JSIANE : Vol. 2, Issue 4, 2022, Page 24–33 ISSN (Online) 2583-2093

Journal of Science Innovations and Nature of Earth

Journal homepage : www.jsiane.com

# CARBON NANOTUBES

**Jyoti Sarwan, Prathimesh, Anushkakumari, Vanshika and Jagadeesh Chandra Bose K***
University Institute of Biotechnology
Chandigarh University-Mohali
Email: jcboseuibtlab@gmail.com

**Abstract**

Carbon nanotubes can be defined as the single layered carbon fibres that are applicable in several fields. These carbon fibres are known as Carbon naotubes. After invention of high resolution of microscopes carbon nanotubes were able to recognize. Carbon nanotubes are the carbon molecules with have sp2 configurations of carbon atoms.The small diameter of CNT is an example of a one-dimensional periodic structure along the nanotube axis the confinement structure in CNT is provided by the monolayer thickness of the nanotube in a radial direction. Therefore carbon nanotubes are recognized as modern technology in various applications like medical, electronics, ceramics and many more. Hence in this chapter it will be try to conclude maximum applications and characteristics to be described.
***Keywords* :** CNTs, crystallography, chiral nanotubes, scanning electron microscopy, graphene.

**Received 01.10.2022** **Revised 28.10.2022** **Accepted 12.11.2022**

## 1. Introduction

In 1991 CNT are experimentally observed by Transmission electron microscopy (Iijima *et al*., 1991). The work was done in past years one is multi-wall carbon which is also known as coaxial carbon which leads to discovery in single-wall CNT which are smaller in diameter (Iijima, *et al*., 1993). It leads to later interest in the experimental and theoretical. On the other hand to the synthesis of a single-wall nanotube with diameter enables through experimental observation there are numerous experiments like Raman scattering, high-resolution TEM, conductance, scanning tunneling. Are compatible escorted by single-wall CNT with sp2 carbon atom of graphene sheets assemble within honeycomb structure such as plane graphene sheets. These nanotubes are prototype hollow cylindrical due to microscopic diameters of rvO.7nm.

The diameter of the CNT is microscopic. As observation says nanotube has an inner diameter of just 2.3 nm and it has particularly two coaxial cylinders (Iijima *et al*., 1991). CNT is framed by a carbon arc process on the other side upon the negative electrode bundles of nanotubes where formed. In intervals, the positive electrode is dominated in a helium atmosphere (Ebbesen *et al*., 1994). CNT is privileged one-dimensional carbon. Some studies emphasized ID properties. Maximum theoretical studies are on single-wall nanotubes.0.34nm is the interlayer distance in multi-wall nanotubes (Iijima *et al*., 1993). Co, Fe catalyst is used to first discover arc discharge chamber (Iijima *et al*., 1993). The multi-wall nanotube is the same as single-wall nanotubes. They have an axis beside hollow cores in the nanotube. Nanotubes have a great attentiveness towards experimental and theoretical studies. Rice University has prepared a single CNT throw the method of vaporization that is utilized at 1200 degrees Celcius (Journet *et al*., 1997). CNT has been reported 14 graphite change at >70%-90% argon gas reach to nanotubes from higher to a lower temperature to downstream from an outermost furnace (Thess *et al*., 1996). The major key of the carbon arc method is single-wall CNT grow with small nanotube diameter distribution or same diameter distribution done by rice group university others are also make single-wall CNT using various techniques like carbon arc methods, laser vaporization or synthesis of the hydrocarbons vapor phase structure (Cheng *et al*., 1998).8/*-

## 2. Structure of Carbon Nanotubes

TEM and STM are of high resolution that analyzes CNT structure. Nanotubes are of graphene sheet single layer or cylindrical. Under the evidence shows that nanotubes are cylindrical or not from the observation done on the number of the same wall shows on the sides of TEM images nanotubes. On the other side, multiwall nanotubes can be synthesized morphologically. In 1960 Bacon form graphite whiskers described scrolls use the same conditions as used in the carbon synthesis of nanotubes (Bacon *et al*., 1960). Carbon fiber is splintered when vapor grows and the inner tube is seen. These CNT are formed by growth(H. M.Endo 1988).In the diameter of 100nm vapors are grow.

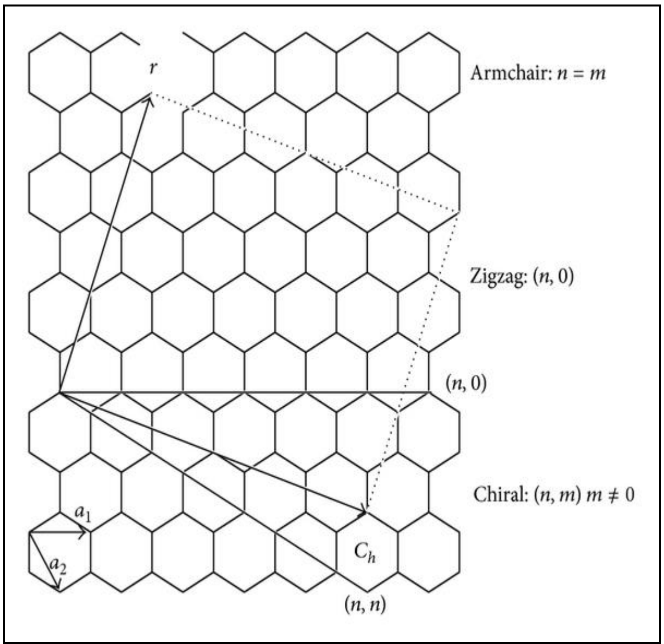


**Fig.1 :** Structure of carbon nanotubes

Chiral vector expressed carbon nanotubes in the term of circumference on 2D graphene it attaches two crystallographically (Dresselhaus *et al.*, 1992). It displays the zig-zag direction and vector between chiral angles. The angle of the chiral nanotube is 0<()<300 and for the armchair, nanotubes is ()=300. Pair of integer collect by the chiral vector and label the vector Ch=nal+ ma2 is denoted (Saito *et al.*, 1994). CNT of cylindrical curvature leads to distortions. Graphene nanotubes' properties bring about the differences between graphene nanotubes and chiral angles. (n,n) vectors show armchair nanotubes and vector (n, O) and (0,m) show zigzag nanotubes (Saito *et al.*, 1992). Chiral nanotubes communicate to all vectors. In integers the distance taken in nanotubes is 1.44A and CC is nearest to the neighbor. The graphene sheet is near to nanotube crystal structure. Brillouin techniques are mostly used to collect phonon dispersion and electron relation of the CNT. Due to the short size of carbon atoms, they inhibited the impurities of CNT or substitutional. Moreover, the screw axis dislocation which can be found in graphite is one of the most common defects which is inhibited by the C60 nanotube monolayer structure. Due to this reason, multi-wall CNT and single wall CNT relate to structural and substitutional impurities. In multiwall CNT and single wall, CNT Pentagon –heptagon or bamboo-like defects are also found (Dresselhaus *et al*., 1996).

