A Review Of Single Wall Carbon Nanotube: Structure And Preparation

Prachi Deshpande, Ankush Mahendru

Abstract: Carbon NanoTubes (CNT) is one of the most interesting material nowadays with significant applications in various fields. Carbon nanotubes (CNTs) are hexagonal networks of carbon atoms which are ~1nm in diameter having a length of 1–100 μm. Single walled nanotube, an important form of nanotubes will be discussed along with its structure, preparation procedures and applications. SWNTs have emerged as a really promising class of electronic materials. Single-walled carbon nanotubes (SWNTs) are nanometre diameter cylinders consisting of a single graphene sheet wrapped up to form a tube. The three types of SWNT structure: zigzag, armchair and chiral nanotubes along with their parameters will be presented. Further, the band structure of SWNT will be illustrated. The four different preparation procedures of SWNTs: electric-arc discharge, laser vaporization, hydrocarbon pyrolysis and solar production will be explored. A comparison of different aspects of synthesis methods will be elucidated. Further the different properties of SWNT and its various applications in the field of nanoelectronics will be discussed. Furthermore, the challenges faced by the SWNTs and their future path in the field of electronics will be reviewed.

I. INTRODUCTION

The ground state configuration of Carbon is $2s^2\ 2p^2$ and the valence shell of C consists of four electrons. Pure Carbon have two naturally occurring crystalline forms which are: Graphite and Diamond. The extreme rigidity in case of diamond can be attributed to the sp^3 hybridization of Carbon whereas sp^2 hybridization occurs in Graphite. In Graphite each Carbon atom have C-C bonds with three other carbon atoms (120°) in the x-y plane, also z axis consists of π- bond [1]. The bond length of C-C bond in sp^2 hybridization is 1.42 Å and spacing between carbon layers is 3.35Å[2,22]. Graphite is a good conductor of electricity because it contains delocalized electrons which are free to move within the structure of graphite. Carbon nanotubes(CNTs),a pure carbon form, are hexagonal networks of carbon atoms ~1 nm in diameter and 1–100 μm in length. CNTs consists of graphene sheets rolled up to form a seamless cylinder[2].Depending on arrangement of graphite cylinders, Carbon nanotubes can be classified into two types: Single walled carbon nanotubes(SWNTs) and Multi walled carbon nanotubes (MWNTs). In the mid 1970s Endo obtained HRTEM images (high resolution transmission electron microcopy images) of CNTs for the first time[3].Later on Iijima & Ichihashi [4]using HRTEM and electron diffraction discovered helical carbon microtubules now known as nanotubes which were synthesized in the Arc-Discharge Fullerene Reactor [4]. Single-walled carbon nanotubes (SWNTs) are nanometer diameter cylinders consisting of a single graphene sheet wrapped up to form a tube. On the basis of chirality of SWNTs, nanowires can be metallic or semiconducting [6, 7, 8,9] as shown in figure 1. The conductivity of carbon nanotubes is determined by the degree of twist of the graphene sheet

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STRUCTURE OF SWNTs

Theoretically, SWNTs is a sp^2-hybridized carbon tube which are prepared by can be constructed by rolling a hexagonal graphene sheet into a cylinder leading to chiral and non-chiral arrangements [1] as shown in figure2. The three types of SWNTs structure: zigzag, armchair and chiral nanotubes as shown in figure 3. There are two C-C bonds present on the opposite sides of all hexagons which lies perpendicularly to the tube axis in armchair structure and are parallel to the tube axis in the zig-zag structure. The C-C bonds is at an angle with tube axis and have spiral symmetry, in chiral arrangement. The chiral angle θ is between 0ºand 30º ($0° < \theta < 30°$)[21]. The nanotube structures are represented by the following set of parameters[21].

1) Chiral vector, Ch = na1 + na2 = (n, m) where vectors a1 and a2 for the hexagonal lattice
2) Translational vector ,T = t1a1 + t2a2 = (t1, t2)
3) Chiral angle, $\cos\theta = (2n+m) / (2*\sqrt{(n^2+m^2+ n*m)})$
4) Length of chiral vector, $L = a\sqrt{(n^2+ m^2+ n*m)}$, where a is the lattice constant
5) Diameter , $d_t = L/\pi$
6) Number of hexagons in the unit cell, $N = (2*(n^2 + m^2+ n*m)/dR)$
7) Symmetry vector, R = pa1 + qa2 = (p, q)
8) Pitch of the symmetry vector, $\tau = ((m*p – n*q)*T)/N$
9) Rotation angle of the symmetry vector ,$\Psi = 2\pi/N$ (in radians)
10) where t1 = (2m + n)/dR ; t2 = - (2n + m)/dR ; dR = gcd (2n+m, 2m+n), n, m are length of chiral vector.[21]

