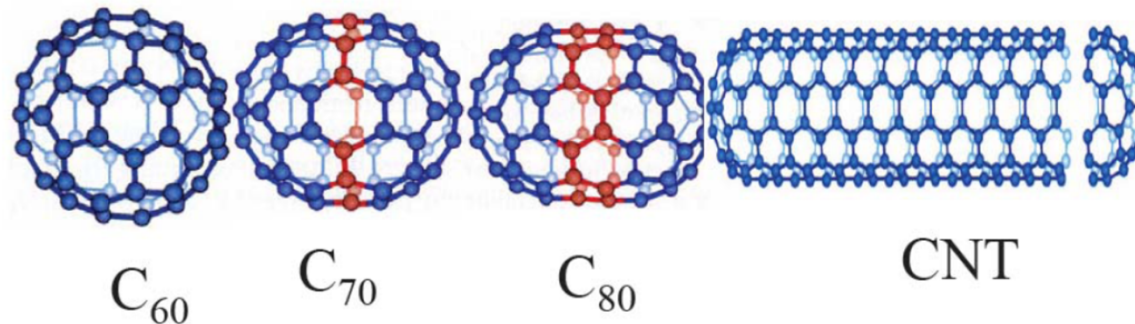


NANOTUBI DI CARBONIO

CNTs discover

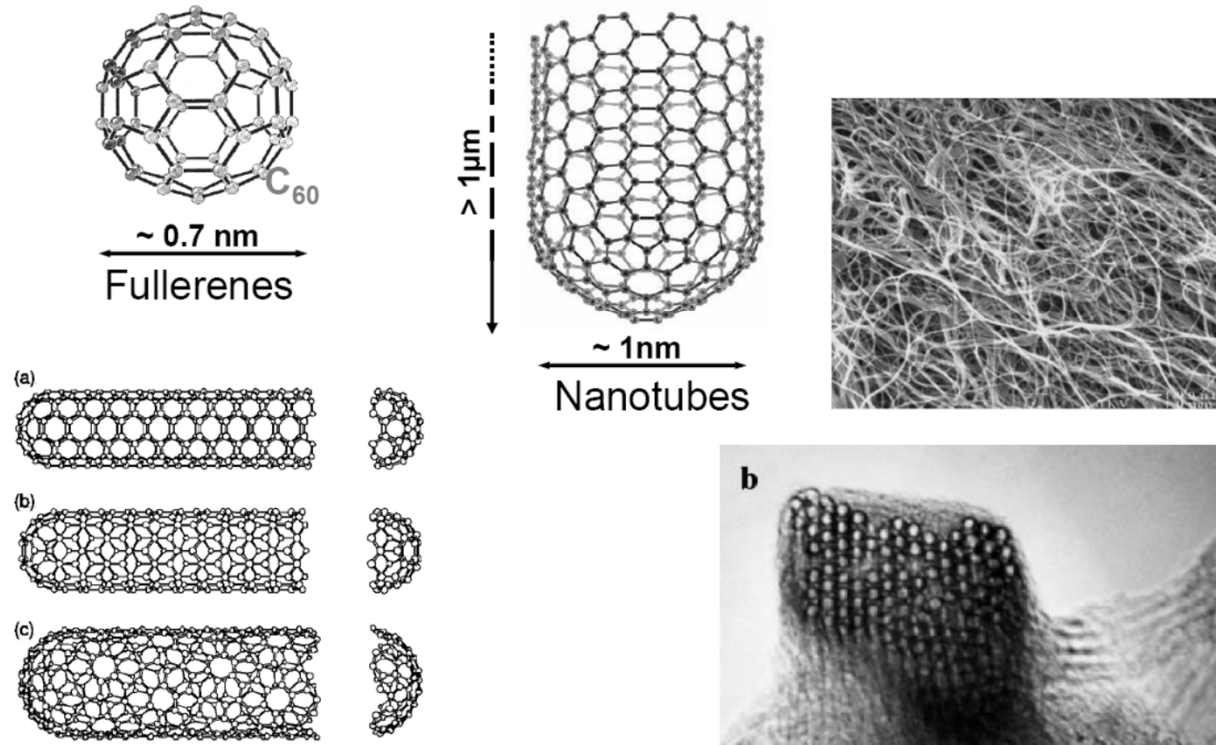
A paper by Oberlin, Endo, and Koyama published in **1976** clearly showed hollow carbon fibers with nanometer-scale diameters using a vapor-growth technique (Oberlin, A.; M. Endo, and T. Koyama, *J. Cryst. Growth* (March 1976). *Filamentous growth of carbon through benzene decomposition*. **32**. pp. 335–349.)

Iijima, Sumio (**1991**). "Helical microtubules of graphitic carbon".
Nature **354**: 56–58.