### 2.1 Electronic structure

The small diameter of CNT is an example of a one-dimensional periodic structure along the nanotube axis the confinement structure in CNT is provided by the monolayer thickness of the nanotube in a radial direction. In real space, the periodic boundary applies to In large unit cells. The periodic boundary of graphene electronic state leads o the remarkable electronic structure for a small diameter of CNT. We first explain the summary of theoretical prediction which is followed by experimental observation which leads to prediction. In this, we found a detailed discussion about this topic (Louie *et al*., 1999). The energy band structure 1Dis related to electronic band structure 2D for CNT. (27-31) nanotube is formed by honeycomb sheet. This calculation shows that there I 2/3 semiconducting and 1/3 nanotubes, depending upon the nanotube diameter and chiral angle. It shows that metallic conduction in an (n,m) CNT is archived when 2n+m=3q where q is the integer. All armchair carbon is metallic and satisfying. As more vectors allowed the circumferential direction (Louie *et al*., 1999). The nanotube semiconducting bandgap was removed and become more two-dimensional. Semiconductor metal or concentric metal-semiconductor is stable if we design an electronic shielded device it consists of two graphene nanotubes with less than 3nm in diameter (Saito *et al*., 1993). It also consists of a small diameter and is surrounded by a larger semiconducting diameter. Without using doping impurities some principal extended the design of all carbon and semiconductor( R. Saito *et al*., 1992). Observation of the semiconducting nanotubes structures, grow on the side of coaxial CNT there are very few developments in future nanotubes applications (Suenaga *et al*., 1997).

Scanning tunneling spectroscopy (STS) is the best present technique for the measurement of the electronic properties of nanotubes. The ability density states of the single-wall nanotube are sensitive to the probe and the outside multiwall cylinder of the nanotube. the distance between the tunneling tip and nanotube due to exponential dependence (Wildoer *et al*., 1998 and Olk *et al*., 1994). With this technique, it is likely to easy for both scanning tunneling microscopy and STS for the measurements on one same nanotube or consequently to measure the diameter of the nanotube with chiral angle and STS spectrum (Odom *et al*., 1998 and Olk *et al*., 1994).

## 3. Properties

CNT shows different properties like thermal, high mechanical strength, and large electrical conductivity. They have an exceedingly large aspect ratio and a high area of a surface. It is very useful for understanding the chemical and physical properties of carbon nanotubes in deep.

### 3.1 Physical properties

CNT has several physical properties. Single-wall nanotube (SWNT) and Multi-wall nanotube (MWNT) have the same properties. They are also showing thermal conductivity and mechanical strength and electrical conductivity. Because of their unique properties, they exhibit different values and the same properties when measured in a different direction. They have numerous applications of Carbon-wall nanotube (CNT) like heat sinks, structural composites, microelectronic interconnects, etc. Multi-wall nanotube (MWNT) and single-wall nanotube (SWNT) have dissimilar properties. Because of their complex construction. SWNT is narrow than MWNT. MWNT has an inner tube that is also shielded due to the outer layer. Differentiation must be given below of the following DWCNT have comprised of just of two nanotubes, it consists of one nested with other as of SWNT. They have the same differentiation. They varied dissimilarity in the middle of the two nanotube diameter as a result the nanotube was attached to the two tubes. This results in the there is moderation made in the outer layer of the nanotubes without modifying the difference of the inner nanotube. There is a synthetic bled between MWNT and Single-wall nanotube (SWNT) and they possess electrical, thermal stability, and flexibility. SWNT is unsafe to breakage (Bhatt *et al*., 2016).

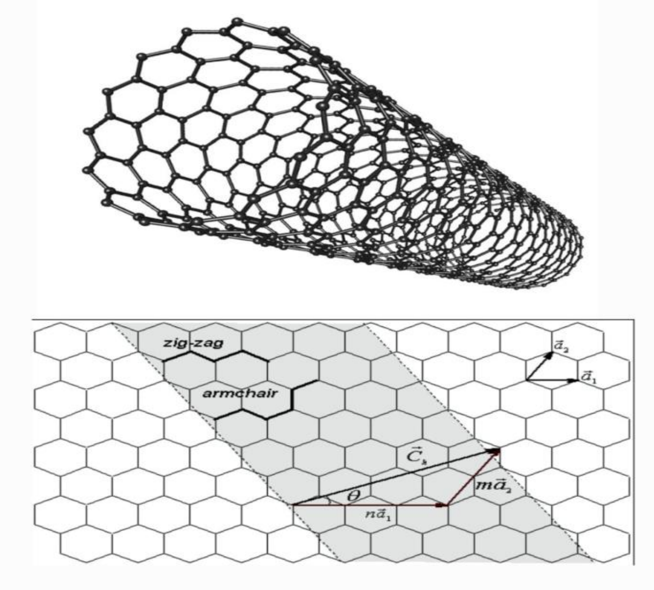


**Fig. 2 :** Carbon nanotube

### 3.2 Thermal property

According to carbon nanotube diamond is a good thermal conductor. Carbon nanotubes show thermal conductivity two times of diamonds. The carbon nanotube is small in size and unique in structure due to its small size and effect. Carbon nanotube has both thermal management and low dimensional band structure both are on microscale and macroscale (Ibrahim *et al*., 2016). Carbon nanotube has a better thermal conductor as a result of the strength of atomic bonds. They affect the temperature of thermal conductivity. Some factors impact the thermal properties like the length of the tube, number of structural defects, and atomic arrangement as well as impurities present in the carbon nanotube (Ibrahim *et al*., 2016). There are many challenges faced like meteorology, microelectronics, transportation manufacturing. MWNT has inter-shell coupling and SWNT as inter-tube coupling that results in the 3D graphite that has low-temperature express.

### 3.3 Mechanical property

We cannot measure the theoretical and mechanical properties of carbon nanotubes because it is difficult to achieve uniform and homogeneous carbon nanotube samples. Singal wall carbon nanotube enhances tensile strength. Multiwall carbon nanotubes also protect the inner wall of the carbon nanotube. Therefore, tensile strength is stronger as compared to steel in a single-wall carbon nanotube. And another one is astonishing property is elasticity. On the other hand, carbon nanotubes turn kind, buckled, and twisted without any harm. They also come back to their original position. Moreover, elasticity can temporarily disfigure in powerful force. As compared to other carbon nanotubes have a mechanical advantage. Therefore carbon nanotube is potentially material of applications like carbon nanotube-polymer composites. It also decreases the mechanical properties due to their structural fault. (Eatemadi *et al*., 2014)

### 3.4 Vibrational property

Phonos take vibration frequency in the same way as photons and phones are vibrations that oscillate single frequency. They have a common mode of vibration that affects condensed matter that comprises mechanical, thermal, and transport properties (Dresselhaus *et al*., 2005) phonon act like a particle that constitutes in a quantiztonzation vibration mode of interacting particle. Crystal has N number of atoms and consists of 3N phone branches. Crystal has zero frequency with their three modes according to a unifortm displacement of crystal. Phonons are bosons they are important in thermodynamics and thermal conducting process like the scattering process to make the electrons equal with numerous electron phenomenon. Like thermoelectricity, electrical conductivity, and magnetotransport. Optical properties and transport play a major role which decaying lower energy by electrons and quasiparticles.

### 3.5 Chemical properties

Carbon atoms are the construct of carbon nanotube that take have the versatility of carbon and it has potential to form dissimilar combinations. It can be used by numerous reactions. A few are given below.

