Peoples democratic republic of algeria

Ministry of higher education and scientific research

University of Msila

Faculty of Technology
Department of mechanical engineering
Materials engineering
Nano technology module

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Theme

Carbone nanotube

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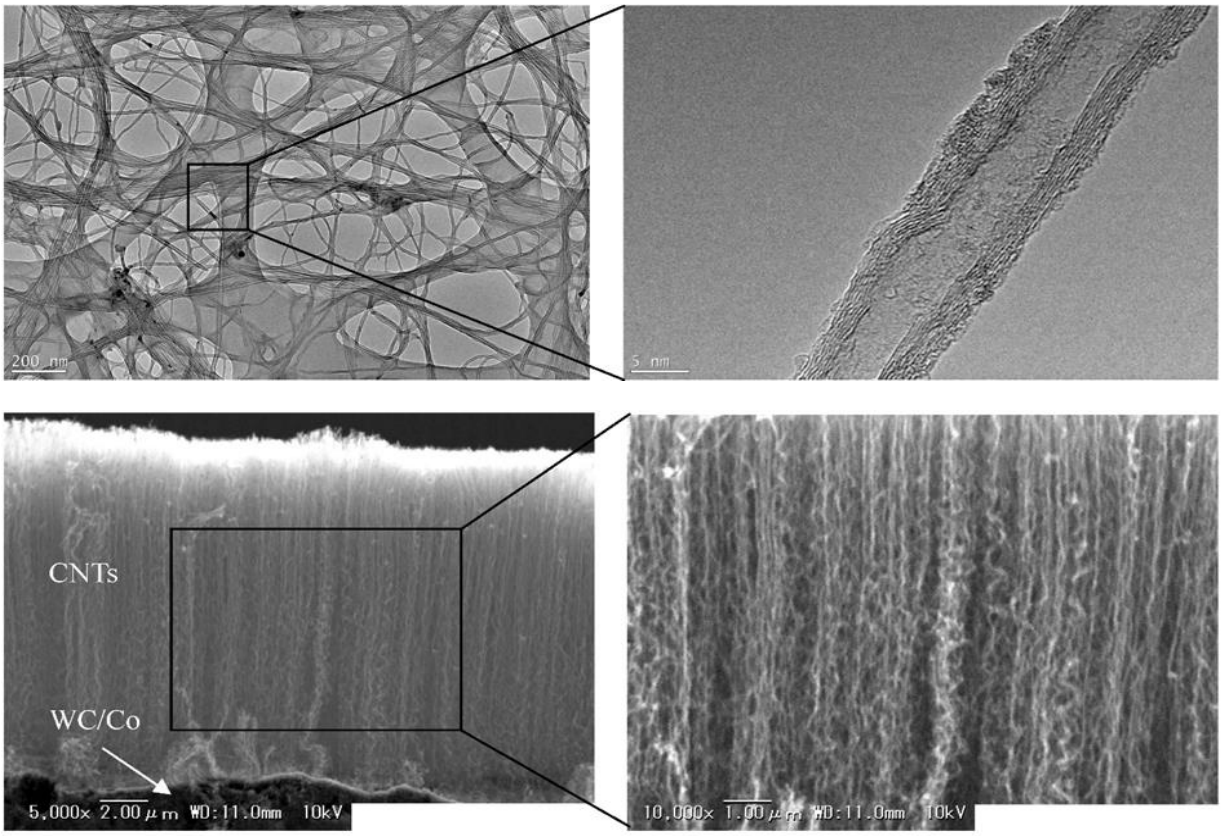
Work plan

I. Introduction

Diamond and graphite are considered as two natural crystalline forms of pure carbon. In diamond, carbon atoms exhibit sp^3 hybridization, in which four bonds are directed towards the corners of a regular tetrahedron. The resulting three-dimensional network (diamond) is extremely rigid, which is one reason for its hardness. In graphite, sp^2 hybridization occurs, in which each atom is connected evenly to three carbons (120∘) in the xy plane, and a weak π bond is present in the z axis. The sp^2 set forms the hexagonal (honeycomb) lattice typical of a sheet of graphite. A new form of carbon, Buckminster fullerene (C_{60}), was discovered in 1985 by a team headed by **Korto** and coworkers. Besides diamond, graphite, and fullerene (C_{60}), quasione-dimensional nanotube is another form of carbon first reported by **Ijima** in 1991 when he discovered **multiwalled** carbon nanotubes (MWCNTs) in carbon soot made by an arc-discharge method . Carbon nanotubes (CNTs) are allotropes of carbon. CNTs are tubular in shape, made of graphite. The tubes contained at least two layers, often many more, and ranged in outer diameter from about 3 nm to 30 nm. About two years later, he made the observation of single-walled carbon nanotubes **(SWCNTs**). At about the same time, **Dresselhaus** et al. synthesized single-walled carbon nanotubes by the same route of producing **MWCNTs** but adding some transition metal particles to the carbon electrodes .the single-walled nanotubes are generally narrower than the multiwalled tubes, with diameters typically in the range **1-2 nm**. A significant amount of work has been done in the past decade to reveal the unique structural, electrical, mechanical, electromechanical, and chemical properties of CNTs. Recent research has focused on improving the quality of catalytically-produced nanotubes.



