Nano-containers and nano-scaffolds

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FIR/MIR

MIR/NIR

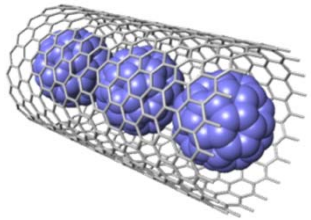
Photoluminescence

Near field/SNOM

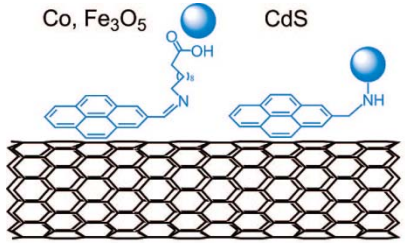
Hybrid structures from nanotubes

- **exceptional properties of nanotubes:**
  - mechanical stability
  - electric conductivity

- **organic components:**
  - selectivity
  - function



peapod



D. Eder: *Chem. Rev.* **110,** 1348 (2010)

adsorbed organic molecule

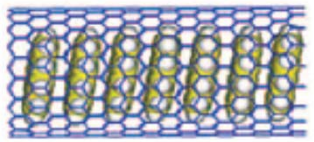
Nano-containers

van der Waals interaction inside
nanosize reaction vessel
packaging of unstable, toxic molecules

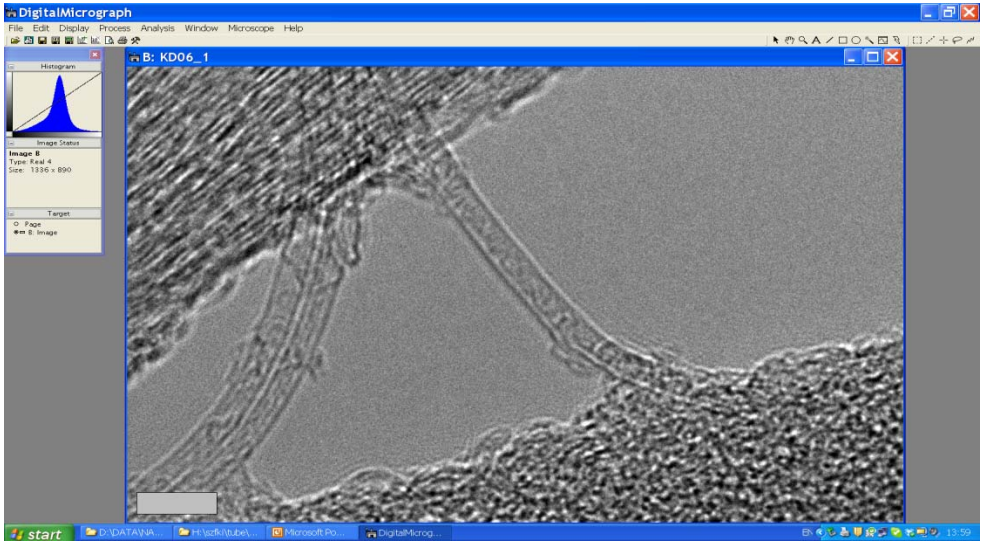
Nano-supports

π-π interaction on surface
increased solubility
“glue”

