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# Carbon Nanotubes, its Synthesis and Applications: A Review

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***Abstract*— The Carbon Nanotubes (CNTs) are versatile materials for the development of biosensors because these have many unique physical, optical, electrical and mechanical properties. These properties of CNTs change with a slight change in Surface to Volume Ratio. So, we can exploit these properties in such a way that CNTs can be used in a wide range of applications ranging from drug delivery to water purification and many healthcare applications. In the recent times, CNTs have allured the attentions of Academicians, Researchers and also Industries due to its wide range of applications. But still there is not a single commercial product based on Carbon Nanotubes due to certain challenges. This paper provides the review of the recent vigorous researches done in the field of Biosensors based on Carbon Nanotubes**

***Keywords*— Biosensors, SWCNTs, MWCNTs, Carbon Nanotubes, Functionalization.**

## I. Introduction

Carbon Nanotubes have been extensively used in many applications including Biomedical Engineering and Healthcare Sector as carrier agents, diagnostic tools, for diseases detection, biosensors and many more. The researches and studies of biosensors based on CNTs have been done for the last two decades to detect glucose, DNA, insulin, Dopamine, Urea etc. The biosensors or other nano-scale devices that are used in biomedical applications come in direct contact with human body or bloodstream. This is the first step that a researcher should keep in his mind while forming a biosensor or other nano-device because this affects the subsequent performance of biosensor or nano-device. It has been realized since a long time that the surface properties of a wide range of materials and devices have utmost importance in the field of healthcare and other areas. There has been a huge development in the field of nano science and nano technology and it has opened a wide area of applications of these materials after being functionalized and characterized by novel approaches.

In the nanometer scale, the properties of the materials changed rapidly with a slight change in the surface to volume ratio of the material, so the devices/sensors performance also changes. There has been a thorough research on the nano materials for the development of biosensors. Carbon Nanotubes have enormous and flexible potential for biomedical and healthcare applications. The CNTs can have a wide range of applications including abnormalities diagnosis and their treatments.

In human body, during metabolism and as a result of different ongoing processes in the body, some bio-molecules are produced, some of these are desired by our body and others are waste. If these bio-molecules are produced in a prescribed limit, they cause no harm to our body. But in case these bio-molecules produced in excess or in exiguous quantity, they can harm our body as they lead to development of different diseases. So the detection of these bio-molecules is of enormous importance for diagnosis of diseases, food safety, nano-medicine and for the formation of new drug molecules of the size of these bio-molecules which have potential to give off early warning against their production [1-3]. Hence, discovery of new materials and formation of such compact, reliable and low cost devices that can provide rapid analysis of these harmful molecules could provide mankind a healthier and safer life. The bio sensors which can be functionalized for the recognition of some specific bio-molecule or harmful agents can be more useful to complement the demands of nano-medicine and as warning agents [4-5].

## II. Structure & Types Of Carbon Nano-Tubes

CNTs are allotropes of Carbon. They are tubular in shape [6]. The backbone of carbon nanotubes is the carbon atom. Carbon Nano tubes are composed of macro molecule of carbon similar to a sheet of graphite rolled into a hollow cylinder. Graphite looks like a sheet of hexagonal rings of carbon. CNTS are light weight, flexible, chemically inert and thermally stable. They can be either of semiconducting or metallic types depending upon energy gap. [7]. CNTs are 100 times stronger than steel. [8].

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The CNTs can be Single walled Carbon nanotubes and Multi walled carbon nanotubes depending upon the number of layers of graphite sheet [9-10]. The diameter of SWCNTs can be of the range 0.75–3 nm and its length can be l–50 micrometers.

While MWCNTs can have diameter in the range of 2-30 nm and, the distance between each layer is approximately 0.42 nm [11]. Single Walled Carbon NanoTube and Multi Walled Carbon NanoTube are shown in Figure 1.