II. Classification of carbon nanotube

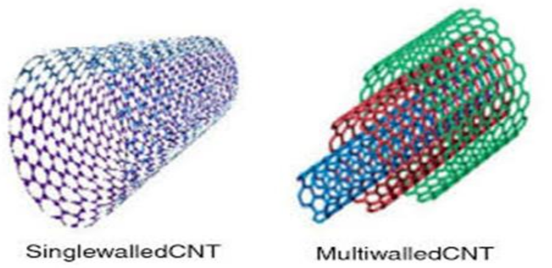
Carbon nanotubes are classified in following two types:

- **SWCNTs**—Single-walled carbon nanotubes
- **MWCNTs**—Multiple-walled carbon nanotubes

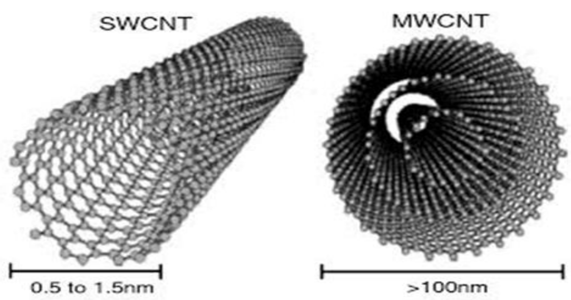
Comparison between SWCNT and MWCNT is as presented in Table

SWCNT	MWCNT
Single layer of graphene.	Multiple layer of graphene
Catalyst is required for synthesis.	Can be produced without catalyst.
Bulk synthesis is difficult as it requires proper control over growth and atmospheric condition.	Bulk synthesis is easy.
Not fully dispersed, and form bundled structures.	Homogeneously dispersed with no apparent bundled formation.
Resistivity usually in the range of 10^{-4}–10^{-3} $\Omega \cdot m$.	Resistivity usually in the range of 1.8×10^{-5}–6.1×10^{-5} $\Omega \cdot m$
Purity is poor. Typical SWCNT content in as-prepared samples by chemical vapour deposition (CVD) method is about 30–50 wt%. However high purity up to 80% has been reported by using arc discharge synthesis method.	Purity is high. Typical MWCNT content in as-prepared samples by CVD method is about 35–90 wt%.
A chance of defect is more during functionalization.	A chance of defect is less especially when synthesized by arc-discharged method.
Characterization and evaluation is easy.	It has very complex structure
It can be easily twisted and are more pliable.	It cannot be easily twisted.

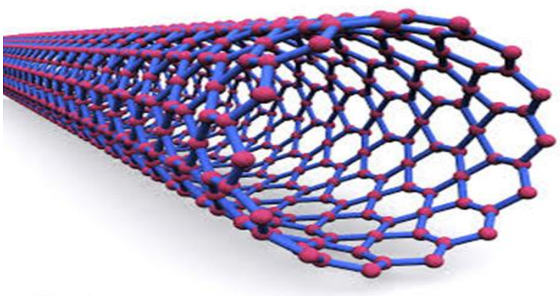
Comparison between SWCNT and MWCNT



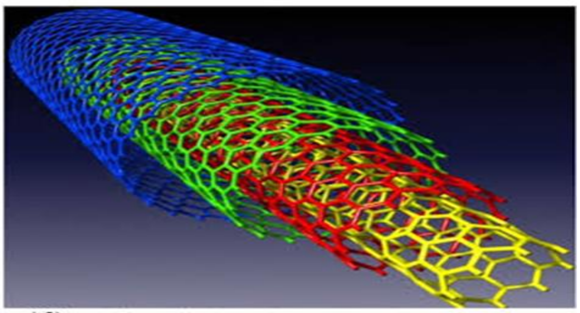
(a) Single and Multi-Walled Carbon Nanotubes



(b) Diameters of SWCNT and MWCNT



(c) Single-Walled Carbon Nanotube (SWCNT)