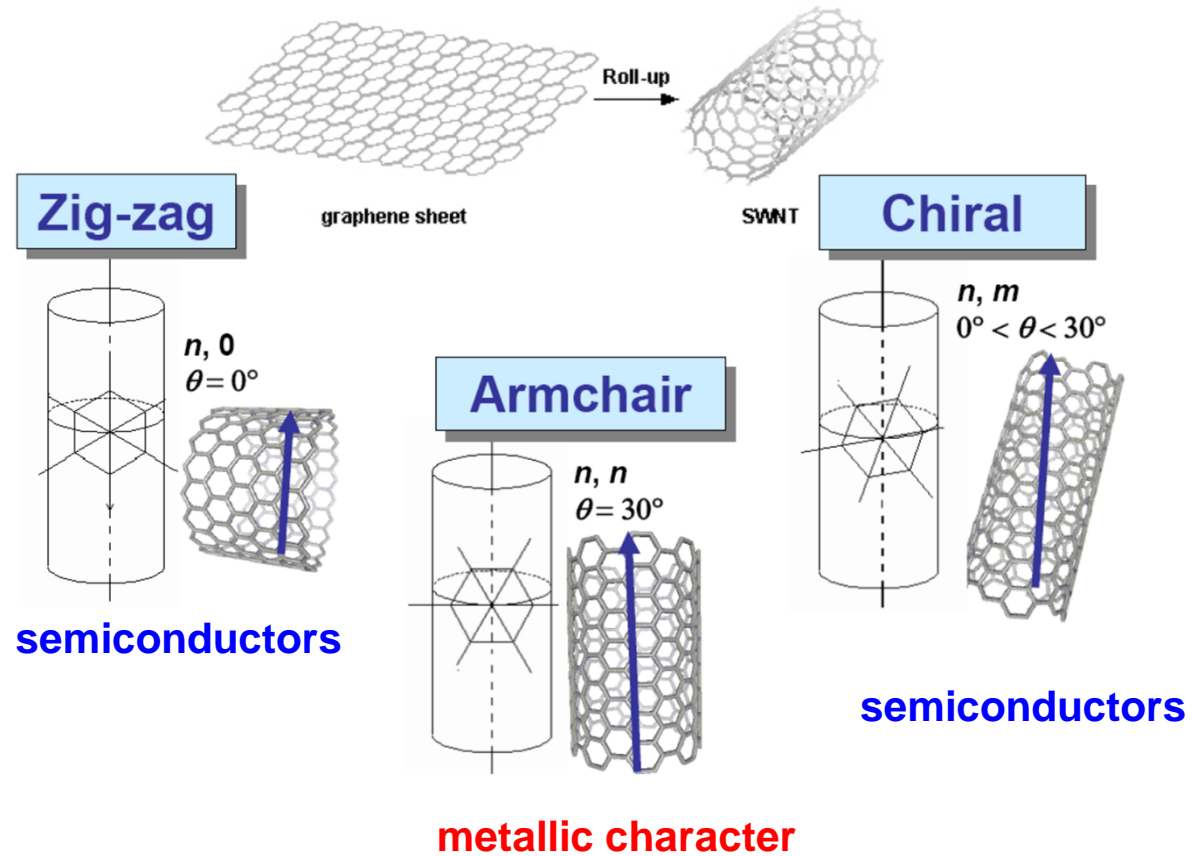
COMPOSTI AROMATICI POLICICLICI

nanotubes



COMPOSTI AROMATICI POLICICLICI

structure



COMPOSTI AROMATICI POLICICLICI

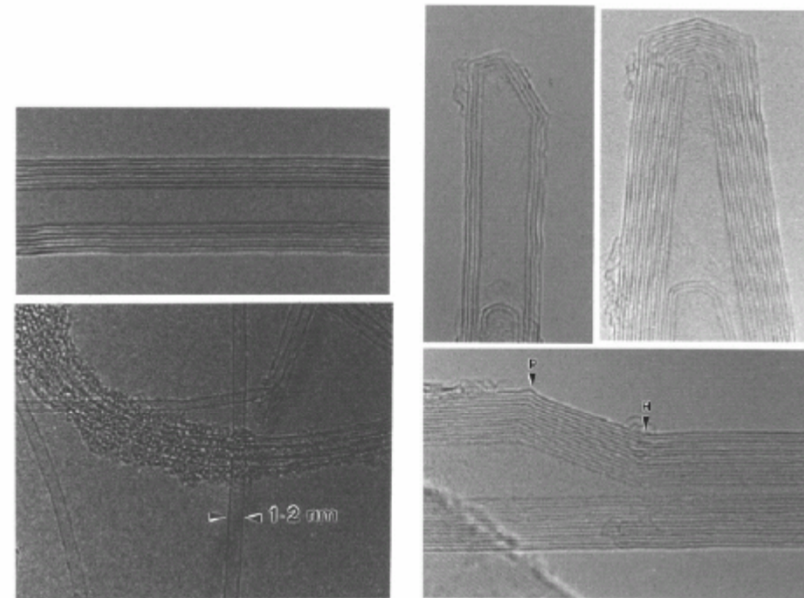


Figure 1-4: Different structures of MWNTs. Top-left: cross-section of a MWNT the different walls are obvious, they are separated by 0.34nm. Rotation around the symmetry axis gives us the MWNT. Top-right: Symmetrical or non-symmetrical cone shaped end caps of MWNTs. Bottom-left: A SWNT with a diameter of 1,2nm and a bundle of SWNTs covered with amorphous carbon. Bottom-right: A MWNT with defects. In point P a pentagon defect and in point H a heptagon defect.⁶

COMPOSTI AROMATICI POLICICLICI

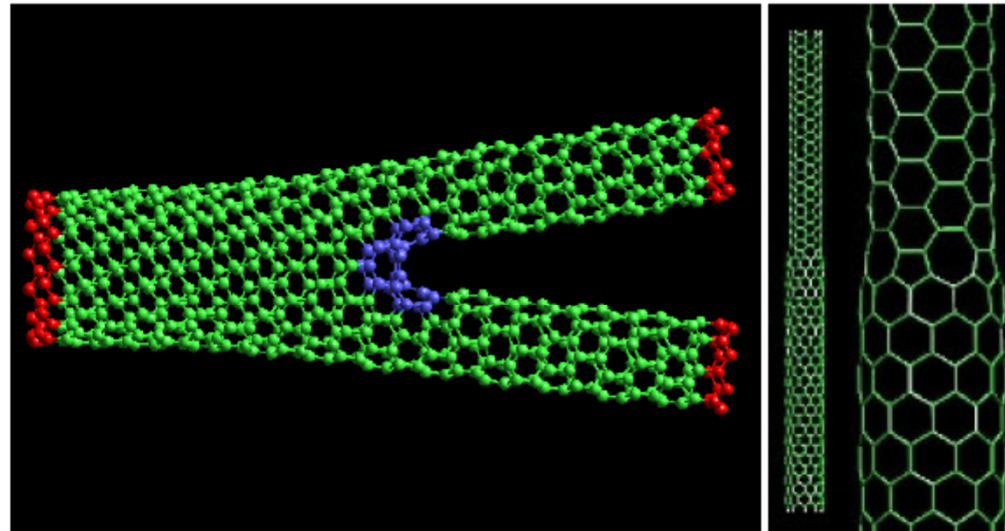


Figure 1-5: Left: A Y-branch, the defects are marked in blue. Right: A transition from a metallic to a semi-conducting SWNT. The change is made by insertion of pentagons and heptagons.

CNTs properties

SWNTs with different chiral vectors have dissimilar properties such as optical activity, mechanical, strength and electrical conductivity.