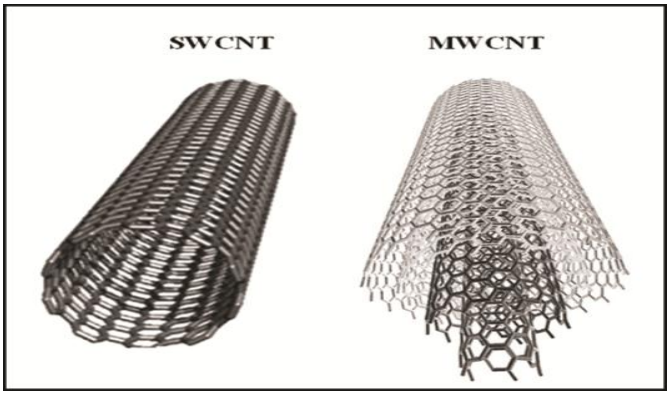


**Figure 1: Single Walled CNTs and Multi Walled CNTs [111]**

CNTs are hydrophobic and insoluble in aqueous solution, and tend to aggregate due to strong Van Deer Waals interactions [12].

In order to make CNTs more compatible with biological systems, the insolubility and aggregation issues have been overcome by the attachment of functional groups to the external surface of CNTs in a process known as functionalization [13].

**Table 1:**
**Differences between SWCNTs and MWCNTs**

| | SWCNTs | MWCNTs |
|---|---|---|
| 1. | These have a simple structure | These have a complex structure |
| 2. | Purity is low | Purity is high |
| 3. | Catalysts are required for the synthesis. | These can be synthesized without a catalyst. |
| 4. | Chance of defects is more during the process of Fictionalization | Chance of defect is less. |
| 5. | These have single layer of Graphene. | These have two or more layers of Graphene. |
| 6. | The accumulation of SWCNTs is less in the body | The accumulation of MWCNTs is high as compared to SWCNTs |
| 7. | These can be easily twisted | These cannot be easily twisted |
| 8. | Synthesis of SWCNTs require control over growth and conditions in vacuum chamber, so bulk production is difficult | Bulk production of MWCNTs is easy |

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Carbon Nanotubes form different shapes. The shapes of Carbon Nanotubes can be described by a vector known as Chiral vector (n, m) where n & m are integers of the equation R = na1 + ma2 , known as Chiral indices and R is a linear combination of vectors a1 and a2. The values of n and m determine the Chirality or twist of the Carbon Nanotubes.

The chirality of a nanotube affects density, lattice structure, conductivity and other properties of Carbon Nanotubes [14]. The structural parameters of CNTs can be obtained for the chiral indices n and m [15-16]. Depending on the twisting, Carbon nanotubes can be classified into 3 different structures which are armchair structure, zigzag structure and chiral structure as shown in figure 2 below.

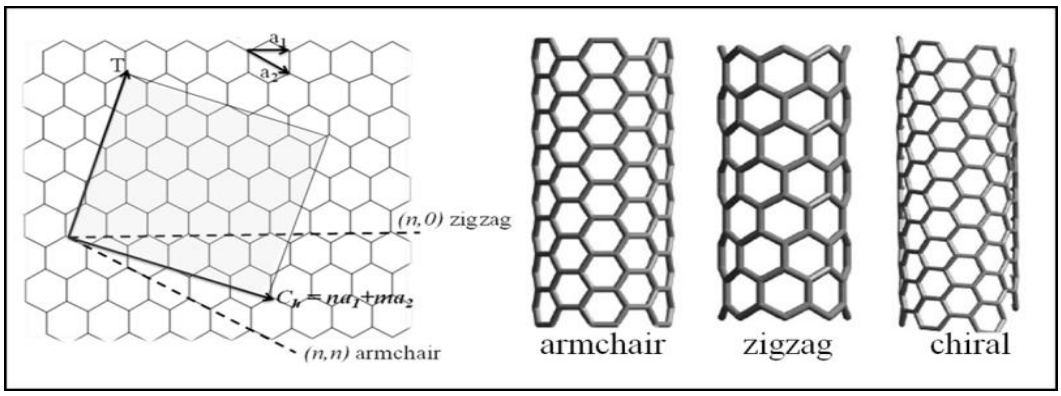


**Figure 2: Armchair, Zigzag and Chiral structure of Carbon nanotubes [19]**

The type of structure of CNTs is dependent on its Chiral vector (n, m) and the spiral angle. When n = m, spiral angle is equal to 30 between Chiral vector Ch and lattice vector a1, the type of CNTs is called arm-chair; when m = 0, θ = 0◦, the type of CNTs is called zigzag; and when0 < θ< 30◦, the type of CNTs is called Chiral. The electrical properties of SWCNTs strongly depend on diameter and Chirality [17]. If the chiral vector (n, m) of a CNT is given then its diameter D can be calculated by equation no. 1