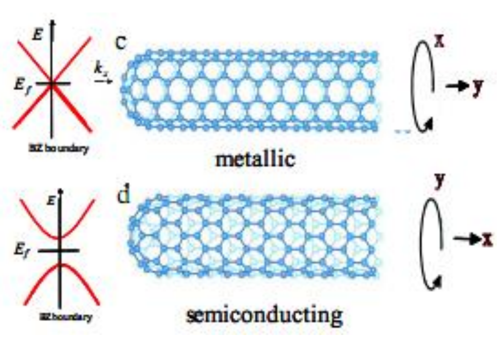

Figure 1:*SWNTs Metallic and Semiconducting Bandgap Structure[5]*

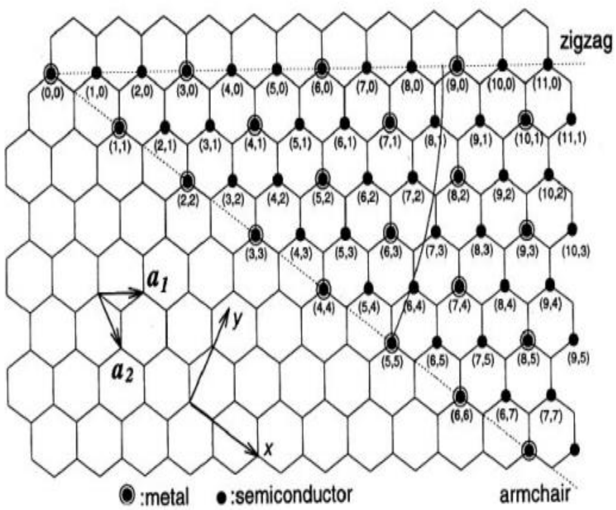

Figure 2: *Graphene sheet can be rolled in several ways and, hence a variety of tubules can be formed. [2]*

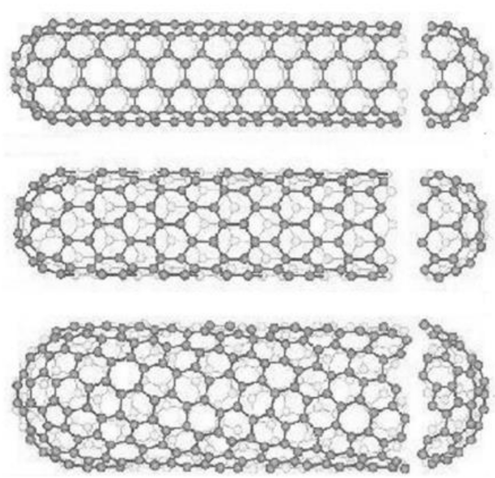

Figure 3: (a) *Armchair,* ***(b)*** *zigzag, and* ***(c)*** *chiral nanotubes [2]*

II. PREPARATION

Single Walled Carbon Nanotubes(SWNTs) can be synthesized using different techniques that are summarized in this section.

1. Electric Arc-Discharge

The electric arc-discharge method is a method to produce SWNTs in which metal is used as a catalyst. The SWNTs were first prepared by arcing the Fe-graphite electrodes in an atmosphere consisting of methane argon by the Iijima & Ichihashi [10, 11].

In this process, the nanotube can be generated by passing the direct current through two high purity graphite electrode separated by 1-2 mm approximately. The preparation of SWNTs using Electric Arc Discharge method is expensive because mostly the process uses highly pure graphite electrodes and metal powders for the production of the SWNTs .

2. Laser vaporization

In the laser vaporization technique, SWNTs can be generated by adding the metal particles as catalysts to the graphite targets. In the framework to generate SWNTs, pure graphite targets have to undergo High-power vaporization inside a furnace at a temperature of 1200 ºC in the presence of Argon atmosphere and metal catalyst (figure 5) [1]. The first SWNT bundles of diameter mainly 13.8 A were first obtained by Thess A, Lee R and group of scientists [12] using the graphite-Co-Ni targets [12].

The laser vaporization method is not considered economically viable as the high purity graphite rods are involved and high laser power is required and the amount of nanotubes manufactured per day are lesser.

3. Hydrocarbon pyrolysis over Metals

Sen and coworkers [13] produced SWNTs by the pyrolysis of Iron Pentacarbonyl $[Fe(CO)_5]$ in the presence of Carbon monoxide and Benzene. Large quantities of SWNT bundles can be produced by using this technique. Henceforth, SWNTs were produced via pyrolysis of different Carbon sources in the presence of various metal or metal alloys[16-19].Nikolaevet. al. [20]developed a novel method for production of SWNTs that involved thermolysis of the Iron Pentacarbonyl $[Fe(CO)_5]$ in the presence of Carbon Monooxide at an elevated pressure of less than 10 atm and temperature in the range of 800ºC –1200ºC. This technique is proved to be very efficient because SWNTs can be produced in bulk using this method [20].