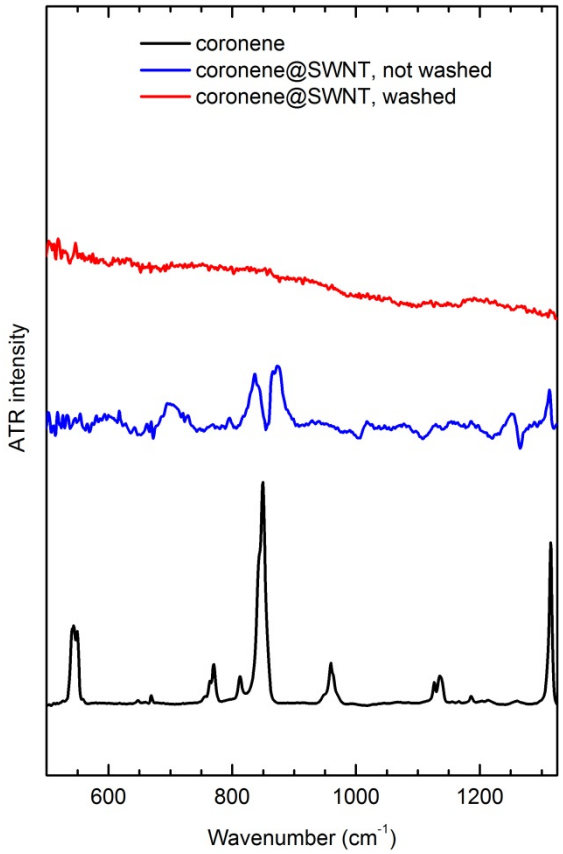
Incorporation of functional units



Coronene@SWNT



ATR-IR

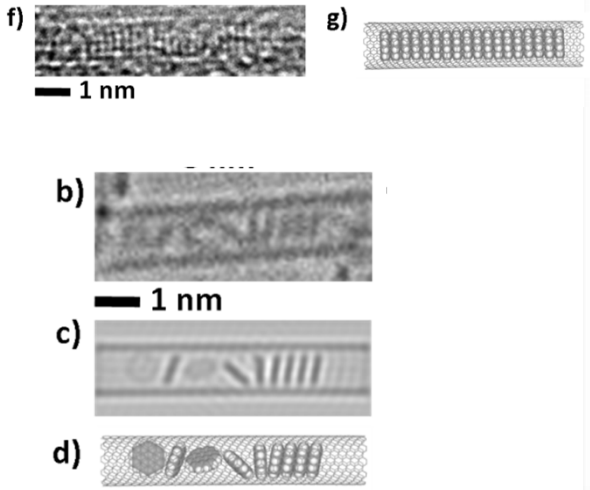


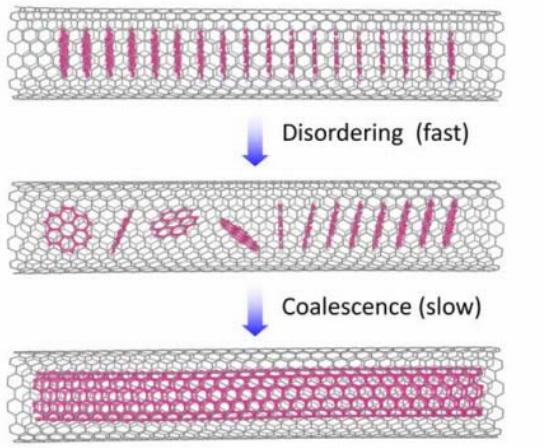
coronene both encapsulated and adsorbed

adsorbed coronene dissolves in toluene

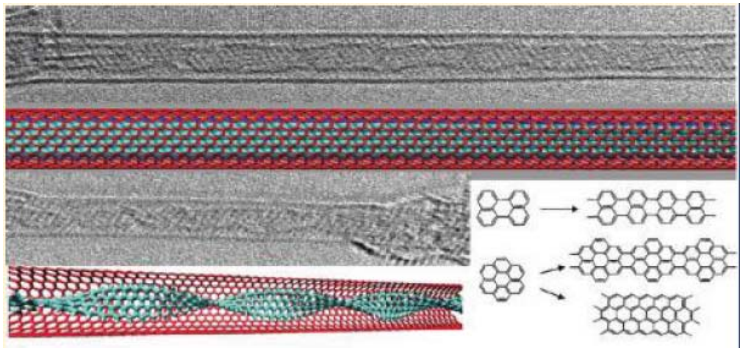
Reactions inside nanotube

low-temperature filled nanotubes: no side reactions on adsorbed molecules
surface can be cleaned by toluene washing
adsorbed molecules do not obscure encapsulated ones



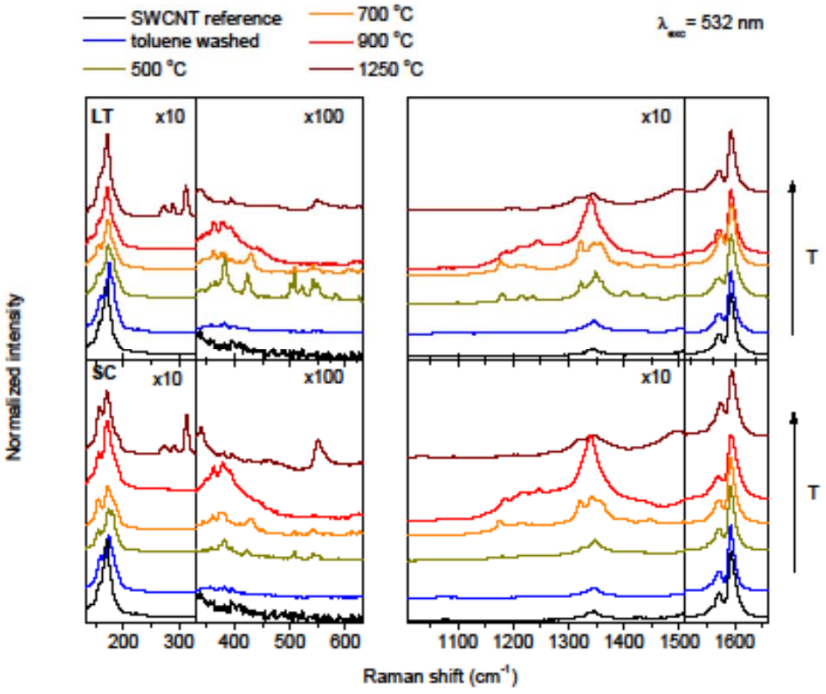


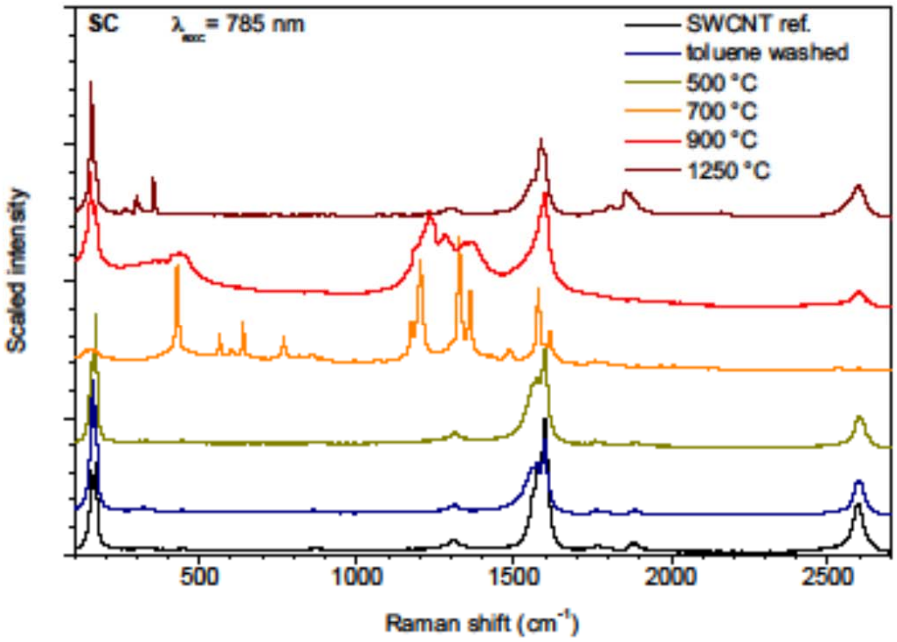
Can we stop the process at the nanoribbon stage?