$$D = \frac{|C|}{\pi} = a \sqrt[2]{(n^2 + m^2 + nm)}\ 0.0783 \text{ nm} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where a, is the distance between two adjacent carbon atoms. Depending on their n, m values, nanotubes can be either electrically metallic or semiconductor. In general, an (n, m) SWNT will be metallic when n - m = 3q, where q = 0, 1, 2, 3, 4, 5……

A SWCNT is metallic if the value n - m is divisible by three or n-m= 3r, where r is any integer, otherwise, the Nanotube is Semiconducting. When tubes are formed with random values of n and m, we would expect that two-thirds of Nanotubes would be Semi-conducting, while the other third would be Metallic, which happens to be the case.

The Armchair Structure of CNTs is of metallic attribute and is the most stable structure. [18].

## III. Methods Of Productions Of CNTs

The use of CNTs is becoming more and more in healthcare and other industries due to different advantages of CNTs over other materials and due to their unique properties like strength, thermal stability, high surface to volume ration etc. There has been continuous research for cost effective, simple and easier method for the development of Carbon Nanotubes. The methods more commonly used for the synthesis of CNTs are Arc Discharge method, LASER ablation and Chemical Vapor Deposition. Since the research on CNTs is increasing extensively, some improvements have been made over the years. The most commonly used techniques for CNTs synthesis are discussed as below

### *A. ARC Discharge Method*

This was the first method for the production on CNTs introduced by Iijima in 1991 [4]. The schematic for Arc Discharge method is shown in figure 3 below.

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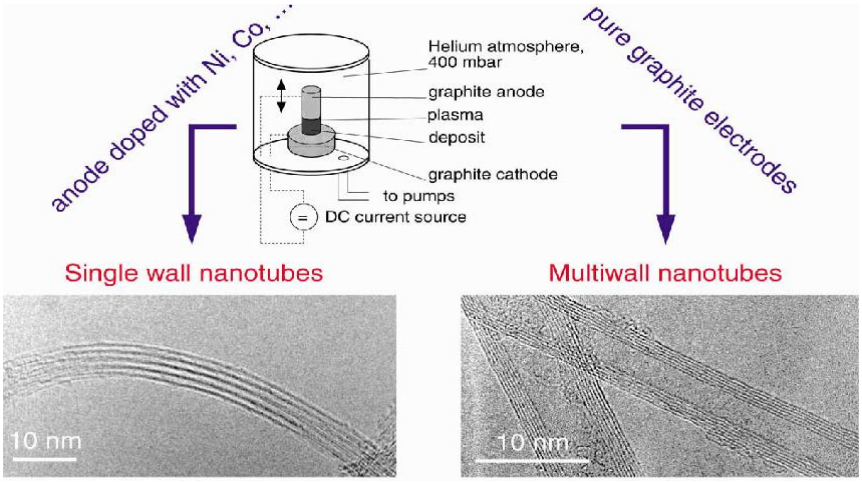


**Figure 3: Apparatus for the Arc Discharge Method and synthesized SWCNT and MWCNT [19]**

This method can be used for the synthesis of SWCNTs and also for MWCNTs. In this method, two carbon rods are placed end to end at a distance of 1 mm, in a vacuum reactor and that vacuum reactor is filled with inert gas like Argon or Helium. From the two rods of Carbon, rod acting as cathode is heavier than the rod acting as anode. The arc is kept steady. The pressure is kept low from 50 to 700 mbar. The temperature remains greater than 3000°C. Under the application of direct current of value 50 to 100 A driven by voltage of 20-30 V, arc discharge vaporizes the cathode carbon rod, and it will get deposited to anode as rod shaped tubes [20-21]. The catalysts used are Cobalt and Molybdenum. The key features to be controlled while the Arc Discharge Method is Inert gas, plasma arc, temperature and choice of catalyst and value of the current used.