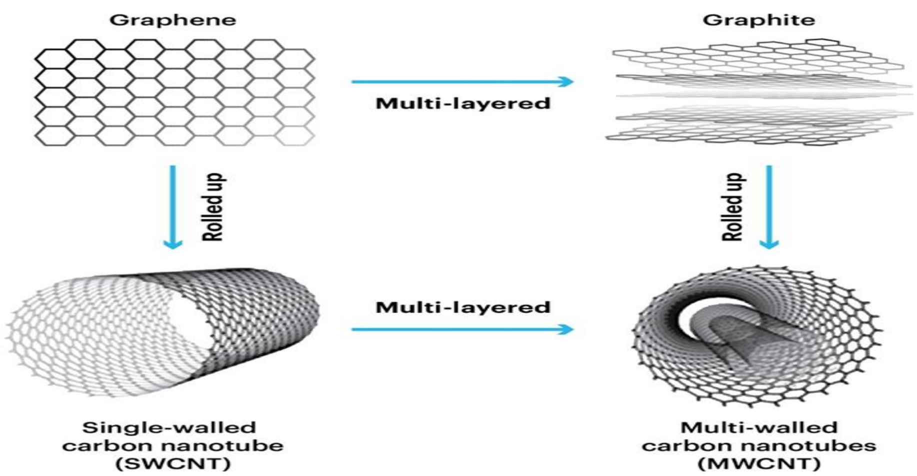


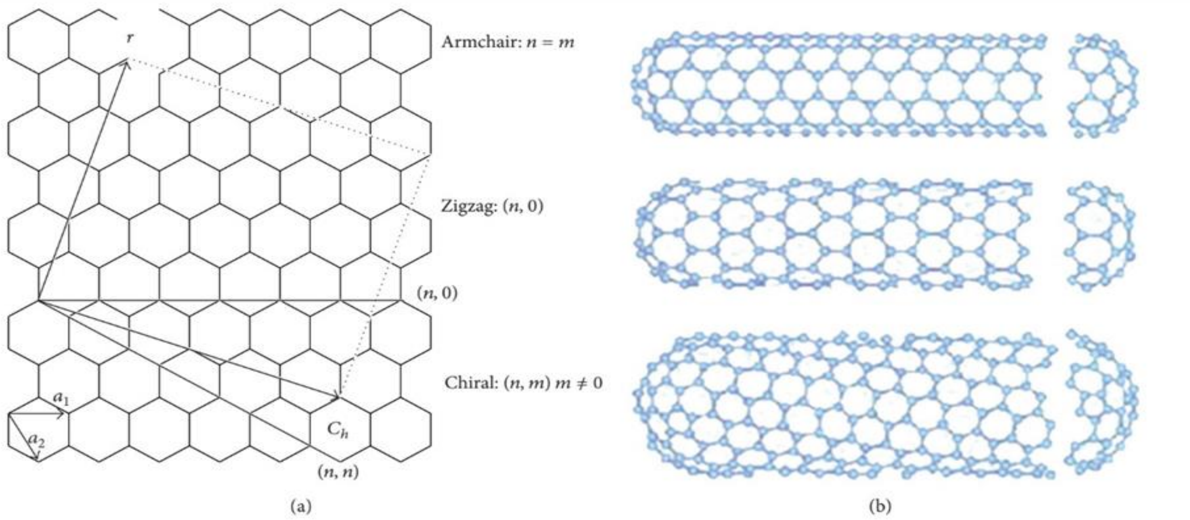
(d) Multi-Walled Carbon Nanotube (MWCNT)

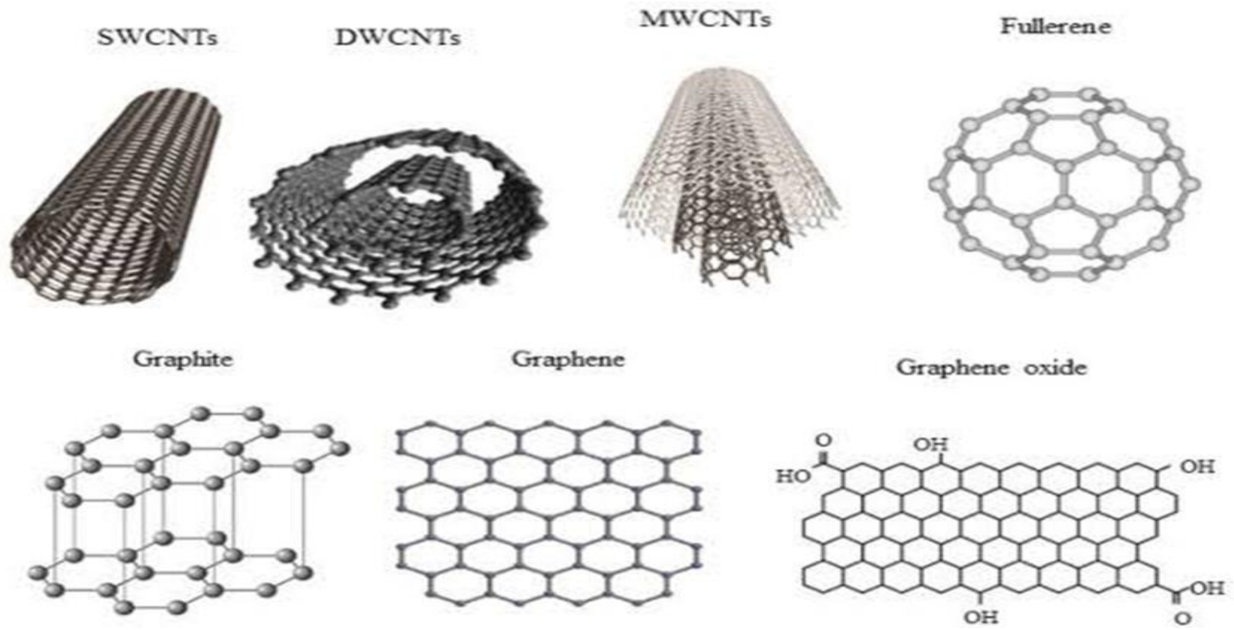
III. Structure and Morphology

Comprised entirely of carbon, the structure of pure SWCNT can be visualized as rolled-up tubular shell of graphene sheet which is made up of benzene type hexagonal rings of carbon atoms **(Figure 2(a)).** Graphene sheets are seamless cylinders derived from a honeycomb lattice, representing a single atomic layer of crystalline graphite. A **MWCNT** is a stack of graphene sheets rolled up into concentric cylinders. Each nanotube is a single molecule composed of millions of atoms and the length of this molecule can be tens of micrometers long with diameters as small as 0.7 nm. The **SWCNT**s usually contain only 10 atoms around the circumference and the thickness of the tube is only one-atom thick. Nanotubes generally have a large length-to-diameter ratio (aspect ratio) of about 1000, so they can be considered as nearly one-dimensional structures. **MWCNT**s are larger and consist of many single-walled tubes stacked one inside the other. The name **MWCNT** is restricted to nanostructures with outer diameter of less than 15 nm, above which the structures are called carbon nanofibers. CNTs are distinct from carbon fibers, which are not single molecules but strands of layered-graphite sheets.

In addition to the two different basic structures, there are three different possible types of carbon nanotubes. These three types of **CNT**s are armchair carbon nanotubes, zigzag carbon nanotubes, and chiral carbon nanotubes. The difference in these types of carbon nanotubes are created depending on how the graphite is **"rolled up"** during its creation process. The choice of rolling axis relative to the hexagonal network of the grapheme sheet and the radius of the closing cylinder allows for different types of **SWCNTs**. The chiral vector is represented by a pair of indices, n and m, where these two integers correspond to the number of unit vectors along the two directions in the honeycomb crystal lattice of grapheme. When $\mathrm{n} = \mathbf{0}$ the nanotube is called **"zigzag",** when $\mathrm{n} = \mathrm{m}$ the nanotube is called **"armchair",** and all other configuration are designated as chiral. Figure 2 shows the three different types of **SWCNTs**: armchair, zigzag, and chiral.







