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Synthesis, Characterization and Applications of Carbon Nanotubes: A Review

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ABSTRACT

Researchers have been paying close attention to carbon nanotubes lately because of all of their prospective uses, special qualities, and applications. Today, carbon nanotubes have a wide range of uses in the fields of biology, chemistry, medicine, materials science, mechanical engineering, electrical engineering, and electronics. Its applicability for radio wave applications is being revealed by its electromagnetic characteristics. Meanwhile, the kind of carbon nanotube employed in its manufacturing and the synthesis process used all affect the product's quality, characteristics, and efficacy. As a result, this review paper discusses several carbon nanotube kinds, synthesizing processes, characterization techniques, and applications.

KEYWORDS: *carbon nanotubes, synthesis, characterization, application*

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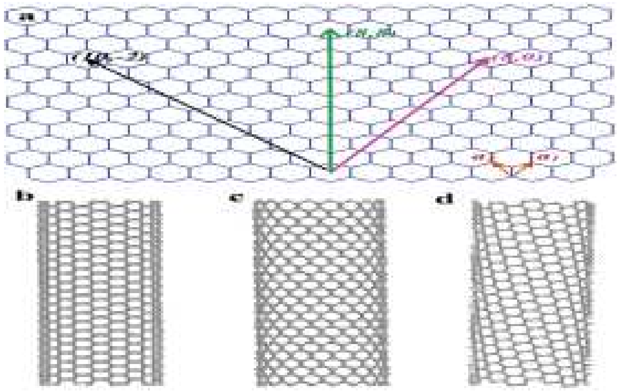
1. INTRODUCTION

One of the most prevalent and interesting elements on earth is carbon. It manifests in a variety of forms, or allotropes, each with quite different characteristics. Amorphous carbon, graphite, and diamond are some of these allotropes. Additionally, it creates a wide range of unique structures that are constantly being discovered in the past several years. Due to its basic and technological interests, the discovery of novel carbon allotropes or carbon nanostructures (CNSs) has received a lot of attention. [1, 2, 3]. Although they have been widely recognized for almost 20 years, carbon nanotubes (CNTs) have a slightly longer history than other relatively new nanomaterials. The first scientists to notice carbon nanotubes (CNTs) were Radushkevich and Lukyanovich in 1952 [4,5], and later in 1976, Oberlin observed single and double-walled carbon nanotubes [4-6]. In more modern times, Iijima is credited with discovering CNTs as the first scientist to explain the multiwall carbon nanotube (MWNT) preparation process in response to a chance occurrence while testing a new arc evaporation technique for the production of C60 carbon molecules in 1991 [7]. Many studies in recent years have concentrated on nanotechnology and nanocomposites [8]. To create a specific composite with altered qualities, researchers choose a certain filler and mix it with a particular polymer. The composite is known as a nanocomposite if the filler is a nanomaterial. [9]. Graphene, a one-atom-thick sheet of graphite, is a planar-hexagonal arrangement of carbon atoms arranged in a honeycomb lattice, and according to [10, 11], the structure of a carbon nanotube can be seen as a rolled-up sheet of graphene. Single-wall carbon nanotubes (SWCNTs), double-wall carbon nanotubes, and multi-wall carbon nanotubes (MWCNTs) carbon nanotubes can be produced from it [12-14]. [Due of their multiple potential uses and distinctive characteristics, CNTs have drawn the interest of numerous researchers. [15].