The Method used for the synthesis of MWCNTs using Arc Discharge methods includes synthesis in Liquid Nitrogen [21], Magnetic Field Synthesis [21], and Plasma Arc Rotating Discharge [22].

*B. Laser Ablation Method*

The LASER ablation method for the synthesis of CNTs is simpler and easier method [23]. This method was derived from the Arc Discharge Method Smalley and his co researchers (2001). The schematic diagram of the LASER Ablation method is shown in the figure 4.

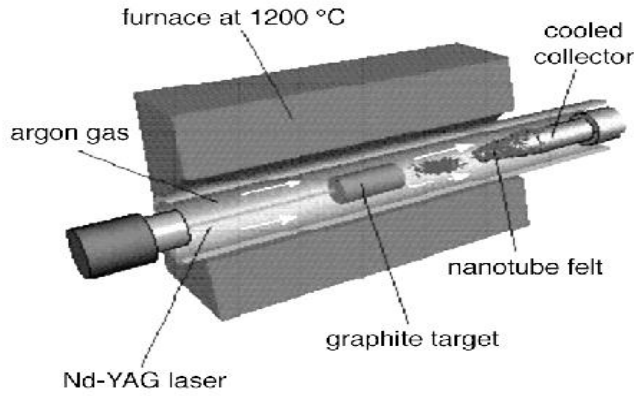


**Figure 4: Apparatus for Laser Ablation Method for CNTs Synthesis**

In this method, firstly a piece of graphite is placed in an oven, then a LASER either pulsed or Continuous is used to vaporize the graphite. The pulsed laser uses much higher light intensity as compared to continuous laser. The temperature remains at 1200°C. The pressure is maintained at 500 torr by filling the oven with inert gas like Helium or Neon. The high energy laser beam irradiate the graphite and catalyst, due to which generation of high temperature causes them to vaporize, the carrier gas takes the molecules at high temperature region and then these molecules are deposited on the collector to form CNTs.

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A very hot plume develops, expands and then also cools rapidly. This method for the synthesis requires high cost and high energy consumption. The CNTs produced by this method are highly pure and defect free. This method cannot be used for bulk synthesis because it is not cost effective [24].

*C. Chemical Vapor Deposition*

Chemical Vapor Deposition is the most widely used method for the synthesis of CNTs. This method requires a transition metal catalyst. It is a thermo dehydrogenation reaction [22]. The schematic for Chemical Vapor deposition is shown in figure 5.

This reaction takes place on the surface of gas-solid substrate. The reaction takes place in 2 steps. The nucleation of catalyst is carried via chemical etching or thermal annealing after the Catalyst is deposited on substrate. Ammonia as an etchant and Ni, Fe or Co is used as Metal catalysts [25-26] Then Carbon source gas along with carrier gas enters into the reaction chamber under the temperature of 600-1000 °C.

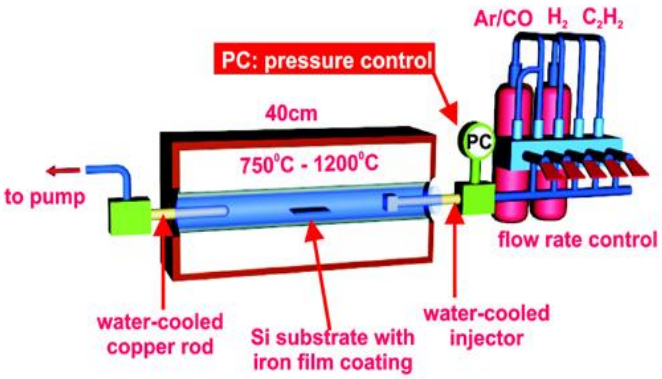


**Figure 5: Schematic apparatus for Chemical Vapor Deposition [19]**

The Carbon molecule get converted into atomic level using energy, get diffused towards substrate coated with catalyst and CNT get synthesized on the metal catalyst. The carbon sources used are methane, acetylene, ethanol, ethylene, benzene and so on. Using the Carbon source helps in reducing the temperature required for the decomposition of Carbon sources into carbon molecules [27]. The parameters to be controlled in this process are temperature, catalysts, carrier gas and Pressure.