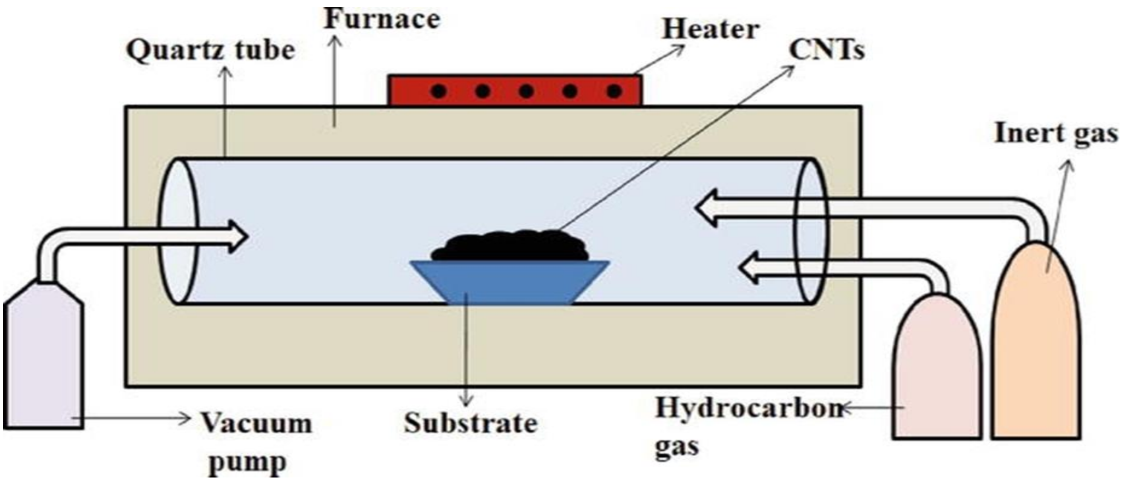
Schematic representation of (a) formation of single-walled carbon nanotubes by rolling of a graphene sheet along lattice vectors

IV. Synthesis of carbon nanotubes

There are many methods to synthesize CNTs, but these three methods are most important and commonly used methods. They are as follows.

1. Chemical vapor deposition method

Chemical vapor deposition (CVD): CVD is a technique in which the vaporized reactants react chemically and forms a nanomaterial product that is deposited on the substrate Figure 1.



CVD Method

- ✓ **Sources for carbon**: The precursor for carbon nanotubes are hydrocarbon gases such as acetylene, ethylene, methane, etc.
- ✓ **Substrate used**: Substrates are materials on which the CNTS are grown. The commonly used substrates in CVD method are zeolite, silica, silicon plate coated with iron particles, etc.
- ✓ **Catalyst used:** To produce single-walled carbon nanotubes metal catalyst nanoparticles such as iron, cobalt, nickel, molybdenum, iron-molybdenum alloys, etc. are used.

Sources for CVD used: Based on the heating source, the CVD can be:

- Thermal activated CVD which is heated by IR radiation, RF heater, etc.
- Photo assisted CVD which is heated by Arc lamps, CO_2 laser, Argon ion laser, Nd:YAG laser, etc.
- Plasma assisted CVD which is heated by microwave radiation, etc.

Conditions maintained: The following conditions are maintained inside the furnace.

- **Temperature:** 500–900°C.

- **Inert gas atmosphere:** Argon gas.

2. Procedure for synthesis of CNTs by thermal CVD method

CNTs are synthesized by thermal CVD method by using hydrocarbon gas as carbon source. In this method, a quartz tube is placed inside a furnace maintained at high temperature (500–900°C) heated by RF heater. A crucible containing the substrate coated with catalyst nanoparticles is placed inside quartz tube filled with inert gas such as argon gas. The hydrocarbon gas (carbon source) is pumped into the quartz tube which undergoes pyrolysis reaction and forms vapor carbon atoms. These carbon atoms bind to the substrate and join to eachother by Vanderwaal force of attraction and grow as multi-walled carbon nanotubes (MWCNTs) on the substrate. To synthesize single-walled carbon nanotubes catalyst nanoparticles of Fe, Co, Ni are used. The obtained CNTs are further purified to get the pure form of CNTs.

3. Electric arc discharge method

Carbon nanotubes are synthesized by electric arc discharge method which is also called Plasma Arcing method.

3.1. Description

Electrodes: Pure graphite rods (both positive and negative electrode). The positive electrode is adjustable from outside to maintain the gap between the two electrodes.

- ✓ **Diameter of electrodes:** 5–20 µm.
- ✓ **Gap between electrodes:** 1 mm.
- ✓ **Current:** 50–120 amperes.
- ✓ **Voltage:** 20–25 V.

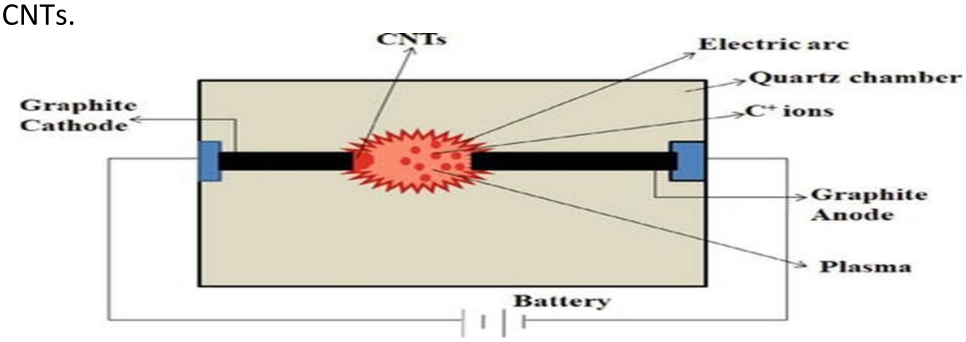
Inert gas pressure: 100–500 torr (No CNT formed below 100 torr). Inert gas is used for cooling and condensation of atoms to form the CNTs. Inert gas determines the structure of carbons to be present in CNTS. Commonly used inert gas is helium gas.

