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Carbon Nanotubes and their Application: Current Scenario

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Abstract

Carbon nanotubes (CNTs) attracted significant interest due to their unique combination of properties including high mechanical strength, high surface area, distinct optical characteristics, high thermal and electrical conductivity, which make it suitable for a wide range of applications in areas from electronics to biotechnology and other applications Controlled synthesis, assembly and assimilation of CNTs is essential for the practical realization of current and future nanotube applications for society. The present study focuses on progress in the field of CNT assembly and incorporation for various applications.

Key Words: Carbon nanotubes, X-ray Diffraction, Sensors etc.

I. Introduction

Brief overview of carbon nanotubes (CNTs) and their unique properties

Carbon nanotubes are the materials of SP^2 nanocarbon with the structure of tubular which consists of rolled-up graphene sheets. In addition with specific nanostructures, reveal valuable properties. Some of these properties generate from the similar properties of graphite and the rest from the one-dimensional aspects. CNT is treated as either metal or semiconductor. Metalic properties of carbon nanotubes bear an electron density of 4×10^{9} A/cm^2. This rage is 1000 times greater than copper (Zhang et al. 2020). As a cause of having the conductivity of 1D, carbon nanotubes show ballistic transport with the direction of the tube.

This gives a result in high intrinsic mobility. Their mechanical strength is many times larger than steel, and carbon nanotubes' thermal conductivity is also better than diamonds. Carbon nanotube has a ratio of high aspect because of their small diameter and unique tubular characteristics. Carbon nanotubes are made up of small carbon atoms and as a cause of this CNT is a highly stable compound (Rasheed et al. 2019). These features make carbon nanotubes the ideal element for many applications like biosensors, hydrogen storage cells, emitters of electron fields, and supercapacitors.

Importance of CNTs in various fields

. The important features of carbon nanotubes are their small size, good conducting features, weight, and high aspect ratio which make CNT more useful in different fields (Rahman et al. 2019). CNT also have huge applications in the field of sensors, membranes, transistors, nanotechnology, actuators, and nanomedicine. There are several procedures that can be used for the synthesis of carbon nanotubes along with the sol-gel process, arc-discharge process, Chemical Vaporized Deposition (CVD), and laser ablation method. Carbon nanotube has some special feature of electrical, mechanical, and optical properties.

The reconstructive medicine sector is devoted to improving modern methods of giving functional tissues, along with improving mechanisms for replacing organs that are damaged by wounds or diseases (Iqbal et al. 2021). Having structural and mechanical properties CNT is superior for this application, in which CNT is greatly useful as composites in tissue engineering. CNT can deliver therapeutics across the barrier of blood-brain and it is also suitable for the therapeutics of tumor-targeted.

II. Synthesis and Characterization of CNTs

Methods of CNT synthesis (e.g., arc discharge, chemical vapor deposition)

The challenge of CNT is still the subject of many research groups. There are three main synthesis processes of carbon nanotubes. The methods are chemical vapor decomposition (CVD), arc discharge, and laser ablation (Saravanakkumar et al. 2019). The beginning period of the production of carbon nanotube arc discharge method and laser ablation methods were mainly used for the utilization of SWNTs while the third method is used mainly for MWNTs. The concept of chemical vapour deposition (CVD) is composed of several hydrocarbons over the transition metal that supports the catalyst.

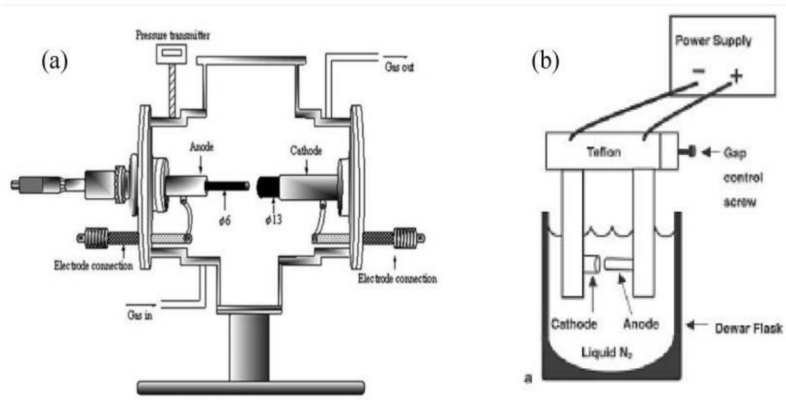

Figure 1: Schematic representation of arc discharge apparatus
(Source: Saravanakkumar et al. 2019)

