# DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
# SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

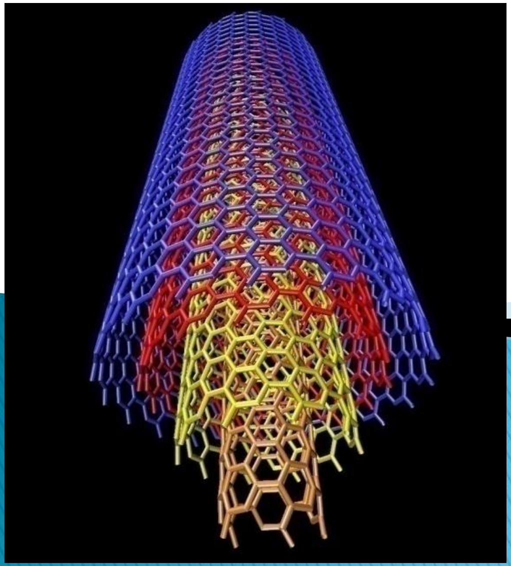
## 18PYB103J –Semiconductor Physics

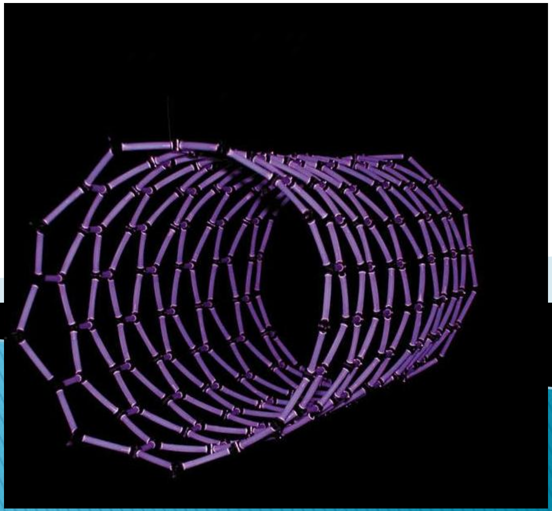
## Module-V Lecture-7

## Carbon Nano Tubes-Properties, Synthesis and Applications

# Carbon Nanotubes

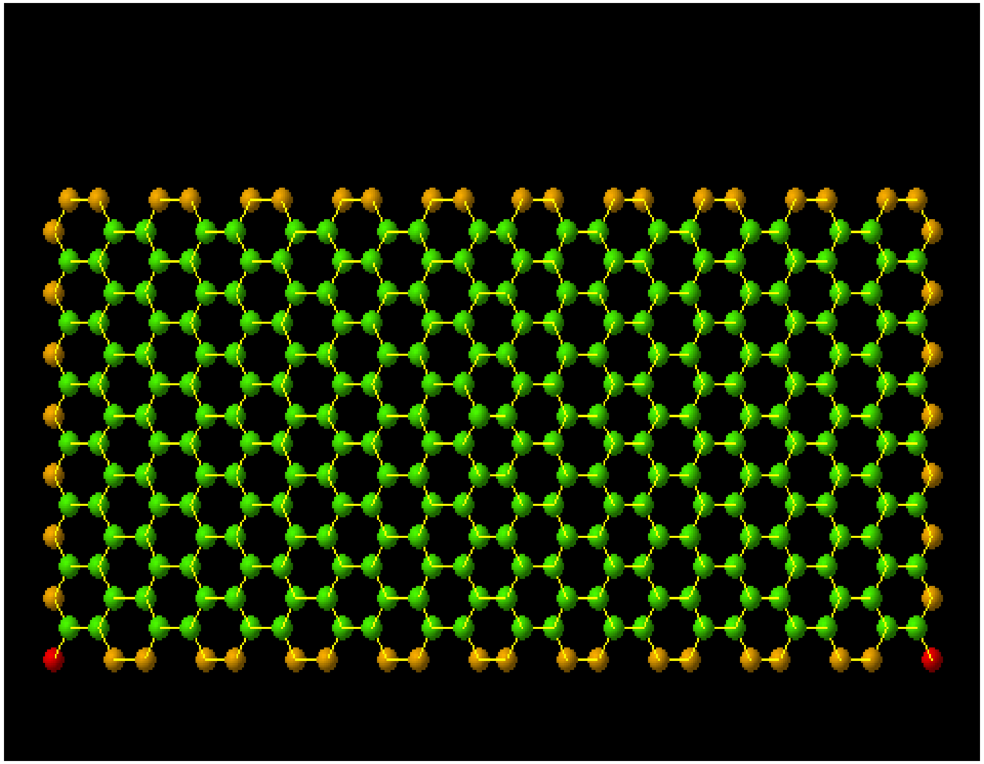
**Carbon nanotubes (CNTs)** are allotropes of carbon. These cylindrical carbon molecules have interesting properties that make them potentially useful in many applications in nanotechnology, electronics, optics and other fields of materials science, as well as potential uses in architectural fields. They exhibit extraordinary strength and unique electrical properties, and are efficient conductors of heat. Their final usage, however, may be limited by their potential toxicity.





# What Are Carbon Nanotubes

- CNT can be described as a sheet of graphite rolled into a cylinder
- Constructed from hexagonal rings of carbon
- Can have one layer or multiple layers
- Can have caps at the ends making them look like pills