A.V. Talyzin, I.V. Anoshkin,
A.V. Krasheninnikov, R.M. Nieminen,
A.G. Nasibulin, H. Jian, E.I. Kauppinen:
Nano Lett. **11**, 4352 (2011)

Following reactions by Raman spectroscopy





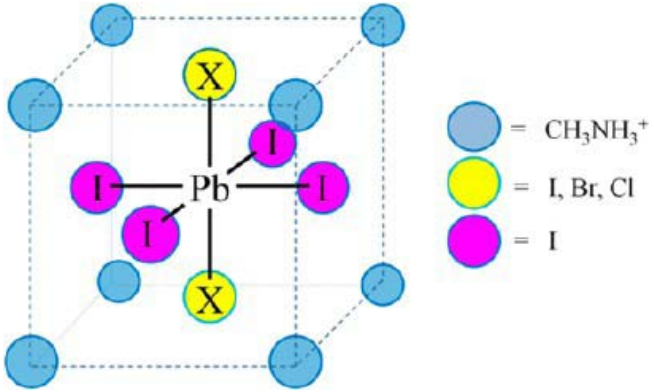
Resonance with nanoribbons: 500, 700, 900 ºC

Resonance with nanoribbons: 700, 900 ºC

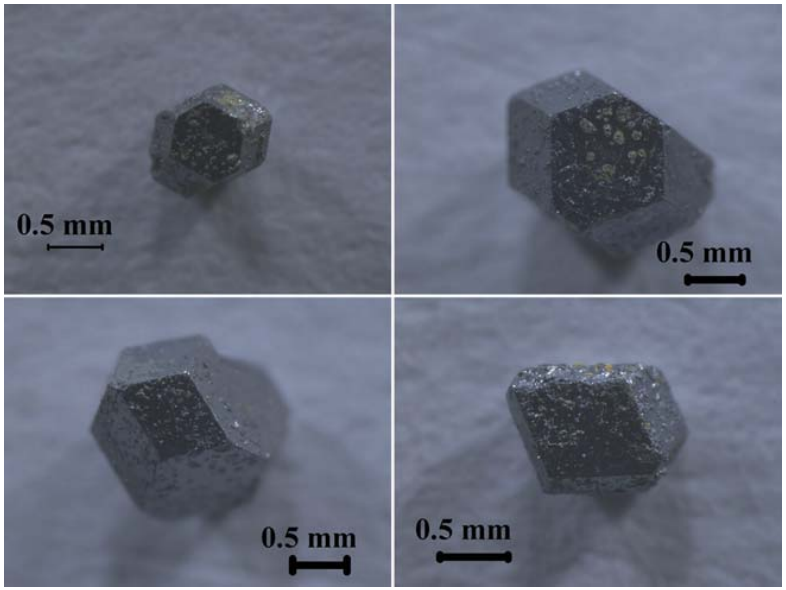
DWNT formation: 1250 ºC

Lead halide perovskites

the solar cells of the future

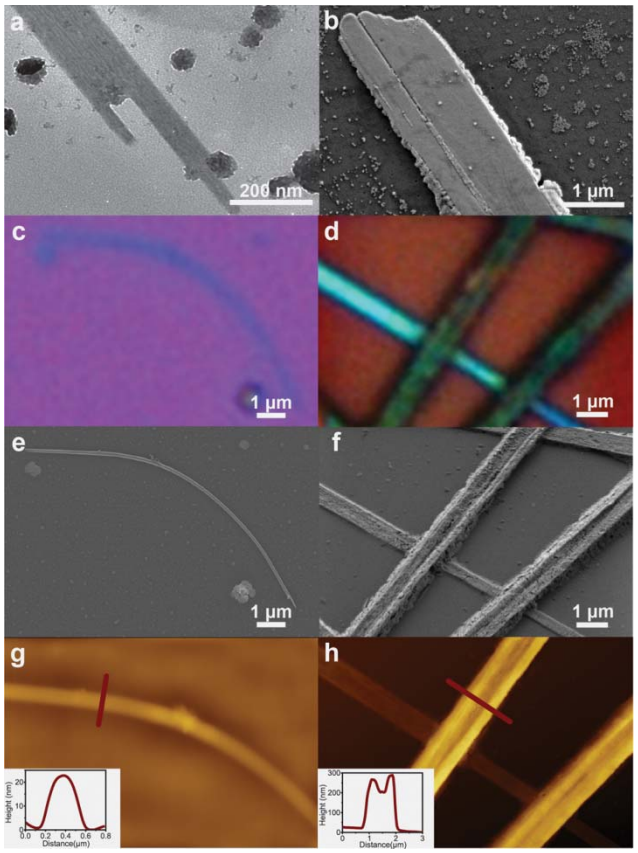


E. Mosconi, A. Amat, Md.K. Nazeeruddin,
M. Grätzel, F. De Angelis:
J. Phys. Chem. C **117,** 13902 (2013)



T. Baikie, Y. Fang, J.M. Kadro, M. Schreyer, F. Wei,
S.G. Mhaisalkar, M. Grätzel, T.J. White:
J. Mater. Chem. A **1,** 5628 (2013)