Then Single Walled Nano Tubes (SWNT), Multi-Walled Nano Tubes (MWNT), and Coiled Carbon Nanotubes (CCNT) are created. In most cases, compulsive carbonaceous compounds are prepared during the time of synthesis method, like onions, bamboo-like tubes, and horn-like tubes (Rathinavel et al. 2021). Some attempts were made to look at other possibilities to develop carbon nanotubes but they have not been successful and the cause may be the expensive reaction apparatus and the cost of the catalysts. In present-day arc discharge and CVD processes are hugely applied for the production of carbon nanotubes. As a result of this different types of CVD processes were discovered like radiofrequency enhanced, plasma enhance, and microwave enhanced chemical vapour deposition.

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Product	Comments	Conditions
CNTs	Metal filled	Deionized water
MWNTs	Distorted morphology	Liquid environment
SWNTs	High yield	Ho/Ni Catalyst
DWNTs	Large quantity	KCL/FeS Catalyst

Table 1: Variation of synthesis parameters in the method of Arc discharge
(Source: Rathinavel et al. 2021)

Structural and morphological characterisation techniques (e.g., scanning electron Microscopy, transmission electron microscopy)

Electron microscopy is an important tool for the characterization of any type of nanomaterial. Because it permits straight regulation of structure, size, and share. As per Ismail et al. (2019), the common structure of carbon nanotubes can be examined at the nanometer level by using the tools such as SEM, AFM, and TEM. This tool produces damage to the nanotubes as a cause of using an electron beam. Electron microscopy is the scientific procedure that is used to inspect objects on a fine scale. This narrow sample is eliminated with a beam of electrons of uniform current density. Among the nanostructures of carbon, CNT is treated as the most important structure as a cause of possessing the most determinant characteristics. Features revealed by carbon nanotubes are created qualitatively by electron microscopies (Zhou et al. 2019). Moreover, SEM analysis gives the outlook of nanostructures, and more appropriate investigation by TEM exhibits huge defects. All these microscopies conceal some observations regarding the arrangement of carbon nanotubes.

III. Properties and Functionalization of CNTs

Electrical and thermal properties of CNTs

Polymers are also known as effective insulators, charging to the electrical and thermal conductivity. Among the several nanofillers, the fillers which are carbon-based such as CNTs, graphene, and carbon black have to get notable attention for their important physical properties. Before calculating the electrical conductivity, an efficiency engagement process was conducted. First of all UV etching was activated on the composite film surface for 300s to reveal the MWCNTs implanted beneath the edge of the PDMS matrix (Ivanov et al. 2019). To create an electrode, the paste of silver is coated to the four points of the composite film at the same distances.

When this electronic device is used, heat is the main problem of not only degradation in the performance of electronic gadgets but also shortening of life. However, it is crucial to release heat quickly from the devices. Even polymers have been acclimated largely in different electronic fields as a cause of their flexible shape, lightweight, and mechanical properties (Cheng et al. 2021). Maximum polymers have a low thermal conductivity that can affect the presentation of electronic gadgets. Thus the thermal and electrical properties can depend on the significant ratio that is considered as the geometric variables of CNTs.

Functionalization methods (e.g., covalent and non-covalent modifications) and their effects on CNT Properties

The high volume ratio of carbon nanotube permits high bio-molecules to load per unit geometric area that aims in the amplification of the high signal. As per Zhou et al. (2019), then the fictionalization methods are classified into two categories as covalent functionalization and non-covalent fictionalization. Covalent functionalization of carbon nanotubes can be gained bt inscribing chemical functional groups on the sidewalls of carbon nanotubes. The functional group could behave with the other functional groups that exist in the structure of biomolecules to create a covalent bond. Such other processes were also developed to immobilize biomolecules on the surface of carbon nanotubes.