*D. Flame Synthesis Method*

SWNTs can also be synthesized in a controlled flame environment from hydrocarbon fuels. The schematic is shown in figure 6

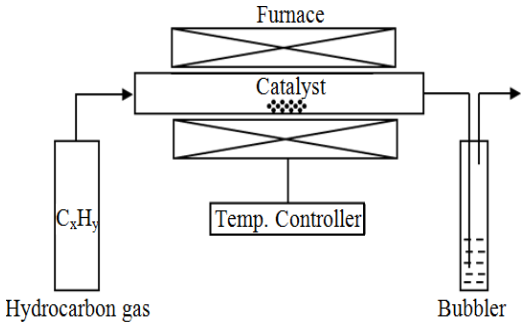


**Figure 6: Apparatus for Flame Synthesis Method [28]**

In this process, small aerosol metal catalyst is used. [27, 29] SWCNTs have been observed in the post-flame region of a premixed acetylene/oxygen/argon flame when operated at a pressure of 50 Torr and the metallic catalyst used was iron pentacarbonyl vapors.

*E. Silane Solution Method*

CNTs can also be produced using a saline solution method. In this method, carbon paper or stainless steel mesh is used as substrate and immersed in the saline solution of a metal catalyst. The Co: Ni in a 1:1 ratio is used as catalyst; ethylene is fed through the substrate and the catalyst deposited thereon. The substrate was heated by applying an electrical current to cause a reaction between the catalyst and the gas to yield CNTs [30].

## IV. Purification Of CNTS

After the synthesis of CNTs, the main problem in the path of using them in the Nano applications, is the purification of CNTs. CNTs contain a large amount of impurities such as wrapped up graphite, amorphous carbon, metal particles and much more like smaller fullerenes. Without purification, CNTs cannot be used in the applications. There are several methods for the purification of CNTs which are Acid treatment/acid refluxing in which metal is exposed to Oxidation or Sonication, and then metal catalyst is exposed to acid and solvated, resulting SWCNTs as suspended form after removing metal catalyst. The acids used are either $HNO_3$ having effect on metal catalyst or HCL having a little effect on CNTs. The second method is Ultrasonication in which Ultrasonic vibrations are used to vibrate and disperse Nano particles. Solvents and regents like alcohol [31] and acids [32] are used for the separation of particles. Other methods are Magnetic purification for removing ferromagnetic metallic catalytic particles [32] and Chromatography having the problem of solvating the SWCNTs [33].

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## V. Toxicity Of CNTs

Despite, numerous applications of CNTs in every field like water purification, drug delivery, cancer treatment and many biomedical applications, CNTs have toxicological and harmful effects also. The harmful effects of CNTs may owe to different factors which are high surface area, smaller size, degree of bundling of Carbon molecules; on the toxicity of Functional groups and on concentration of CNTs also. CNTs have some degree of toxicity both in vivo and in vitro. The toxic effects of CNTs can be reduced using the purification of CNTs to remove metal catalyst particles like Fe, Co and Ni [34]. The Toxicological effects of CNTs have been studied in the recent years by different researchers. CNTs have been studied by researchers to study in vitro and in vivo toxicological effects. The toxicity of CNTs depends on the other factors in addition to concentration. These factors may be physical form of the CNTs [35], degree of Functionalization [36] and state of agglomeration [37]. CNTs can disrupt the model membrane of cell [38]. CNTs can cross membrane barriers and can cause inflammatory and fibrotic reactions. CNTs can enter the cell and get deposited in the cytoplasm and can cause death of entire cell [39]. Exorbitant use of CNTs can cause pleural Mesothelioma, which is a cancer of the lining of the lungs and also cause peritoneal Mesothelioma, a cancer of the lining of the abdomen [110]. Carbon Nanotubes deposit in the alveolar ducts by aligning lengthwise with the airways; the Nanotubes will often combine with metals. In a study, the effects of pristine and oxidized Multi walled Carbon Nanoutubes effect on human T lymphocytes, used 40 µg/ml for 5 days and cells were approximately damaged [35]. It was found that human monocytes were exposed to purified and unpurified MWCNTs with concentration of 20 µg/ ml for 4 days, and cells become 57% viable [40]. The effects of SWCNTs on Human A549 cells (ATCC, CCL-185) human lung carcinoma epithelial cell line were studied in-vitro [41]. Exposed to concentration of 800 µg/ ml for 1 day and it was found that toxicity was very low and toxicity increased in the absence of serum. The toxicity effects of SWCNTs Functionalized with aryl sulfonate groups were studied in vitro on Human epithelial-like Hela cells [42] in 2007, and exposure conditions were 1 mg/ml for 4 days, the results obtained are Adsorption of essential micronutrients from cell culture medium results in the toxicity (Cell viability, DNA Damage and apoptosis). Human dermis fibroblast cells were exposed to Refined and Unrefined SWCNTs with concentration of 25-100 µg/ml for 1-5 days and toxicity effects were studied in vitro [43], and it was found that Refined SWCNTs are more toxic than its unrefined counterpart.