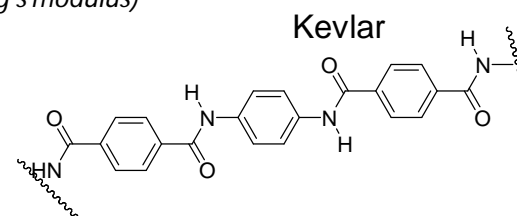
CNTs are 100 times stronger than steel

Comparison of Mechanical Properties

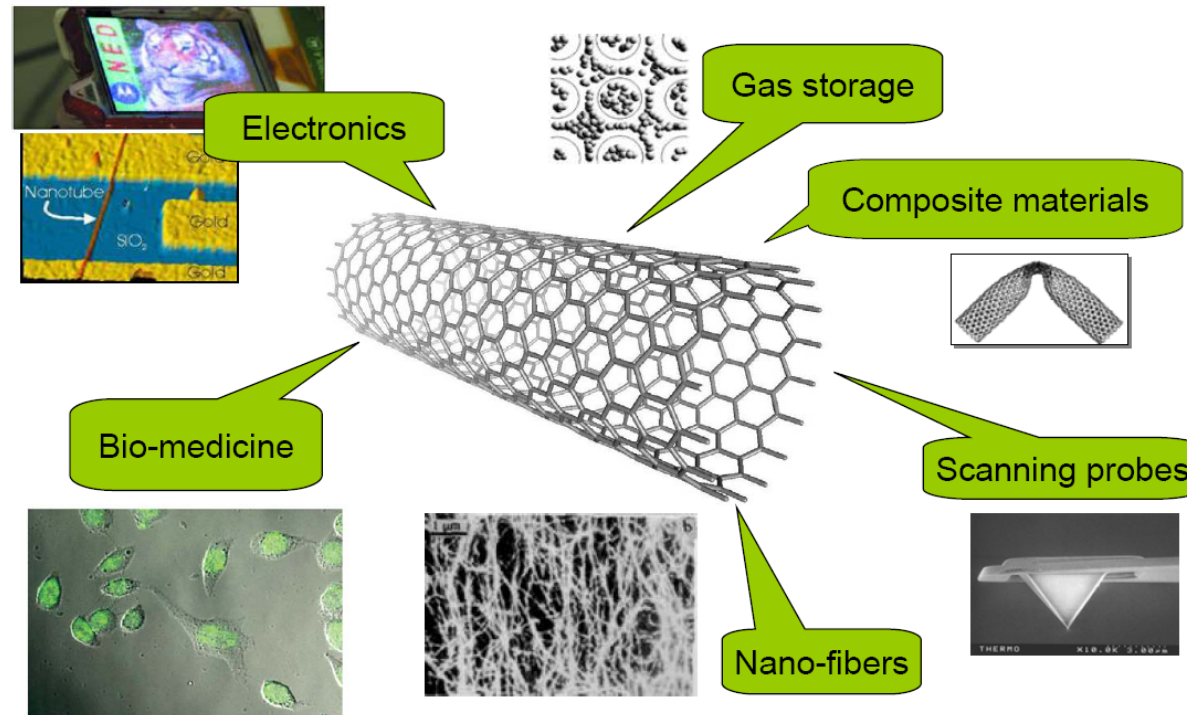
Material	Young's Modulus ⁽¹⁾ (GPa)	Tensile Strength (GPa)	Elongation at Break (%)
SWNT	~1 (from 1 to 5)	13-53 ^E	16
Armchair SWNT	0.94 ^T	126.2 ^T	23.1
Zigzag SWNT	0.94 ^T	94.5 ^T	15.6-17.5
Chiral SWNT	0.92		
MWNT	0.8-0.9 ^E	150	
Stainless Steel	~0.2	~0.65-1	15-50
Kevlar	~0.15	~3.5	~2
Kevlar ^T	0.25	29.6	

1. misura della durezza di un materiale elastico

(The tangent modulus of the initial, linear portion of a stress-strain curve is called *Young's modulus*)



COMPOSTI AROMATICI POLICICLICI



I CNT sono meccanicamente molto più resistenti delle tradizionali fibre di carbonio (sono 100 volte più forti dell'acciaio, 2 volte più leggeri dell'alluminio) ed eccezionalmente flessibili quando assoggettati a distorsioni (possono essere piegati a grandi angoli e poi raddrizzati senza danno).

COMPOSTI AROMATICI POLICICLICI

purification

Oxidation

- acid solution
- air at high T

Separation

- surfactants
- chromatography

Annealing

10.5 %

1 %



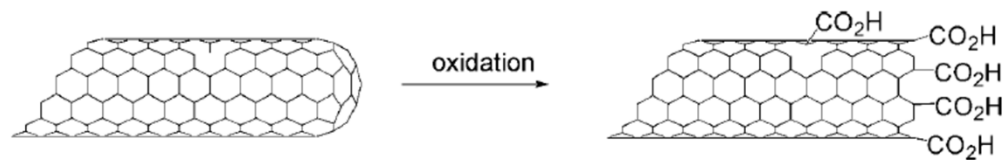
C. Furtado et al., *J. Am. Chem. Soc.* **2004**, *126*, 6095-6105

R. C. Haddon et al., *Mrs Bulletin* **2004**, *29*, 252-259.

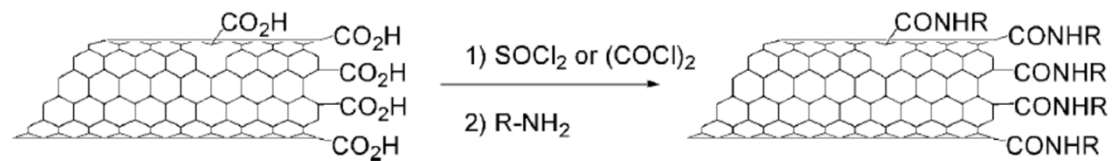
COMPOSTI AROMATICI POLICICLICI

funzionalizzazione di CNT

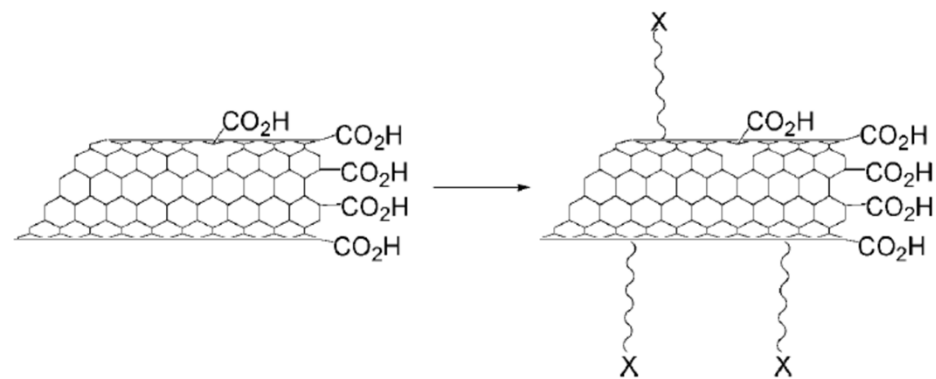
SCHEME 2. Oxidation of Carbon Nanotubes



SCHEME 3. Amidation Reaction of Oxidized Carbon Nanotubes

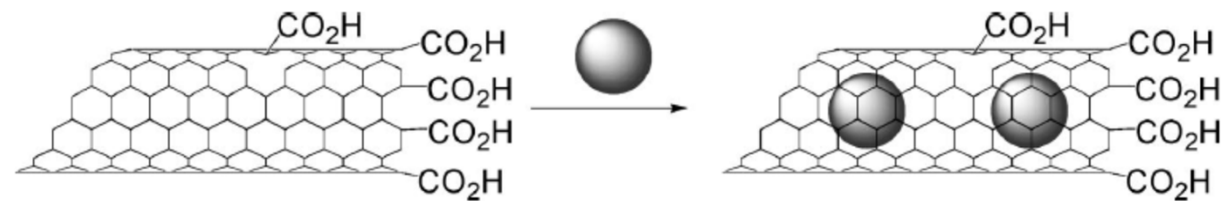


SCHEME 4. Functionalization of Carbon Nanotubes Using Addition Reactions (X = Functional Groups)



COMPOSTI AROMATICI POLICICLICI

SCHEME 5. Insertion inside Carbon Nanotubes



fullerenes, porphyrins, and metals, have indeed been included in the internal space of CNT, mostly due to hydrophobic interactions

COMPOSTI AROMATICI POLICICLICI

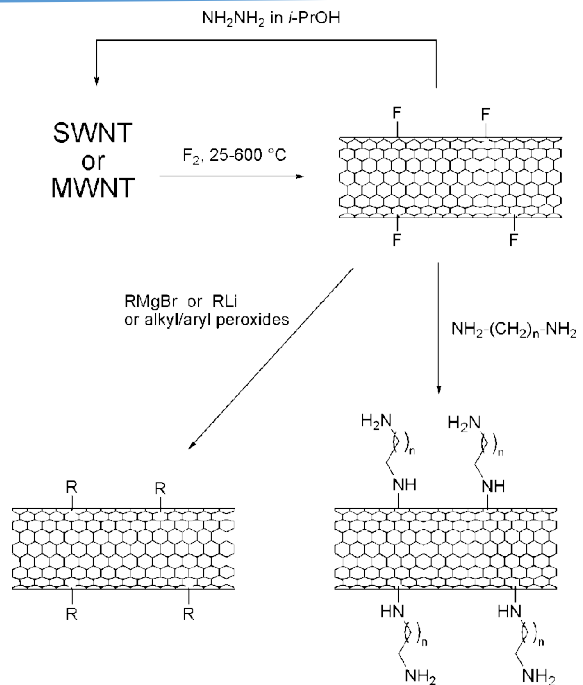


Figure 1. Reaction scheme for fluorination of nanotubes, defunctionalization, and further derivatization.

