Novel Dispersion and Self-Assembly of Carbon Nanotubes

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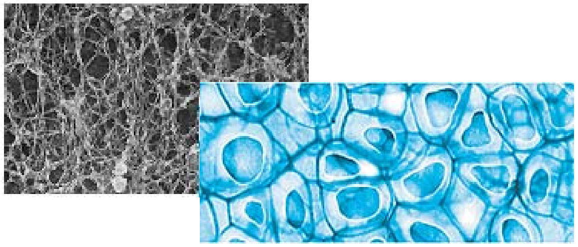
Sloan Foundation
DARPA

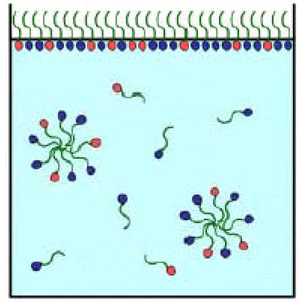
Carnegie Mellon

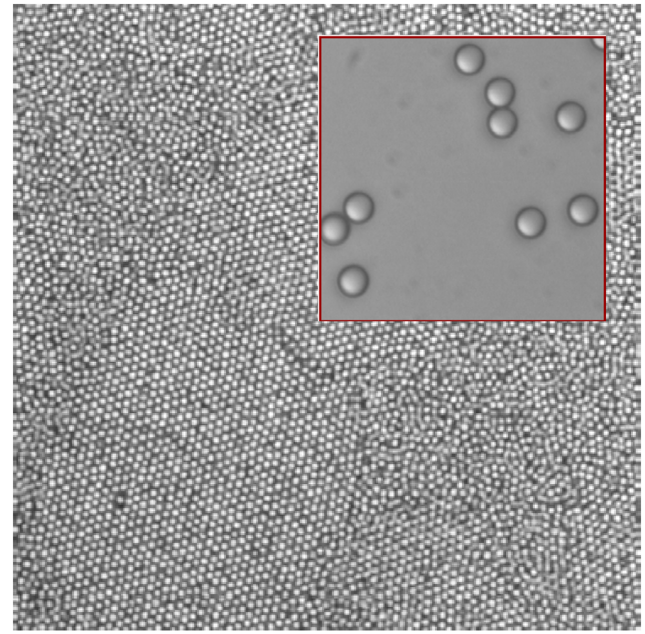
Outline

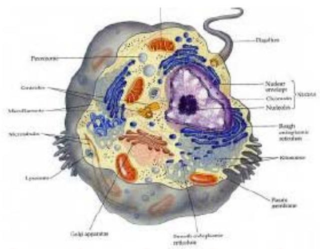
- *Introduction to Soft Materials*
- *Single Wall Carbon Nanotubes (SWNTs)*
  - *Purification, Dispersions and Their Properties*
- *Carbon Nanotube Aerogels*
- *Conclusions*

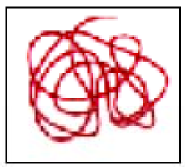
Soft Materials - Introduction

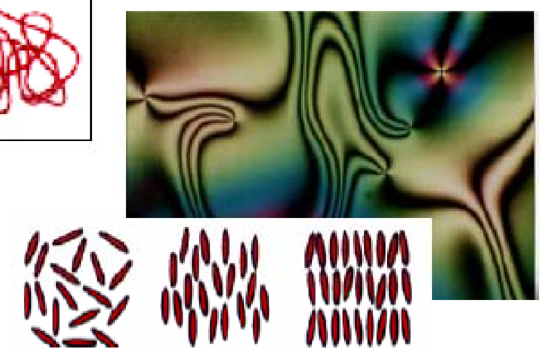


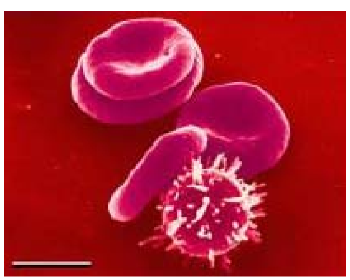


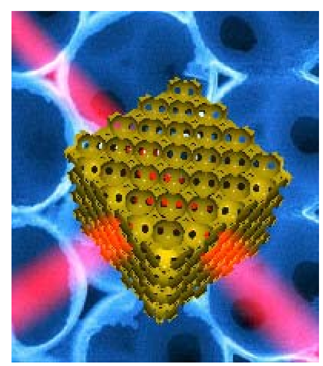




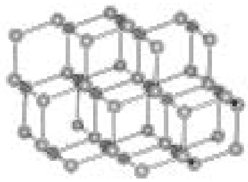




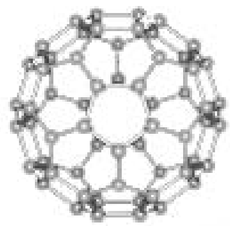




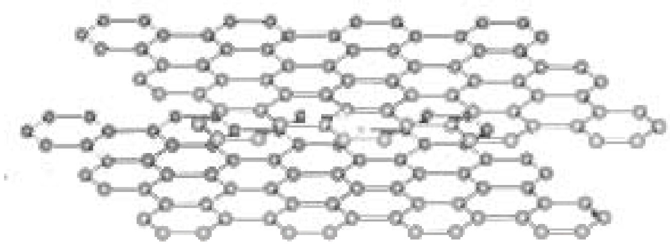
Introduction to Single Wall Carbon Nanotubes



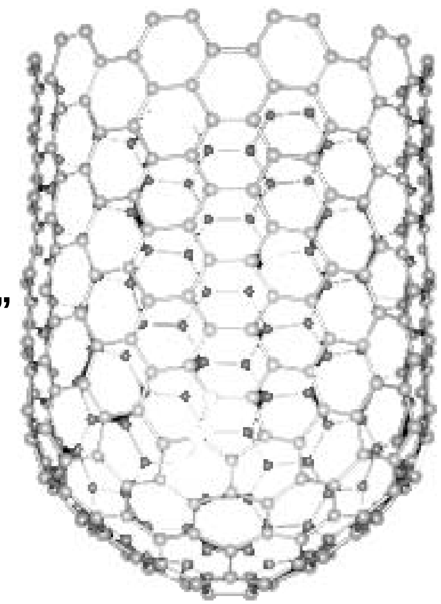
Diamond



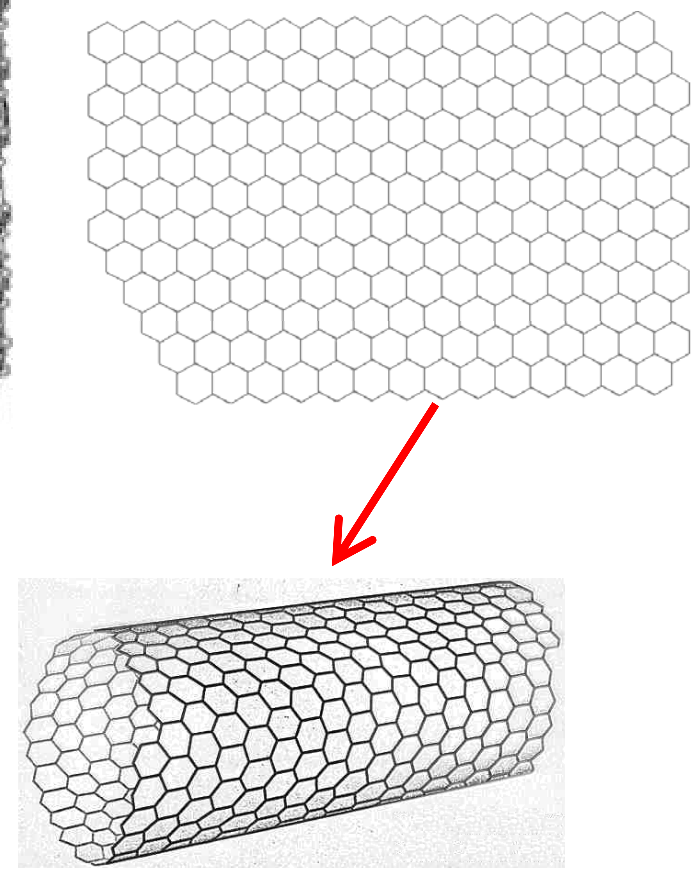
C60
“Buckminsterfullerene”

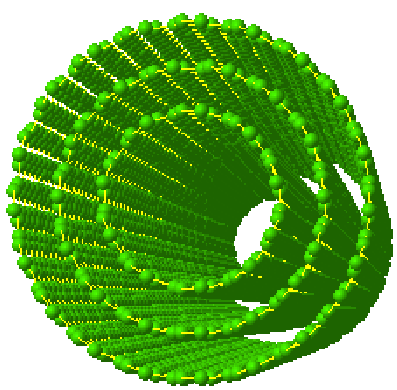


Graphite



Single wall Carbon Nanotube (SWNT)