#### 3.5.1 Solubility

For enhancing the reactivity degree, purification and homogeneous dispersion property of solubility play an important role. But the problem that occurs with CNT is the collection of tubes that create problems in dispersion in various solvents and other polymeric mediums. Due to the hydrophobic nature of CNT, it is not soluble in water. Their insolubility and difficulty in dispersion in solvents give limitations in their applications. To overcome the issue of dispersions sonication is being used but immediately after this process precipitation occurs. The single-wall nanotube is mostly insoluble but the suspension can be formed in THF, CMF, toluene, etc. (Singh *et al*., 2016) For nanodevice fabrication supramolecular complexes and interaction of CNT with various compounds provide better processing. Apart from that, the reaction of CNT with the different chemical make it more soluble and can be used in different applications.

#### 3.5.2 Functionalization

In value chain functionalization of the nanotube is the main component due to dissimilar groups, it is easy to interchange solubility, physicochemical and chemical reactivity. At the end of the carbon nanotube and sidewalls, there is a functional group (Ibrahim *et al*., 2016). It is easy to break the nanotube bundles (Adamska *et al*., 2017). On the other hand, chemical functionalization is of two types it is endohedral and exoherdal it is convenient or non-covalent functionalization. In endohedral On the defect sites, there is molecule or atom of the nanotube is filled (Singh *et al*., 2016). The functional group of carbon nanotube refers to covalent linkage.

## 4. Toxicity

Toxicity is one the very important field of study in CNT, as different application and production of CNT is in use on large scale and it increases constantly. Directly or indirectly but the general public is to be exposed to carbon nanotubes. Due to this, it is necessary to pay attention to human health especially to the pulmonary system of humans, as it is the primary root of carbon nanotube exposure. Human lungs when exposed to nanoparticles then show toxicity due to modification in protein structure, initiating inflammatory, escaping from the phagocytic barrier, and by immunological reactions (Ibrahim *et al*., 2016). The various properties like size, surface area, agglomeration, structure, surface chemistry, purity play their role in the toxicity and reactivity of CNT. In CNT single-wall nanotube is more harmful than the other one (Ghasempour *et al*., 2018). Before using CNT there is still a need of doing more research and study to avoid further harmful effects on humans. CNT depends on catalysts present in it, functionalization, and their types and aggregation. It is shown that the functionalized CNT is non-toxic to animals whereas it is shown in in-vivo that the raw CNT is toxic to the lungs of mice (Khalid *et al*., 2016). By attaching a covalently polar functional group in functionalization there is a decrease in cytotoxicity to zero. Same as that toxicity of functionalized CNT with non-covalent bond depends on the functional group and their nature. Coting of CNT can useful as that coting allows the CNT for external modification to control toxicity without affecting the internal one or internal properties.

## 5. Types of carbon nanotubes

### 5.1 Single-wall carbon nanotube

Single-wall nanotube comprise of diameter 0.4-2 nm in range. It consist of cylindrical carbon layer they are based on temperature at which they synthesize. It was initiate that larger is the diameter higher the higher is the growth of CNTs.

SWCNTs structure are helical, arm chair or zig-zag. The SWCNTs have more area for bio- conjugation (14) and drug loading and have a larger surface area of 1300m/g. In drug loading MWCNTs are less efficient than SWCNTs. SWCNTs are more efficient. Because SWCNTs have higer-ultra surface area and more drug delivery capacity. SWCNT anticancer have longer blood circulation .which leads to more assist and protract of drug by tumor cell and increase retention effect and permeability. SWCNT is excreted from body and SWCNT is let go from particular area and best platform for cancer therapeutic agent and SWCNT is easy for drug loading.

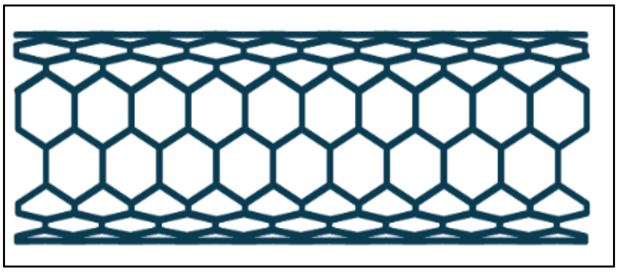

**Fig. 3 :** Single Wall Nanotube

### 5.2 Multiple-wall carbon nanotube

Multiple Wall CNTs is made of graphene single sheet round by hollow core carbon. Its inner diameter ranges from 1-3nm and outer diameter ranges from 2-100. In multiple wall CNT delocalized electron is generated along with the wall due to $hp^2$ hybridization that lead to adjacent cylindrical layer interactions in multi wall CNT that results in defects in structure and flexibility.

There are two categories of multiple wall CNT. One is based on graphite layer arrangement that has structure of parchment-like around which graphene sheet is rolled up and the second one is Russian doll model in which concentric structure is arranged with graphene sheet layers.

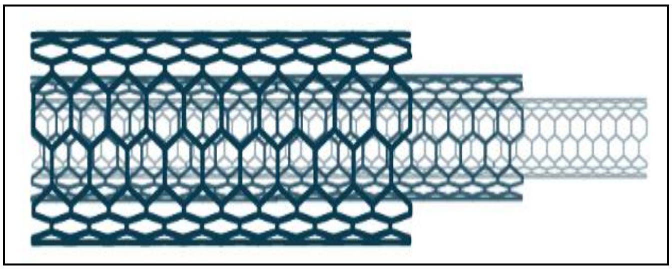

**Fig. 4 :** Multiple Wall Nanotube

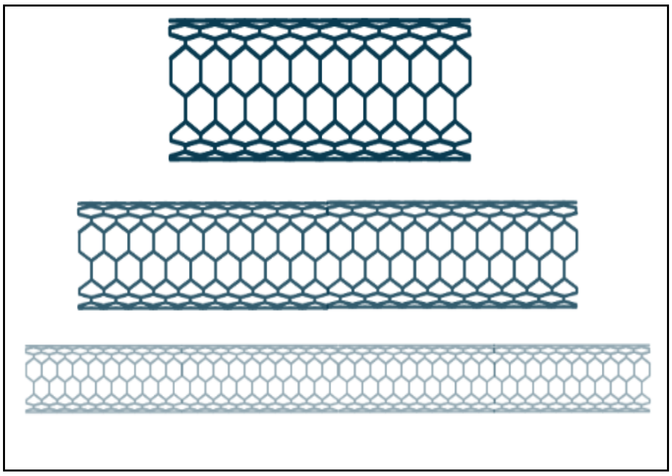

**Fig. 5 :** Different layers of MWNT

## 6. Applications of carbon nanotube

- Carbon contains some unique properties which when combines with molecules of single-wall carbon nanotubes then it endow some extraordinary material properties like very electrical and thermalconductivity, toughness in them, strength, and stiffness.
- Carbon has the only properties to form bonds to itself with the extended network with C-C bond strength. Each atom donates a delocalized pi-electron which is free to move in the entire structure, rather than left with their donor atom, giving the first metallic type molecule with electrical conductivity. Furthermore, high-frequency vibrations of the C-C bond offer an intrinsic high thermal conductivity.
- Due to the defect that occurs in their structure in most of the material, some of the observed properties of material like their electrical conductivity, their strength, and many more are degraded. For example, steel with high strength generally fails at 1% of its breaking strength.
- For owing molecular perfection of CNTs structure, the achieved value should be close to the theoretical limits. The diameter of CNT is in nanometre, but it can be manipulated in different useful ways physically and chemically. That property allows it to give different applications in different fields like energy management, electronics, chemical processing, and many more.

