CARBON NANOTUBES (CNT)

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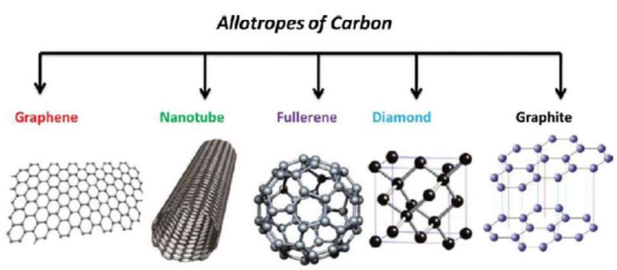
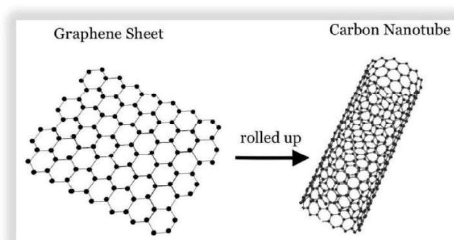
What are Carbon Nano Tubes (CNTs) ?

- CNTs are allotropes of carbon with cylindrical nanostructure.
- The structure of CNT is formed by a layer of carbon atom that are bonded together in hexagonal (honeycomb) mesh.
- This one atom thick layer of carbon is called Graphene.
- Graphene is wrapped in the shape of a cylinder to form CNTs.
- Tube diameter has dimensions in nanometer-2D quantum confinement-Quantum wire.

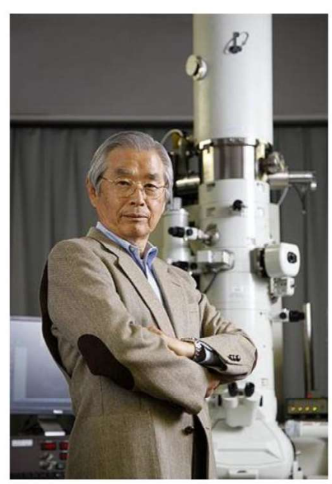




Discovery of CNTs

1991:Sumio Iijima - NEC Laboratory in Tsukuba- used high-resolution transmission electron microscopy to observe carbon nanotubes.

(carbon soot of graphite electrodes during an arc discharge, that was intended to produce fullerenes)

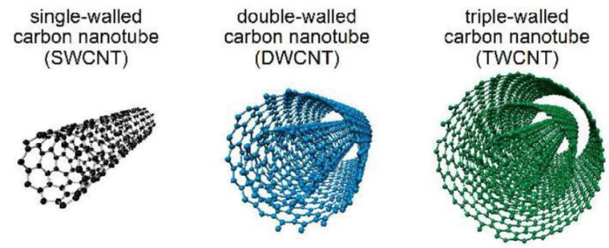


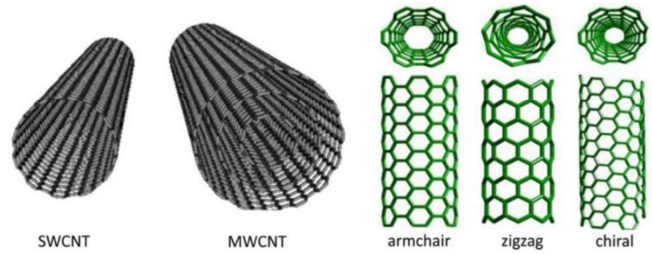
Types of Carbon nanotubes

Based on their shape and size. CNTs are classified as single walled carbon nanotube (SWCNT) and Multiwalled carbon nanotube (MWCNT)

1. SWCNT-single outer wall of graphene rolled up
2. MWCNTs-Multiple CNTs one inside the other.

Further classification of CNTs based on their Chirality. Angle of twist in the rolled up carbon layer.





Properties of CNTs

- The cylindrical carbon molecules have interesting properties that make them potentially useful in many applications in nanotechnology, electronics, optics , fields of materials science, potential uses in architectural fields.

- Exhibit extraordinary strength and unique electrical properties, and are efficient conductors of heat.

Strength Properties

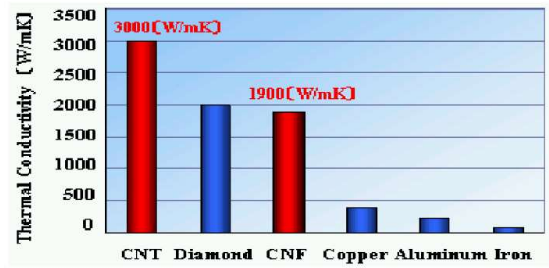
Carbon nanotubes have the strongest tensile strength of any material known. **It also has the highest modulus of elasticity.**

Electrical Properties

- If the nanotube structure is armchair, then the electrical properties are metallic.
- If the nanotube structure is chiral then the electrical properties can be either semiconducting with a very small band gap, otherwise the nanotube is a moderate semiconductor.
- In theory, metallic nanotubes can carry an electrical current density of 4×109 A/cm^2 which is more than 1,000 times greater than metals such as copper.