Lead halide perovskites: nanoscale

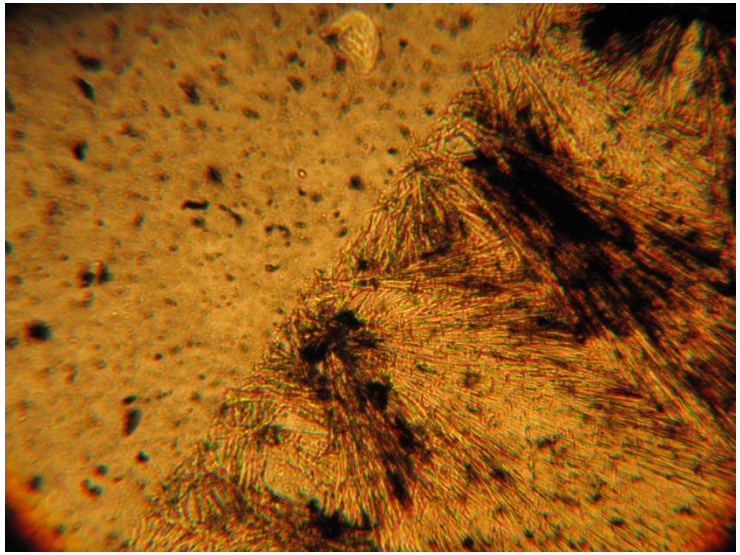


E. Horváth, M. Spina, Zs. Szekrényes, K. Kamarás, R. Gaal, D. Gachet, L. Forró:
Nano Lett. **14,** 6761-6766 (2014)

$CH_3NH_3PbI_3$ nanowires with 50 – 200 nm diameter

Perovskite nanowires: using carbon nanotubes as scaffolds

Transparent CNT film



$CH_3NH_3PbI_3$ nanowire

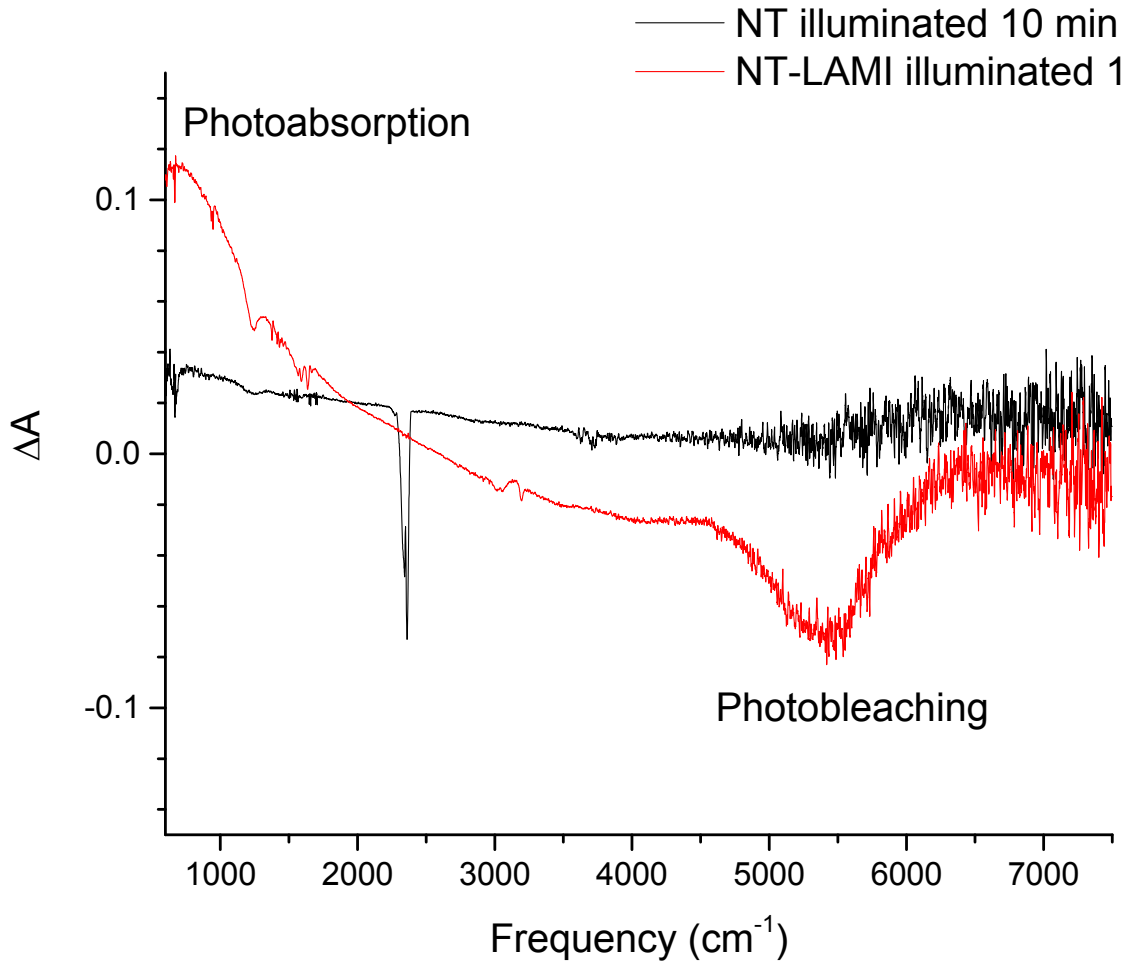
M. Spina, B. Náfrádi, H.M. Tóháti, K. Kamarás, E. Bonvin, R. Gaal, L. Forró, E. Horváth: *Nanoscale* **8,** 4888 (2016)