Multiwall Carbon Nanotube (MWNT)

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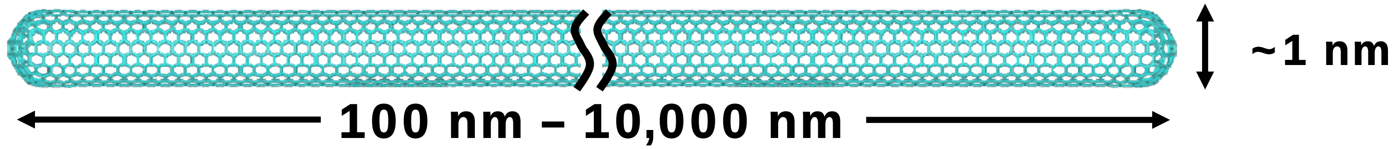
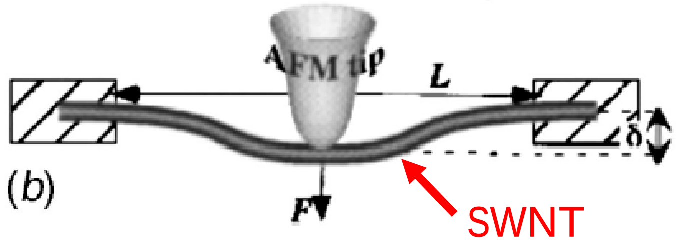
SWNTs have extraordinary anisotropic properties

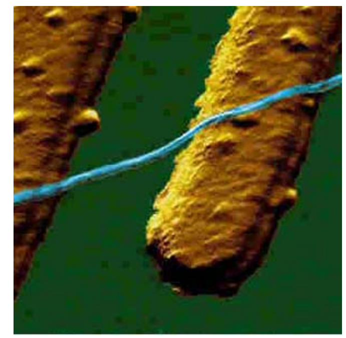




Strength (~100x Steel)

Tensile strength ~200 GPa
Stiffness ~1 TPa
Elongation ~30%

Salvetat *et al.*, *PRL* **82**, 944 (2000)



Electrical Conductivity (~Copper)

Dekker *et al.*, *Nature* **386**, 474 (1997)

Thermal Conductivity ~3x Diamond

Incorporate anisotropic properties of SWNTs into composites

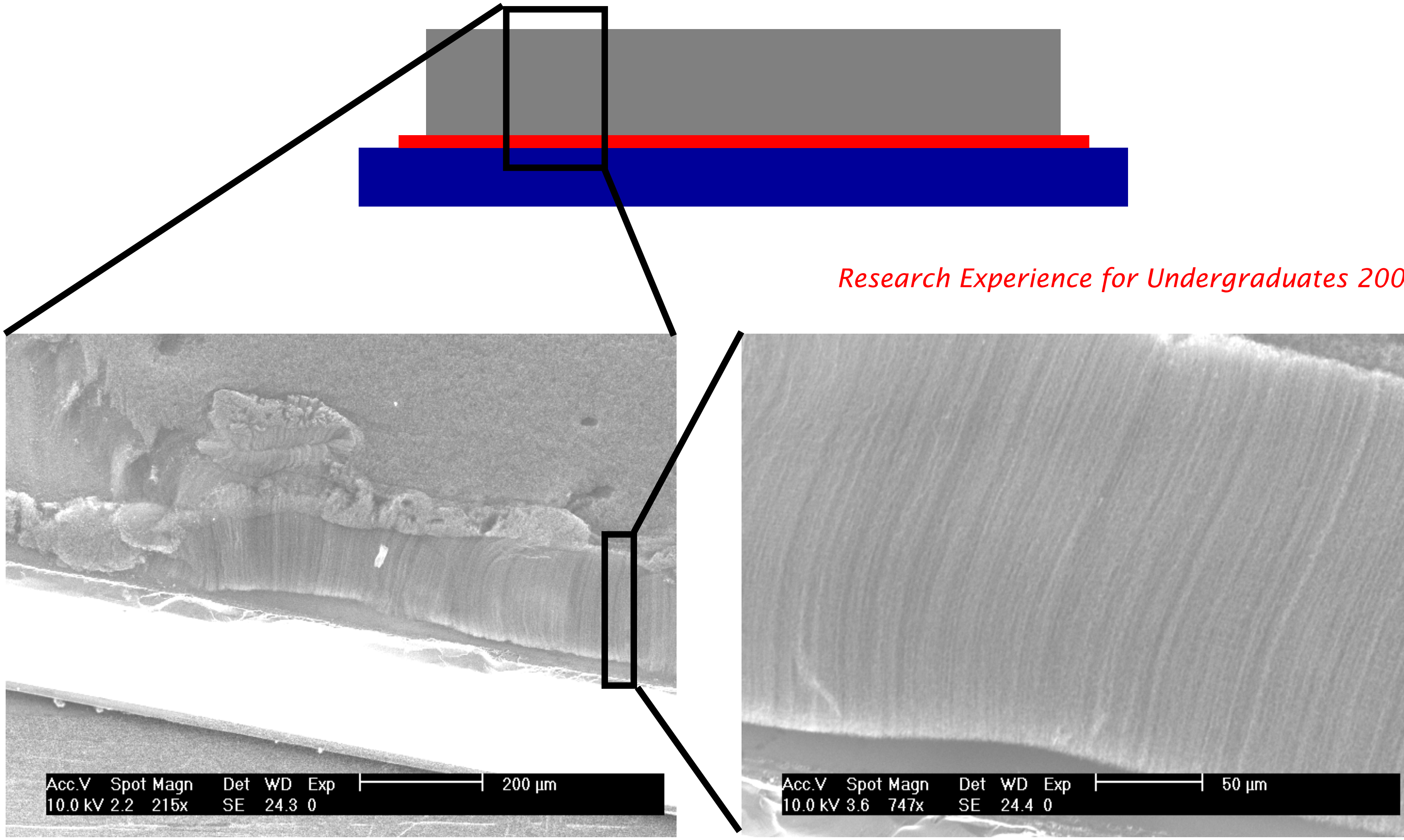
Challenges

- Large scale production of **clean** nanotubes.
- Homogeneous dispersion in solvents and host materials.

  van der Waals attraction: 40 KBT/nm

- Control of diameter, chirality and length.
- Determination of bulk properties and structural behavior.
- Effective integration into composites.
- Controlled integration into electronic circuits.

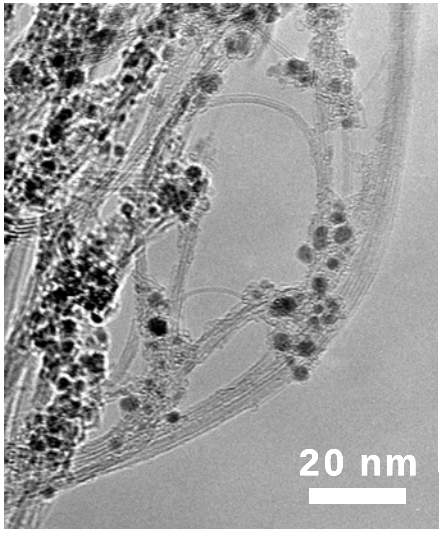
Synthesis of SWNTs



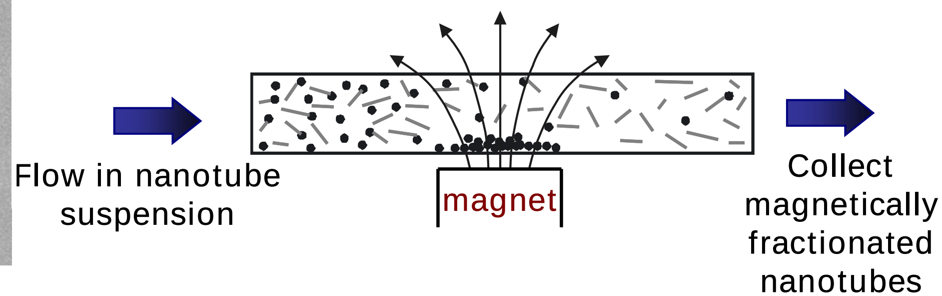
Research Experience for Undergraduates 2007

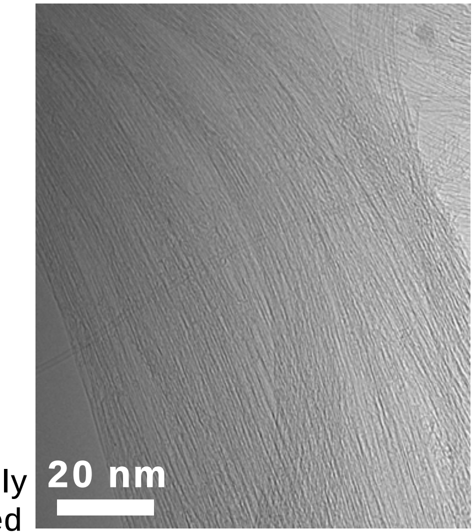
Hata et. al., Science **306**, 1362 (2005)