In a study, Human epidermal keratinocytes (HaCaT) exposed to SWCNT in KGM basal medium with different concentration ranging from 0.02 to 0.1 mg/ml, for different duration between 1 hour and 48 hours and it was found that release of pro-inflammatory cytokine was exposure time dependent [44].

Many researchers studied the in vivo toxicity issues of CNTs with various conditions on animals. These in vivo studies include study on BALB nu Male with Magnetic MWCNTs exposed to dosage of 0.94 mg administered subcutaneously and after 15 days of exposure, no agglomerate, no abnormalities were resulted [45]. Another in vivo study on Nude mice with dosage of 151 mg of SWCNTs inserted intravenously for 120 days were studied [46], no toxicity was observed. In an in vivo study of effects of MWCNTs administered Intratracheally into SD rats for 60 days, dosage of MWCNTs from 0.5 to 5 mg caused Granulomas formation in Bronchial Lumen and alveolitis in surrounding tissues [47]. Other in vivo study for the toxicity issues of CNTs includes studies on Wistar Rats [48], Single Walled Nano Horns administered peroraly and no abnormality was found with dosage of 2g/Kg even after 14 days. Another in vivo study is SWNTs with dosage of 40-1000 µg given intravenously to CD ICR male mice for 90 days, caused Serum Biological changes [49]. The toxicity issues related to CNTs is completely no known. More insight study is needed to understand toxicity issues of CNTs,

## VI. Applications Of CNTs

There has been a wide range of applications of CNTs from the time of their discovery. CNTs can have wide range of application due to their unique properties like high surface to volume ratio, thermal stability, and mechanical strength 100 times more than that of steel, smaller size and many more. CNTs are the base of different types of biosensors like DNA biosensors, enzyme biosensors, glucose biosensors, and for cancer treatment, drug delivery, gene therapy, probes, quantum dots, implantable biomedical devices, cellular imaging, biomedicine etc. CNTs can be functionalized to expand the applications of CNTs in different areas. CNTs can be functionalized in two ways which are Covalent Bonding [106] and Non Covalent wrapping[107], but these functionalisation methods must be such as not to alter the physical, chemical, electrical and mechanical properties of CNTs. Covalent Bonding is used less as compared to Non Covalent wrapping due to the fact that non covalent bonding causes less structural damage to CNTs.

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Covalent bonding refers to chemical attachment of desired species at the end of tubes or at any defect sites, whereas non covalent wrapping is physical adsorption of a species around the CNT walls.

Covalent bonding includes oxidation process for preparation of chemically active site for the desired species to be attached to CNTs [107]. CNTs can be used for different application as shown in the following table.