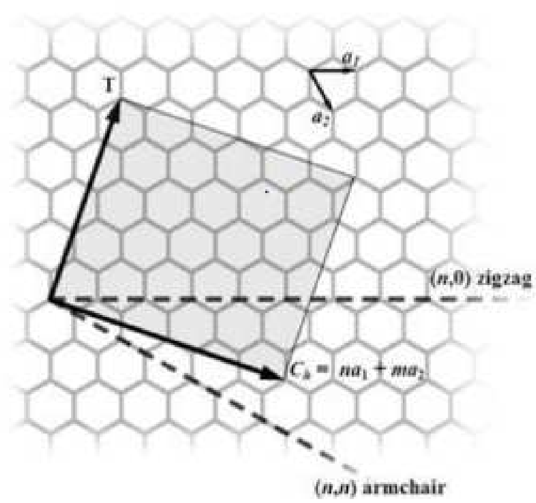
2. Types of Carbon Nanotubes

2.1. Single-Walled Carbon Nanotubes

Three distinct shapes of single-walled carbon nanotubes are possible: armchair ($m = n$), chiral ($m \neq n$), and zigzag ($m = 0$). The diameter and chirality of the nanotube are determined by the (m, n) indices. The (m, n) indices determine the diameter and the chirality of the nanotube [16, 17]. Consider rolling a piece of paper from its corner, which can be thought of as one design, and considering rolling the piece of paper from its edge, which can be thought of as another design. The design depends on how the graphene is wrapped into a cylinder. The chiral vector (n, m) is a pair of indices that describes the structure of a single-walled nanotube. (Figure 1) [17].



(a)



(b)

Figure 1: (a) Schematic honeycomb structure of a graphene sheet single walled carbon nanotubes formed by folding the sheet along lattice vectors a_1 and a_2. (b) schematic diagram of single wall carbon nanotube chiral vector

2.2. Multi-Walled Carbon Nanotubes

Iijima created the first multi-walled carbon nanotubes (MWCNTs) in 1991 [17, 18], using graphite arc-evaporation in a helium environment [18, 19, 20]. Two structural types of multi-walled nanotubes exist. [21[In the Russian doll model, a carbon nanotube has an inner and an outer nanotube; the inner nanotube is smaller in diameter than the outer nanotube. Figure 2 shows the parchment model, where a single graphene sheet is repeatedly wound around itself to resemble a scroll of paper [17, 22]. Although multi-walled carbon nanotubes have characteristics that are comparable to those of single-walled carbon nanotubes, the exterior walls of these nanotubes can shield the interior carbon nanotubes from chemical reactions with external substances. Additionally, multi-walled nanotubes are more tensile-stable than single-walled nanotubes. [23].

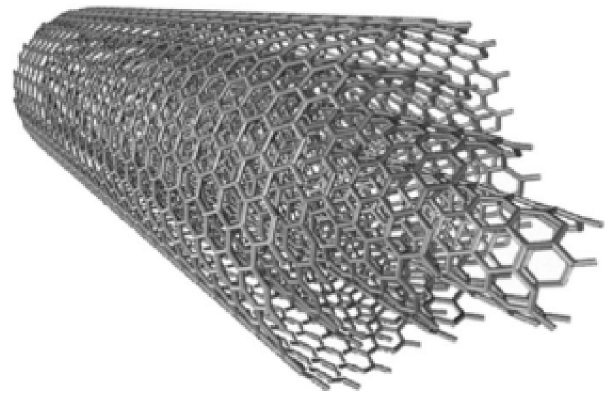


Figure 2: Structure of Multi-Walled Carbon Nanotube

3. Synthetization of Carbon Nanotubes

Depending on the necessary physical qualities, different processes, including arc discharge, laser ablation, and chemical vapor deposition (CVD), are employed to create carbon nanotubes.

3.1. Arc Discharge Method

Electric-arc discharge is the most popular technique for creating carbon nanotubes (Figure 3.1). [24]. An electric arc is an electrical breakdown of a gas that results from a current travelling through typically nonconductive material like air. This breakdown creates an ongoing plasma discharge that resembles an instant spark [25]. An extremely high temperature is produced by the arc, which takes place in a gaseous gap between two conductive electrodes (typically formed of carbon), and is capable of melting or vaporizing just about everything. When a current is passed via an anode, which is a positively charged piece of carbon, it leaps through a certain type of plasma material to a cathode, which is a negatively charged piece of carbon, where carbon particles are deposited and evaporated in the plasma. Finally, an inner core region with loosely packed columns built of straight, stiff multishell carbon nanotubes and nanoparticles from the anode can be obtained at around 25%, followed by an exterior hard-shell zone made of decomposed graphite. At 4000 k (about 6740 °F), the plasma where the nanotubes are generated has an extremely high average temperature. [25]. The advantage of this process is that it yields a lot of nanotubes, but the main drawback is that there isn't much control over the alignment, or chirality, of the nanotubes that are created, which is important for their characterisation and function. Additionally, the products need to be filtered after the reaction because of metallic catalyst used [17,25].