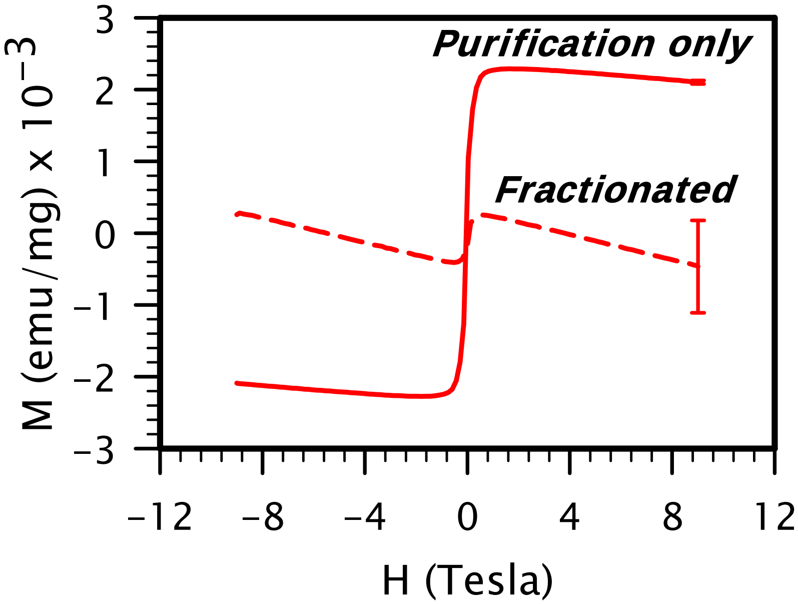
Purification of SWNTs

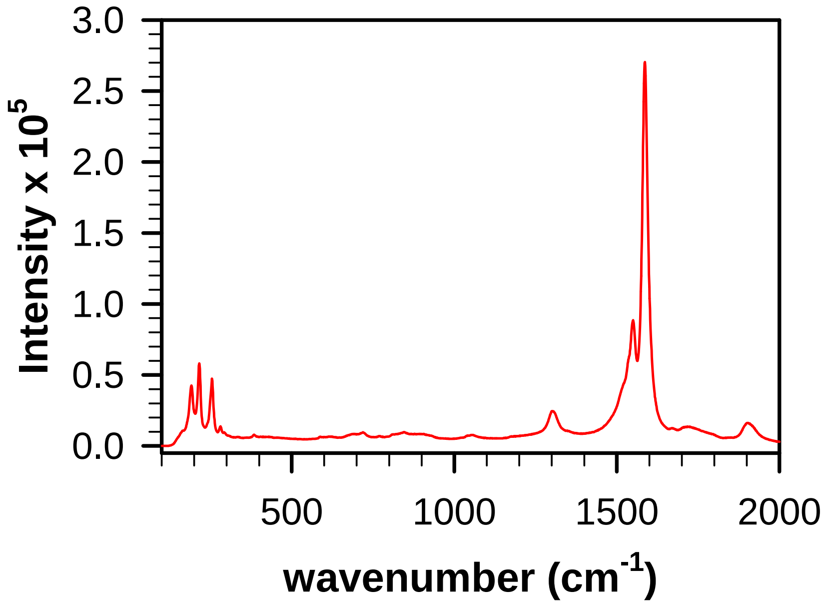


Standard wet air burn with H_2O_2
Mild acid reflux
Magnetic gradient fractionation
Vacuum anneal



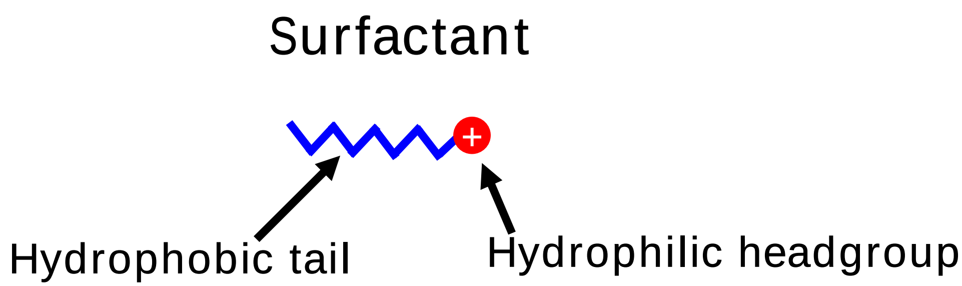


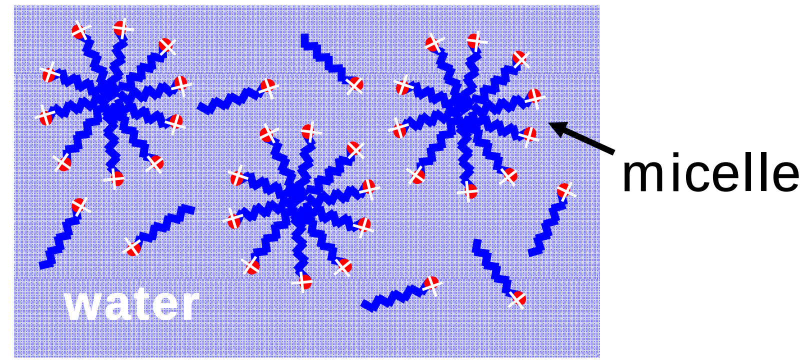


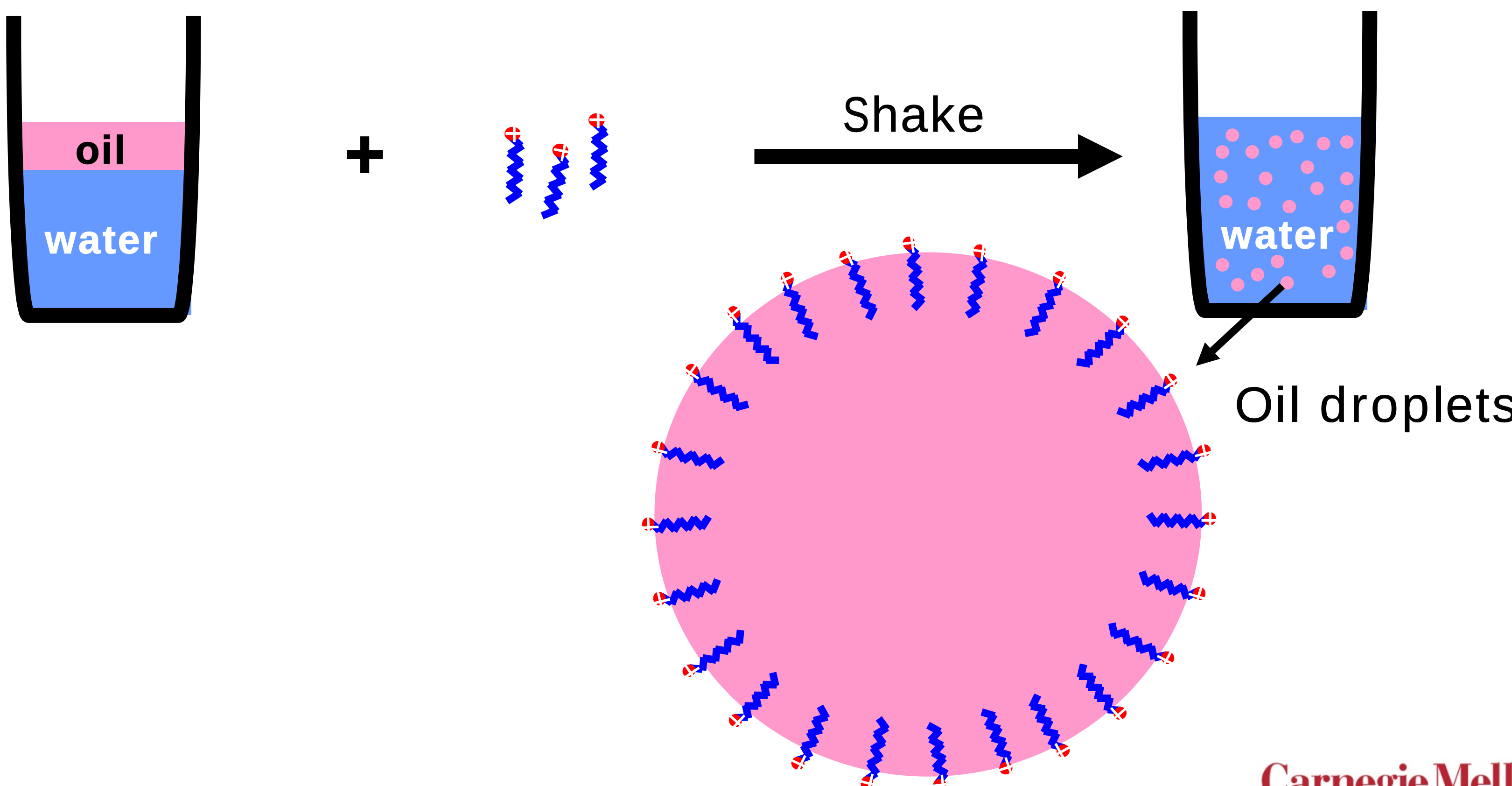


Nature Materials **4**, 589 (2005)