**Table 4:**
**Applications of Carbon Nano tubes**

| Area of application of CNTs | Applications of CNTs | Reference |
|---|---|---|
| As Diagnostic tools | ➢ Nano size robots for studying cells and biological systems<br>➢ Radiation Oncology<br>➢ CNT based Microfocus X-Ray Tube | [50]<br>[51]<br>[52-54] |
| As Cancer therapy | ➢ Targeted Drug Delivery<br>➢ Thermal Therapy<br>➢ Gene Therapy<br>➢ Lymphatic Targeted<br>➢ Chemotherapy | [95-96]<br>[98-99]<br>[100]<br>[101-103]<br>[104] |
| Tissue Engineering | ➢ Tissue Regeneration<br>➢ As Biodegradable and Biocompatiable support for in vitro cell growth<br>➢ Cell Tracking and labeling<br>➢ Sensing cell Behavior | [55]<br>[56]<br>[57-59]<br>[28, 60-64] |
| Cardio-Vascular Applications | ➢ Autonomic Cardiovascular Control Regulation | [65] |
| Preservative (as antioxidant) | ➢ To prevent Drug Formulations<br>➢ Antiaging Cosmetics | [66] |
| Imaging | ➢ Cellular Imaging | [67] |
| Biomedical Applications | ➢ Blood Glucose Detection<br>➢ Diseases Diagnosis<br>➢ Hyperthermia application<br>➢ Markers<br>➢ Artificial Implants such as Bone substitute and as artificial joints without host rejection reaction | [68] |
| Genetic Engineering | ➢ Development of Bioimaging Genomes and Proteomics | [69] |
| Catalyst | ➢ Using Carbon Nano horns incorporated CNTs | [50] |
| Sensors | ➢ Pressure Sensor<br>➢ Flow Sensor<br>➢ Probes and other sensors | [70-71]<br>[72-73]<br>[74-80] |

CNTs based field Emission X –Ray can be used for the Micro Cardiac Computed Tomography imaging [104]. CNTs have also been used to transport Genetic Materials and have the ability to express Protein [68]. Due to the controlled lipo-philicity of CNTs, the anti-cancer drug Polyphosphazene Platinum Enhanced Permeability, Distribution and Retention in the Brain. CNTs were used to deliver Antibiotic for improving the Intracellular Penetration. Due to sliding nature and smaller size of CNTs, they have been used in Tablet Manufacturing as Lubricants [68]. CNTs have been functionalized and are used for targeting of Amphotericin B to Cells [50].

Due to anti oxidation nature of CNTs, they have been used to preserve drugs. CNTs have been used to prevent anti-aging factors in cosmetics [81]. Different studies including cells and other systems of human body can be done by using nano-size robots based on CNTs [68]. CNTs can be functionalized with enzyme, proteins and exhibits fluorescence capabilities and used for the implantable biosensors [82]. CNTs have also antiviral effects against a Virus Respiratory Syncytical Virus (RSV), which can cause severe bronchitis and asthma [82]. A screen printed on polycarbonate substrate immobilized with Cholesterol esterase, cholesterol oxidase, peroxidase and potassium Ferro-cyanide and reference Carbon electrode has been studied [83-84]. The Researches for making biosensors for detecting glucose was started in 1960s.

The first glucose biosensor was made by Clark and Lyons which was an electrode coated with thin layer of Glucose Oxidase [85]. This biosensor was replaced by other glucose biosensor [86]. Their biosensor used two electrodes instead of one electrode. One electrode was coated with enzyme GOx and other was used for measuring current [86]. After that glucose biosensors have been made by different researchers with different techniques overcoming the shortcomings of previously developed glucose biosensor. Multi-walled Carbon Nanotubes based Glucose biosensor synthesized via Chemical Vapor deposition and mobilized with GOx using the entrapment technique, has been used as constant Glucose biosensor. It was reagent free Glucose Bio-sensor [87]. The entrapment method is rapidly growing technique for the mobilization of Carbon Nanotubes because it enhances the direct Electron transfer rate [88] The Carbon Nanotubes Functionalization with the enzymes is the most effective method for making Electrochemical Biosensors [88-89]. The Gelatin is a polymer obtained from Collagen. It is present in Connective tissues and skin in human body. Gelatin is widely used as immobilization matrices for different biosensors [90].

Gelatin's gel forming capability and its biocompatibility with different polymers makes it suitable for synthesis of Electrochemical Biosensors [91].