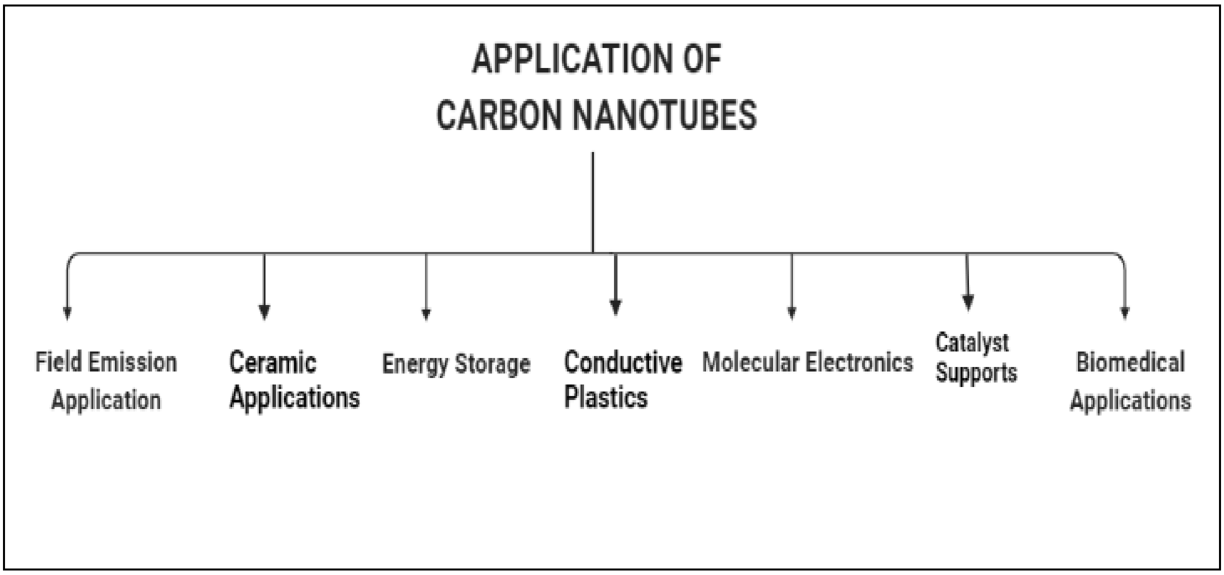


**Fig. 6 :** Applications of CNTs in different fields

### 6.1 Field Emission Applications

In the field of emission, CNTs are considered as the best of any other material. This can be understood as their electrical conductivity is very high and their tip has great sharpness (smaller the radius of the tip of curvature, more will be the concentration in the electrical field, gives higher field emission). Tip's sharpness is the indication of the emission of low voltage, that helps in making electrical device of low power. Its current density is high at about 1013 A/cm$^2$. Moreover, it gives a stable current and it uses in making flat panels that are based on field emission. In-display that based on CNTs every individual pixel uses a different electron gun. In the application of field emission, CNT is very attractive due to its higher density in current, stability, long-lived property, and low voltage. Other than that field emission property of CNT is also utilized in cold cathode lighting with low voltage, as a source of an electron microscope, and lighting arrestors (Wei *et al.*, 2001).

#### 6.1.1 Array entries

Currently, the normal vacuum condition of CNT is 10 to 8 Torr, and of metal filed is 10 to 10 Torr. It is one of the advantages of a CNT emitter over a metal field. (Saito *et al.*, 1998). At 1mA/cm$^2$ current density of the CNT, the emitter is stable, and it gives 2% fluctuation with no bias resistors. In displays like flat-panel, this type of current emission is enough for practical use (Lan *et al.*, 2011). In 1999 Zhu et al. observed that CNT-made field emitters have excellent properties of microscopic emission, and even at a very high current density of up to 4 A/cm$^2$, they are easily operatable. Other than that, they can emit 10 mA/cm$^2$ of current density at a shallow electric field (4-7 V/mm). Nanotube ends originate the emission, which possesses structured ring characteristics. Those characteristics and CNT durability offer various applications in the device of vacuum microelectronics.

#### 6.1.2 Lightning

There are three types of CNT-based lightning devices. The first one is of cylindrical geometry, light-emitting cathode luminescent. In this system, the light is emitted by supporting a conductive cathode placed on a cylindrical anode's axis. An anode is a conductive coating glass tube with a layer of phosphor on its inner surface (Chung *et al.*, 2008). The second one is flat-panel diode structure luminescent light with emission cathode of carbon nanotube array field (Murakami *et al.*, 2000). In this panel source, the growth of CNT arrays is vertical on the substrate and other catalyst particles. CNT tips can be bombarded by the electrons on the phosphor source with high voltage to generate the light source of the first type. (Lan *et al.*, 2011). Lights based on CNTs can emit colored and white light both. The CNT-based light source can give stable light emission, its lifetime is a log over 4000h, and its threshold voltage is also low (Saito *et al.*, 2000). The white color light device of CNT based is stable with 2% of fluctuation with no bias resistors. Carbon nanotube cold cathode gives about $6\times10^4$ cd/m$^2$ luminance of green light. The third one is the light source of planner incandescent, which contains CNT sheets. Generally, the CNT sheets are fabricated due to dry spinning, and those pure carbon nanotubes have two electrodes. Within 1 min, CNT heated over 1000°C when current passes through CNT sheets and then light emits.

### 6.2 Optical devices

Nanoscale dimensions help CNT in the weak interaction. All the elements of CNT look physically identical when the light incident with the same size of CNT arrays. When the semiconducting nature of CNT interacts with light, then in the process of photoelectric, a carrier (photo-induced) is generated, and that can be utilized in solar cells, especially in photoelectrochemical cells. All aligned CNT is in a 3D form used in optical devices and by PECVD; these are generally fabricated.

#### 6.2.1 Photonic crystals

Diffracted light of periodically aligned carbon nanotube arrays acts as polaritonic crystals along with photonic bandgap and polaritonic formation (Kempa *et al.*, 2003). Behaviour of those crystals lies in the high aspect of individual CNT ratio, their periodic distribution of wavelength – scale perpendicular to the alignment, which is the reason behind the periodic modulation of the system's dielectric function in high contrast (Wang *et al.*, 2004). Coated CNT can extend photonic crystal variation, and to obtain photonic array (non- metallic) structural templet of photonic crystals can also be used (Kempa *et al.*, 2003).

#### 6.2.2 Optical antennae

If the length of CNT is about a few hundred, then the visible light interaction of arrays gives a series of a peak with an intense reflection spectrum. And that interaction is due to the oscillation of the carbon nanotube's free electron in an excited state by EM field (electromagnetic field). Suppose the length of CNT matches with wavelength field so that $L= m\lambda/2$, that may further change into a resonating state. Therefore, CNT belongs to optical antennas in which high absorption or scattering efficiencies show by metallic nanostructure. These properties of CNT of working as optical antenna gives various opportunities in future applications in optoelectronic devices like in solar cells, detectors, polarizer, etc.