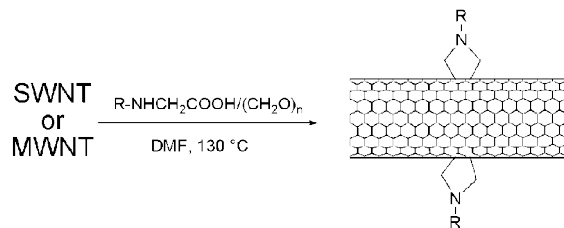


Figure 5. 1,3-Dipolar cycloaddition of azomethine ylides.

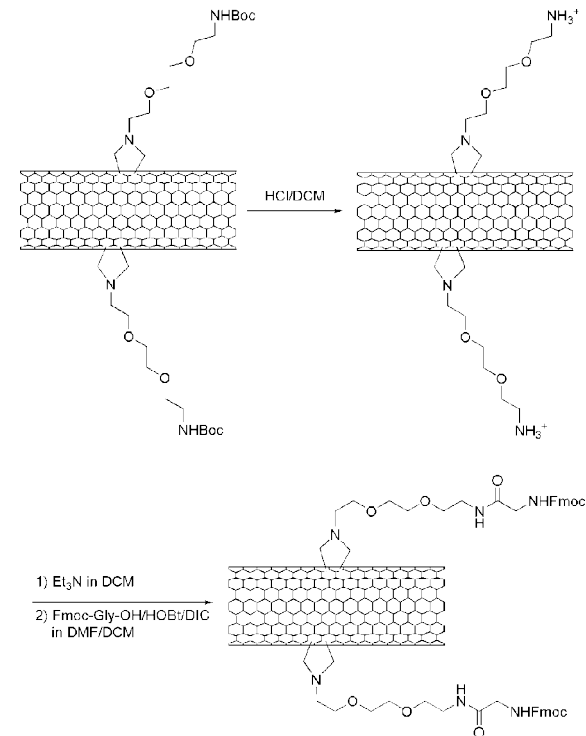


Figure 6. Reaction pathway for obtaining water-soluble ammonium-modified nanotubes. The latter can be used for the delivery of biomolecules.

COMPOSTI AROMATICI POLICICLICI

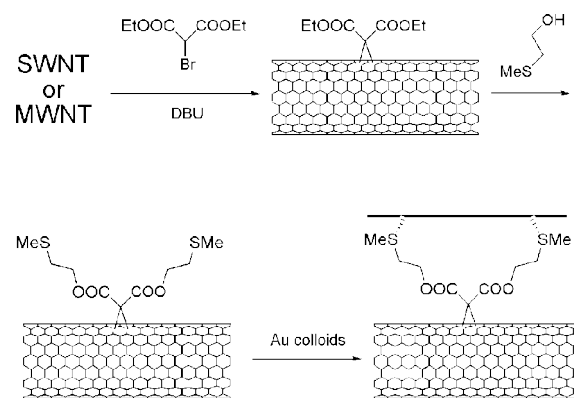


Figure 8. Bingel reaction on nanotubes and subsequent attachment to gold nanoparticles.

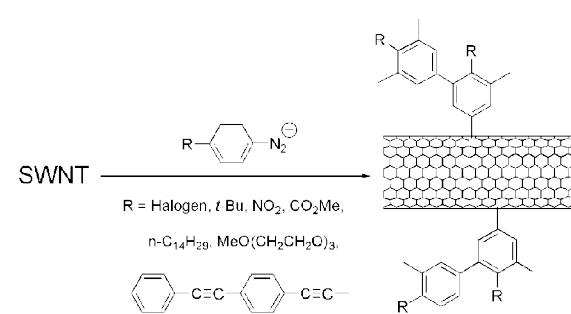


Figure 9. Derivatization scheme by reduction of aryl diazonium salts.

COMPOSTI AROMATICI POLICICLICI

funzionalizzazione via interazioni deboli

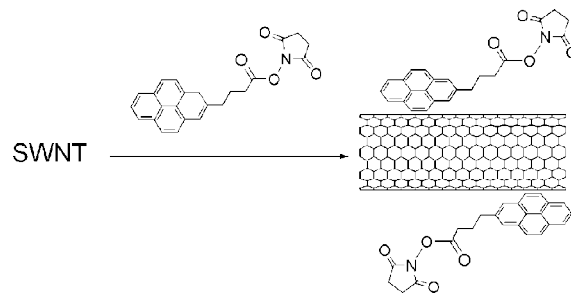
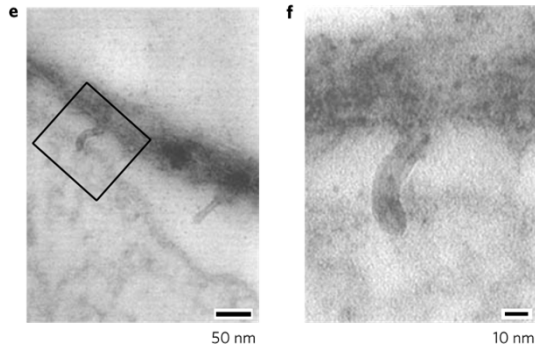


Figure 19. Interactions of nanotubes with pyrene derivatives.

Carbon nanotubes might improve neuronal performance by favouring electrical shortcuts

Giada Cellot¹, Emanuele Cilia^{1†}, Sara Cipollone², Vladimir Rancic¹, Antonella Sucapane¹, Silvia Giordani^{2‡}, Luca Gambazzi³, Henry Markram³, Micaela Grandolfo⁴, Denis Scaini⁵, Fabrizio Gelain⁶, Loredana Casalis⁵, Maurizio Prato², Michele Giugliano^{3,7*} and Laura Ballerini^{1,3*}

we show, using single-cell electrophysiology techniques, electron microscopy analysis and theoretical modelling, that nanotubes improve the responsiveness of neurons by forming tight contacts with the cell membranes that might favour electrical shortcuts between the proximal and distal compartments of the neuron.



tight contact between nanotubes and membranes. The morphology of such contacts is indicative of the development of hybrid nanotubes – neuronal units .

High-magnification micrographs from a section consecutive to those of b and c. The rectangular area in e is magnified in f. Note how nanotubes are ‘pinching’ neuronal membranes.