Surfactants







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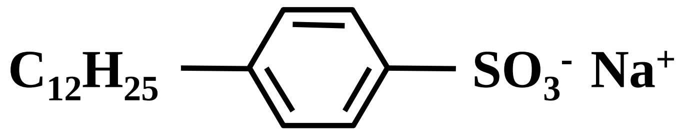
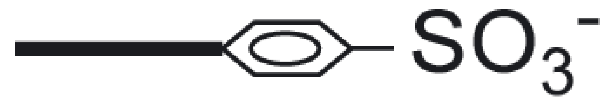
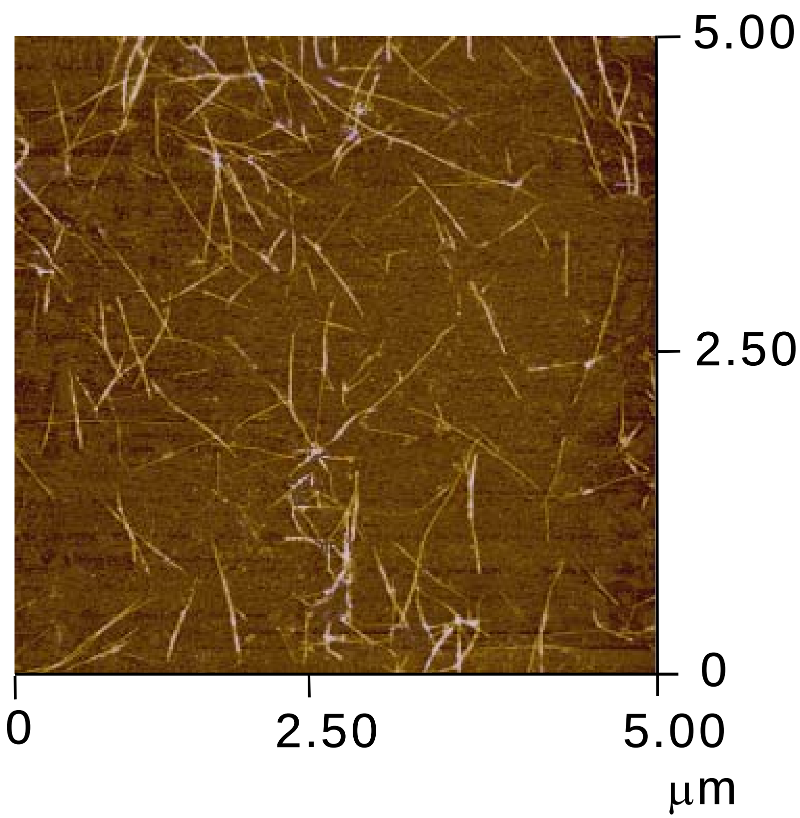
Dispersing SWNTs: Our Work

Sodium Dodecyl Benzene Sulfonates (NaDDBS)





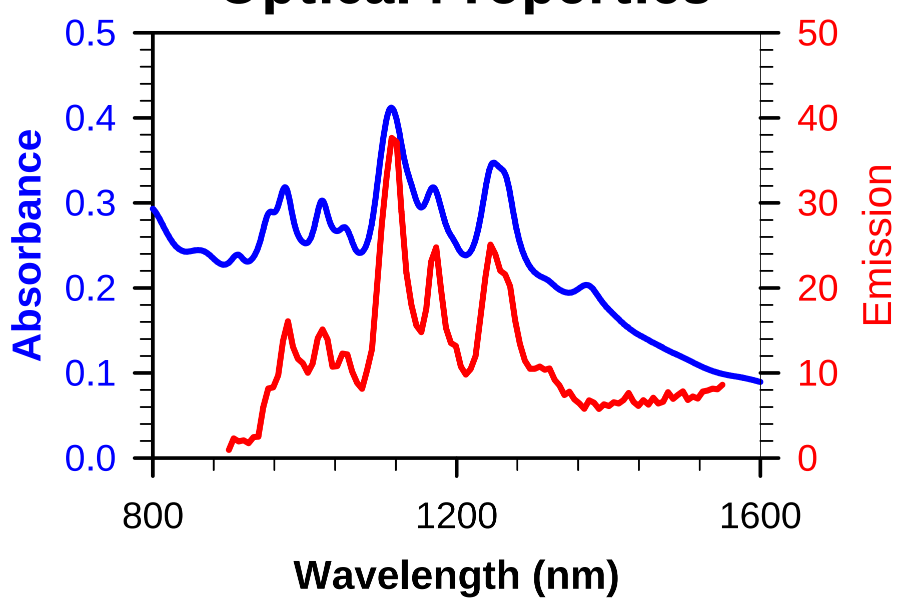
Surfactant:	SDS	TX-100	NaDDBS
SWNTs:	$3x10^{-4}$	$6x10^{-4}$	$\mathbf{2x10^{-2}}$
Time:	5 days	5 days	**2 months**



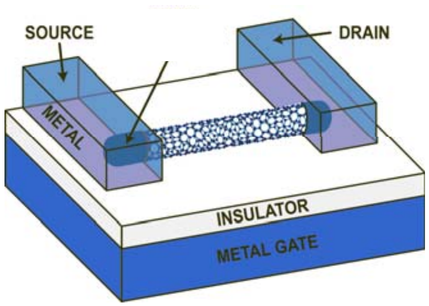
Nano Letters **3**, 269 (2003)

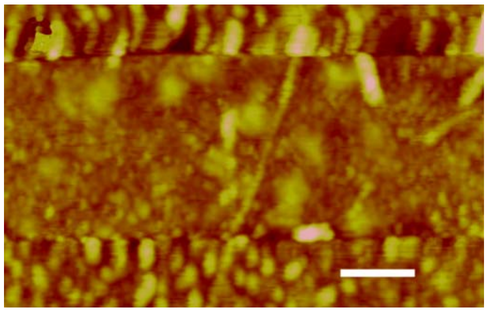
Purified and Suspended SWNTs Are Undamaged

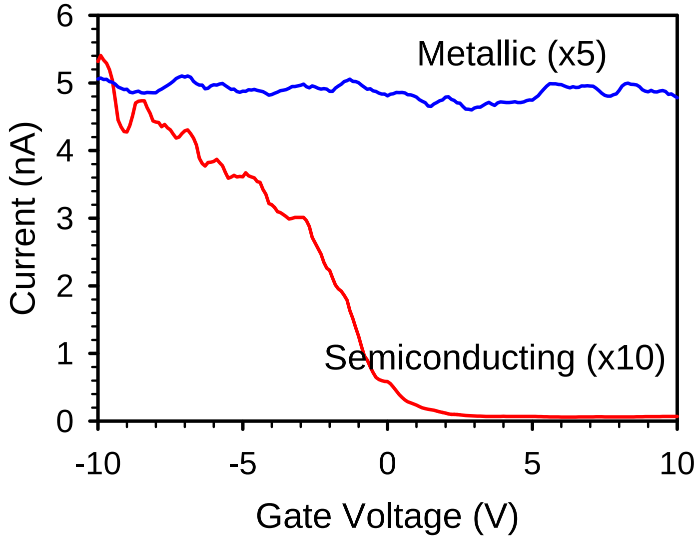
Optical Properties



Electrical Properties







*Nature Materials **4**, 589 (2005)*

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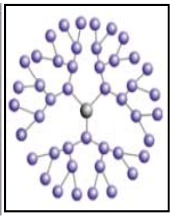
Aerogels: Ultra-light Mesoporous Materials