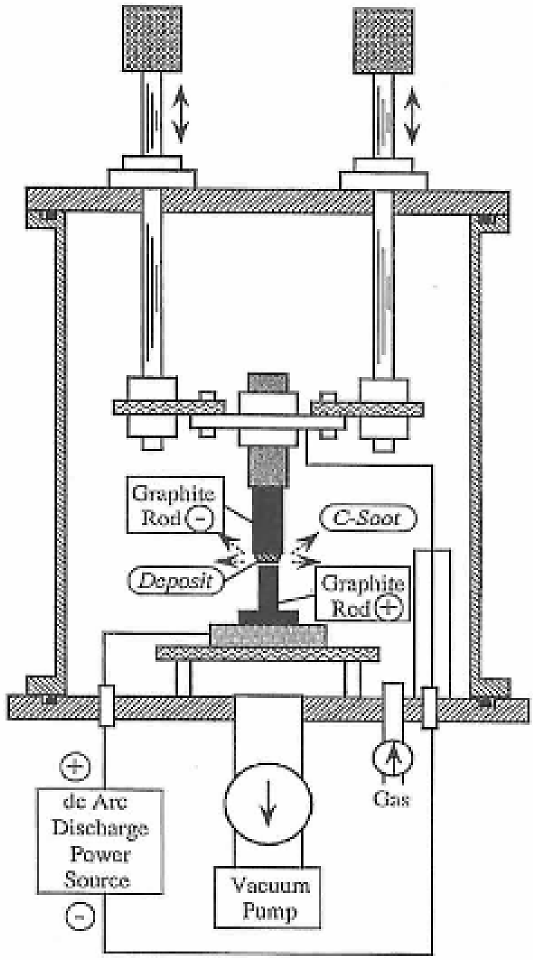


Figure 3.1: Schematic diagram of Arc discharge technique for CNTs synthesis

3.2. Laser Ablation Method

In the laser procedure, a pulse laser is used to vaporize a graphite target by striking it in a high-temperature reactor (figure 3.2) with an inert gas like helium present. On the reactor's cooler surface where the vaporized carbon condenses, carbon nanotubes grow [26]. Other procedures involve heating a quartz tube containing a graphite block in a furnace. The reaction is carried out using an ongoing flow of argon gas. The graphite inside the quartz is vaporized using a laser. In the downstream region, on the cooler quartz walls, the carbon condenses after it vaporizes, is transported away by the argon, and does so. SWNT and metallic particles are present in this condensation. Then, this mixture is subjected to purifying techniques. The setup of a curved sheet of graphene with a metallic catalyst atom close at the place where carbon atoms start to condense is crucial for the proper creation of condensed nanotubes [17, 27]. Since the metallic atoms involved tend to evaporate from the end of the tube after it is sealed, this approach has the advantage of having relatively low metallic impurities. One drawback is that this approach results in some branching in the nanotubes, which is not always uniformly straight.

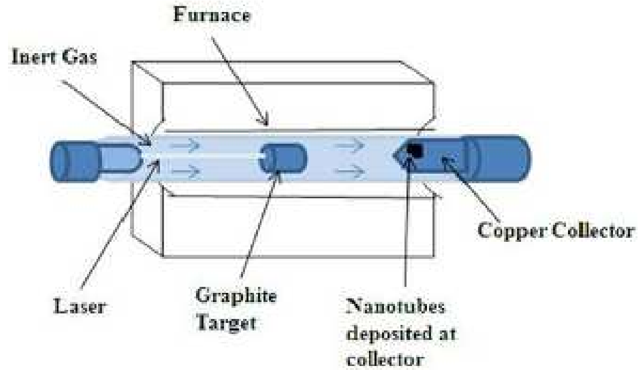
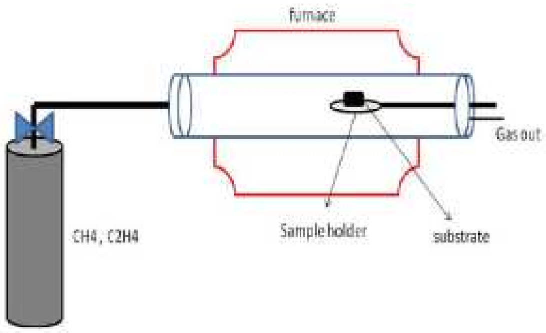