Efficient water oxidation at carbon nanotube-polyoxometalate electrocatalytic interfaces

Francesca M. Toma^{1,2}, Andrea Sartorel³, Matteo Iurlo⁴, Mauro Carraro³, Pietro Parisse^{2,5}, Chiara Maccato³, Stefania Rapino⁴, Benito Rodriguez Gonzalez⁶, Heinz Amenitsch⁷, Tatiana Da Ros¹, Loredana Casalis^{2,5}, Andrea Goldoni⁵, Massimo Marcaccio⁴, Gianfranco Scorrano³, Giacinto Scoles², Francesco Paolucci⁴, Maurizio Prato^{1*} and Marcella Bonchio^{3*}

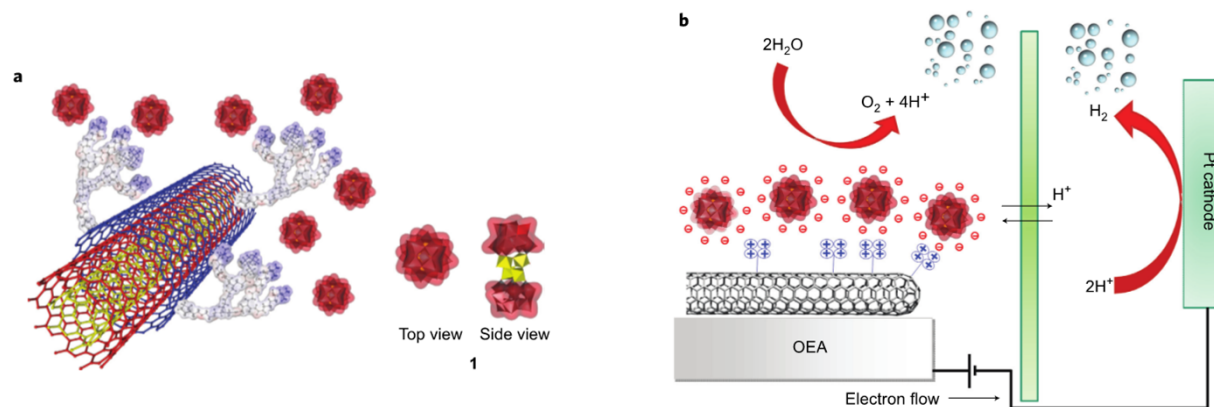
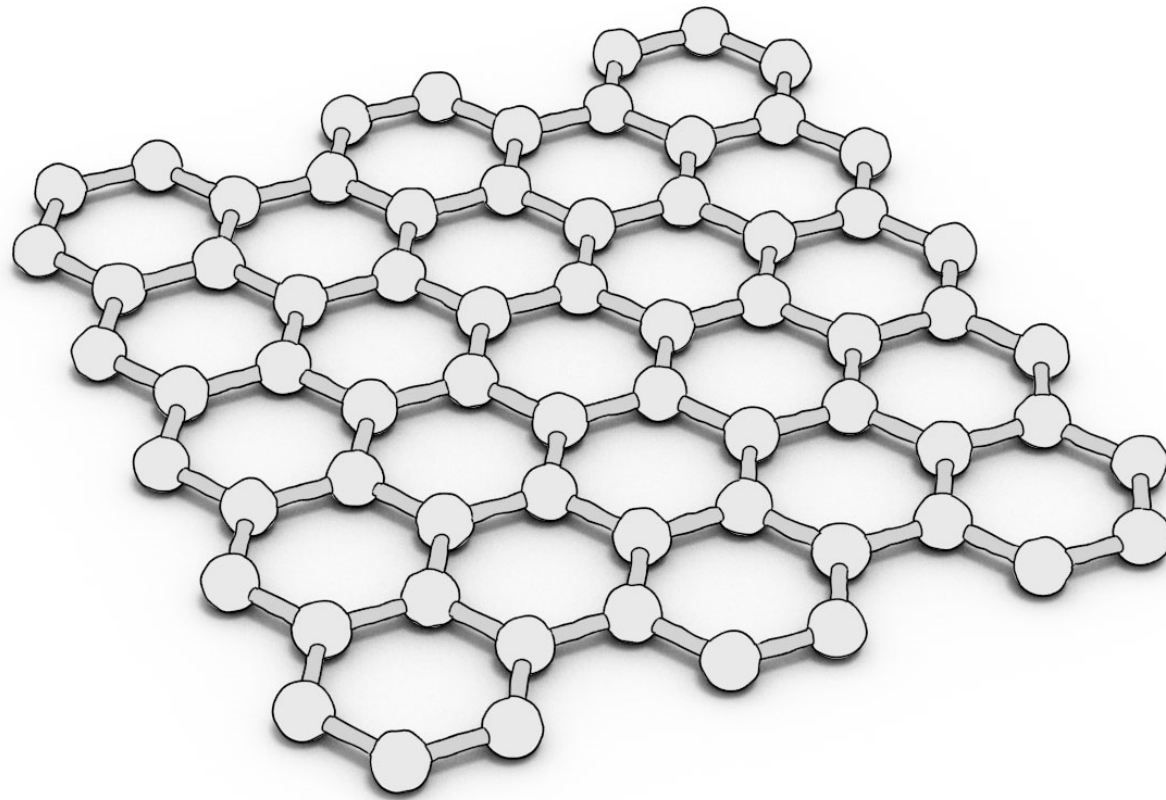


Figure 1 | Nanostructured oxygen-evolving material. **a**, Electrostatic capture of polyanionic ruthenium-containing clusters **1** (negatively charged, red surface) by polycationic dendrons on the MWCNT surface (positively charged, blue surface) and polyhedric structure showing the side and front view of the POM (red)-embedded tetraruthenate core of **1** (yellow). **b**, General scheme for a water-splitting electrocatalytic cell with the integrated nanostructured OEA.

Graphene



Graphene is an allotrope (form) of carbon consisting of a single layer of carbon atoms arranged in an hexagonal lattice.

It can be considered as an indefinitely large aromatic molecule, the ultimate case of the family of flat polycyclic aromatic hydrocarbons.

The material was rediscovered, isolated, and characterized in **2004** by **Andre Geim** and **Konstantin Novoselov** at the University of Manchester.

This work resulted in the two winning the **Nobel Prize in Physics in 2010** "for groundbreaking experiments regarding the two-dimensional material graphene".