- strong
- transparent
- chemically inert? **yes**

Photoinduced spectral changes

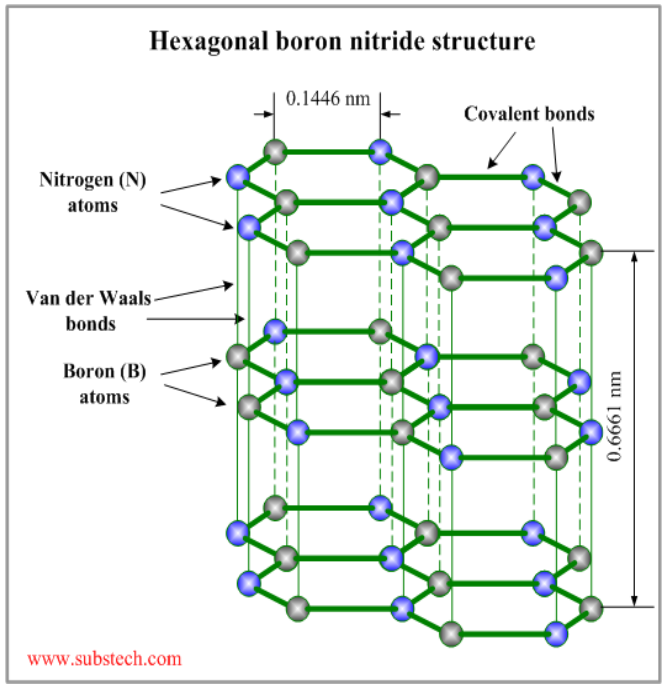
Illumination by 633 nm light

Presented as $\Delta A = \frac{T_{dark} - T_{illum}}{T_{dark}}$



Carbon nanotubes are ideal hole transport layers!

Boron nitride nanotubes

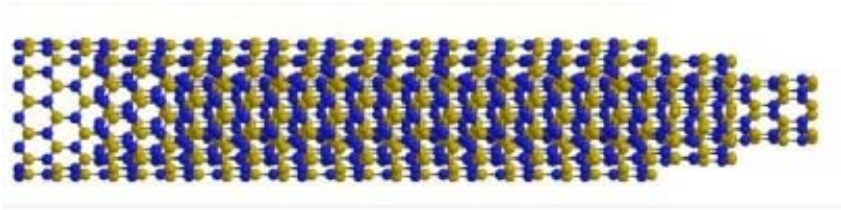


Both covalent and van der Waals bonds have ionic character

electrons are less delocalized

h-BN is an insulator with a bandgap of 6 eV

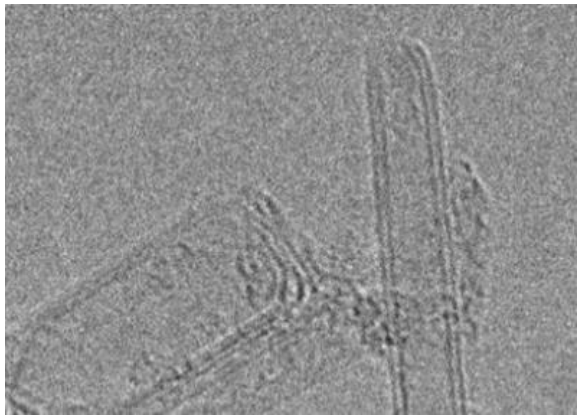
folding



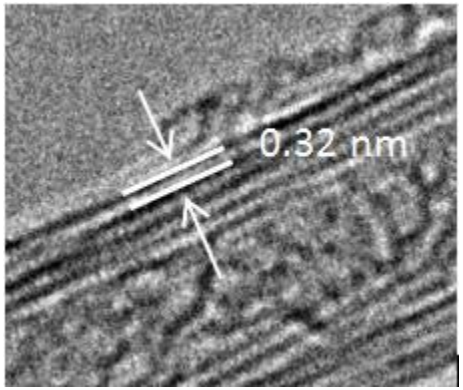
BNNT nanotube

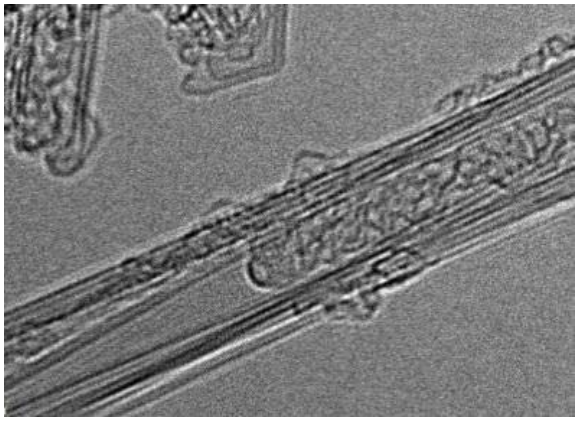
Z. Gao et al.: *Nanobiomedicine*, 2014, **1**:7.