### 6.3 Energy Storage

CNTs are uses as an electrode in different batteries and capacitors (the two most fast going technology significance) because of its intrinsic properties. The surface area of CNT is high, it's about ~1000m$^2$/g and the linear geometry that CNT posses allow electrolyte to easily get accessed through their surface.

Carbon nanotubes can also be used in lithium-ion batteries due to having the highest capacity of reversibility (Geo *et al*., 2000). Furthermore, CNT is also the best material for an electrode in a superconductor (Ma *et al*., 2000) and is currently in demand for this application.

#### 6.3.1 Fuel cells

Fuel cells are constructed of three-segment that is the same as batteries and ultracapacitors in this energy is kept in a cell. Fuel cells are consist of cathode, anode, and electrolyte. In the existence of electrolytes, electricity is produced due to the reactions of oxidants and external fuel. In anode hydrocarbons, alcohols and hydrogen are usually oxidized to produce positive and negative charge electrodes. It consists of the polymer membrane, molten carbon, solid oxide substance, and aqueous alkaline solution that stops the passage of electrons in ions. On the other's hand, In fuel cells, methanol is used to transport carbon dioxide or water. An electrolyte is transported are recombined throw the reaction with similarly chlorine dioxide and oxygen or chlorine to make carbon dioxide and water.

#### 6.3.2 Lithium-ion batteries

The conversion of chemical energy in a closed system at cathode and anode via redox reaction and generation of electrical energy in batteries. In batteries, electrolyte solvent has a contribution to interphase to solid electrolyte, on the other hand, electrolyte solvent has no involvement in the mechanism of storage of charge in ultracapacitors (Lan *et al*., 2011). The wide use of rechargeable lithium-ion batteries in most electronic devices. When lithium-ion passes between electrodes of graphite and metal oxide, there is the release of charge in batteries. CNT fabrication of electrodes in comparison with amorphous electrodes of carbon is ten times lighter and thinner and has a thousand times greater conductivity. In comparison with materials of carbon, lithium batteries are utilized nanofibers and N-doped CNT and have efficiency in reversible Li storage (Souza Filho *et al*., 2009).


**Fig. 7 :** Lithium ion battery

#### 6.3.3 Hydrogen storage

Usually, graphite, carbon fiber, and carbonaceous metal-made electrodes are used in fuel cells, in some batteries, etc. Some of the properties which make CNT applicable for energy storage are its small size, flawless surface, smooth topology surface, specificity. Due to combustion products with water, hydrogen can use as an energy source. Other than that, the generation of hydrogen is also easy. This is why storing hydrogen is necessary, and it also overcomes the limitation of a combination of weight and volume. The two common ways to store hydrogen are adsorption of electrochemical and gas phases. Due to the hollow cylindrical structure and size in the nanometer of CNT, it can be applicable in storing hydrogen by using the capillary effect. By using physisorption, SWNT can also be used. Nowadays, the mechanism of storing hydrogen and its process is not available, as electrochemical storage is another way of storing hydrogen. The adsorption of the H atom is done by chemisorption, not by hydrogen molecules.

### 6.4 Molecular Electronics

For the last 5 years, the thought of making electronic circuits is in growth and it is one of the important parts of nanotechnology. When the dimensions in any circuit reduce to nanoscale then the interconnection became more important between other devices and switches. All the ability which required for suitable connections in molecular electronics like electrical conductivity, precisely derived, and geometry are there in CNTs which make them more suitable for this application.

#### 6.4.1 Artificial implants

Generally, post-administration pain, when implanted with a body it shows rejection. And to avoid this rejection, nanotubes, and nanohorns can be used with amino acids and proteins. Other than that, to prevent rejection reaction in artificial joint form as implant they can be used. Furthermore, because of high tensile strength, CNT can be used as a bone substitute when calcium is filled and arranged in bone structure.

### 6.5 Conductive Plastics

For the last few years, plastics have been used as a substitute for metals. In general applications, plastics have grown vigorously, but there is no need for electrical conductivity as plastic is one of the best-known insulators. To minimize this deficiency of plastics can be loading up with conductive fillers, like graphite fibers and carbon. Typically high loading is required for heavy parts, especially those parts that contain highly degraded structural properties to get the conductivity in plastics by using conventional fillers. As the aspect ratio of filler is high, the required loading becomes low. That's why CNT has been used because as compared to other fibers CNT contains the highest aspect ratio. Moreover, it has a natural tendency of forming ropes that gives long conductive pathways even after low loading.

These properties of CNT can be utilized in different applications like in ESD which stands for electrostatic dissipation; enclosures, gaskets coating, shielding, and many more; materials that absorb radar for application of low observable; and antistatic materials and another coating like conductive coatings.

### 6.6 The Thermal Conductivity

Carbon nanotubes have heat and electrical conductivity along with other mechanical properties. And because of this, probably they are the best possible electron field emitter. They are pure carbon and can make polymers of it and they can be manipulated by using extremely advanced chemistry. Due to this, they offer to change in structure for the optimization of their solubility and their dispersion. CNTs can be considered as molecularly perfect as their nanotube structure is free from degrading flaws properties. Their property makes them intrinsic and that allows them to be prospectively used in different applications.

### 6.7 Biomedical Applications

Since we know that the human body is made up of carbon, thus it is considered a biocompatible material. Although CNT application in biomedical is still in progress. CNT has no toxic effect on humans as shown in one of the demonstrations, also CNT does not adhere to human cells. There are other applications like for ship's anti-fouling coatings and prosthetics coating.

CNT is useful in neuron growth, in regeneration, and also in vascular stents when sidewalls of it get chemically modified. Nanotube can form bonds with single-strand DNA which can get inserted into the cell subsequently.

.