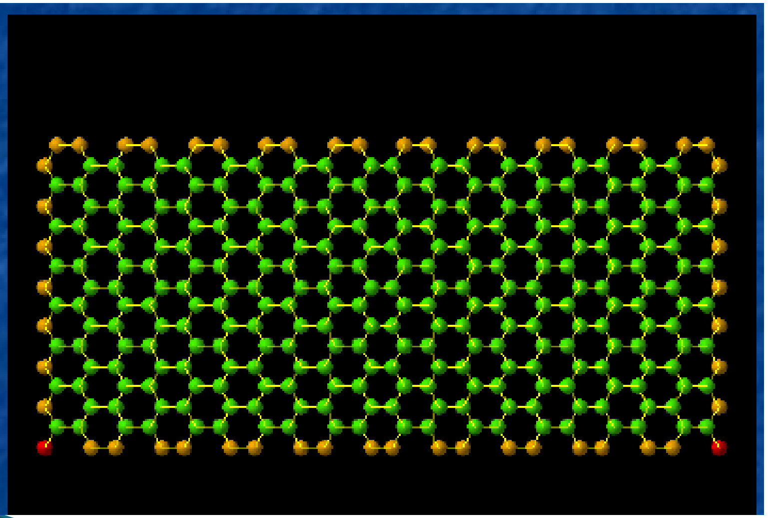
# Discovery

## Nano-tubes

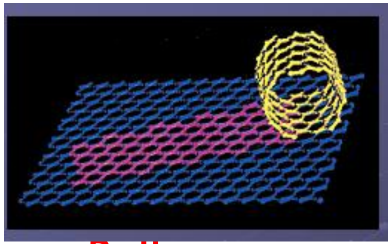
They were discovered in 1991 by the Japanese electron microscopist Sumio Iijima who was studying the material deposited on the cathode during the arc-evaporation synthesis of fullerenes. He found that the central core of the cathodic deposit contained a variety of closed graphitic structures including nanoparticles and nanotubes, of a type which had never previously been observed

➢Carbon Nanotubes are built up using graphite sheet, which is the most stable form of crystalline carbon.

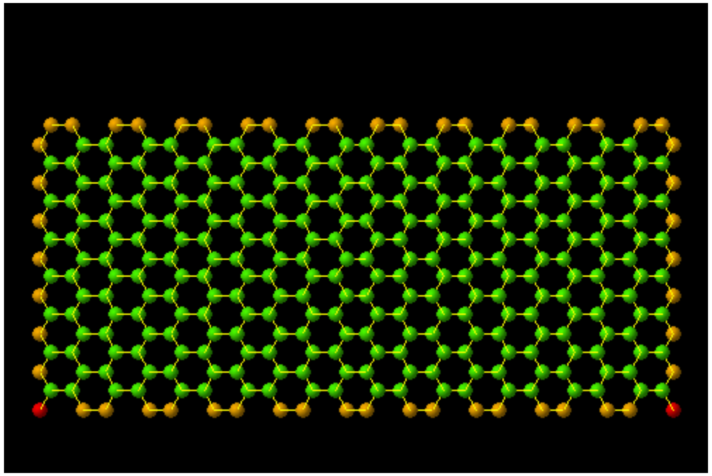
➢A carbon Nanotube is obtained by rolling up a plain graphite sheet into a tubular shape.



Graphite Sheet



Roll up



Carbon Nano Tube

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Carbon Nanotube can be classified into Two type

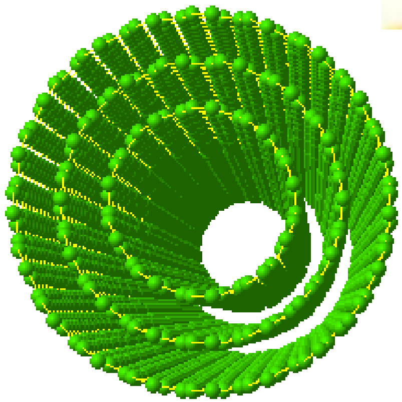
1. Single wall carbon Nanotube (SWNT)
2. Multiwall Carbon Nanotube (MWNT)

Single-wall carbon Nanotubes (SWCNTs) can be considered to be formed by the rolling of a single layer of graphite into a seamless cylinder.

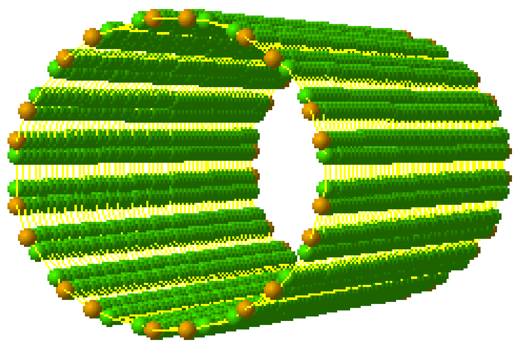
A Multiwall carbon Nanotube (MWCNT) can similarly be considered to be a coaxial assembly of cylinders of SWCNTs, one within another.

The separation between tubes is about equal to that between the layers in natural graphite. Hence, Nanotubes are one-dimensional objects.

- **MWNT**
  - Consist of 2 or more layers of carbon
  - Tend to form unordered clumps
- **SWNT**
  - Consist of just one layer of carbon
  - Greater tendency to align into ordered bundles
  - Used to test theory of nanotube properties



Multi wall CNT



Single wall CNT

# *Nanotube's characteristic*

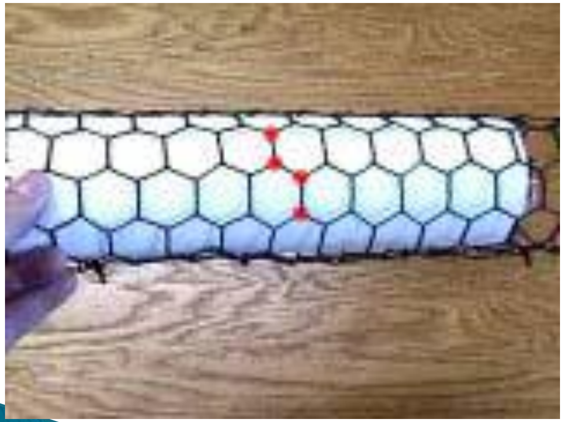
- Seemless cylindrical molecules
- Diameter as small as 1 nm.
- Length: a few nm. to serveral micron
- As a monoelemental polymer: Carbon atoms only
- As hexagonal network of carbon atoms
- CNTs are single molecules comprised of rolled up graphene sheets capped at each end.