Electron microscopy of BNNT



external diameter 5.62 ± 2.16 nm
internal diameter 2.61 ± 1.05 nm
interlayer spacing 0.32 nm (h-BN)

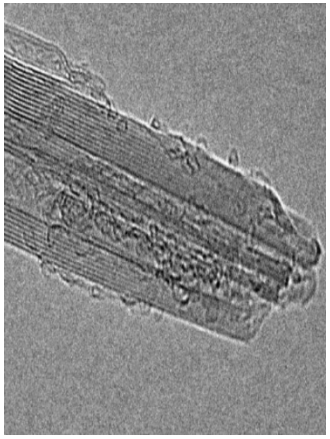




Samples: BNNT LLC
Measurements: Andrei N. Khlobystov

Filling of BNNT

BNNT as is



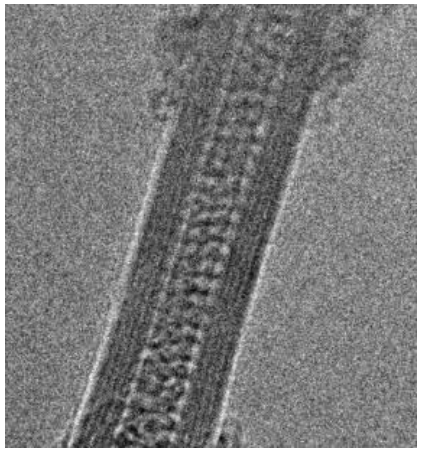
shortening (~2 μm → ~500 nm)
opening
purification (ammonia, annealing)