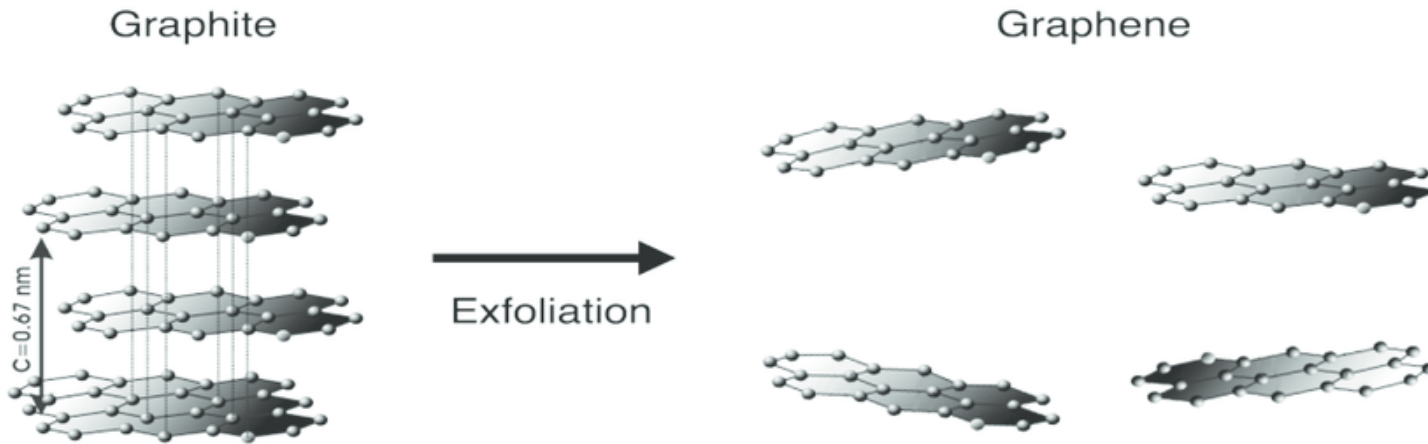


Andre Geim



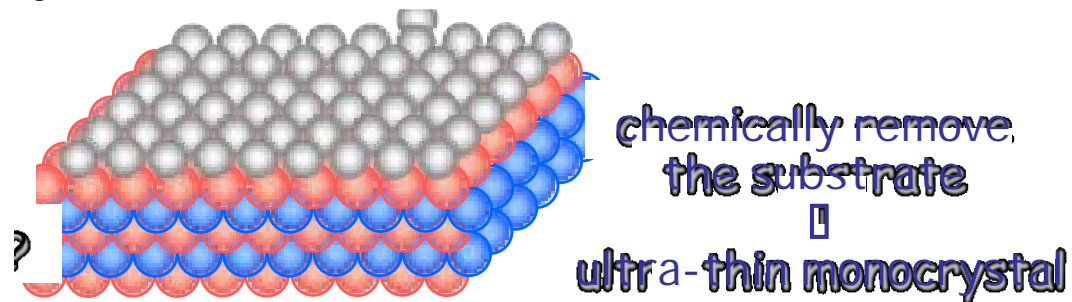
Konstantin Novoselov

exfoliation



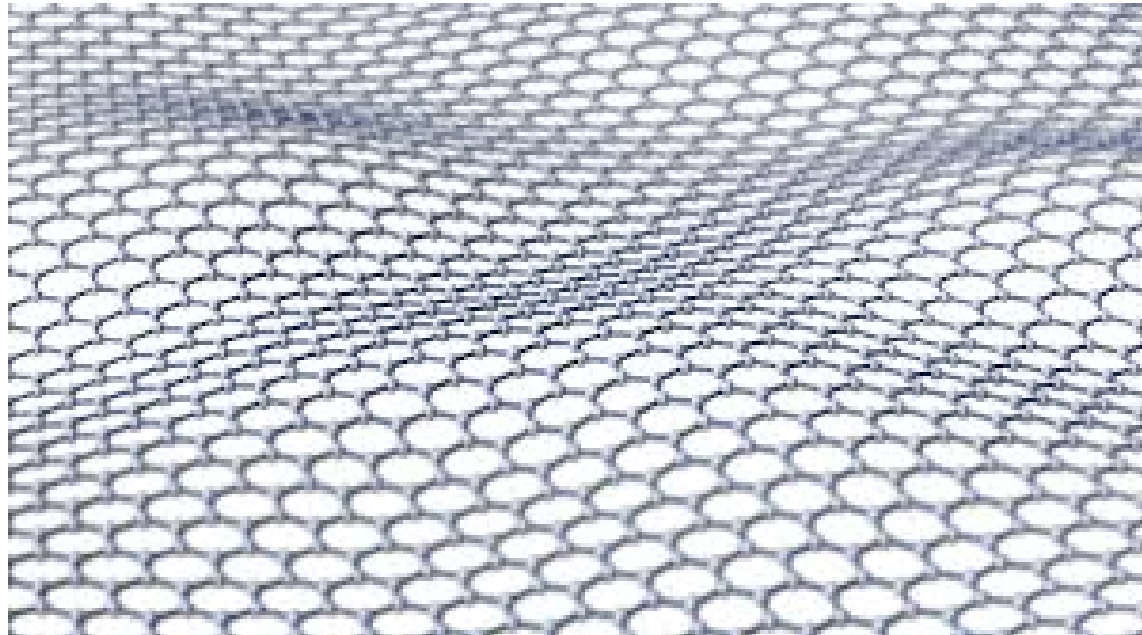
highly oriented pyrolytic graphite (HOPG)

Epitaxial growth



"Graphene" is a combination of "graphite" and the suffix -ene, named by Hanns-Peter Boehm, who described single-layer carbon foils in 1962.

Graphene can be considered an "infinite alternant" (only six-member carbon ring) polycyclic aromatic hydrocarbon



nanoscale corrugation

Electric Field Effect in Atomically Thin Carbon Films

2 OCTOBER 2004 VOL 306 SCIENCE, p. 666

K. S. Novoselov,¹ A. K. Geim,^{1*} S. V. Morozov,² D. Jiang,¹
Y. Zhang,¹ S. V. Dubonos,² I. V. Grigorieva,¹ A. A. Firsov²

We describe monocrystalline graphitic films, which are a few atoms thick but are nonetheless stable under ambient conditions, metallic, and of remarkably high quality. The films are found to be a two-dimensional semimetal with a tiny overlap between valence and conductance bands, and they exhibit a strong ambipolar electric field effect such that electrons and holes in concentrations up to 10^{13} per square centimeter and with room-temperature mobilities of $\sim 10,000$ square centimeters per volt-second can be induced by applying gate voltage.

Field effect

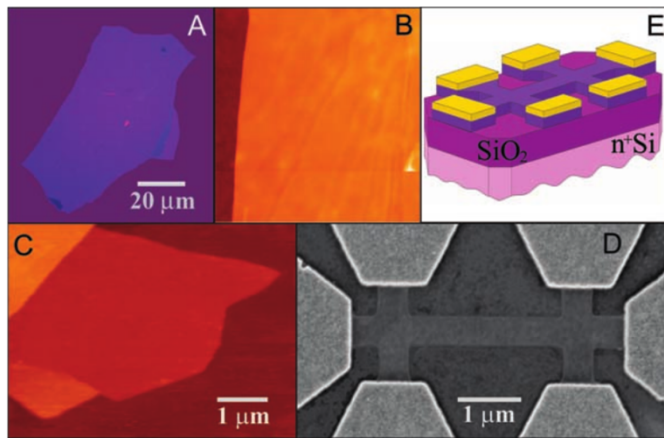


Fig. 1. Graphene films. (A) Photograph (in normal white light) of a relatively large multilayer graphene flake with thickness ~ 3 nm on top of an oxidized Si wafer. (B) Atomic force microscope (AFM) image of $2 \mu\text{m}$ by $2 \mu\text{m}$ area of this flake near its edge. Colors: dark brown, SiO_2 surface; orange, 3 nm height above the SiO_2 surface. (C) AFM image of single-layer graphene. Colors: dark brown, SiO_2 surface; brown-red (central area), 0.8 nm height; yellow-brown (bottom left), 1.2 nm; orange (top left), 2.5 nm. Notice the folded part of the film near the bottom, which exhibits a differential height of ~ 0.4 nm. For details of AFM imaging of single-layer graphene, see (15). (D) Scanning electron microscope image of one of our experimental devices prepared from FLG. (E) Schematic view of the device in (D).