Ultra-light

Highly porous materials

Very high strength-to-weight

Very high

surface-area-to-volume ratio

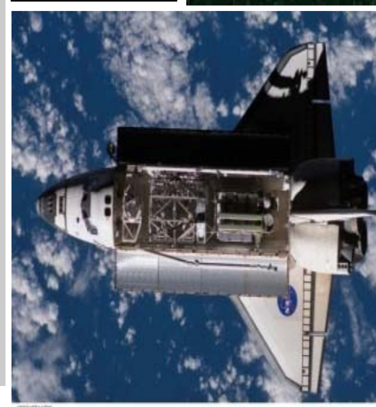
Ultra-light structural media

Radiation detector

Thermal insulator

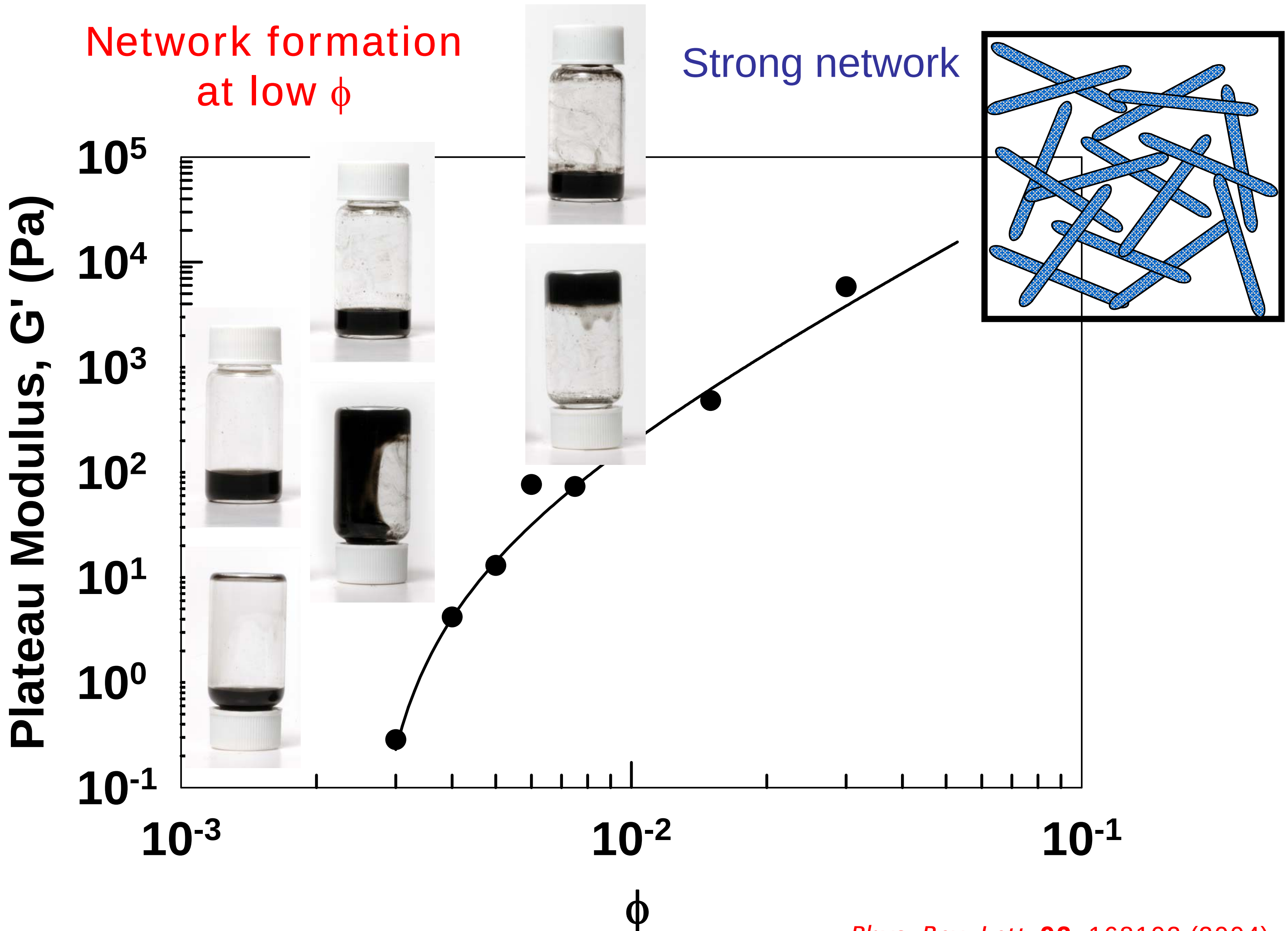
Battery electrode

Supercapacitor



Aerogel type	Electrical Conductivity (S/cm)	Thermal Conductivity (W/m-K)	Density (g/cm^3)
Silica	N/A	~ 0.003	0.0019 ~ 0.1

Rigidity Percolation



Phys. Rev. Lett. **93**, 168102 (2004)

CNT Aerogels

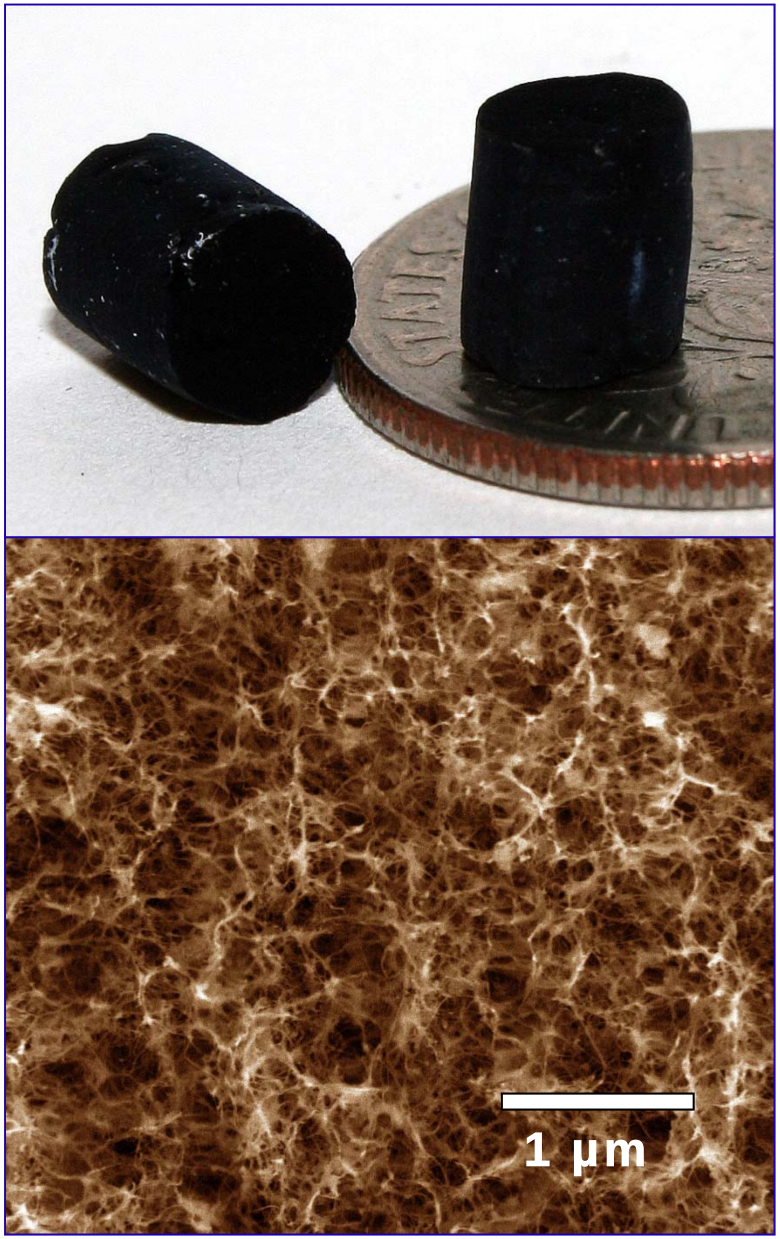
Increasing CNT → concentration

Phys. Rev. Lett. **93**, 168102 (2004)

NanoLetters **6**, 313 (2006)

CNT gels do not break apart

CNT Aerogels



Density: 0.02 g/cm^3

Advanced Materials **19**, 661 (2007)

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SWNT Aerogels

100g weight on 3 aerogel posts

Total aerogel mass:

12.8 mg

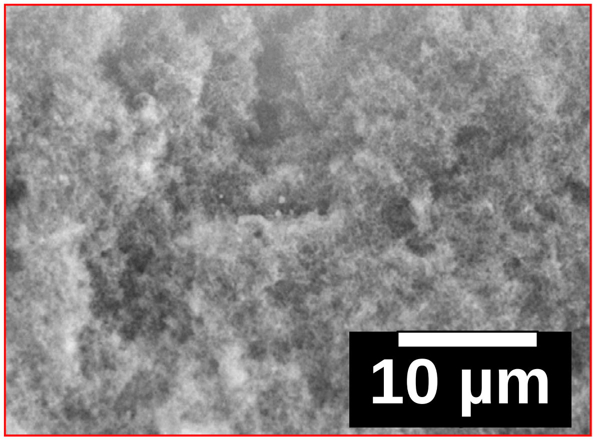
Density 0.02 g/cm^3

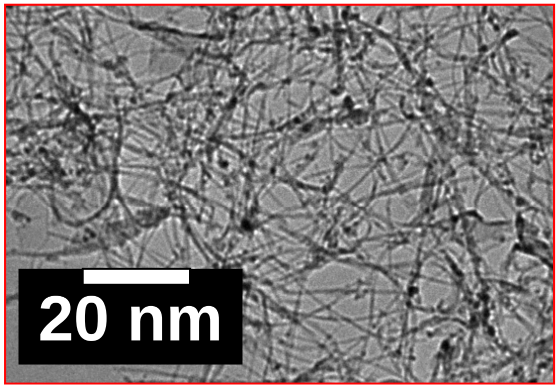
Supports at least

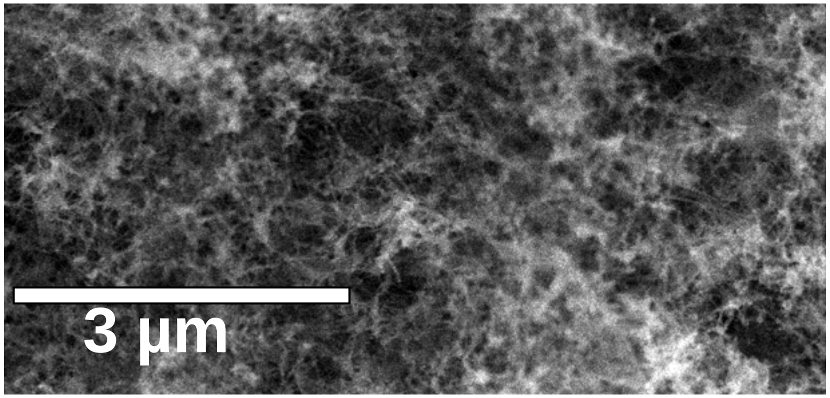
~8,000x

own weight

SWNT Aerogel posts



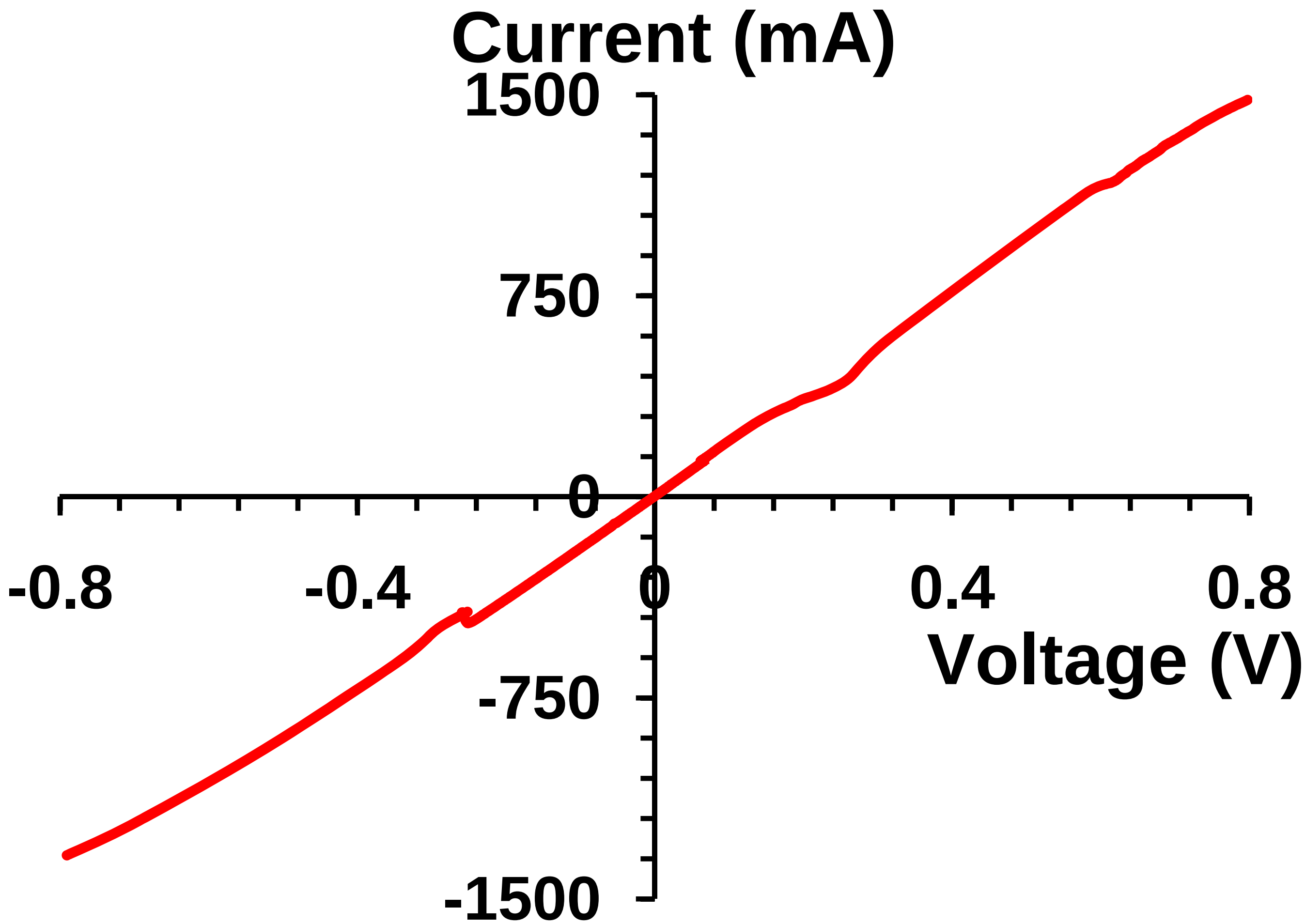




Electrical Conductivity up to ~10 S/cm
Surface area 1860 m^2/g
Thermal Conductivity ~0.3 W/m-K

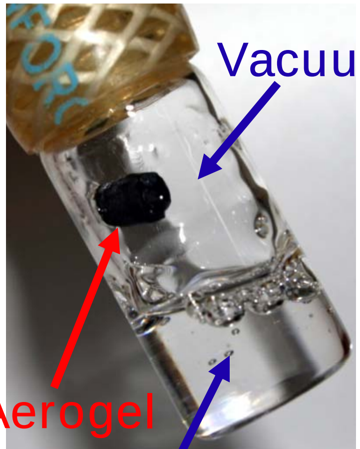
Advanced Materials **19**, 661 (2007)

CNT Aerogels



Backfilling with epoxy

Epon 828 Resin +EpiKure 3234 Crosslinker



Resin “wicks” into sample

Vacuum removed

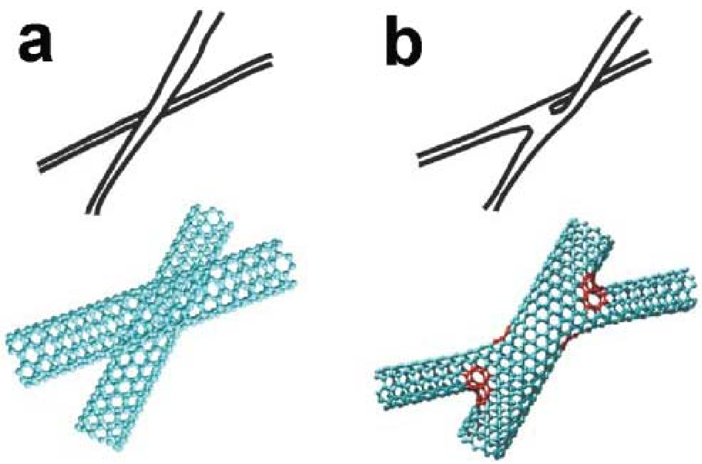
Fracture - Complete fill

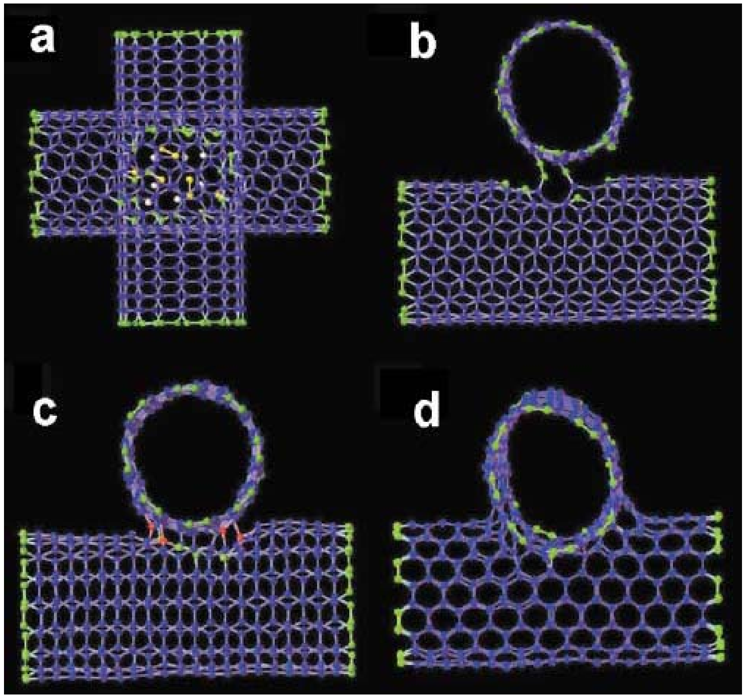
- Conductivity largely unaffected by backfilling
  - Improved composite conductivity