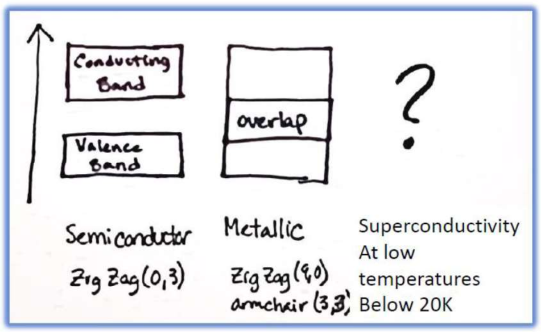
Thermal conductivity of CNTs

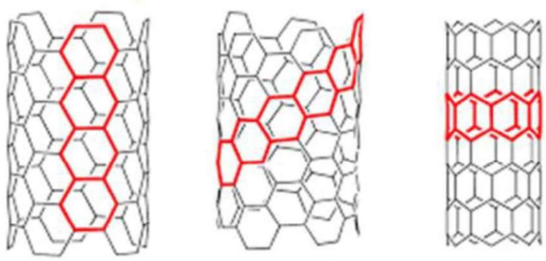
- Excellent thermal conductivity along the length of the tube but not along lateral direction
- Thermal conductivity for CNT, K=3500 W/mK. This value is 100 times greater than aluminum.



Electronic property of CNTs

- Electronic properties are determined by the shape and structure of CNTs.
- Nanotubes are mostly metallic or semiconductors based on their chirality.
- Chirality changes band gap and hence the electrical conductivity of SWCNT





[5,5] CNT
Armchair
Metallic

[7,5] CNT
Chiral
Semiconducting

[7,0] CNT
Zigzag
Semiconducting

Chirality	Band gap Eg (eV)	
Arm chair (3,3)	0.73eV	Metal
Zig zag (0,3)	2.72eV	Semiconductor
Chiral (2,3)	0.93eV	Semiconductor

Properties of Carbon Allotropes

Allotrope	Hardness	Tensile strength	Conducts heat	Conducts electricity
Coal	+	+	+	no
Graphite	++	++	+++++	+++++
Diamond	+++++	Not known	+++	no
Buckyballs	+++++	++++	+	+
Carbon Nanotubes	++++++	+++++	+++++	++++++

Structure of Carbon Nanotubes

- **Single-wall carbon nanotube (SWNT)**
- **Multiwall Nanotubes (MWNT)**

Single-wall nanotubes (SWNT)

Tubes of graphite that are normally capped at the ends and a single cylindrical wall. The structure of a SWNT can be visualized as a layer of graphite, a single atom thick, called graphene, which is rolled into a seamless cylinder.

Typically have a diameter of **close to 1 nm**. The tube length, however, can be **many thousands of times longer**.

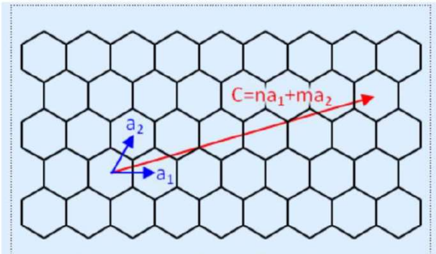
They can be twisted, flattened, and bent into small circles or around sharp bends without breaking.

Unique electronic and mechanical properties which can be used in numerous applications (field-emission displays, nanocomposite materials, nanosensors, and logic elements). Expected as next generation of miniaturized electronics.

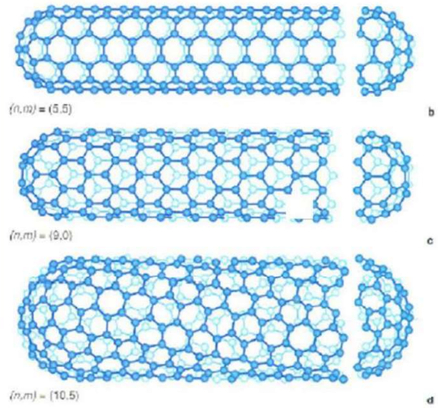
Chirality of single-walled carbon nanotubes

- A sheet made of carbon atoms arranged in a honeycomb lattice is called a graphene sheet.
- Single-walled carbon nanotubes are made by rolling up such a graphene sheet into a tube with a diameter of few nanometers.
- In order to form a seamless tube, you would need to take two of the hexagons and overlap them.
- A vector connecting the centers of the two hexagons is called the chiral vector, and it determines the structure of a single-walled carbon nanotube.
- Chiral vector C can be written as C = n a1 + m a2 where a1 and a2 are basis vectors of the graphene lattice. The pair of integers (n,m) is called the chiral index or just chirality. This implies that the structure of a single-walled carbon nanotube is completely determined by chirality.
- What's really interesting about single walled carbon nanotubes is that their electronic structure can become either semiconducting or metallic depending on this chirality, and the bandgap energy also depends on chirality.
- Unfortunately, currently we do not have control over chirality when we synthesize carbon nanotubes. Nevertheless, measurements on individual nanotubes can clarify the different characteristics that depend on the chirality.