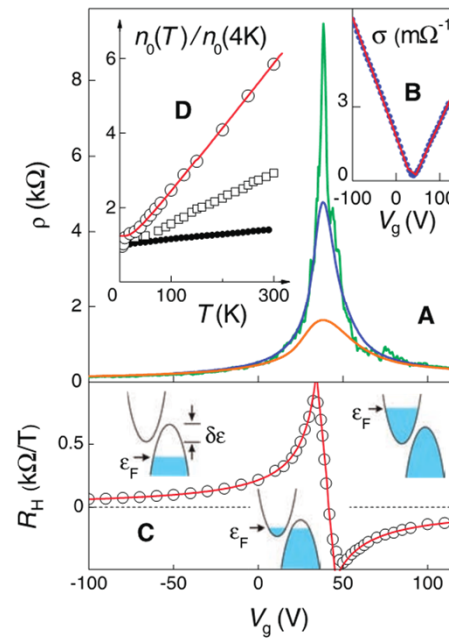
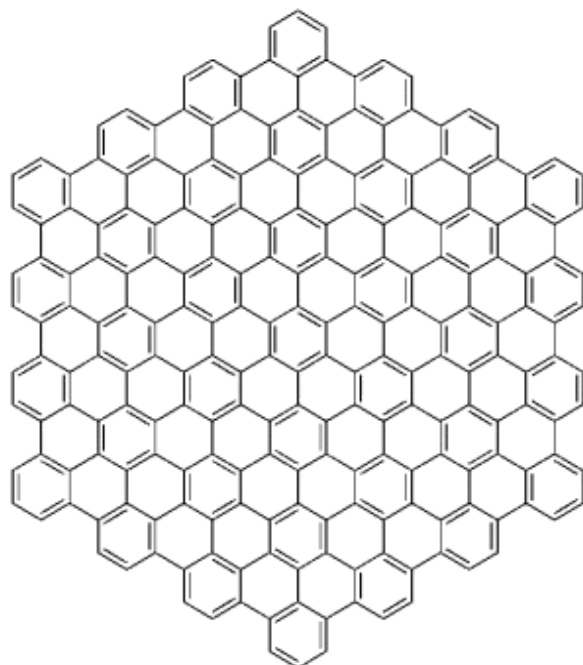


Fig. 2. Field effect in FLG. (A) Typical dependences of FLG's resistivity ρ on gate voltage for different temperatures ($T = 5, 70,$ and 300 K for top to bottom curves, respectively). (B) Example of changes in the film's conductivity $\sigma = 1/\rho(V_g)$ obtained by inverting the 70 K curve (dots). (C) Hall coefficient R_H versus V_g for the same film; $T = 5$ K. (D) Temperature dependence of carrier concentration n_0 in the mixed state for the film in (A) (open circles), a thicker FLG film (squares), and multilayer graphene ($d \approx 5$ nm; solid circles). Red curves in (B) to (D) are the dependences calculated from our model of a 2D semimetal illustrated by insets in (C).



*largest known
flat hydrocarbon:
222 atoms or 37 benzene rings*

(K. Müller 2002)

GRAPHENE

0.142 nm

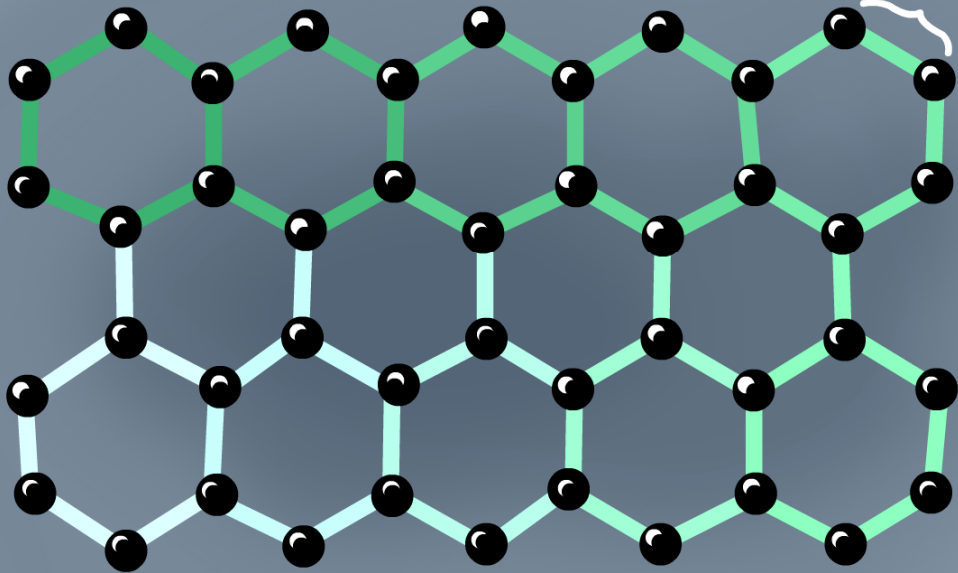
LIGHT!

RIGID

100x
STRONGER
THAN
STEEL

PERFECT
THERMAL
CONDUCTOR

A CRYSTALLINE ALLOTROPE OF CARBON



Properties

Graphene has no band gap

The top five industries that target the production of graphene is in Life Sciences for medical device, electronics TV, chemical biosensors, smart phone and smart pad and desalinization membranes.

Strength and stiffness: some 200 times stronger than steel, elastic like rubber

Thinness and lightness

Heat conductivity: it has very high thermal conductivity than any other material—better by far than brilliant heat conductors such as silver and copper

Electrical conductivity carrying electricity better than even superb conductors such as copper and almost as well as superconductors

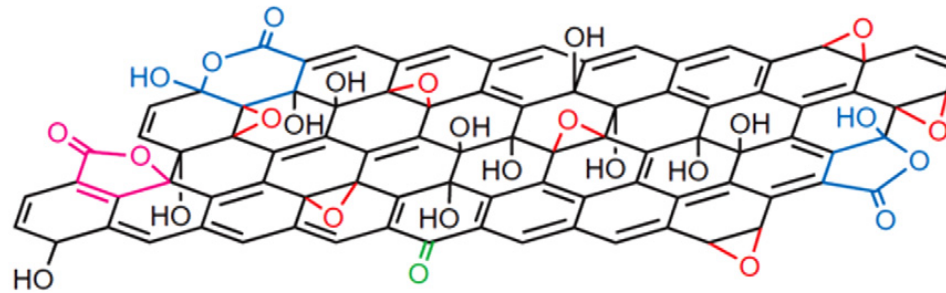
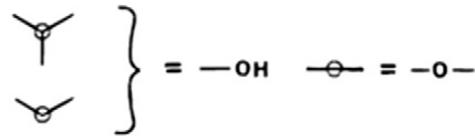
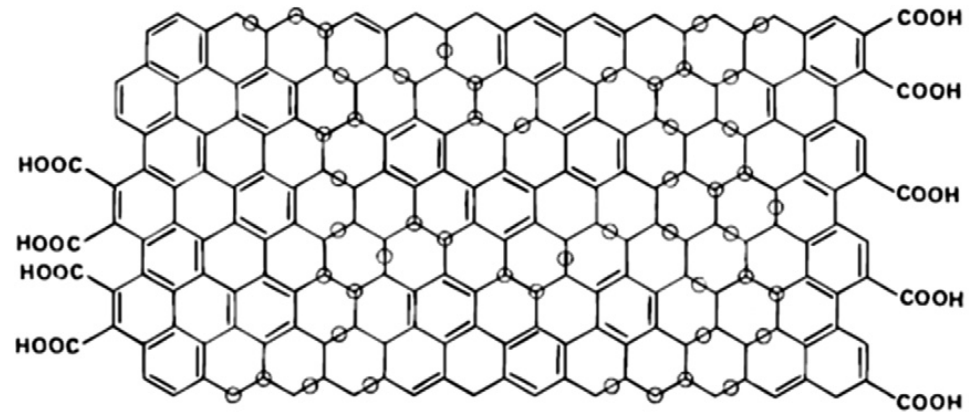
Electronic properties