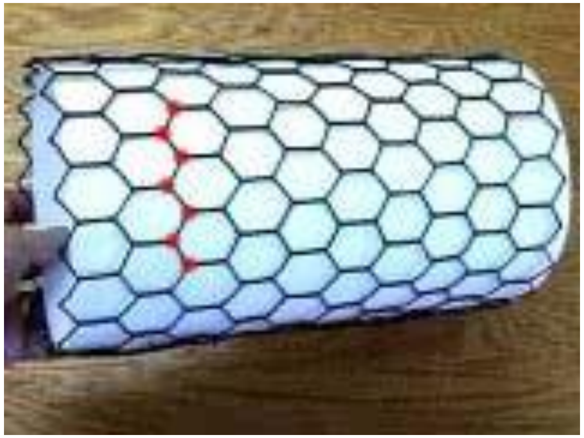
## NANOTUBE GEOMETRY:

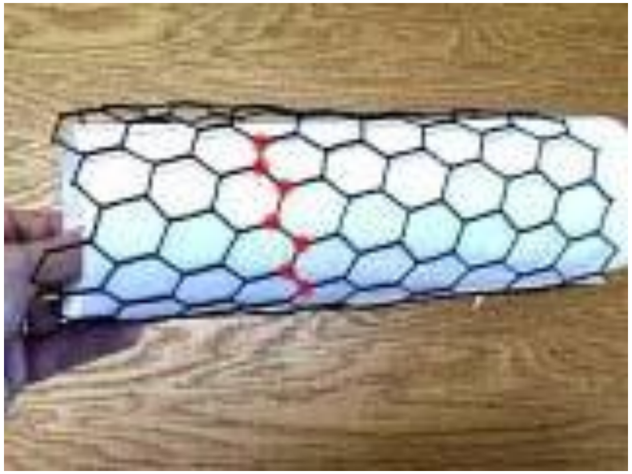
➢There are three unique geometries of carbon nanotubes. The three different

➢geometries are also referred to as flavors. The three flavors are armchair, zig-zag, and chiral [e.g. zig-zag (n, 0); armchair (n, n); and chiral (n, m)]. These flavors can be