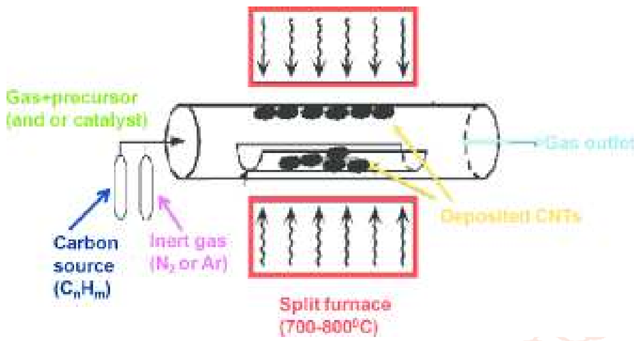
Figure 3.2: Schematic diagram of Laser Ablation set-up for CNT synthesis

3.3. Chemical Vapor Deposition (CVD) Method

As a result of the CVD method's ability to grow CNTs on a range of substrates, it is more practical to include it into techniques that are already in use for the synthesis of electronics. Here, a hydrocarbon in a substance is chemically broken down [17]. In the chemical process known as chemical vapor deposition (CVD), which operates at temperatures between 350°C and 1000°C, volatile precursors are employed to supply a carbon feed source to a catalyst particle or pore. In this procedure, the carbon precursor is added to the reaction chamber, and as the reaction develops, the hydrocarbon decomposes at a temperature of 700°C to 900°C and air pressure to create nanotubes, which are then generated and deposited on the metal catalyst [28, 29]. The catalyst particles in CVD reactors (Figure 3.3) can either sit in free space (the so-called floating catalysts) or on a substrate (the supported catalysts). Carbon saturates the catalyst particles in such a process, and it precipitates as carbon nanotubes. The breakdown of a volatile precursor can also produce the catalyst particles. Due to their ease of setup, CVD procedures are more favorable to the mass manufacture of CNTs [30]. This approach has the benefits of a very high yield, consistent nanotube alignment (important for producing specific types of nanotubes, such as metallic or semiconductor ones), and potentially arbitrary growing area size. The main drawback is that large portions (several centimetres) have a propensity to crack, shrink, and bend even if the size of the growing area is essentially arbitrary. To avoid this, the substrates must be completely dried [17, 27–31].



(a) Single furnace without inert gas



(b) Double furnace with inert gas

Figure 3.3: Schematic diagram of Chemical Vapor Deposition method for CNTs synthesis

4. Characterization of Carbon Nanotubes

The field emission scanning electron microscope (FESEM), which is capable of viewing structures as small as 1 nm on the surface of materials, is the most efficient method for analyzing the samples [32]. The structure and crystalline makeup of the MWCNTs are assessed using the X-ray diffraction (XRD) method; The elemental and quantitative composition of CNT has been identified and obtained through energy dispersive x-ray spectroscopy (EDS) analysis. Raman spectroscopy is used to investigate the physical properties and morphological characteristics of CNTs. The general morphology of CNTs is primarily studied using atomic force microscopy (AFM), nuclear magnetic resonance (NMR), and light scattering techniques. The existence of functional groups on CNTs can be confirmed using NMR and IR spectroscopy.

5. Applications of Carbon Nanotubes

Carbon nanotubes are frequently used. in Biological, Chemical, Medical, Material Science, and Engineering [33]. Due to their outstanding optical, electrical, and mechanical properties, CNTs are widely used as carbon nanomaterial in a variety of applications. They are used in solar cells, fuel cells, batteries, super-capacitors, hydrogen storage devices, adsorbents, membranes, sensors, conductive coatings, and photo-catalysts [34]. They are also used in biomedicine, particularly in the treatment of cancer, as extraordinarily sensitive biosensors and drug delivery devices [34,35]. Because of their exceptional mechanical, electrical, and thermal conductivity, CNTs are used as additives in a variety of structural materials [36]. Due to their many uses in different industries, CNTs are the nanomaterial with the fastest increasing market in nanotechnology.

6. Conclusion

An overview of the synthesis, characterisation, and applications of CNTs is provided in the review. Brief explanations of the various CNT kinds and CNT synthesis techniques (SWNTs and MWNTs) were also provided. The different sectors in which they can be employed as well as some of the CNT characterization techniques were covered. It is obvious that unique technology will develop in CNT in the future due to its elevated potential. The quantity and cost of CNTs are cause for concern in nanotechnology.

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