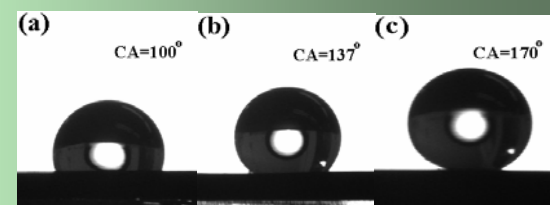
(a-d) HRTEM images of individual DWNTs with different diameters; (e-i) HRTEM images of deformed DWNTs



(a) Diameter histograms of nanotube samples grown from different Fe thicknesses. (b) Nanotube type (walls) histograms at different Fe thickness.



First and second-order Raman spectrum of the large-diameter DWNTs. The second order of D line is located at  $2696 \text{ cm}^{-1}$ , which is the same as that of two-layer graphene



Surface wettability of DWNT arrays and its tunable feature by changing catalyst thickness: Fe 1 nm (a), Fe 1.5 nm (b), and Fe 4nm (c)

The authors acknowledge the support of the Interconnect Focus Center, one of five research centers funded under the Focus Center Research Program, a Semiconductor Research Corporation program.