Non-covalent functionalization is also attractive for the immobilization of biomolecules on the surface of carbon nanotubes. This process helps to conserve the confirmation structure of the biomolecules after the immobilization on to carbon nanotube (Bourkaib et al. 2020). Generally the process of non-covalent functionalization compounds is stable with the attachment on the surface of carbon nanotubes under versatile environment and gives suitable functional moieties for connecting to several biomolecules.

IV. Applications of CNTs

Electronics and optoelectronics (e.g., field-effect transistors, solar cells)

Transparent conductive electrodes are the intervention of many electronic gadgets with wide applications in wearable electronics, field-effect transistors, solar cells and others. Carbon nanotubes are an important element for realizing field-effect transistors (Saliev 2019). To produce carbon nanotubes field effect transistors and several types of carbon nanotubes are used as the channel of the gadgets with modern lithographically source, drain and gate regions.

Carbon nanotube-based transistors are great sensing devices and also very challenging for their potential to operate different technologies with outstanding properties of carbon nanotubes. The training structure of carbon nanotubes gives those many features when treated as sensitive elements in sensors and electrical execution superior to CNTs. Mentioning the detection ability of different elements and the exceptional outcomes, carbon nanotube field effect transistors are anticipated to create an expanding role in the sensing field (Rahman et al. 2019). Carbon nanotubes also can be used in photovoltaic technology, significantly several components of solar cells like carrier-sensitive contacts, and components of light-sensitive. Utilization also increased to resourcing layers that are used for photo resistance, which provides metals with a thin coating surface.

Energy storage and conversion (e.g., batteries, fuel cells)

Wearable electronics demand flexible and stretchable energy storage devices like secondary batteries of thin film ions and micro-super capacitors. In addition with commercial batteries with lithium-ion and super capacitors are commonly heavy and partly rigid (Pei et al. 2019). Therefore, flexible storage of energy emerges for properly implemented miniaturized energy storage for customer electronics. This part listed the present advances in the flexible storage of energy gadgets, along with architecture development and innovations of materials. Several anode elements are produced by carbon nanotubes. They are various composites like yarns of carbon nanotubes and their fiber composites. But in the case of batteries that are made up of lithium-ion, the total architecture of the battery should be favorable with flexible. As an example, the porous textile conductor is another metal collector which has shown high weight loading of anode elements and has a huge capacity of flexibility (Li and Shi 2019). The attempts of fabricating secondary ion batteries of low coat are made in the addition and ejection of larger ions such as sodium, potassium, and zinc except for lithium ions.

Biomedical and environmental applications (e.g., drug delivery, water purification)

There are several applications such as drug delivery, biosensors, bio-imaging, tissue engineering, and cancer treatment of carbon nanotubes in the field of biomedical and environmental applications. Drug administration can be done by different processes and routes for targeted drug delivery. Nanotechnology has become one of the most trending industries in the present scenario. Carbon nanotube has proven largely applicable in different sectors of biomedical and environmental applications (Wang et al. 2019). Carbon nanotubes became the most versatile element in this field. Fictionalization of carbon nanotubes with reagents of biocompatible helps to build up solubility and suppress toxicity.

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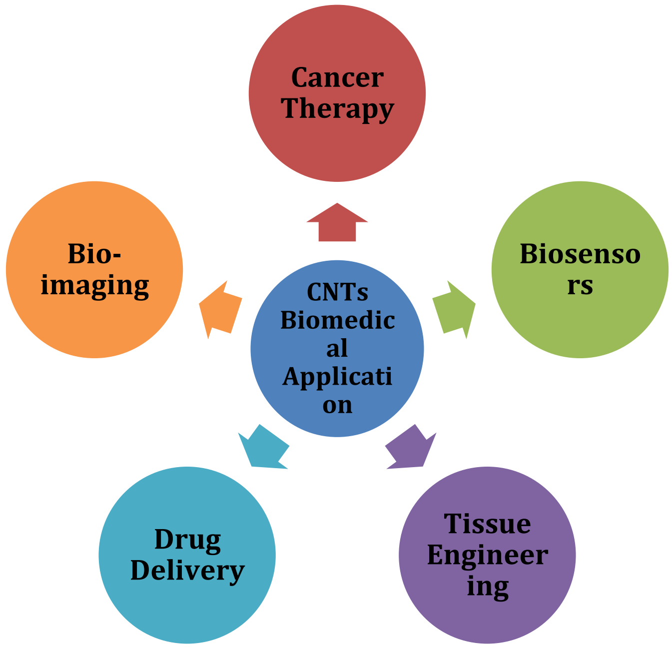