➢classified by how the carbon sheet is wrapped into a tube



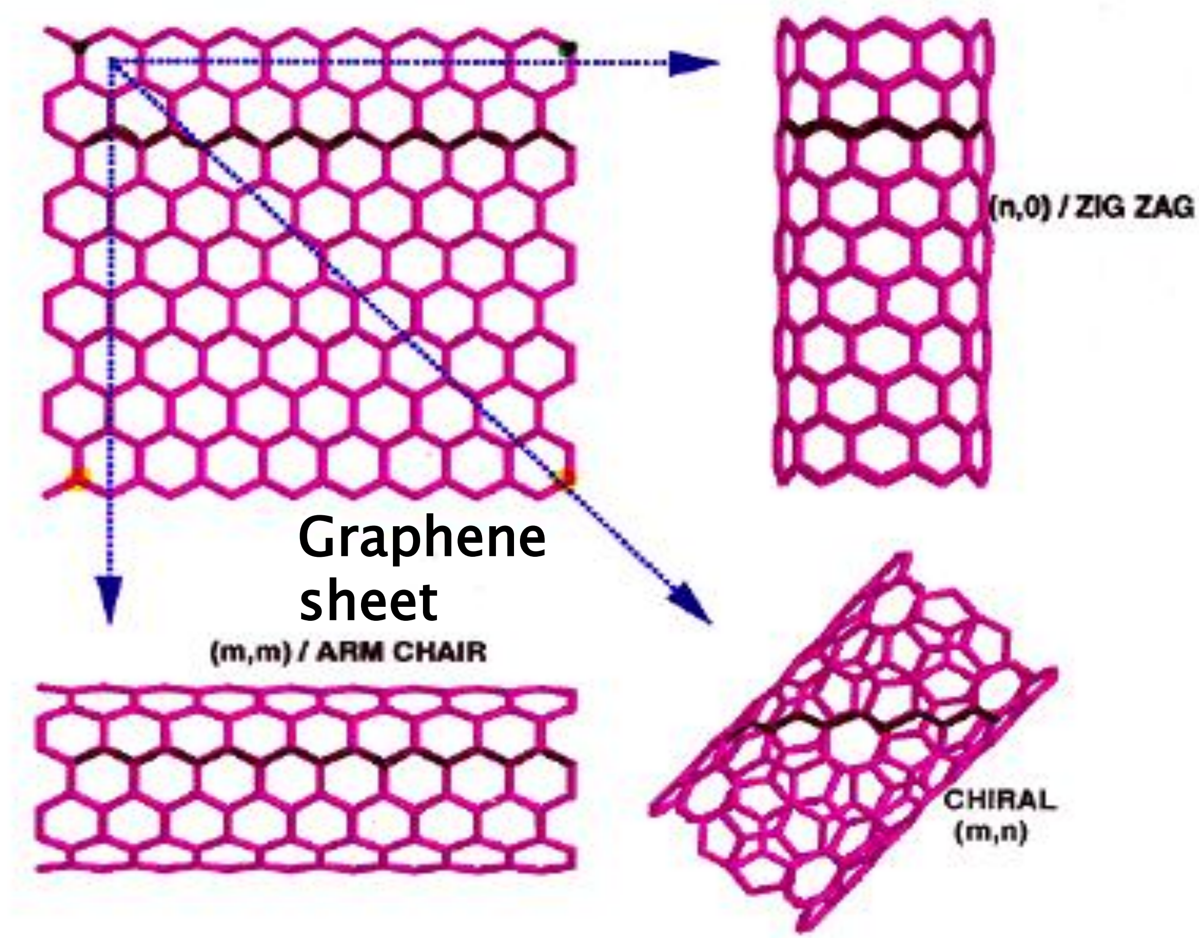


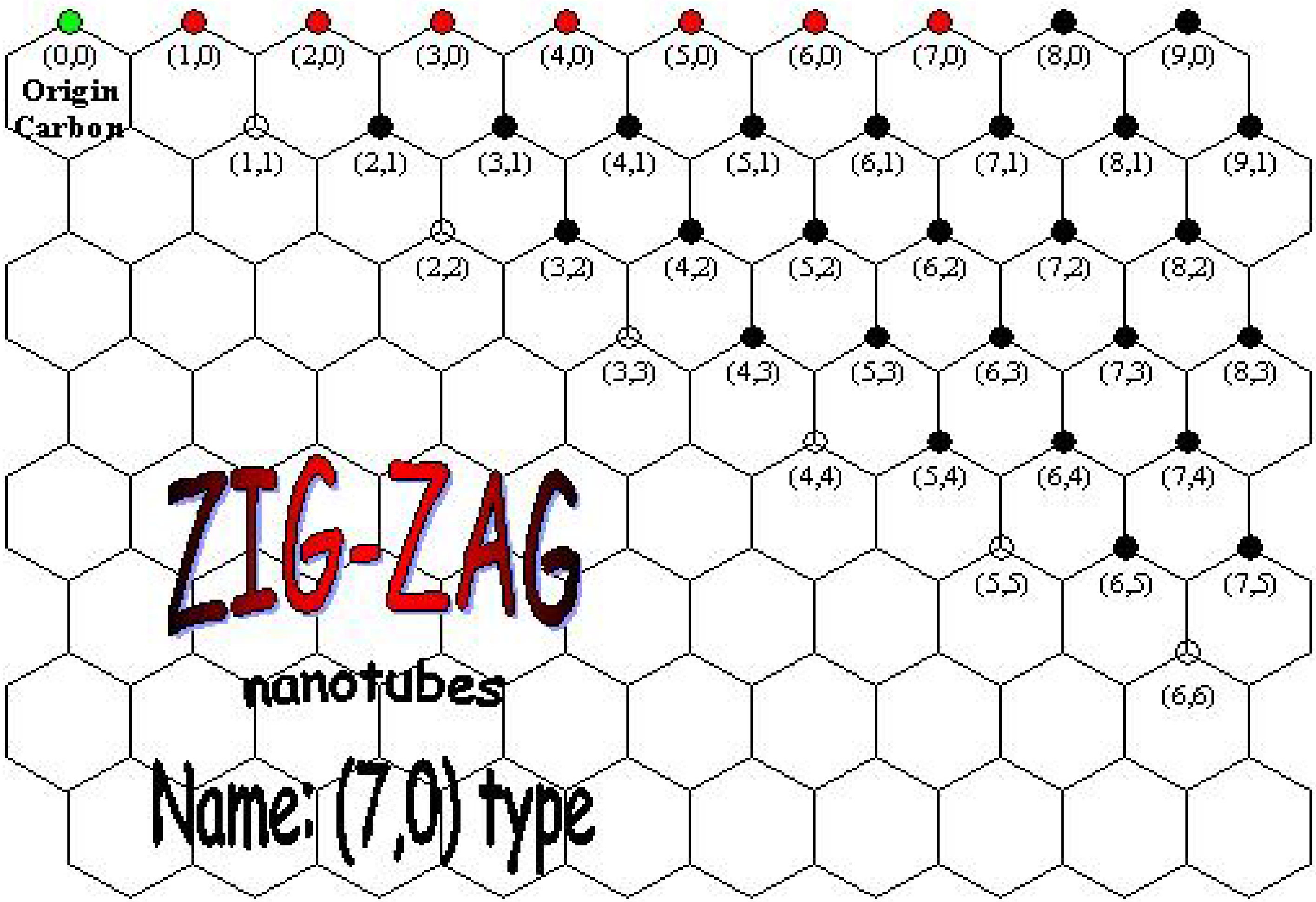


- If the Chiral vector passes through mid point of atomic bonding, it called "zig-zag line" Nanotube
- If the Chiral vector passes through the atoms of six fold axis, it armchair line" Nanotube
- If the Chiral vector line not along a mirror line then it is called chiral Nanotube

- The Chiral angle and Chiral vector($C_h$) of zigzag Nanotubes is 0º and ($n$,0)
- The Chiral angle is 30º and Chiral vector ($C_h$) is ($n$,$n$) for armchair Nanotubes
- The Chiral angle is $0 \leq \theta \leq 30°$
The Chiral vector $n \neq m$ for Chiral Nanotube