- ✓ **Temperature:** 3000–3500°C.

Reactor: It contains a quartz chamber which is connected to vacuum pump and a diffusion pump to inert gas supply. Initially the chamber is made vacuum by the vacuum pump and then the chamber is filled with helium gas by the diffusion pump.

4. Procedure for synthesis of CNTs by Electric arc discharge method

In this method, a potential of 20–25 V is applied across the pure graphite electrodes separated by 1 mm distance and maintained at 500 torr pressure of flowing helium gas filled inside the quartz chamber Figure 2. When the electrodes are made to strike each other under these conditions it produces an electric arc. The energy produced in the arc is transferred to the anode which ionizes the carbon atoms of pure graphite anode and produces C+ ions and forms plasma (Plasma is atoms or molecules in vapor state at high temperature). These positively charged carbon ions moves towards cathode, gets reduced and deposited and grow as CNTs on the cathode. As the CNTs grow, the length of the anode decreases, but the electrodes are adjusted and always maintain a gap of 1 mm between the two electrodes. If proper cooling of electrodes are achieved uniform deposition of CNTs are formed on the cathode which is achieved by inert gas maintained at proper pressure. By this method multi-walled carbon nanotubes are synthesized and to synthesize single-walled carbon nanotubes catalyst nanoparticles of Fe, Co, and Ni are incorporated in the central portion of the positive electrode. The obtained CNTs are further purified to get the pure form of CNTs.



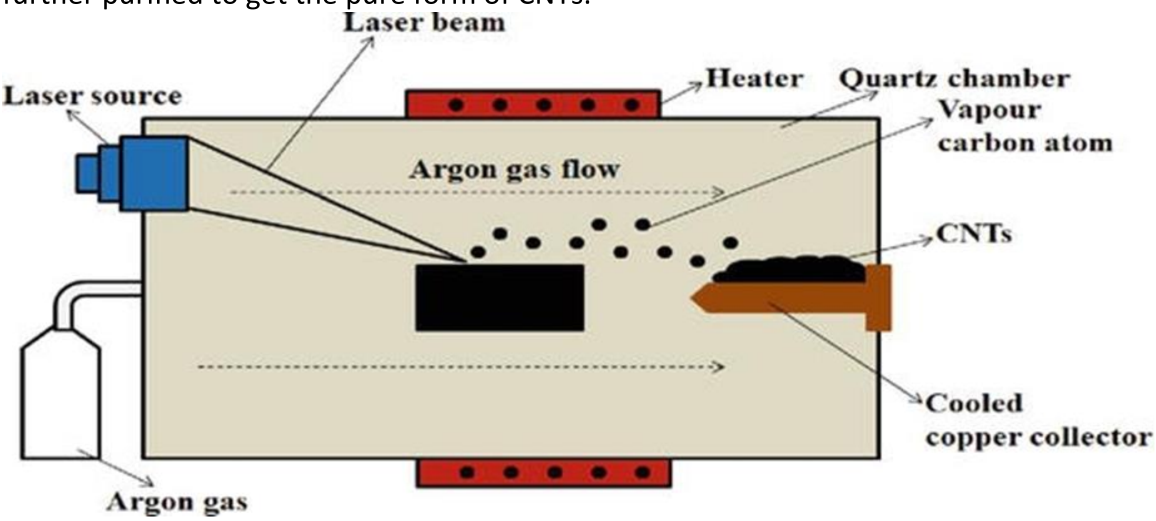
Electric arc method

5. Laser ablation method

Physical vapor deposition (PVD): PVD is a technique by which a material can be vaporized into gaseous form and then deposited on the surface of a substrate.
Target source: The most common carbon source target used is solid graphite which is irradiated by laser source and vaporized into vapor carbon atoms.
Laser source: Laser source used for vaporization of target material into target vapor atoms can be continuous laser source such as CO2 laser or pulsed laser source such as Nd:YAG laser (Neodymium doped Yttrium Aluminum Garnet, Nd:Y3Al5O12) .
Substrate used: The substrate used in this method is the water cooled copper collector on which the vaporized carbon atoms deposit and grow as CNTs.
Inert gas atmosphere: Argon gas is commonly used as inert gas which flows at a constant flow rate towards the water cooled copper collector.