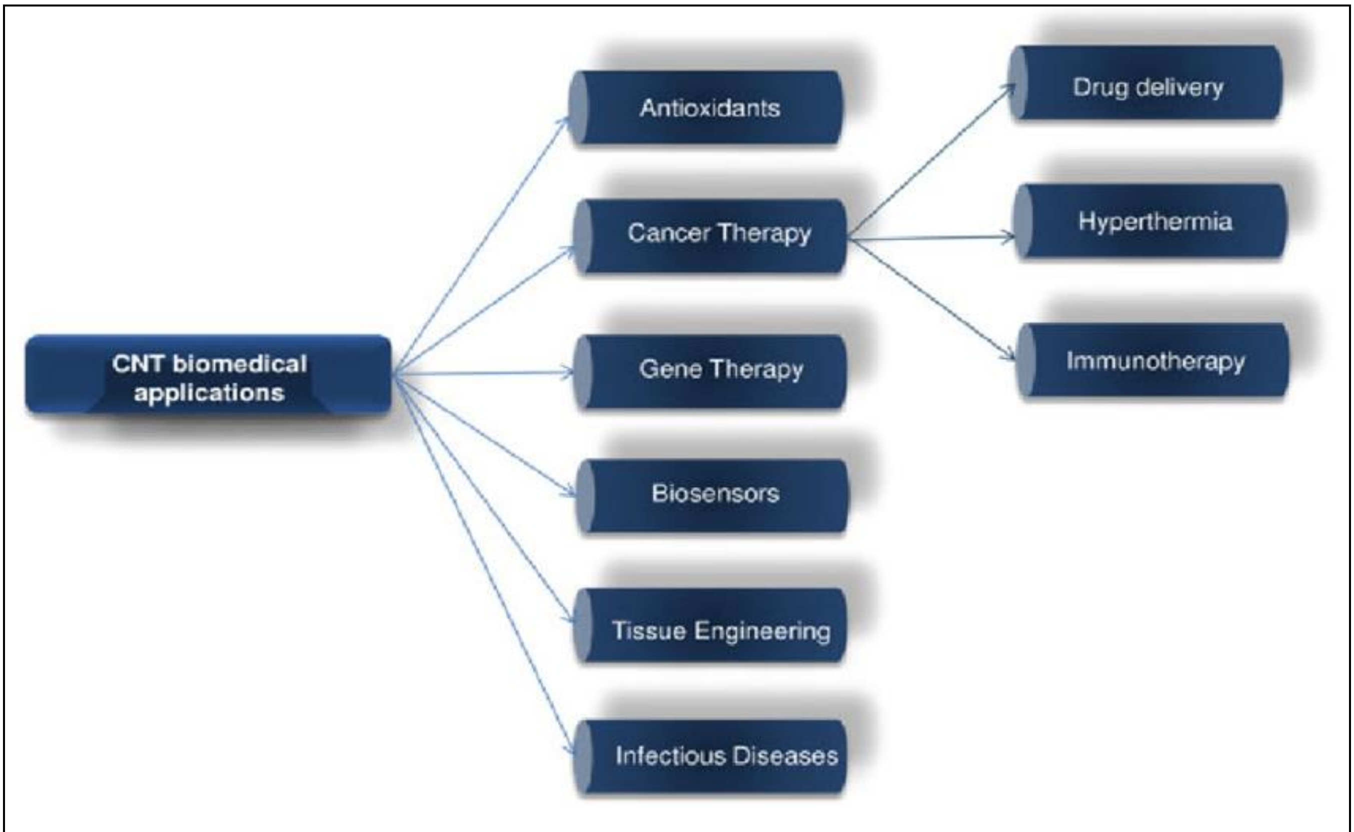


**Fig. 8 :** Biomedical applications of CNT

#### 6.7.1 Cancer Therapy

CNTs have high drug capabilities, small size, and divide unbounded, which leads to the growth of tumors differentiated into diverse nanocarriers.CNTs build up site-specific delivery.

#### 6.7.2 CNTs in gene therapy

CNTs in gene therapy are a new method to use the obtain disorders by transferring effective molecules similarly to micro-ribonucleic acid, small-interfering ribonucleic acid, and short hairpin ribonucleic acid (Qu *et al*., 2018). The complicated capability enables CNT to transmit the perspective of gene therapy and transfer different types of nucleic acid.

It is decisive for CNTs and essential for the transport of nucleic acid (Bates and Kostarelos, 2013) CNTs are curious about the delivery of genes because, in the plasma membrane, they penetrate cell straight through the plasma membrane because of size and lipophilicity without endocytic pathways.

#### 6.7.3 CNTs in vaccine delivery

CNTs have unique characteristics like multiple antigen copies, low toxicity, in vivo stability, and deficiency of immunogenicity, which have been utilized for vaccine delivery for cancer. The hollow structure of CNTs has the capability of multiple antigen conjugation.CNTs can repress innate immune responses and cause normal vaccines.

### 6.7.4 CNTs in antibacterial and antifungal treatment

CNTs are used in the transport of antifungal and antibacterial agents.

CNTs greater bacterial activity and interrelate with microorganisms or damage cell membranes.

### 6.7.5 Diagnostic imaging

CNTs do not encourage the diagnosis of stages of cancer. Moreover, biomedical imaging is used as a probe to enhance tissue penetration and perform the multimodal treatment.CNTs are used as a contrast agent.

### 6.7.6 CNTs in photothermal Therapy

photothermal Therapy is an approving strategy used near-infrared to generate heat for the ablation of tumor cells (Zou *et al*., 2016). It also decreases generated in normal cells.

### 6.8 Ceramic Applications

Ceramic material produced by UC Davis was strengthened with CNT as a material scientist. Comparing with the traditional one the new material is tougher, electricity conductor, and can use as a thermal barrier, and can conduct heat also.

Though ceramic materials are heat resistant, hard, brittle, and resistant to chemical attack. That makes it useful in various applications like turbine blade coating. Aluminum oxide in powdered form mixed with 5 to 10% of CNT, with milled niobium (5%) used in spark-plasma process sinter by researchers. This process is more useful as compare to the traditional process because it can collect more ceramic powder at low temperatures.

New materials have up to 5 times more fracture toughness than alumina (traditional). The new material made with CNT exhibits seven times more electrical conductivity than the earlier one. It also has other properties that make it perfect for coating thermal barriers like fascinating thermal, unidirectional heat conductor, the reflection of heat at a right angle, and nanotube alignment.

### 6.9 Catalyst Supports

Carbon nanotubes have different properties and catalyst support is one of the competitive properties in them (Mintmire *et al*., 1995). These properties make CNT more attractive and useful in various fields (Serp *et al*., 2003). Some factors such as abrasion resistance, some specific absorption properties, thermal stability, dimensional stability are important ones for catalytic activity in reproducibility and final activity. High purity, the effect of specific metal on catalytic activity, and also on selectivity and mesoporous nature are some of the advantages of CNT supports over other activated carbon.

## 7. Conclusion

CNT shows different properties like thermal, high mechanical strength, and large electrical conductivity. They have an exceedingly large aspect ratio and a high area of a surface. It is very useful for understanding the chemical and physical properties of carbon nanotubes in deep. Properties of Carbon Nanotube is not limited to only thermal conductivities or electrical conductivities, it also has mechanical properties like toughness, stiffness (rigid nature), and strength. These properties allow it to be used for other applications, as in advanced composites. Therefore carbon nanotubes have numerous uncountable applications in various fields. In this chapter neither we are confirming all over the applications of nanotubes nor concluded every research related to carbon nanotubes but still there are some more to be discovered.

## References


Adamska, M. and Narkiewicz, U. (2017). Fluorination of carbon nanotubes– a review. *Journal of Fluorine Chemistry*, 200: 179-189.

ALOthman, Z.A. and Wabaidur, S.M. (2019). Application of carbon nanotubes in extraction and chromatographic analysis: A review. *Arabian Journal of Chemistry*, 12(5): 633-651.

Babita, S.K., Gupta, S.M. and Kumar, A. (2006). Effect of surfactant on cnt dispersion in polar media and thermal conductivity of prepared cnt nanofluids.

Bacon, R. (1960). *J. Appl. Phys*. 31: 283-290.

Baughman, R.H. (2000). Putting a new spin on carbon nanotubes. *Science*, 290(5495): 1310-1311.