- STRIP OF A GRAPHENE SHEET ROLLED INTO A TUBE

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nanotubes
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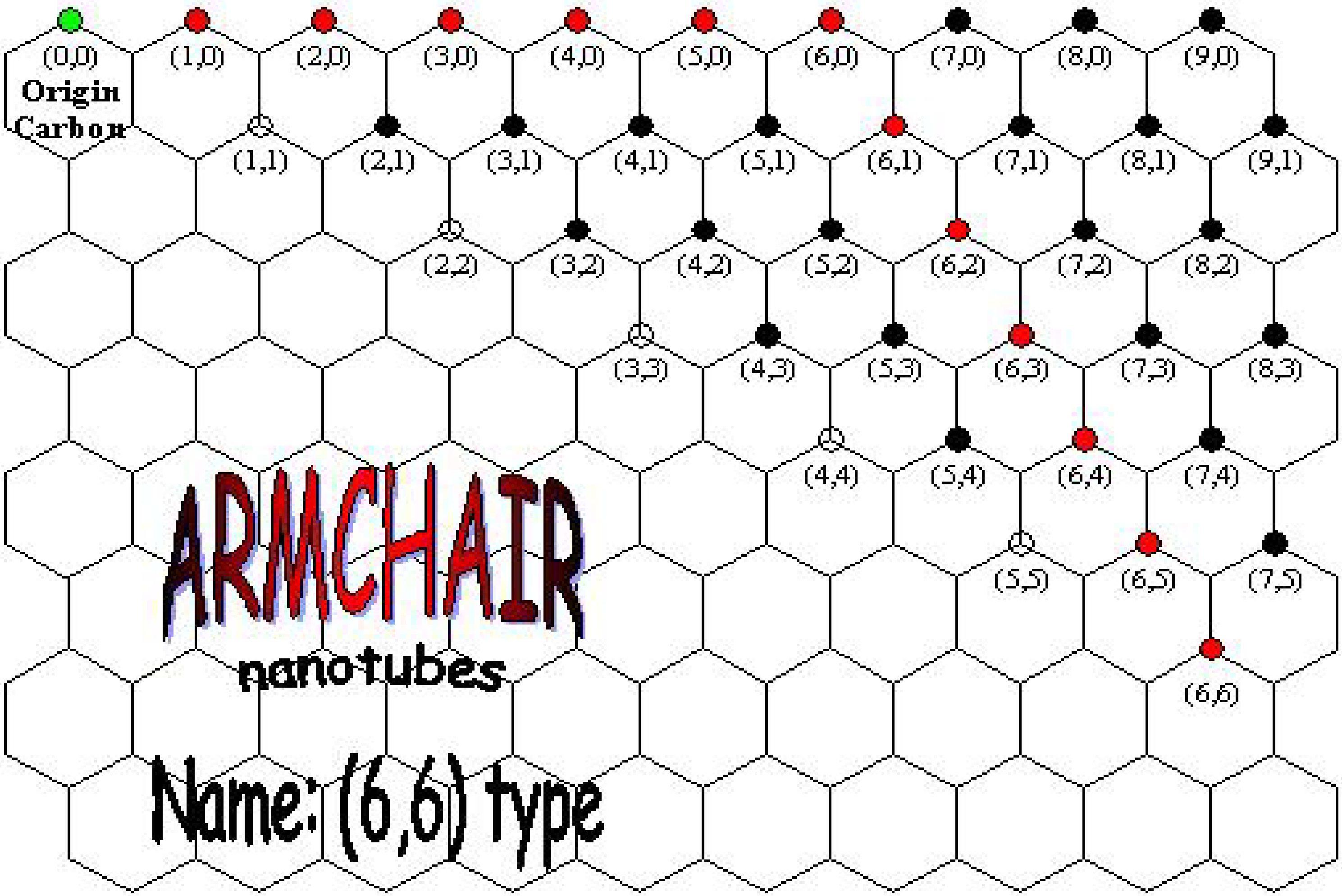
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ARMCHAIR
nanotubes
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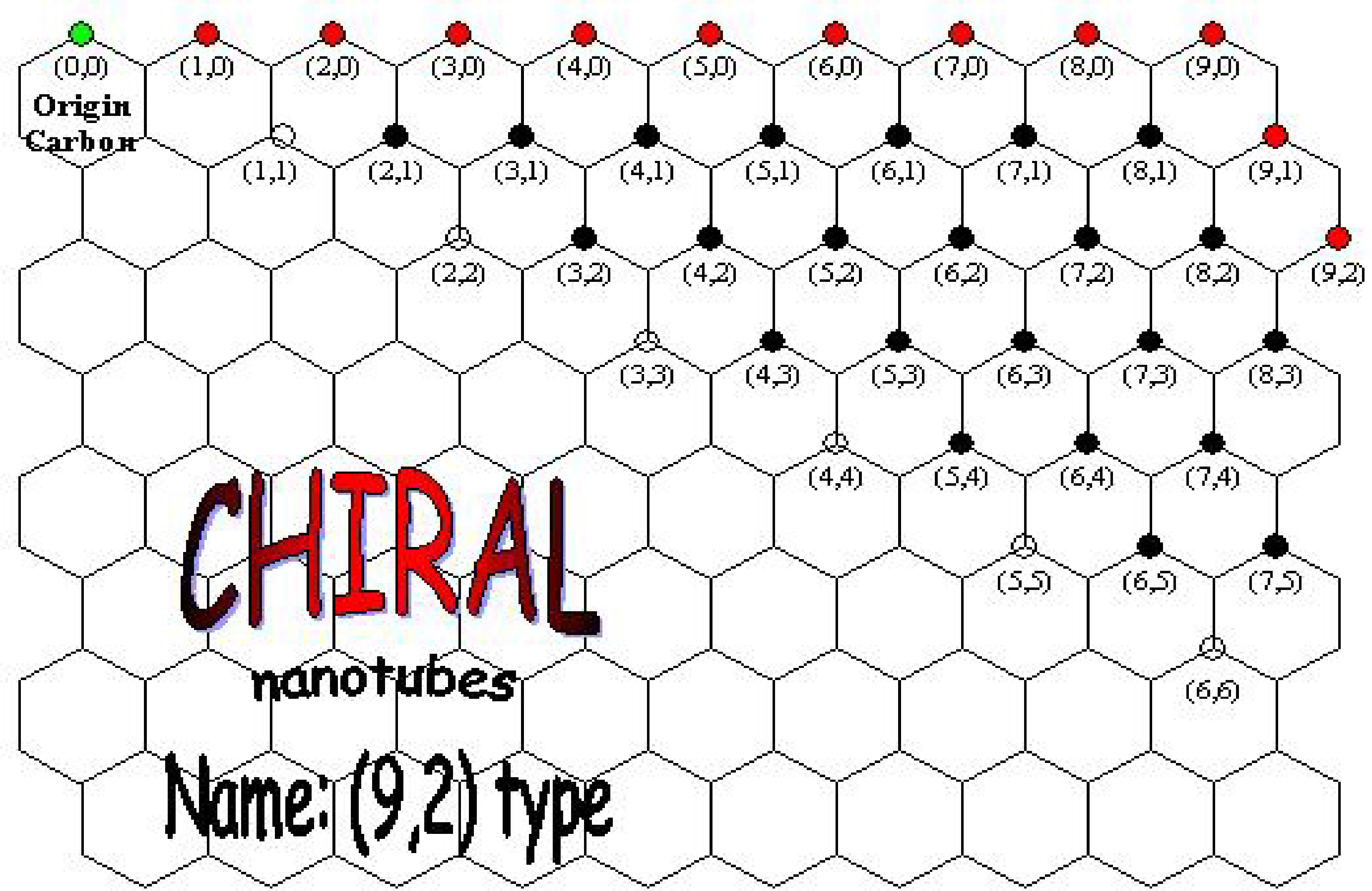
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CHIRAL
nanotubes
Name: (9,2) type

CNT exhibits extraordinary mechanical properties:

- The Young's modulus is over 1 Tera Pascal. It is stiff as diamond.
- The estimated tensile strength is 200 GPa. These properties are ideal for reinforced composites, Nano electromechanical systems (NEMS)