6. Procedure for synthesis of CNTs by Laser Ablation method

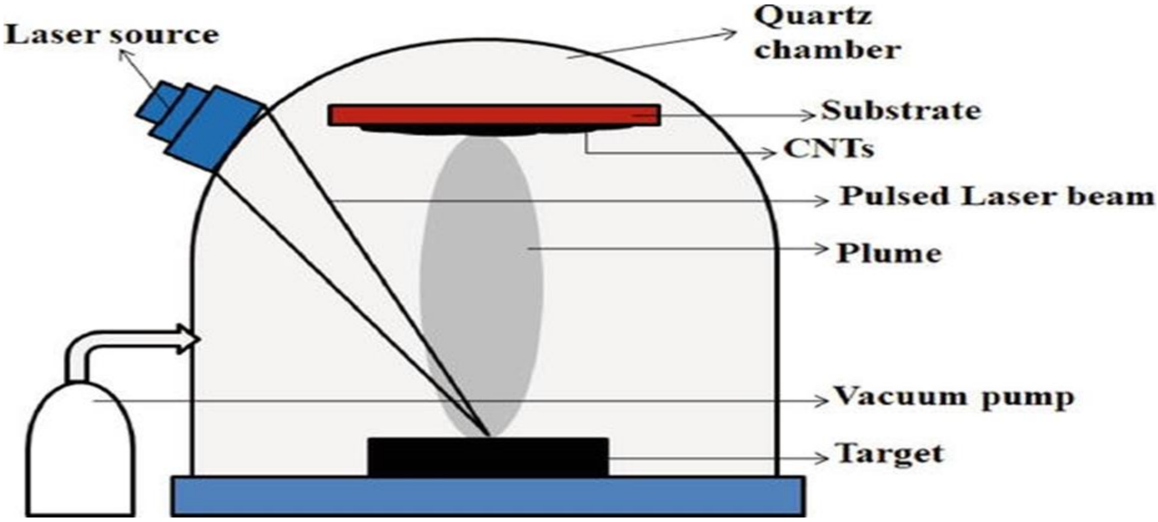
Laser Ablation method is a Physical Vapor Deposition method in which graphite target is vaporized by laser source Figure 3. In this method the graphite target is placed at the center of quartz chamber filled with argon gas and maintained at 1200°C. The graphite target is vaporized by either continuous laser source or pulsed laser source. The vaporized target atoms (carbon) are sweeped toward cooled copper collector by the flow of argon gas. The carbon atoms are deposited and grown as CNTs on cooled copper collector. In case of continuous laser beam, the carbon atoms are continuously vaporized whereas in case of pulsed laser beam the amount of CNTs produced can be monitored as each shot of pulsed laser beam is directly proportional to the amount of carbon atoms vaporized [26]. By this method multi-walled carbon nanotubes are synthesized and to synthesize single-walled carbon nanotubes catalyst nanoparticles of Fe, Co, Ni are used. The obtained CNTs are further purified to get the pure form of CNTs.



Laser ablation method—schematic representation.

6.1 Procedure for pulsed laser deposition method

Pulsed Laser deposition is a thin film deposition technique in which the target material is vaporized by pulsed laser beam and vaporized target atoms are made to deposit on substrates Figure 4. The furnace contains a target at bottom and substrate mounted on the top. A pulsed laser beam from Nd:YAG laser source is made to strike the target to produce vaporized target atoms called the plume (plume is vaporized atoms at high temperature). The plume moves towards the substrate and it is deposited and grown as CNTs. Each shot of laser is directly related to the amount of material ablated, thus deposition rate can be controlled and calibrated.



Pulsed laser ablation method—Schematic representation

6.2 Purification of CNTs

The synthesized CNTs can be separated from the amorphous carbon, carbon nanoparticles, residual catalyst and other impurities by various methods. The conventional methods of purification are not very successful but methods like gas phase, liquid phase and intercalation methods show good results.

Gas phase purification of CNTs: In this method the CNTs are subjected to a high temperature oxidation followed by repeated extractions with nitric acid and hydrochloric acid. This procedure makes the synthesized CNTs purer and high stability with fewer amounts of residual catalyst and other non CNTs forms.

Liquid phase purification of CNTs: A series of steps are followed in the liquid phase purification of synthesized CNTs. They are:

Preliminary filtration to remove bulk graphite particles.

Dissolution in both organic solvents and concentrated acids to remove the fullerenes and catalyst, respectively.

Centrifugal separation of CNTs (Solid part) from the solution (containing impurities).

Microfiltration.

Chromatography to isolate multi-walled carbon nanotubes, single-walled carbon nanotubes, etc.

Intercalation purification of CNTs: In this method the nanoparticle impurities present are oxidized by metallic copper which acts as oxidation catalyst formed from the reduction of copper chloride added during the process. This process introduces intercalate residues and damage CNTs during oxidation process.

Method	Arc discharge	Laser ablation	Chemical vapour deposition
Process	Connect two graphite rods to a power supply, place them a few millimetres apart. At 100 amps, carbon vaporizes and forms hot plasma.	Blast graphite with intense laser pulses; use the laser pulses rather than electricity to generate carbon gas from which the CNTs form; try various conditions until hit on one that produces prodigious amounts of SWNTs.	Place substrate in oven, heat to high temperature, and slowly add a carbon-bearing gas such as methane. As gas decomposes it frees up carbon atoms, which recombine in the form of NTs.
Condition	Low-pressure inert gas (Helium).	Argon or Nitrogen gas at 500 Torr.	High temperatures within 500 to 1000°C at atmospheric pressure.
Typical yield	30–90%	Up to 70%	20–100%
SWCNT	Short tubes with diameters of 0.6–1.4 nm.	Long bundles of tubes (5–20 microns), with individual diameter from 1-2 nm.	Long tubes with diameters ranging from 0.6 to 4 nm.
MWCNT	Short tubes with inner diameter of 1–3 nm and outer diameter of approximately 10 nm	Not very much interest in this technique, as it is too expensive, but MWNT synthesis is possible.	Long tubes with diameter ranging from 10 to 240 nm
Carbon source	Pure graphite	Graphite	Fossil-based hydrocarbon and botanical hydrocarbon.
Cost	High	High	Low
Advantage	Can easily produce SWNT, MWNTs. SWNTs have few structural defects; MWNTs without catalyst, not too expensive, open air synthesis possible.	Good quality, higher yield, and narrower distribution of SWNT than arc-discharge.	Easiest to scale up to industrial production; long length, simple process, SWNT diameter controllable, and quite pure.
Disadvantage	Tubes tend to be short with random sizes and directions; often needs a lot of purification.	Costly technique, because it requires expensive lasers and high-power requirement, but is improving.	Often riddled with defects.