BNNT open

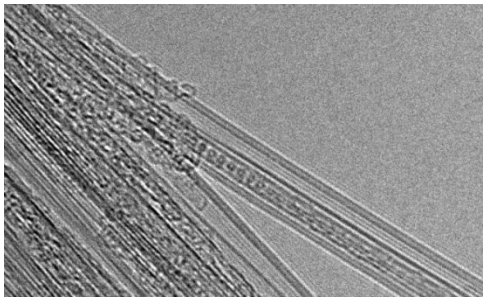
sublimation filling 600 °C

W. Mickelson, S. Aloni, W.-Q. Han, J. Cumings, A. Zettl: *Science* **300,** 467 (2004)

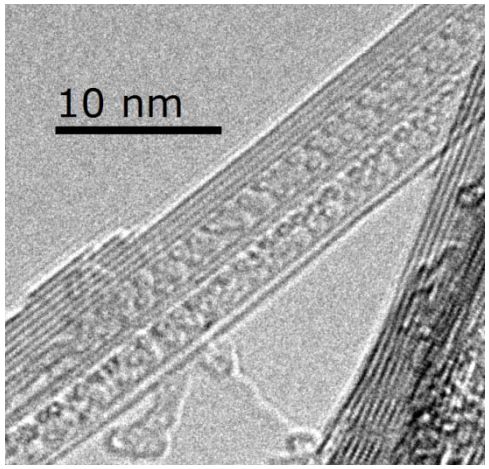
C_{60}@BNNT



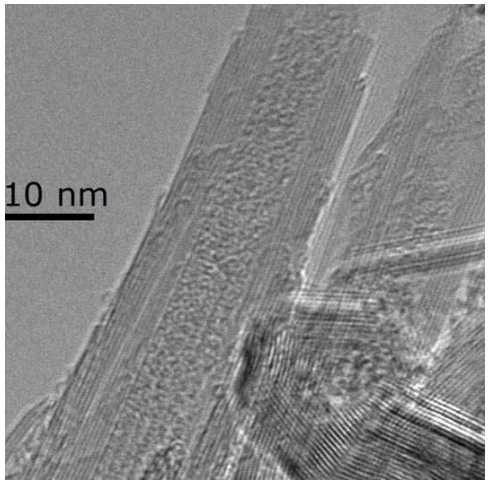
Microscopy of BNNT peapods



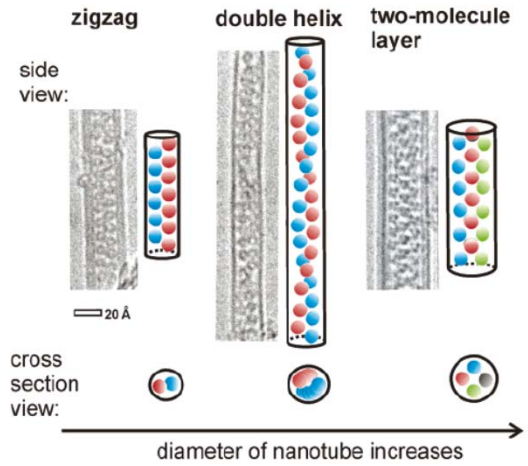
linear chain



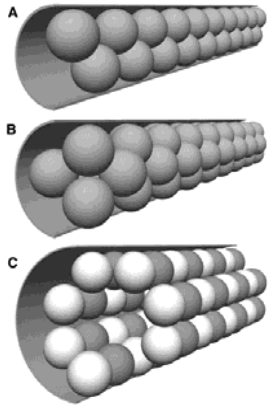
zigzag



two-molecule layer

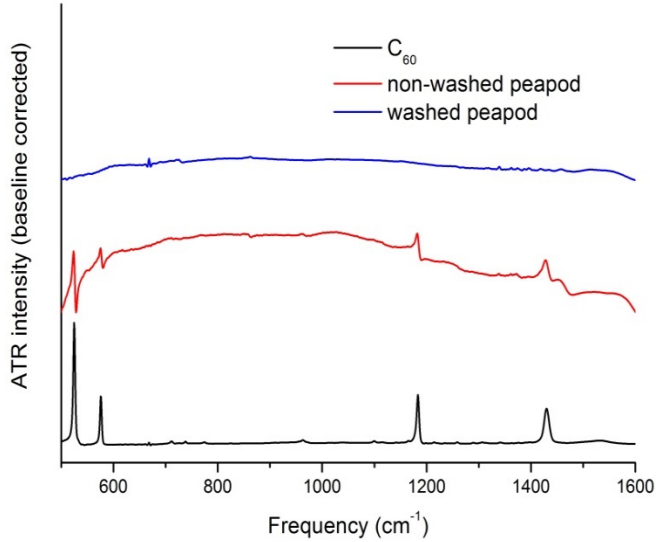


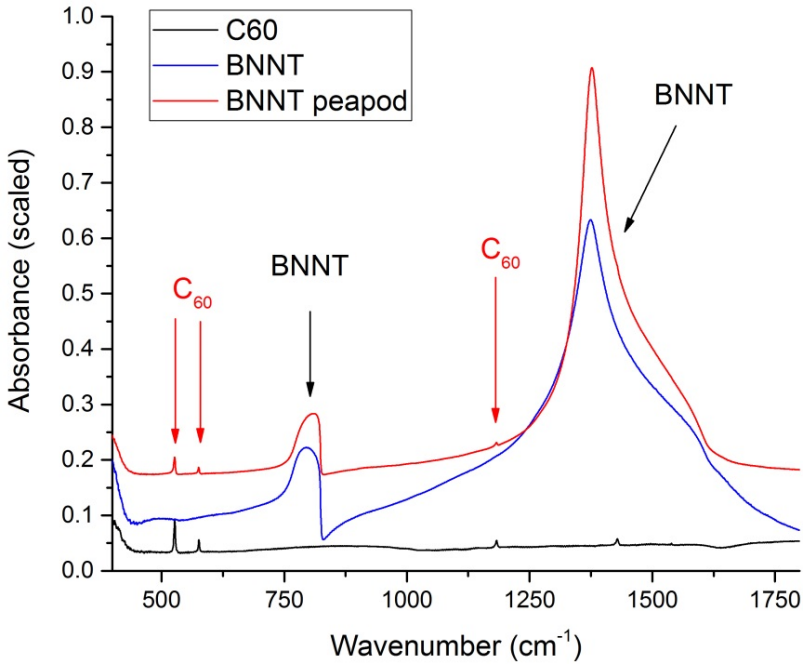
A.N. Khlobystov, D.A. Britz, J. Wang, S.A. O'Neil, M. Poliakoff, G.A.D. Briggs: *J. Mater. Chem.* **14,** 2852 (2004)

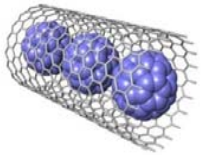


W. Mickelson, S. Aloni, W.-Q. Han, J. Cumings, A. Zettl: *Science* **300,** 467 (2004)

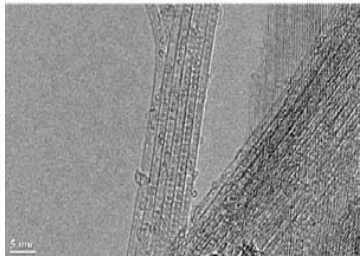
Infrared spectra of peapods



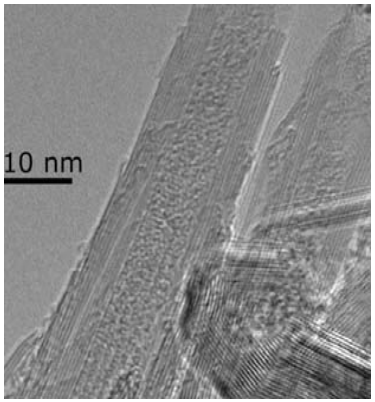




CNT



Infrared spectra of C_{60} shielded



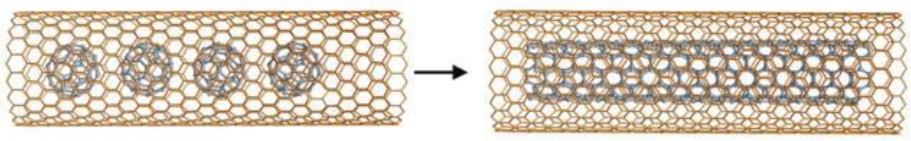
BNNT

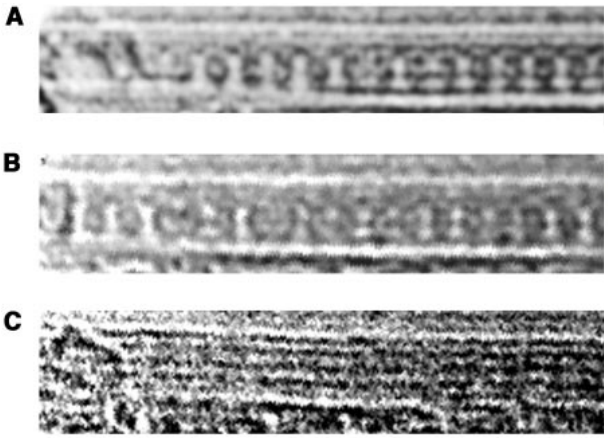
C_{60} vibrations can be clearly seen

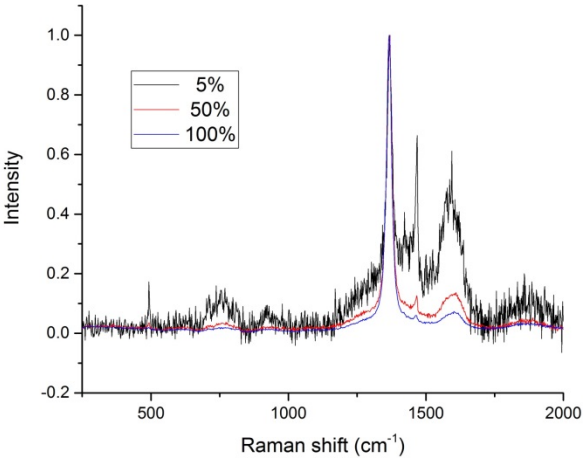
C_{60} retains I_h symmetry (no splitting of vibrational bands)