Bhatt, A., Jain, A., Gurnany, E., Jain, R., Modi, A. and Jain, A. (2016). Carbon nanotubes: a promising carrier for drug delivery and targeting. *Nanoarchitectonics for Smart Delivery and Drug Targeting, 1st ed.; William Andrew: Norwich, NY, USA*, 465-501.

Bonard, J.M., Stöckli, T., Noury, O. and Châtelain, A. (2001). Field emission from cylindrical carbon nanotube cathodes: possibilities for luminescent tubes. *Applied Physics Letters*, 78(18): 2775-2777.

Che, G., Lakshmi, B.B., Fisher, E.R. and Martin, C.R. (1998). Carbon nanotubule membranes for electrochemical energy storage and production. *Nature*, 393(6683): 346-349.

Cheng, H.M., Li, F., Sun, X., Brown, S.D.M., Pimenta, M.A., Marucci, A., Dresselhaus, G. and Dresselhaus, M.S. (1998). *Chem. Phys. Lett*. 289: 602-610.

Choi, W.B., Chung, D.S., Kang, J.H., Kim, H.Y., Jin, Y.W., Han, I.T., ... & Kim, J.M. (1999). Fully sealed, high-brightness carbon-nanotube field-emission display. *Applied physics letters*, *75*(20): 3129-3131.

Chung, K.J. and Pu, N.W., Youh, M.J., Liu, Y.M., Ger, M.D. and Huang, W.K. (2015). Improvement of lighting uniformity and phosphor life in field emission lamps using carbon nanocoils. *Journal of Nanomaterials*, 2015.

Daenen, M., De Fouw, R.D., Hamers, B., Janssen, P.G.A., Schouteden, K., & Veld, M.A.J. (2003). The wondrous world of carbon nanotubes. *Eindhoven University of Technology*, *27*.

Dag, S., Ozturk, Y., Ciraci, S. and Yildirim, T. (2005). Adsorption and dissociation of hydrogen molecules on bare and functionalized carbon nanotubes. *Physical Review B*, 72(15): 155404.

Dresselhaus, G., Dresselhaus, M.S. and Saito, R. (1998). *Physical properties of carbon nanotubes*. World scientific.

Dresselhaus, M.S., Dresselhaus, G. and Eklund, P.C. (1996). Science of Fullerenes and Carbon Nanotubes (Academic Press, New York).

Dresselhaus, M.S., Dresselhaus, G., Saito, R. and Jorio, A. (2005). Raman spectroscopy of carbon nanotubes. *Physics reports*, 409(2): 47-99.

Eatemadi, A., Daraee, H., Karimkhanloo, H., Kouhi, M., Zarghami, N., Akbarzadeh, A., ... and Joo, S.W. (2014). Carbon nanotubes: properties, synthesis, purification, and medical applications. *Nanoscale research letters*, 9(1): 1-13.

Ebbesen, T.W. (1994). *Annu. Rev. Mater. Sci*., 24: 235-264.

Evans, R. (1979). The nature of the liquid-vapour interface and other topics in the statistical mechanics of non-uniform, classical fluids. *Advances in physics*, 28(2): 143-200.

Ewels, C.P. and Glerup, M. (2005). Nitrogen doping in carbon nanotubes. *Journal of Nanoscience and Nanotechnology*, 5(9): 1345-1363

Fischer, W.W., Hemp, J., & Johnson, J.E. (2016). Evolution of oxygenic photosynthesis. *Annual Review of Earth and Planetary Sciences*, 44: 647-683.

Gao, B., Bower, C., Lorentzen, J.D., Fleming, L., Kleinhammes, A., Tang, X.P., ... & Zhou, O. (2000). Enhanced saturation lithium composition in ball-milled single-walled carbon nanotubes. *Chemical Physics Letters*, 327(1-2): 69-75.

Ghasempour, R. and Narei, H. (2018). CNT basics and characteristics. In *Carbon nanotube-reinforced polymers* (pp. 1-24). Elsevier

Ghozatloo, A., Rashidi, A.M. and Shariaty-Niasar, M. (2014). Effects of surface modification on the dispersion and thermal conductivity of CNT/water nanofluids. *International Communications in Heat and Mass Transfer*, 54: 1-7.

Gooding, J.J., Wibowo, R., Liu, J., Yang, W., Losic, D., Orbons, S., ... and Hibbert, D.B. (2003). Protein electrochemistry using aligned carbon nanotube arrays. *Journal of the American Chemical Society*, 125(30): 9006-9007.

Harish, S., Ishikawa, K., Einarsson, E., Aikawa, S., Chiashi, S., Shiomi, J. and Maruyama, S. (2012). Enhanced thermal conductivity of ethylene glycol with single-walled carbon nanotube inclusions. *International Journal of heat and mass transfer*, 55(13-14): 3885-3890.

Harris, P.J. (2004). Carbon nanotubes and related structures: new materials for the twenty-first century.

Hasobe, T., Fukuzumi, S. and Kamat, P.V. (2006). Stacked‐cup carbon nanotubes for photoelectrochemical solar cells. *Angewandte Chemie*, 118(5): 769-773.

Hirlekar, R., Yamagar, M., Garse, H., Vij, M. and Kadam, V. (2009). Carbon nanotubes and its applications: a review. *Asian journal of pharmaceutical and clinical research*, 2(4): 17-27.

Ibrahim, K. S. (2013). Carbon nanotubes-properties and applications: a review. *Carbon letters*, 14(3): 131-144.

Iijima, S. (1991). *Nature* (London) 354: 56.

Iijima, S. and Icbihashi, T. (1993). *Nature* (London) 363: 603.

Issi, J.P. Growth And Agglomeration of Carbon Materials Under Microgravity Conditions.

Journet, W.K., Bernier, P., Loiseau, A., Lamy de la Chapelle, M., Lefrant, S., Deniard, P., Lee, R. and Fischer, J.E. (1997). Nature (London) 388: 756-758.

Kempa, K., Kimball, B., Rybczynski, J., Huang, Z.P., Wu, P.F., Steeves, D., ... & Ren, Z.F. (2003). Photonic crystals based on periodic arrays of aligned carbon nanotubes. *Nano Letters*, 3(1): 13-18.

Kempa, K., Rybczynski, J., Huang, Z., Gregorczyk, K., Vidan, A., Kimball, B., ... & Ren, Z.F. (2007). Carbon nanotubes as optical antennae. *Advanced Materials*, 19(3), 421-426.

Khalid, P., Hussain, M.A., Suman, V.B. and Arun, A.B. (2016). Toxicology of carbon nanotubes-a review. *International Journal of Applied Engineering Research*, 11(1): 148-157.

Kong, J., Chapline, M.G. and Dai, H. (2001). Functionalized carbon nanotubes for molecular hydrogen sensors. *Advanced Materials*, 13(18): 1384-1386.

Kumaresan, V. and Velraj, R. (2012). Experimental investigation of the thermo-physical properties of water–ethylene glycol mixture based CNT nanofluids. *Thermochimica Acta*, 545: 180-186.

Lieberman, M.E. and Levitt, M.A. (1989). Spontaneous rupture of the spleen: a case report and literature review. *The American journal of emergency medicine*, 7(1): 28-31.