  Adv. Mater. 17, 1186, **2005**

- Can be backfilled with various substances

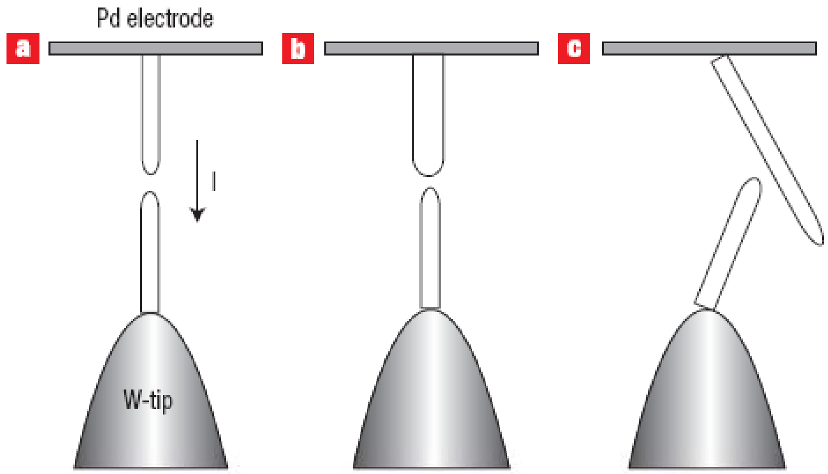
Fusing CNT Aerogel

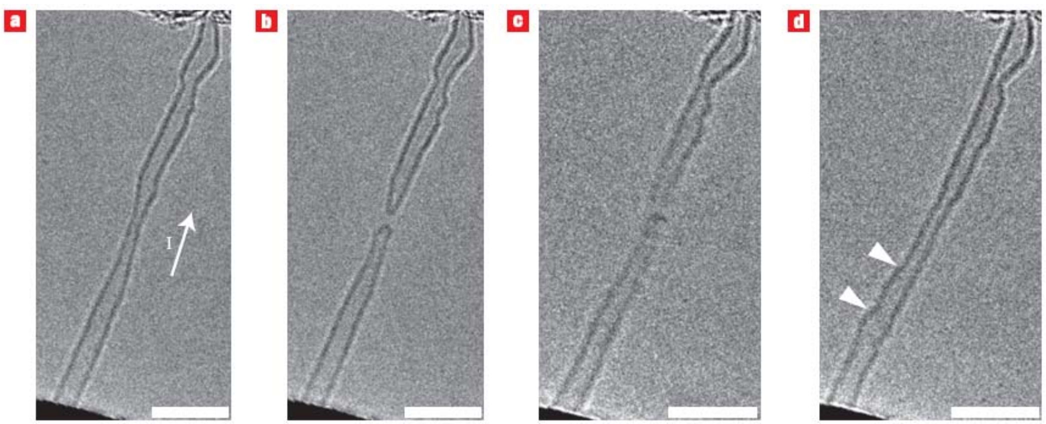




PRL **89**, 075505 (2002)

Fusing CNT Aerogel





Nature Nanotech. **3**, 17 (2008)

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Fusing CNT Aerogel

Irradiation gives rise to covalent bonds between the tubes.

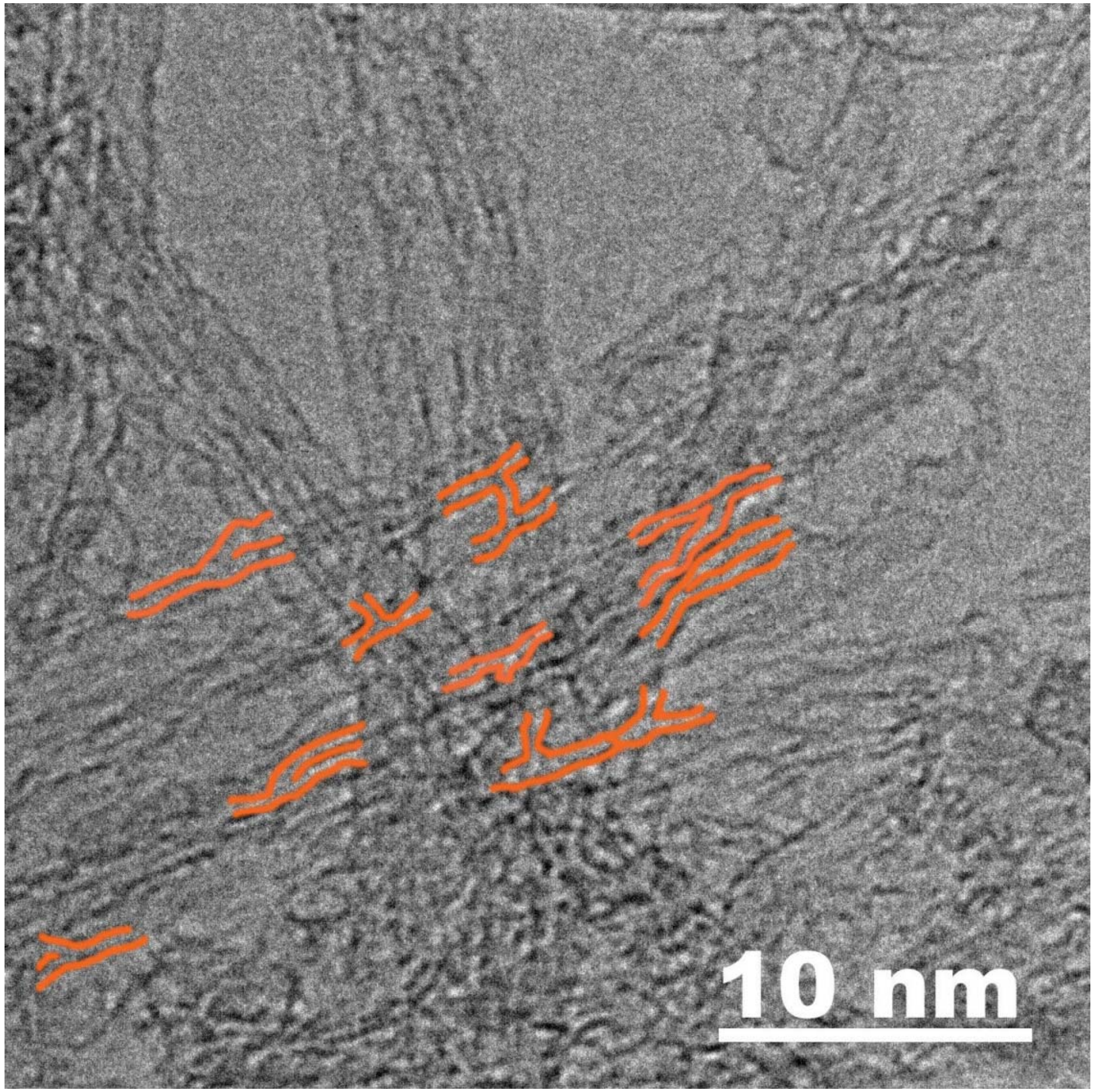
The overall strength of the nanotube materials may increase.
→Increase the tensile strength of macroscopic nanotube products.

A beneficial effect on the electronic properties
→ Irradiation with moderate doses may increase the conductivity of nanotube networks.
→ Spatially localized irradiation can be used for creating functional electronic nanotube-based devices.