A summary of the major production methods and their efficiency

V. Properties of carbon nanotube

1. Elasticity property

An amazing feature of CNTs is its elasticity. Under maximum force and high pressure by exposing it to greater compressive forces along axial direction, it can even bend, kink, twist and ultimately buckle without causing any damage to CNT. Thus nanocarbon tubes can retain its original geometric structure. But sometimes, elasticity tends to cope up with a limit and hence under the influence of stronger physical pressure forces, it can even undergo a temporary deformation to form the nanotube shape. Few defects may weaken its structure which includes the atomic defects or else rearrangement developed on the carbon bonds.

The elasticity property for both single walled and multi walled CNTs is examined by the term known as modulus of elasticity or elastic modulus. Such property of multi-walled CNTs can be analyzed using transmission electron microscopy (TEM). Using such an apparatus, the researchers examine and investigate the molecular vibrations owing to thermal forces created at both edges of tubes.

As the atomic bond strength is high, CNTs not only withstand elevated temperature levels but also act as excellent thermal conductors. Hence under vacuum atmospheric pressure ranges, they are able to withstand 2900°C and nearly 800°C at normal pressure conditions. But the prevailing tube temperature and ambient environment may have an impact on thermal conductivity of carbon nanotubes. The prescribed physical properties were outlined in Table.

Physical properties	Parameter	Range
Structure during equilibrium	Mean diameter	1.3–1.5 nm
Density	Zig zag (16,0)	1.33 g/cm^3
/	Armchair (10,9)	1.32 g/cm^3
/	Chiral (12,5)	1.41 g/cm^3
Lattice parameter	Zig zag (16,0)	16.53 nm
/	Chiral (12,5)	16.53 nm
/	Arm chair (10,9)	16.55 nm
Interlayer distance	Zig zag	3.40 Å
/	Chiral	3.38 Å
/	Arm chair	3.37 Å
Elastic nature	Young's modulus	1.0–1.27 TPa
/	Tensile strength	About 100 GPa
Thermal property	Mean free path	Around 100 nm
/	Thermal conductivity	Around 2000 W/m-K
Electrical behavior	Current density	1015 A/m^2
/	Conductance	13.0 (K.Ohms)$^{-1}$

Table Physical properties of CNTs.

Various types of indigenous single walled CNTs obtained using chemical vapor deposition technique onto a supporting chemical agent are mostly of semi-conducting nature (I type). Such nanotube type depicts the impact of field transistor (FET) nature at atmospheric conditions and these have been recently attaining greater interest and also achieved extensive exploration towards their application as nanoelectronic materials indulging logic circuit devices and electronic transistors. Such growing CNTs are seemed to be p-type containing doped holes with absolute hole depletion and reduced conductance values (100 kΩ to 1 MΩ) in specific to positive logic gate voltages. in the present context, it has been demonstrated that adsorption of molecular oxygen onto the CNTs is a contributing factor do drive the hole doping effect of SWCNTs. Oxygen removal can even lead to mere existence of semi-conducting nature. Instead, day by day investigations on CNTs reveal that the electrical properties of such carbon nanotubes are much sensitive to chemical doping impacts and charge transfer mechanism in spite of exhibiting extreme robustness.
The 2 type CNTs developed by CVD technique appears to be quasi metallic consisting smaller band gaps in the order of 10 meV. Such CNTs are not sensitive compared to semi-conducting type due to their electrostatic doping mechanism through gate potentials but exhibit a mere conductance dip occluded with that of smaller band gap. These CNTs origin

towards a class of non-armchair single walled CNTs and band origin may be due to shift of sp^2 to sp^3 orbital hybridization which occurs prominently by the existence of non-flat hexagonal nature of tube walls. Quasi metallic types exhibit enhanced electrical conductivity at low temperature levels when subjected to temperature dependent experimental studies. Even quantum interfering impacts were also being observed: (1) phonon acts as the basic scattering mechanism existing in single walled CNTs at ambient conditions and (2) excellent levels of ohmic frequency contacts can be proliferated in the nanotubes with a probability of adequate transmission T = 1 and 3 electron transfer is explicitly phase coherent along with ballistic ability in CNTs at even low temperature levels. This also suggests a lengthy mean distance for ballistic electron transfer in super quality CVD developed SWCNTs.

2. Electromechanical properties

Schematic pattern of growth has been extensively used to obtain suspended CNTs in single wall across certain trenches along with normal nanotubes which may be electrically wired up with relative easiness. By manipulating a suspended CNT using an AFM probe while measuring its electrical conductivity, the impact of mechanical deformation on electrical characteristics of CNT can be judged. The wide scope of CNTs based on nanoelectro-mechanic (NEM) devices are invented to explore twisting pattern of single nanowires, pure stretching levels and also due to their high frequency characteristics of resonance measurements. Operated NEMs switches and accessible memory devices have also been envisioned in nearby future. Powerful control and deterministic mode of synthesis of CNT will further explore exciting opportunities and greater possibilities of finding novel nanomaterials and other devices.

3. Chemical properties and species interaction

SWCNTs are mostly inert in nature. The covalent attachment agglomerated the molecular species with fully bonded sp^2 hybridization onto sidewalls of CNT proves to be complex. The adsorbed molecules onto CNTs through the development of non-covalent forces have evidently turned to be facile and consequently lead to possible effects on their physical properties and also with their potential applications. Desorption of orientation molecules from single walled tubes can be achieved by heating the nanotubes to higher temperature levels.