- The dimensions of CNT are variable (down to 0.4 nm in diameter)
- Apart from remarkable tensile strength, CNT nanotubes exhibit varying electrical properties (depending on the way the graphite structure spirals around the tube, and other factors, such as doping), and can be superconducting, insulating, semiconducting or conducting (metallic)

- CNT Nanotubes can be either electrically conductive or semi conductive, depending on their helicity ( shape), leading to nanoscale wires and electrical components.
- These one-dimensional CNT fibers exhibit
  - Electrical conductivity as high as copper,
  - Thermal conductivity as high as diamond,
  - Strength 100 times greater than steel at one sixth the weight, and high strain to failure

- **Chemical reactivity.**

- The chemical reactivity of a CNT is very high as compared with a graphene sheet because of its curved surface.
- A Nanotube with smaller diameter results in increased reactivity.

# Synthesis of CNTs- Arc Discharge Method

- A direct current creates a high temperature discharge between two electrodes (carbon is vapourized)
- Atmosphere is composed of inert gas at a low pressure
- Originally used to make $C_{60}$ fullerenes
- Cobalt is a popular catalyst
- Typical yield is 30-90%

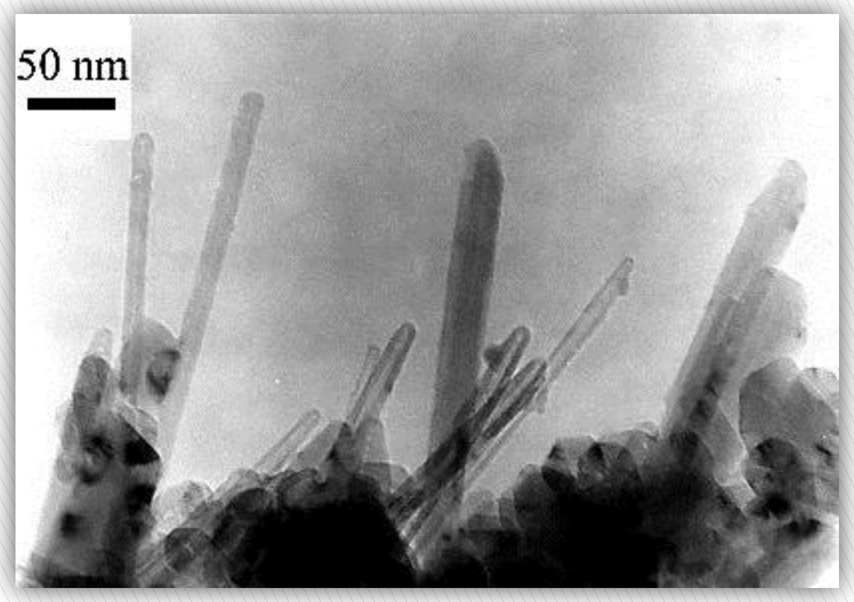
# Arc Discharge Method

## Advantages

- Simple procedure
- High quality product
- Inexpensive

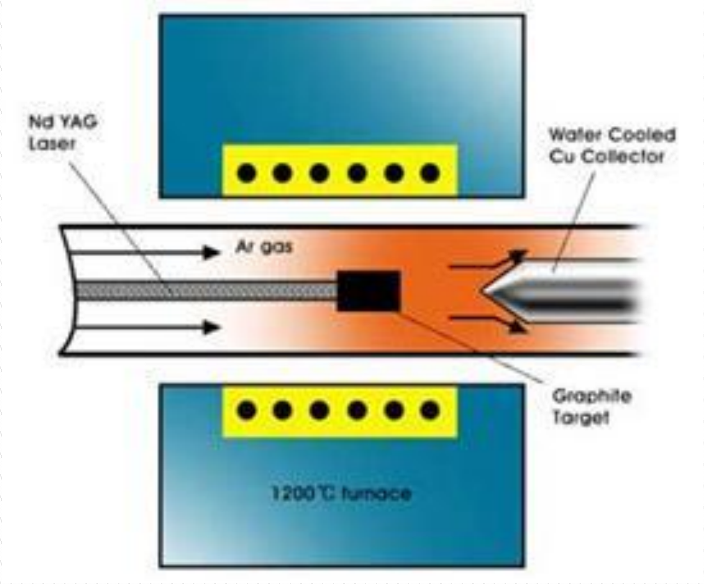
## Disadvantages

- Requires further purification
- Tubes tend to be short with random sizes



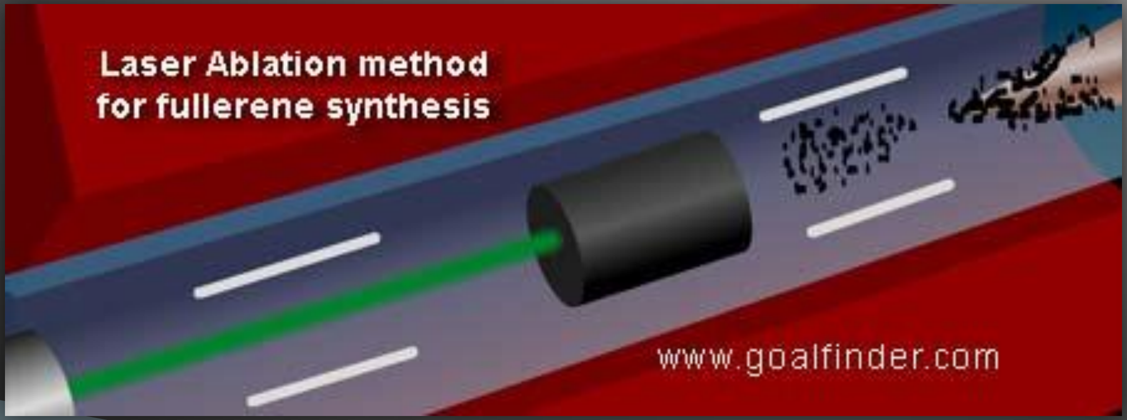
# Laser Ablation Method

- Discovered in 1995 at Rice University
- Vaporizes graphite at 1200 $^0$C
- Helium or argon gas
- A hot vapor plume forms and expands and cools rapidly
- Carbon molecules condense to form large clusters
- Similar to arc discharge
- Yield of up to 70%