Chirality of single-walled carbon nanotubes



A chiral vector C can be specified by a chiral index (n,m) using basis vectors a_1 and a_2 of a graphene sheet.



Chiral angle is θ

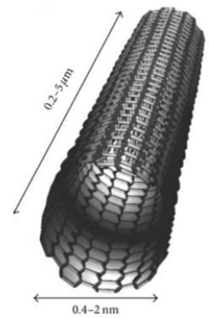
Armchair (n,m) = (5,5)
$\theta = 30°$

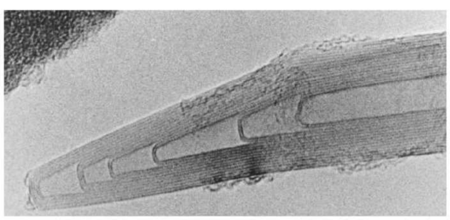
Zig Zag (n,m) = (9,0)
$\theta = 0°$

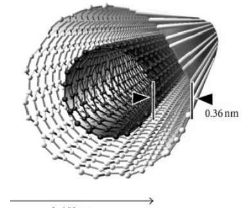
Chiral (n,m) = (10,5)
$0° < \theta < 30°$

Two types of CNTs

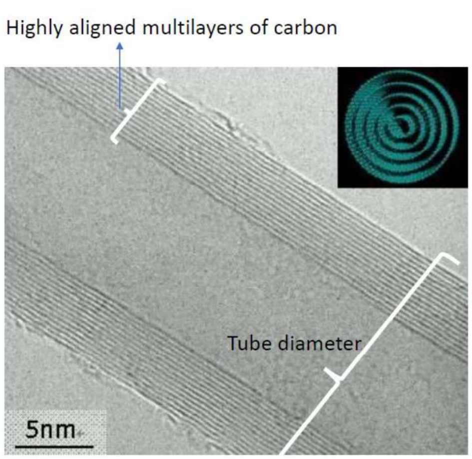
- Single walled (SWNT): A single-atom thick graphite (graphene) sheet rolled into cylinder and capped with fullerene hemisphere.
- Multi-walled (MWNT): Multiple rolled layers (concentric tubes) of graphene.



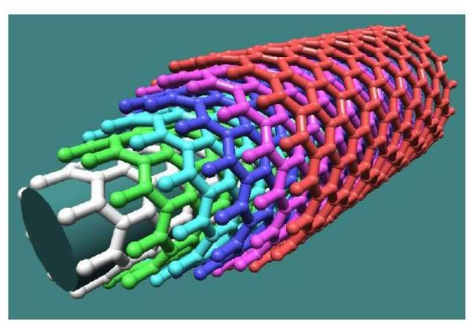


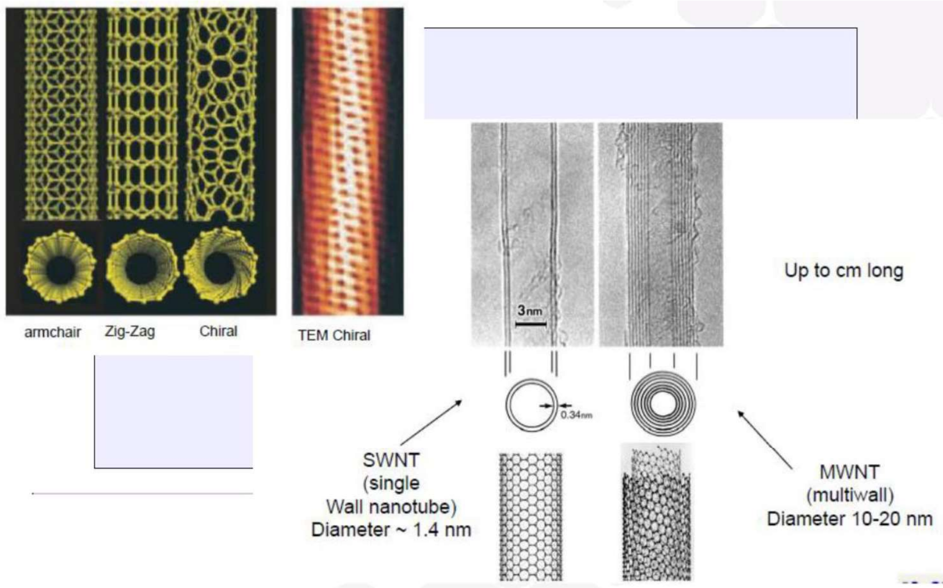


Multiwall Nanotubes



TEM image of multi walled carbon nanotube (MWCNT)




armchair
Zig-Zag
Chiral
TEM Chiral
3nm
0.34nm
Up to cm long
SWNT
(single
Wall nanotube)
Diameter ~ 1.4 nm
MWNT
(multiwall)
Diameter 10-20 nm