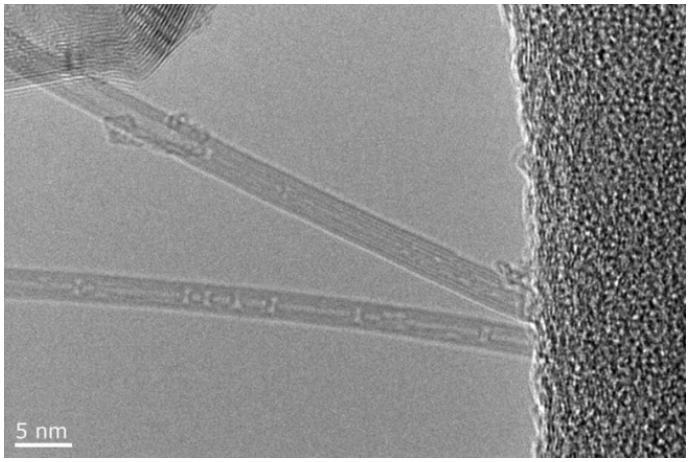
free rotation at room temperature

Formation of inner nanotube







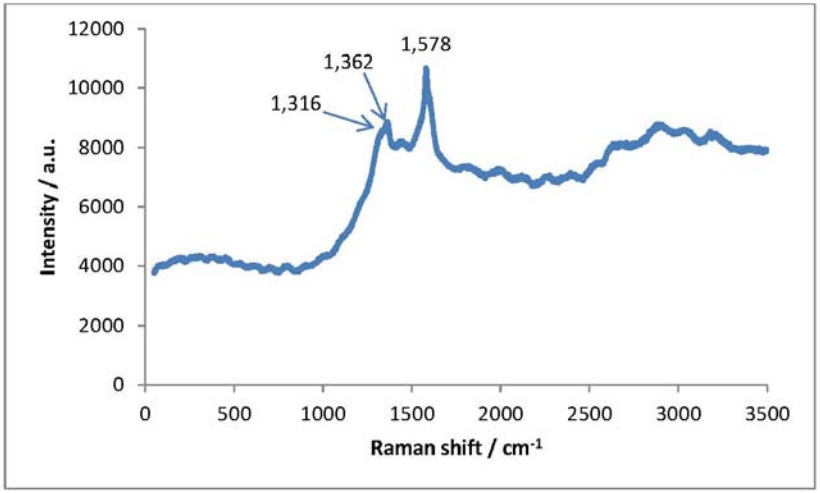


annealing 1200 °C

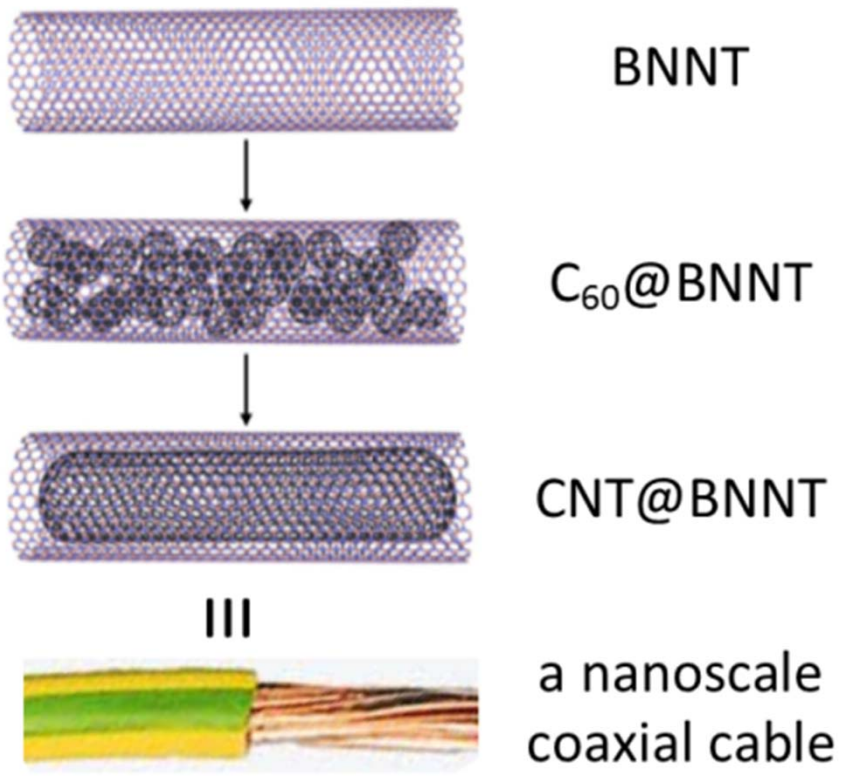
electron beam

W. Mickelson, S. Aloni, W.-Q. Han, J. Cumings, A. Zettl: *Science* **300,** 467 (2004)

laser 355 nm



“Towards the world’s smallest coaxial cable”



K.E. Walker, G.A. Rance, Á. Pekker, H.M. Tóháti, M.W. Fay, R.W. Lodge, C.T. Stoppiello, K. Kamarás, A.N. Khlobystov:
Small Methods, published online, DOI: 10.1002/smtd.201700184

Collaborators

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