4. Solar production of SWNTs

The SWNTs were produced by focusing solar energy on carbon metal target in the presence of inert atmosphere by Laplaze and coworkers [14]. The graphite metal targets can be easily vaporized by solar energy as the average value of incident solar flux is equal to 500 W/cm² approximately and because solar energy can attain temperature value of 2800 K [15].

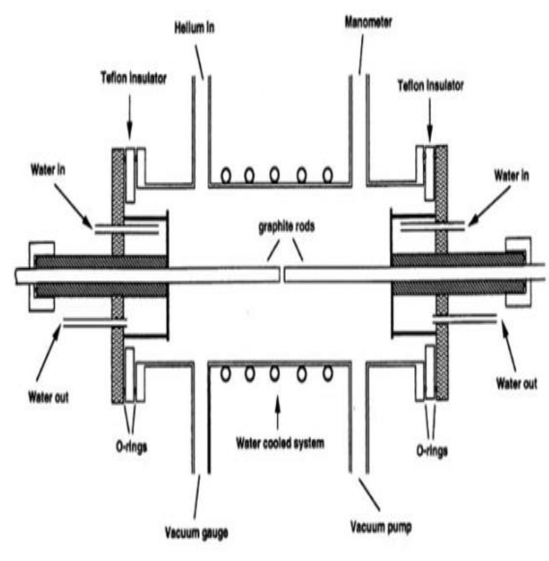

Figure 4: *Arc-discharge apparatus for SWNTs production [1]*

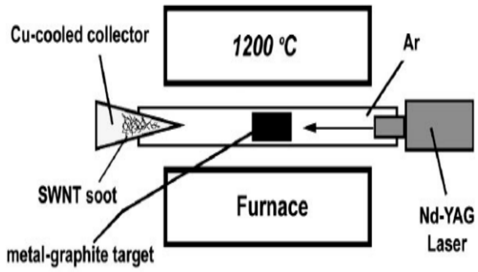

Figure 5: *Laser Vaporization Experimental setup used to produce SWNTs [1]*

III. PROPERTIES OF SWNTs

SWNTs exhibit unique electrical, thermal, optical and mechanical properties due to the atomic arrangement of carbon atoms.

A. Electrical Conductivity

A metallic CNT is a highly conductive material. Measurement of resistivity and conductivity of different parts of SWNT rope can be done by using electrodes. The measured resistivity of the SWNT ropes is in the order of 10^{-4} Ω cm at 27 ºC [24]. Hence, SWNT ropes are known to be the most conducting carbon fibers [23].Due to some defects that may be present in its structure , SWNT can behave as a transistor. When used as interconnects on semi-conducting devices, SWNTs can route electrical signals at speeds upto 10 GHz.

B. Strength and elasticity

When the SWNT tip is pressed it will bend but will return to its previous state when the force is released. The elastic modulus and tensile strength of SWNTs is observed to be much higher than that of steel which makes SWNTs highly resistant. The value of Young's modulus is normally around 1 TPa for SWNTs, but value of 1.8 TPa is also observed [25].

C. Thermal Conductivity

SWNTs exhibit high flexibility to non-axial strains because of the zero in-plane and large interplane thermal expansion of SWNTs. Hence the thermal and thermo-mechanical properties of composite materials can be improved by using SWNTs.

IV. APPLICATIONS OF SWNTs

a. SWNTs can be used as structural materials and thus have applicability in textiles ,body armour, concrete, bridges, polyethylene and fire protection.
b. Conductors, semiconductors and insulators can be manufactured using SWNTs. [27]
c. Solar cells: SWNTs can also be used i n electromagnetic devices as an antenna because its durable, light in weight and can act as a good conductor .[27]
d. SWNTS can be used to manufacture loudspeakers that generate sound similar to that of thunder.[26]
e. SWNT find tremendous use in the field of chemical as air pollution filters and water filters.
f. Oscillators that are based on SWNTs achieve higher speed than other technologies.

CONCLUSION

Carbon NanoTubes (CNT) is the one of most interesting material now days with significant applications in various fields. In this draft we have reviewed single walled CNTs for its properties, applications and structure. The SWNTs have a great influence in the era of miniscule components and have both metallic and semiconducting properties. Also, the preparation techniques of SWNTs using four different techniques has been discussed.

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