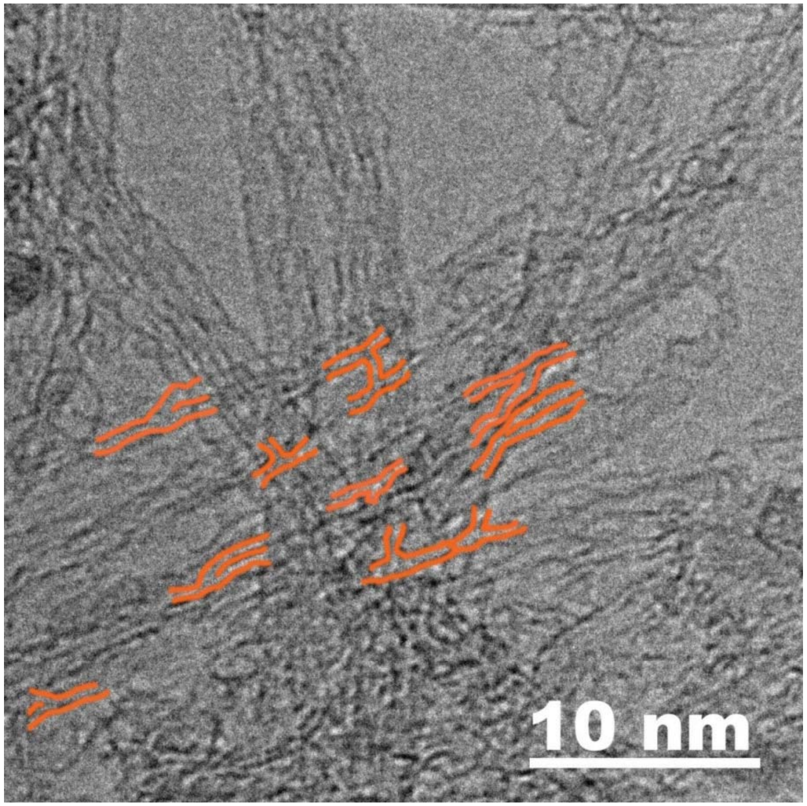
Is it possible to fuse CNTs in 3D structure?

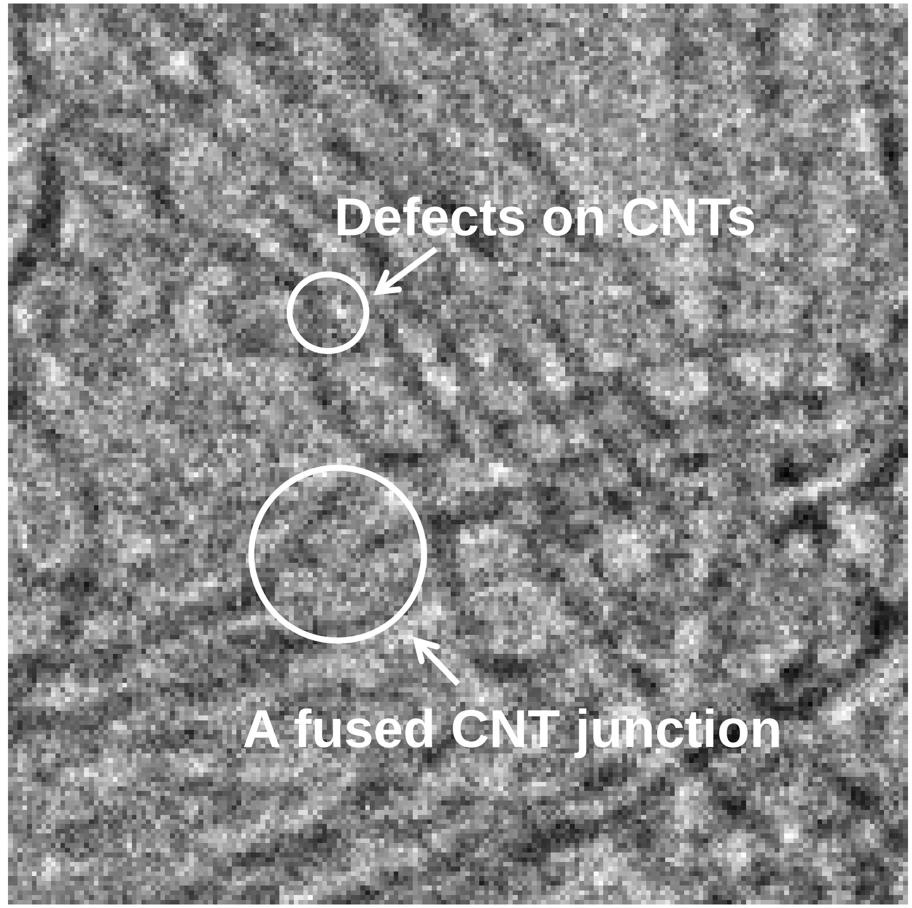
Fused CNT Aerogel

Fused CNT Aerogel

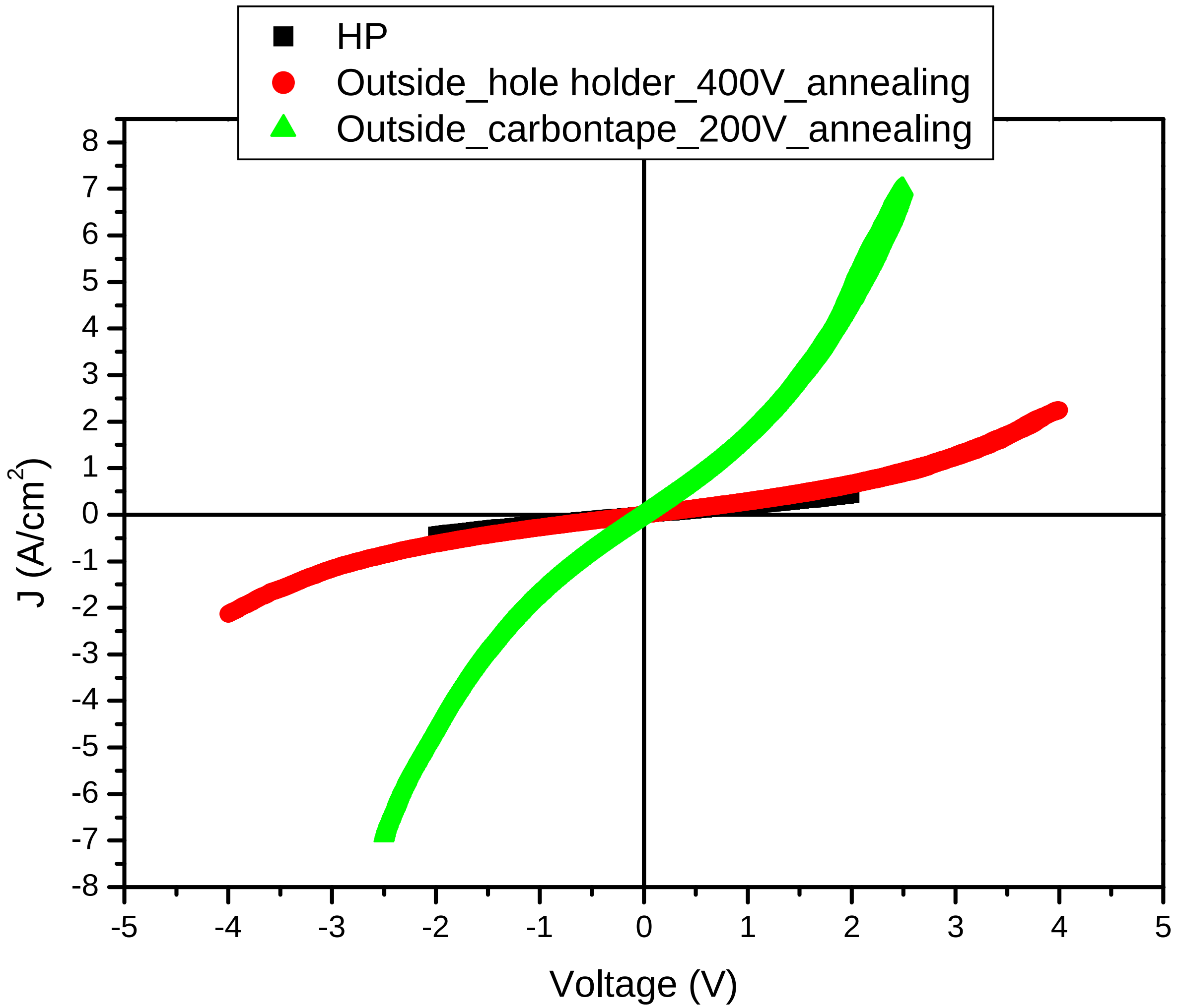


Fused CNT Aerogel





Fused CNT Aerogel



Conclusions

- We fabricated self-assembled carbon nanotube based ultra-light, large surface area-to-volume ratio electrically conducting porous structure – CNT aerogel.
- CNTs can be fused at junction points to increase mechanical strength and thermal properties.