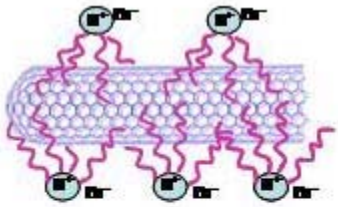
Single Wall Carbon Nanotubes Alignment and Deposition

A one-step process of solubilization of single wall carbon nanotubes (SWCNT) in an organic solvent has enabled us to polarize them asymmetrically in a dc electric field. Quaternary ammonium ion-capped SWCNTs readily suspend in organic solvents; under the influence of a dc electric field they assemble as stretched bundles anchored on the positive electrode. At low dc applied field (~ 40V) all the SWCNT from the suspension are deposited on the electrode, thus providing a simple methodology to design robust SWCNT films. At higher applied voltages (>100V), the SWCNT bundles stretch out into the solution and orient themselves perpendicular to the electrode surface.

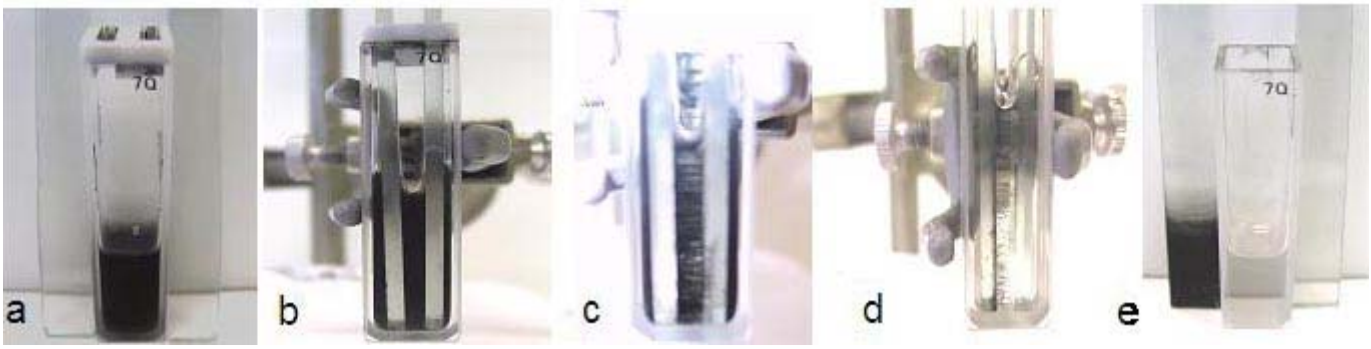


Solubilization of SWCNT in Organic Solvents

Purified SWCNTs synthesized by electric arc method (from SES Research) were solubilized by mixing with tetraoctylammonium bromide (TOAB) in THF (10 mg SWCNT and 0.13 g TOAB in 25 ml THF). Sonication ofthe mixture for 20-30 minutes yields a stable dark suspension. We also solubilized SWCNT in TOAB/THF obtained from another source Nanonics. The black suspension was centrifuged at 10,000 rpm for approximately 10 minutes. The clear supernatant liquid containing unbound TOAB was discarded. This procedure was repeated and the final centrifugate, after removing the solvent was dried. The repeated washing and centrifuging procedure allowed us to discard any unbound TOAB from the SWCNT material. The dried material consisting of TOAB bound SWCNT was readily suspendable in organic solvents. Typically TOAB bound SWCNT was resuspended in 25 ml THF and sonicated for 10-15 minutes. Based on weight gain, capping of 1 mg TOAB per 10 mg of SWCNT is estimated. The quaternary ammonium salt, TOAB allows solubilization by bindingto the SWCNT through hydrophobic interactions of its alkyl chains.

Electrophoretic Deposition of SWCNT film on electrode surfaces

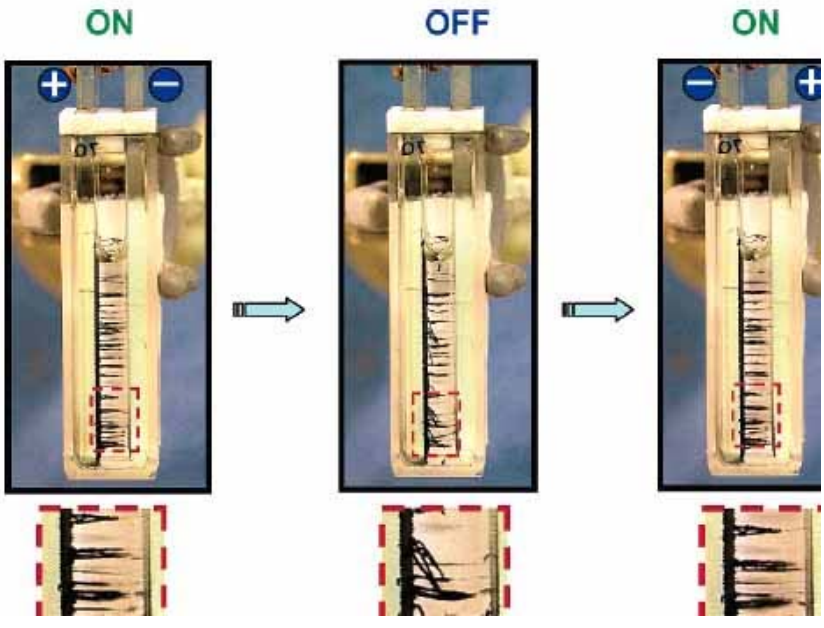
The electrophoresis is carried out in a 1 cm quartz cuvette. The SWCNT solution is transferred into the electrophoretic cell. Two optically transparent electrodes (conducting glass slides, cut 9 mm x 5 cm, to fit into the cell) were kept parallel to each other (~5 mm apart) in an electrophoretic cell. When a dc voltage of ~ 40 V was applied, carbon nanotubes slowly move from the suspension towards the positive electrode. Continued application of dc voltage for 1-2 minutes results in the deposition of SWCNT film on the electrode surface. The thickness of SWCNT films can be increased by increasing the time of electrophoretic deposition. These films are quite robust and are suitable for electrochemical, fuel cell, catalytic and photoelectrochemical applications.



Stages of electrophoretic deposition: (a) SWCNT suspension in the cuvette, (b) insertion of electrodes, (c) Immediately after application of dc field (d) end of deposition cycle, and (e) conducting glass electrode with SWCNT film and colorless solution in the cell.
G. Girishkumar; K. Vinodgoapal, Kamat, P. V. SWCNT Films for methanol oxidation, J. Phys. Chem. B 2004, 108, in press.

Macroscopic Alignment in dc field

The electrophoresis set up as described above can be used for alignment experiment. When dc voltage of >100 V is applied between the two conducting glass electrodes, the nanotubes instead of undergoing deposition, assembled into linear bundles extending across the space



between the two electrodes. These bundles are well separated and aligned perpendicular to the electrode surface. When the dc field is turned off, the aligned nanotubes quickly bend downwards. When the field is restored the tubes align again in the horizontal direction. The sequence in Figure shows the reproducibility of attaining similar alignment during ON periods of dc field. The alignment of SWCNT bundles in a dc electric field and their response to repeated ON-OFF-ON cycles can also be seen in the Movie.

Kamat, P. V., Thomas, K. G., Barazzouk, S., Girishkumar, G., Vinodgopal, K. and Meisel, D., Self-Assembled Linear Bundles of Single Wall Carbon Nanotubes and Their Alignment and Deposition as a Film in a DC-Field. J. Am. Chem. Soc., 2004, 126, 10757-10762.