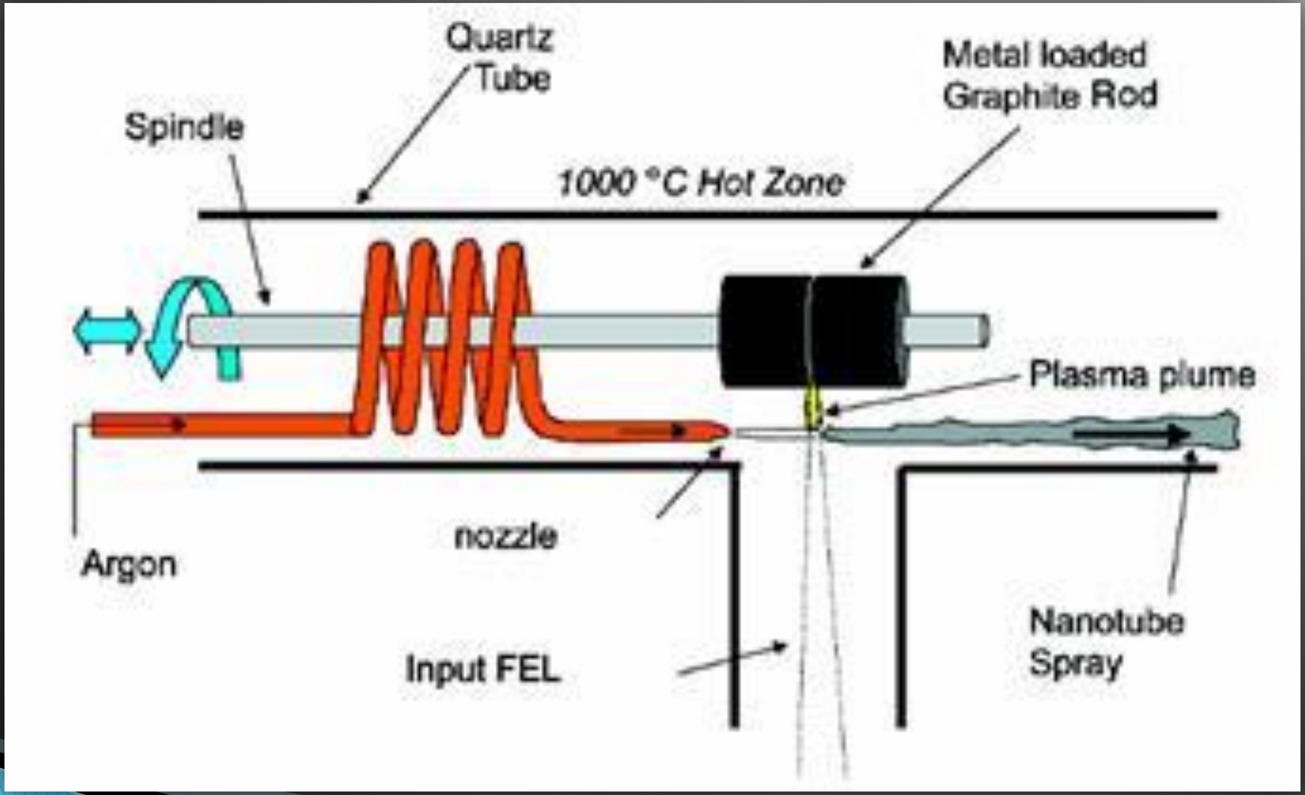


# Types of Laser Ablation

- Pulsed
  - Much higher light intensity (100 $kW/cm^2$)
- Continuous
  - Much lower light intensity (12 $kW/cm^2$)