Biosensors based on CNTs have been used for the diagnosis of Diabetes, a metabolic disorder caused by deficiency of Insulin, a peptide hormone secreted by beta cells in pancreas [92]. Benjamin C. King had developed a CNTs based biosensor for the detection of biomarkers for cancerous cells in breast [109]. It was simple carbon nanotube biosensor for epithelial cell adhesion molecule (EpCAM) for sensing EpCAM positive cells [28]. There has been extensive work for using the CNTs as optical sensors for the detection of glucose [93]. CNTs as optical biosensors have been used for life science applications In-Vitro as well as In-Vivo, because their fluorescence in the near-infrared range of 820-1600 nm, where absorption by biological tissues is often minimal [70, 94].

## VII. Future Scopes

In the future time, the MEMS and NEMS technology along with the Nanotechnology will play significant role in the field of Biomedical Engineering and Healthcare industries. These technologies will impact the future generation devices. All the devices can be reduced to the size of micro and nano-size level using these technologies. Given the toxicity resulted from the CNTs has been controlled, CNTs based biosensors have huge potential for commercial products for easy diagnosis of diseases and also open a huge opportunities for the researchers. CNTs could prove a Wonder Material for many application areas provided the toxicity caused by them can be tackled. The CNTs based biosensor will provide the early detection of diseases and would enable the routine checkups of the patients even at their home. Also, the results obtained from these Nano sensors must be validated with reference to the clinical standards and there may be some misconceptions and misinterpretation about the use of these CNTs Based Biosensors for the diagnostic purposes owing to the percentage of validity of results obtained from these Biosensors.

## VIII. Conclusions

Due to the wide range of applications like gene therapy, Nanomedicine, Implantable Devices, Drug Delivery, Cancer Treatment, Preservative, Cell Tracking and many more, CNTs have become a boon for treating the life threatening diseases; CNTs have crossed the barrier as an alternative for many fields.

Despite many applications, CNTs have some shortfalls also. The insolubility of CNTs is the one of the widest shortcomings of CNTs. But this can be overcome to a small extent by functionalizing by different chemical and physical methods. Other big problem with CNTs is failure to main the quality and minimizing the impurities. CNTs can increase solubility of drugs attached, they can bypass the membranes, can help expressing the proteins, delivering the drugs to specific cells thus acting as non-toxic vehicles. So, CNTs have shown a promising glimpse of future medicine. But still some more deep research needs to be done to overcome the limitations of CNTs to counteract the toxicity of CNTs.

## IX. Present And Future Market Scenario Of Biosensors

A report on the biosensors market analysis titled **"Biosensors Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast, 2014 - 2020,**"was published by Transparency Market Research.

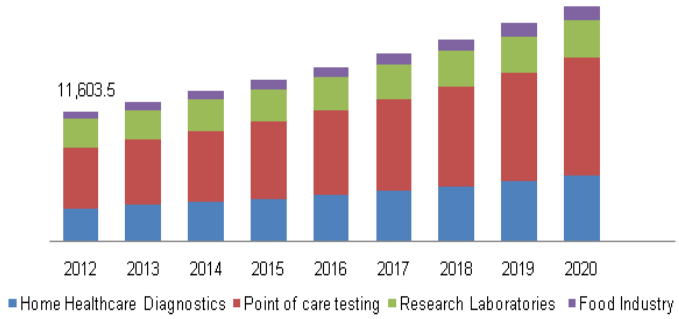


**Fig. 7: Present and future perspective of Biosensors [109]**

According to this report, the global biosensors market was valued at USD 11.60 billion in 2013, USD 12.46 billion in 2013 and is expected to grow from 2014 to 2020, to reach USD 21.64 billion in 2020. The biosensors market is expecting such a significant growth during the forecast period from 2014 to 2020 due to high frequency of occurrence of various diseases and this has raised the demand of the population for simplest, compact and responsive medical diagnostic procedures.The above bar diagram shows the market of biosensors in different application areas like Home Healthcare Diagnostics, Point of Care Testing, Research Laboratories and Food Industry starting from year 2012 to the expected growing market of biosensors in these application areas up to the year 2020, reaching a market value of 21.64 billion in 2020.

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