Similarly, illumination of UV light at low photon intensity forces a drastic molecular desorption rate from SWCNTs at even ambient conditions whereas, wavelength governing measurements predict that photo-desorption process may occur due to sudden excitation of electrons occluded in the nanotubes and perhaps it is a non-thermal process. The excitation of electrons in specific by ∏ plasmons included in SWCNTs due to UV light results in electron/hole pair formation which occur through Landau damping. The studies portray that surface and photochemistry problems are much predominant to exhibit properties and to create molecular nano surface wires that possess ultrahigh surface distribution with each and every atom accommodating onto the surface. Therefore, surface science study can be evaluated at single wire level itself by incorporating both chemical and electrical properties of CNTs as thin probes.

4. Optical properties

Carbon nanotubes have helpful assimilation, photoluminescence (fluorescence), and Raman spectroscopy properties. Spectroscopic strategies offer the chance of speedy and non-dangerous portrayal of moderately a lot of carbon nanotubes. There is a solid interest for such portrayal from the mechanical perspective: various parameters of nanotube union can be changed, purposefully or accidentally, to modify the nanotube quality. As demonstrated as follows, optical assimilation, photoluminescence, and Raman spectroscopies permit brisk and solid portrayal of this “nanotube quality” as far as non-rounded carbon content, structure (chirality) of the delivered nanotubes, and auxiliary imperfections. These highlights decide about some other properties, for example, optical, mechanical, and electrical properties.
Carbon nanotubes are novel “one-dimensional frameworks” which can be imagined as moved single sheets of graphite (or all the more accurately graphene). This rolling should be possible at various points and ebbs and flows bringing about various nanotube properties. The width normally fluctuates in the range 0.4–40 nm (i.e., “just” ~100 times), yet the length can shift ~100,000,000,000 times, from 0.14 nm to 55.5 cm. The nanotube perspective proportion, or the length-to-breadth proportion, can be as high as 132,000,000:1 [44] which is unmatched by some other material. Thusly, all the properties of the carbon nanotubes comparative with those of common semiconductors are incredibly anisotropic (directionally reliant) and tunable.

5. Outline information

While mechanical, electrical, and electrochemical (supercapacitor) properties of the carbon nanotubes are entrenched and have quick applications, the down to earth utilization of optical properties is yet muddled. The previously mentioned tunability of properties is conceivably helpful in optics and photonics. Specifically, light-discharging diodes (LEDs) and photograph detectors dependent on a solitary nanotube have been created in the lab. Their exceptional element is not the effectiveness, which is yet moderately low, however the limited selectivity in the frequency of discharge and recognition of light and the chance of its adjusting through the nanotube structure. What’s more, bolometer and optoelectronic memory gadgets have been acknowledged on groups of single-walled carbon nanotubes. Crystallographic absconds additionally influence the cylinder’s electrical properties. A typical outcome is brought down conductivity through the flawed space of the cylinder. An imperfection in easy chair type tubes (which can lead power) can make the encompassing area become semiconducting, and single monatomic opening incite attractive properties.

VI. Application of carbon nanotube

Carbon nanotubes have several valuable advantages as a structural material. Potential uses include:
Textiles: manufactures tear and water resistant fabrics.)Protection jackets)
Concrete: In concrete, tensile strength is increased and fracture propagation is stopped.
Sports equipment: Carbon nanotubes are used to make tennis rackets, bicycle parts, golf balls, and baseball and golf clubs stronger and lighter.

Artificial muscles: Due to the high rate of contraction/expansion of carbon nanotubes that generate an electric current, the tubes are suitable for use in artificial muscles.
Bridges: Carbon nanotubes can be used instead of steel in suspension bridges.
Ultra-fast speed regulating wheels: The high power-to-weight ratio enables a high rotational speed.
Fire protection: Coating the material with a thin layer of bucky paper greatly improves the fire resistance.
Contamination filter.
Hydrogen storage.
Waterproof filter.
Artificial Intelligence.
Robotics.
Communications and Security.
Computer Graphics and Multimedia.
Numerical Analysis and Scientific Computing.
Electronic Devices and Advanced Materials.

VII. Conclusion

Various modified synthesis techniques have been developed in order to produce CNTs in large scale for commercial application. At the moment, CVD method is the most promising method to produce large quantity of CNTs since the cost is relatively low compared to other methods. Commercial applications of CNTs have been rather slow to develop, however, primarily because of the high production costs of the best quality nanotubes. The chemistry of CNTs has made enormous strides, and it is clear that this subject will drive the applications of carbon nanotubes. Functionalization of CNTs, and particularly CNTs of defined length, diameter, and chirality, will lead to the better control of CNT-based materials and devices at the molecular level. The present paper shows that their immense potential for biotechnology and biomedicine are only just starting to be realized. Various biomolecules (proteins, enzymes, or DNA/RNA) can interact and be immobilized on the CNTs, leading to a wide field of application. However, there is not a universal enzyme support and the best method of immobilization might differ from enzyme to enzyme, from application to application, and from carrier to carrier. In the future, information derived from protein sequences, 3D-structures, and reaction mechanism should be further combined with the fascinating properties of CNTs and physical/chemical methods in order to produce the immobilized enzyme with even more stability and higher catalytic activity. Using noncovalent approaches, enzymes can be less denatured upon immobilization and the intrinsic electronic structure and properties of CNTs are preserved. It is also necessary to study how the linking molecules interact with enzymes and affect the enzyme structure and the arrangement of enzymes on CNTs. the mobility, con- fining effects, solution behaviors, and interfacial properties of nanoscale materials can introduce unique properties to biocatalyst systems, making it possible to develop a revolutionary class of biocatalyst that differs from traditional immobilized enzymes in terms of preparation, catalytic efficiency, and application potential. In the future, new mechanisms and phenomena may continue to appear. Interest in this field is rapidly growing and is likely to fuel more exciting developments in the near future.