Lin, Y.T., Yantasee, W. and Ren, Z. (2005). Carbon Nanotubes based nanoelectrode arrays. *Electroanalysis*, 17(1): 79-84.

Louie, S.G. (1999). In Physics and Chemistry of Materials with Low-Dimensional Structures: Fullerene-Based Materials, edited by Wanda Andreoni, (Kluwer, Dordrecht, 1999) Chapter 9 of this volume.

Mintmire, J.W. and White, C.T. (1995). Electronic and structural properties of carbon nanotubes. *Carbon*, 33(7): 893-902.

Musameh, M., Wang, J., Merkoci, A. and Lin, Y. (2002). Low-potential stable NADH detection at carbon-nanotube-modified glassy carbon electrodes. *Electrochemistry communications*, 4(10): 743-746.

Nugent, J.M., Santhanam, K.S.V., Rubio, A.A. & Ajayan, P.M. (2001). Fast electron transfer kinetics on multiwalled carbon nanotube microbundle electrodes. *Nano letters*, 1(2): 87-91.

Odom, T.W., Huang, J.L., Kim, P. and Lieber, C.M. (1998). *Nature* (London) 391: 62-64.

Olk, H. and Heremans, J.P. (1994). *J. Mater. Res*. 9: 259-262.

Olsen, R.A., Bădescu, Ş.C., Ying, S.C. and Baerends, E.J. (2004). Adsorption and diffusion on a stepped surface: atomic hydrogen on Pt (211). *The Journal of chemical physics*, 120(24): 11852-11863.

Ryu, J.H., Kang, J.S. and Park, K.C. (2012). Carbon nanotube electron emitter for X-ray imaging. *Materials*, 5(11): 2353-2359.

Saito, R., Dresselhaus, G. and Dresselhaus, M.S. (1993). *J. Appl. Phys*. 73: 494 .

Saito, R.G. and Dresselhaus, M.S (1992). *Chern. Phys. Lett*. 195: 537 .

Saito, Y. and Uemura, S. (2000). Field emission from carbon nanotubes and its application to electron sources. *Carbon*, 38(2): 169-182.

Saito, Y., Uemura, S. and Hamaguchi, K. (1998). Cathode ray tube lighting elements with carbon nanotube field emitters. *Japanese Journal of Applied Physics*, 37(3B): L346.

Serp, P., Corrias, M. and Kalck, P. (2003). Carbon nanotubes and nanofibers in catalysis. *Applied Catalysis A: General*, 253(2): 337-358.

Sharma, B., Sharma, S.K., Gupta, S.M. and Kumar, A. (2018). Modified two-step method to prepare long-term stable CNT nanofluids for heat transfer applications. *Arabian Journal for Science and Engineering*, 43(11): 6155-6163.

Singh, R. and Gupta, S. (2016). Introduction to nanotechnology.

Souza Filho, A.G. and Terrones, M. (2009). Properties and applications of doped carbon nanotubes. In *BCN nanotubes and related nanostructures* (pp. 223-269). Springer, New York, NY.

Suenaga, K., Colliex, C., Demoncy, N., Loiseau, A., Pascard, H. and Willaime, F. (1997). *Science* 278: 653.

Swaroop, K.D. (2008). Synthesis of Carbon Nanotubes And Their Use In Phenolic Composites.

Teo, K.B.K., Minoux, E., Hudanski, L., Peauger, F., Schnell, J.P., Gangloff, L., ... and Amaratunga, G.A.J. and Milne WI 2005. *Nature*, *437*, 968.

Thess, A., Lee, R., Nikolaev, P., Dai, H., Petit, P., Robert, J., ... & Smalley, R.E. (1996). Crystalline ropes of metallic carbon nanotubes. *Science*, 273(5274): 483-487.

Thess, R. Lee(1996), P. Nikolaev, H. Dai, P. Petit, J. Robert, C. Xu, Y. H. Lee, S. G. Kim, A. G. Rinzler, D. T. Colbert, G. E. Scuseria, D. Tomanek, J. E. Fischer, and R. E. Smalley, Science 273, 483-487 .

Venkatesan, S.P. and Hemanandh, J. (2020). Experimental investigation on convective heat transfer coefficient of water/ethylene glycol-carbon nanotube nanofluids. *International Journal of Ambient Energy*, 41(4): 428-430.

Walters, D.A., Casavant, M.J., Qin, X.C., Huffman, C.B., Boul, P.J., Ericson, L.M., ... & Smalley, R.E. (2001). In-plane-aligned membranes of carbon nanotubes. *Chemical Physics Letters*, 338(1): 14-20.

Wang, J., Liu, G. and Jan, M.R. (2004). Ultrasensitive electrical biosensing of proteins and DNA: carbon-nanotube derived amplification of the recognition and transduction events. *Journal of the American Chemical Society*, 126(10): 3010-3011.

Wang, L., Liu, D., Zhou, R., Wang, Z. and Cuschieri, A. (2015). Tumour cell membrane poration and ablation by pulsed low-intensity electric field with carbon nanotubes. *International journal of molecular sciences*, 16(4): 6890-6901.

Wang, S. and Zhou, D. (1994). *Chern. Phys. Lett*., 225: 165.

Wang, X., Ren, Z.F. and Kempa, K. (2005). Improved superlensing in two-dimensional photonic crystals with a basis. *Applied Physics Letters*, 86(6): 061105.

Wei, B.Q., Vajtai, R. and Ajayan, P.M. (2001). Reliability and current carrying capacity of carbon nanotubes. *Applied physics letters*, 79(8): 1172-1174

Wildoer, J.W.G., Venema, L.C., Rinzler, A.G., Smalley, R.E. and Dekker, C. (1998) *Nature* (London) 391, 59-62.

Wilson, M., Kannangara, K., Smith, G., Simmons, M. and Raguse, B. (2002). *Nanotechnology: basic science and emerging technologies*. CRC press.

Yu, Y., Cimeno, A., Lan, Y.C., Rybczynski, J., Wang, D.Z., Paudel, T. ... & Cai, D. (2009). Assembly of multi-functional nanocomponents on periodic nanotube array for biosensors. *Micro & nano letters*, 4(1): 27-33.

Zeng, Q., Li, Z., & Zhou, Y. (2006). Synthesis and application of carbon nanotubes. *Journal of Natural Gas Chemistry*, *15*(3), 235-246.

Zhang, H., Cao, G., Wang, Z., Yang, Y., Shi, Z. and Gu, Z. (2008). Tube-covering-tube nanostructured polyaniline/ carbon nanotube array composite electrode with high capacitance and superior rate performance as well as good cycling stability. *Electrochemistry Communications*, 10(7): 1056-1059.

Zhang, L.L., and Zhao, X.S. (2009). Carbon-based materials as supercapacitor electrodes. *Chemical Society Reviews*, 38(9): 2520-2531.

Zhong, D.Y., Zhang, G.Y., Liu, S., Wang, E.G., Wang, Q., Li, H. and Huang, X.J. (2001). Lithium storage in polymerized carbon nitride nanobells. *Applied Physics Letters*, 79(21): 3500-3502.

Zhu, W., Bower, C., Zhou, O., Kochanski, G. and Jin, S. (1999). Large current density from carbon nanotube field emitters. *Applied physics letters*, 75(6): 873-875.