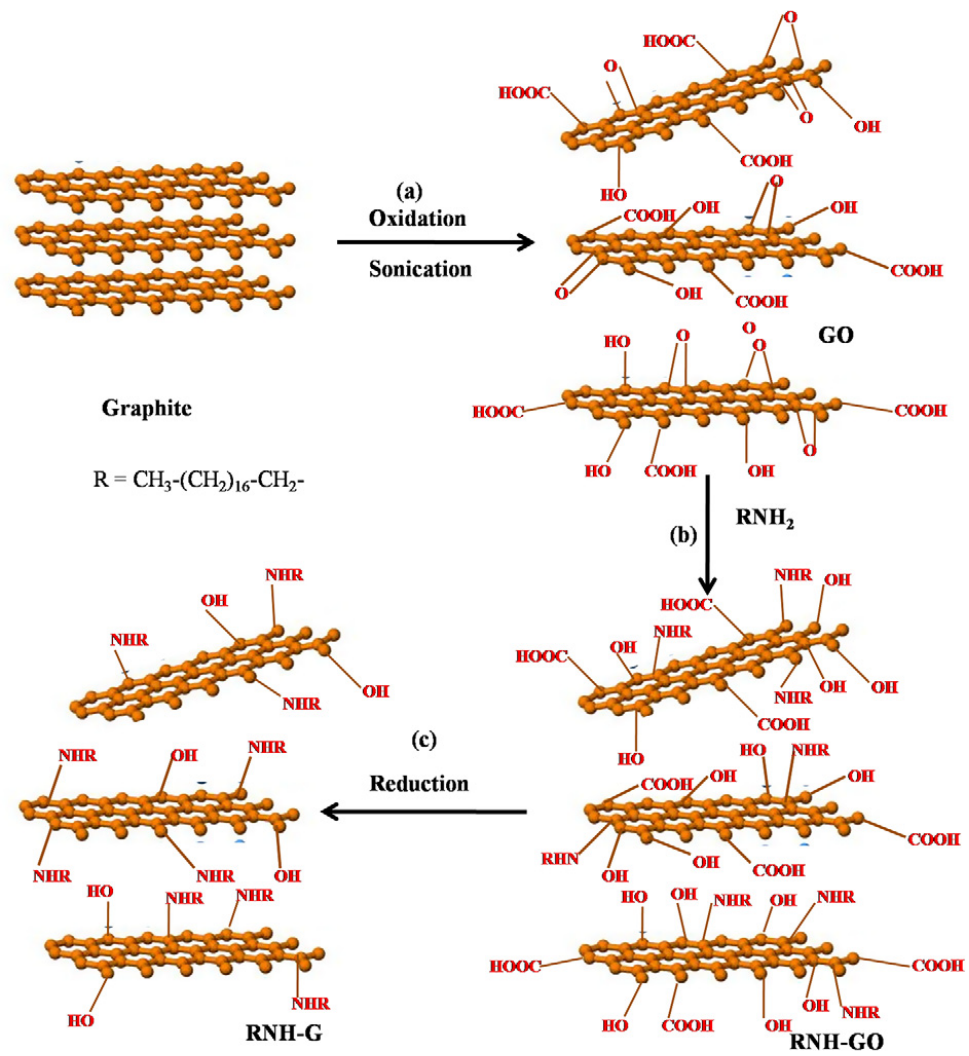
Optical properties: it is transparent

Impermeability

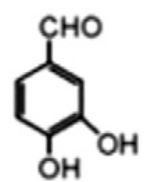
Functionalization

oxidation

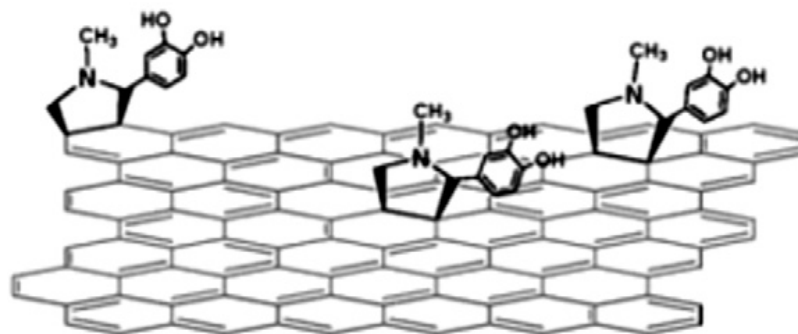




Graphene



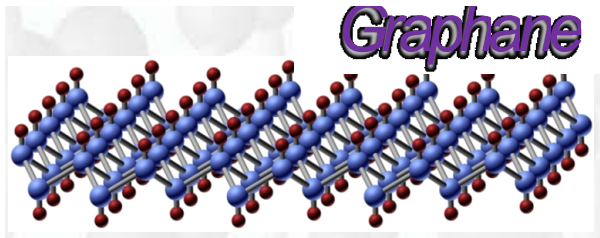
$\text{CH}_3\text{NH}_2\text{CH}_2\text{COOH}$
DMF, reflux 96 h



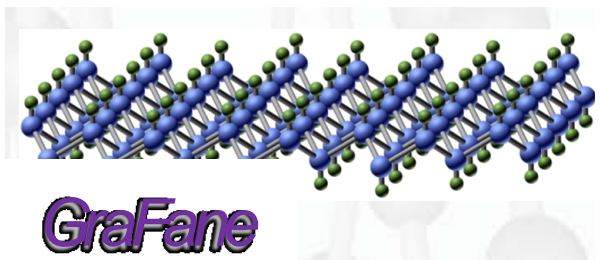
Graphene-*f*-OH



hydrogenation of graphene



Science 2009



fluorographene

Small 2010

Graphene: applications

The exceptional electron and thermal transport, mechanical properties, barrier properties and high specific surface area of graphene and combinations thereof make it a potentially disruptive technology across a raft of industries. In 2010, there were over 400 patents issued on graphene and 3,000 research papers published.

The European Union is funding a 10 year 1,000 million euro coordination action on graphene.

Graphene Flagship starting in 2013.

South Korea is set to spend \$350 million on commercialization initiatives and the United Kingdom has announced investment of £50million in a new commercialization hub.