Figure 2: Different bio medical applications of CNTs
(Source: Wang et al. 2019)

In the field of drug delivery regulation, the release of Cisplatin gives 84.56 % activity of anticancer at a pH range of 6.5. Moreover, CNT combination with Graphene oxide serves as a multifunctional element in the tissue engineering of cartilage and bone which can control the oestrogenic abilities of stem cells. In the field of bio-imaging SWCNTs are used having the ability to noise detect at a range of 7 picograms (Norizan et al. 2020). SWCNTs in the field of biosensors can identify SARS-CoV. The toxic property of CNT is a problem that cannot be treated and should be treated with deliberation durian the time of production and application in the biomedical fields.

Properties	Graphene sheet	Distortion chance	Purity	Elasticity
SWCNT	single layer graphene sheet	It can be distorted during the Functionalization.	less purity	Easily re bonded
MWCNT	More than 2 layer graphene sheet.	Less Distortion chance during Functionalization.	High purity	Cannot be easily rebounded

Table 2: Comparison between SWCNT and MWCN
(Source: Norizan et al. 2020)

V. Current Challenges and Future Directions

Challenges in large-scale CNT production and integration into devices

Advanced electronic gadgets now become an essential part of human activities. One of the elements with a promising future in modern technology is CNT. Different challenges have to be overcome before the adoption of carbon nanotube metal structures. For demand, the quality and length of CNTs, alignment of carbon nanotubes in a metal matrix, manufacturing stability and cost all required to be addressed (Peng et al. 2019). Besides this, it is important to ensure about the method of applied fabrication does not compromise the structural and chemical stability of carbon nanotubes. Different major issues obstruct the large application of CNTs in electronics fields. Some of these challenges are impurities, sorting and separation, interface, and dispersion.

Opportunities for further research and development of CNT-based technologies

The earlier use of carbon nanotubes in contact with living cells with the utilization of carbon nanotubes for development. In this study carbon nanotube and their application deposited on scanning electron microscopy, electronics and optoelectronics, energy storage and conservation, and biomedical and environmental applicants were used to analyze the morphological changes with the presence of MWNTs. Development in CNT-based technology requires a complete knowledge of the structure of carbon nanotubes. Published research for the application of carbon nanotubes is compared (Zhang et al. 2021). Besides this, it is important to overcome the challenges created by the application of carbon nanotubes. Generally, this indicates that in modern technology there is a huge tendency for the implementation of carbon nanotubes rather than basic research. As a result of this, a development in the number of others papers is observed.

VI. Conclusion

Summary of the current state-of-the-art in CNT research and applications

In this study brief overview and unique properties of carbon nanotubes are described in the introduction chapter. In present-day application of carbon nanotubes is increasing in various fields. The important features of carbon nanotubes are their small size, good conducting features, weight, and high aspect ratio which make CNT more useful in different fields. Nanomaterials give a piece of complete knowledge on distinct probability and are also surely well-sound in the biomedical field for their unique chemical properties. Thus carbon nanotubes have a definite potential to establish many applications in several fields. Often the quick investigation of other elements in carbon nanoforms would argue its perspective for their revealing applications in different sectors. Still, there are many doubts on unsolved challenges in where the proximate uniformity of carbon nanomaterial accommodates huge distribution of nanotubes radius and marked sensitivity to several species. There are several methods of CNT synthesis such as arc discharge, and chemical vapour deposition which are also discussed in this study. Different applications and challenges of implementing CNT are also described in this study.

Prospects for CNTs in various fields

The most advisable future work involved in carbon nanotubes will be the transistors with the reliability of a large scale, cheap production of cost, or with more modifying performances such as attaching external effects to the inner transistor of carbon nanotube, drain resistance, series resistance and the effects of scattering. Although having unique properties such as strength, weight, and stiffness CNT contrasted to other elements especially silicon, at present, there is no technology for mass production.

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