# Ultra Fast-pulsed Laser Ablation



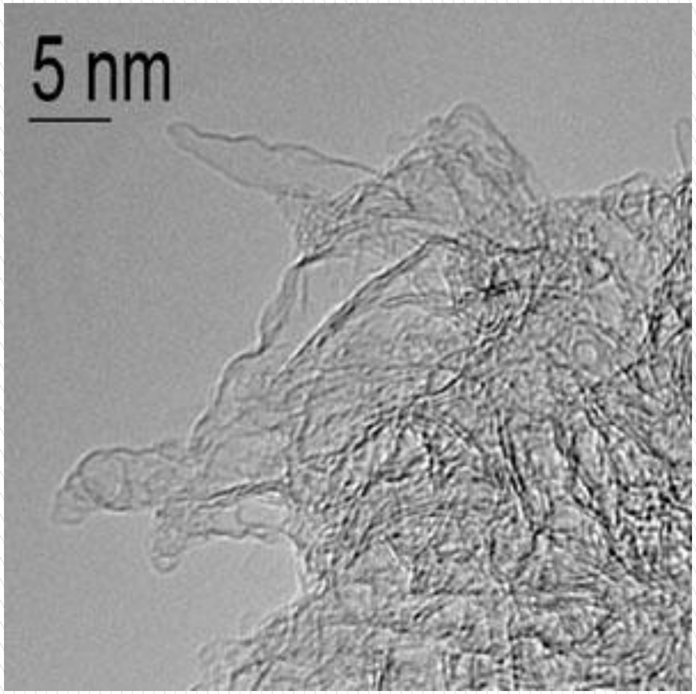
# Laser Ablation

## Advantages

- Good diameter control
- Few defects
- Pure product

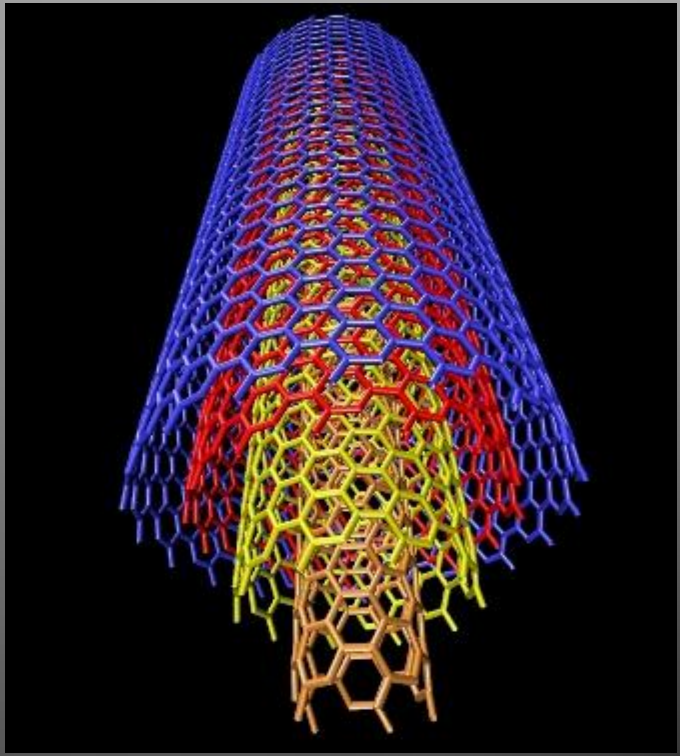
## Disadvantages

- Expensive because of lasers and high powered equipment




# Chemical Vapor Deposition

- Carbon is in the gas phase
- Energy source transfers energy to carbon molecule
- Common Carbon Gases
  - Methane
  - Carbon monoxide
  - Acetylene

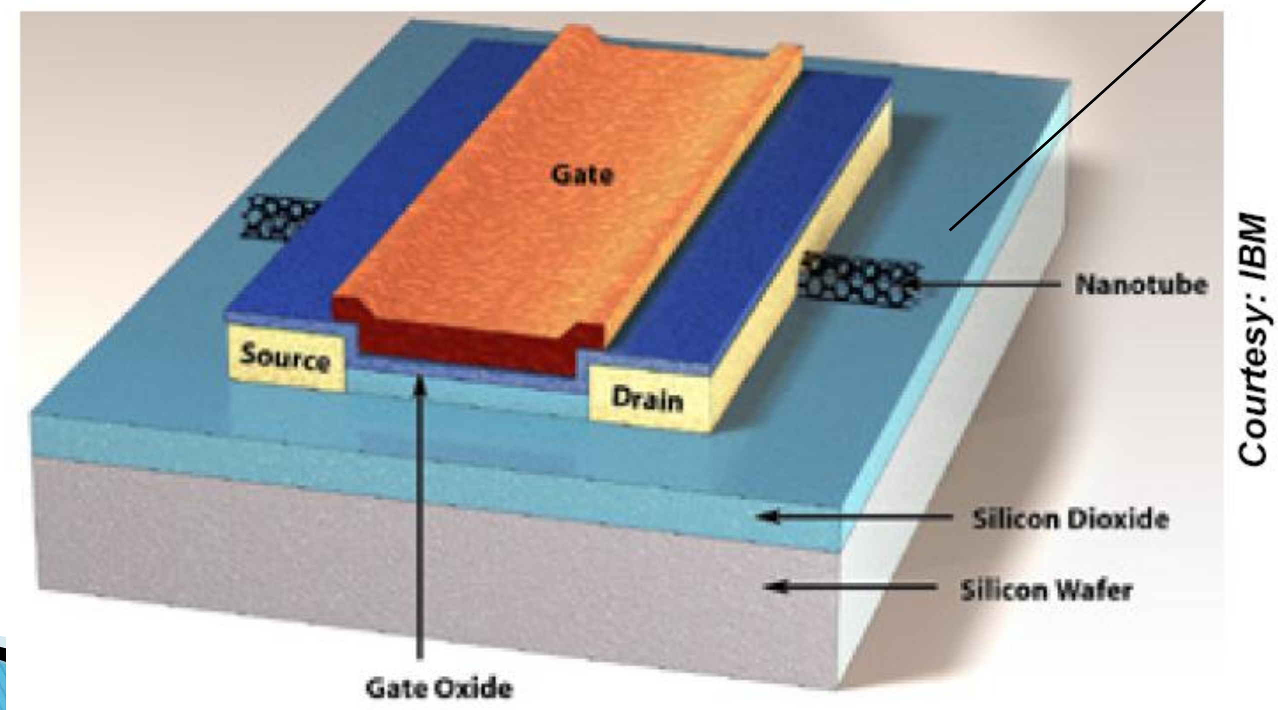


# Applications of carbon Nanotubes

➢Carbon Nanotube can be used as a **conducting channel** in Field emission Transistor

➢CNT conducting channel result the device with low power consumption

CNT conducting tube



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## Nanoprobes and sensors

- Because of their flexibility, nanotubes can also be used in scanning probe instruments.
- Since MWNT tips are conducting, they can be used in STM and AFM instruments.
- Advantages are the improved resolution in comparison with conventional Si or metal tips and the tips do not suffer from crashes with the surfaces because of their high elasticity.
- However, Nanotube vibration, due to their large length, will remain an important issue until shorter nanotubes can be grown controllably.
- Nanotube tips can be modified chemically by attachment of functional groups.

1. Electronic Devices

   Nanotube TV's

   Nano-wiring

2. High Strength Composites

   100 times as strong as steel and 1/6 the weight

3. Conductive Composites

4. Medical Applications

   Encase drug into nanotube capsule for more predictable time release

## Composite materials

- Because of the stiffness of carbon nanotubes, they are ideal candidates for structural applications.
- For example, they may be used as reinforcements in high strength, low weight, and high performance composites.
- Theoretically, SWNTs could have a Young’s Modulus of 1 TPa.
- MWNTs are weaker because the individual cylinders slide with respect to each other.
- Ropes of SWNTs are also less strong.
- The individual tubes can pull out by shearing and at last the whole rope will break.

## Templates

- Because of the small channels, strong capillary forces exist in nanotubes.
- These forces are strong enough to hold gases and fluids in nanotubes.
- In this way, it may be possible to fill the cavities of the nanotubes to create nanowires.