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The Structure, Property, Preparation and Application of Carbon Nanotube in Biosensors

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Abstract. Instruments known as biosensors are highly sensitive to biological materials and have the ability to detect concentrations by converting them into electrical signals. High-sensitivity detection of complex biological samples can be achieved by utilizing the specificity and sensitivity of biomolecules. Due to the high sensitivity, high selectivity and important applications of biosensors, they have attracted much attention. It is reported that the materials used in biosensors have a significant impact on their detection sensitivity. Therefore, exploring new functional materials to modify biosensors is helpful to improve the sensitivity and the accuracy of the biosensors. Carbon nanotubes, exhibit good stability of structure and excellent performance, such as mechanical properties, thermal conductivity and optical properties. As a result, in recent years, research on using carbon nanotubes for biosensor modification has gained a lot of attention. The characteristics and categorization of carbon nanotubes are described in this article. The process required for prepare carbon nanotubes and different biosensors based on carbon nanotubes are also outlined. Additionally, the methods for creating carbon nanotubes and how they are used in biosensors are discussed.

Keywords: Carbon Nanotube; Biosensor; Application; Preparation.

1. Introduction

Biosensors are the most promising testing methods in the medical field. Compared to traditional detection methods, biosensors have the advantage of easy operation. However, the bio-sensing technology still has some limitations in the application. For example, false positive and false negative reactions may occur. The stability and reliability of the results also have some problems. Although there is a lot of progress which has been made on bio-sensing technology, it still needs to face the problems on complex detection problems. They need to be improved and adapt to diversified detect environment. Biosensors can also be affected by aging materials, electrode leakage and other factors during working. Therefore, improving the detection sensitivity and stability of biosensors has become a research hotspot.

Choosing high-performance nanomaterials to modify biosensing technology is considered to be an effective way to solve this problem. Carbon nanotubes (CNTs) are important nanomaterials because of their unique physical and chemical properties [1-3]. A carbon nanotube is a tube which is consisting of several layers of carbon atoms arranged in a hexagonal arrangement. This structure allowed them to perform well in mechanics, electricity, thermal conductivity and optical properties. Furthermore, CNTs also have extremely high tensile strength, Young's modulus and fracture strain. CNTs exhibit good strength and elasticity even compared to steel. These properties make CNTs have high possibility to modify the biosensing technology.

CNT-based biosensors are promising due to their high integration, high sensitivity, low price, and quick reaction time. Clinical biochemical diagnostics can now be done more easily and conveniently because to the invention of CNT-based biosensors. These sensors can detect biological molecules for instance insulin, nitric oxide and fibrinogen in the blood. It is important for the diagnosis and diseases treatment. Thus, the focus of this work is on the CNT-based biosensors. Firstly, the features of carbon nanotube materials and their structures are discussed. These attributes greatly increase the practicality and performance of carbon nanotubes compared to other materials. The second section introduces the preparation process of CNTs. Moreover, the use of CNTs in biological sensors is shown, and employing them as materials significantly increases the precision and robustness of biosensors.

2. Carbon Nanotube

2.1. Structure and Property

With nanoscale diameters and microscale lengths, CNTs have a one-dimensional form. There are now two primary categories of CNTs which are single-walled carbon nanotubes (SWNTs) and multi-walled carbon nanotubes (MWNTs). SWNTs and MWNTs are distinguished by the layers of the graphic shells.

SWNTs is formed by a graphic sheet tube with a diameter of around one nanometer which is rolled into the shape of a cylinder. Fullerene cage covers the end of the tube. The fullerene structure has a pentagon next to alternate configurations of five hexagons. Adjacent hexagonal cells form the graphene sheets that comprise the lateral walls of carbon nanotubes. Typically, SWNTs can assemble into a bundle. Hexagonally organized SWNTs create a structure that resembles a crystal in a bundle configuration. Different rolling techniques can yield nanotubes with various compositions and characteristics. Because of the cylinder structure, the number of effective ways for creating seamless cylinders is restricted. Consequently, the three forms of SWNTs which can be distinguished into chiral, armchair, and zigzag. These different arrangements may differ in terms of conducting electricity and rigidity.

MWNTs are assembled from single-walled carbon nanometers that vary in thickness. Neighbor shells are spaced apart by around 0.34 to 0.39 nm [1]. Because the larger carbon nanotubes cover the smaller carbon nanotubes, it is known as the Russian doll model. Conversely, a parchment model is a graphic sheet that rolls up similarly to a piece of paper. MWNTs and SWNTs exhibit different sizes and characteristics.

Carbon nanotubes have certain novel chemical, mechanical, and electrical features that are not found in other materials. They are initial inertness to the majority of chemicals. For carbon nanotubes, in order to acquire new characteristics and become more chemically reactive, groups of functional surfaces are needed. The chiral vector, which has the indices (n, m), affects the electric conductivity of graphene nanotubes (SWNs). Carbon nanotubes are metallic when n=m or (n-m)=3i (where i is an integer). While CNTs are semiconductors in all other cases when a chiral vector with indices (n, m) is taken into account [2]. By the way, because carbon nanotubes include sp^2 bonds, which are significantly stronger than the sp^3 linkages found in diamonds, they have a greater capacity for bending than steel.

There is another remarkable property of carbon nanotubes which is elasticity. When the CNTs are putted under high force and press, it can bend or twist. Finally, they can return to their original structure without being damaged. But there is a limit on elasticity of CNTs. When they are putted under very large pressure, their shape will be deformed temporarily. If there are some defects on the CNTs including the condition that some of the hexagon fullerene shapes changed to heptagon, these changes will weaken the strength of CNTs. Elastic modulus determines the elasticity of both MWNTs and SWNTs. Due to the strength of bonding in the CNTs, they can withstand high temperatures. In addition, it is proved that they can be a good heat conductors. At normal temperatures, they are capable of surviving up to 750°C. At vacuum atmospheric pressures they can withstand 2800°C.

2.2. The Preparation of Carbon Nanotubes

There are methods for creating carbon nanotube structures, most of which need gas phase operations. These methods have produced carbon nanotubes at a fair price, with great yield and quality in huge quantities. The three main methods commonly employed to produce carbon nanotubes include the chemical vapor deposition (CVD) [3, 4], laser-ablation [5], and carbon arc-discharge [6-8]. Although carbon nanotubes were initially produced using high-temperature techniques like arc discharge or laser ablation, chemical vapor deposition, which produces carbon nanotubes at temperatures below 800°C, is a more practical technology. The total length, size, purity, and average density of carbon nanotubes may be precisely regulated by using the low-temperature conditions chemically vaporized deposition approach.

High temperatures are used in the arc discharge method to produce carbon nanotubes. The temperature is usually above 1700ºC. Unlike previous methods, this one will lead to the expansion of carbon nanotubes while reducing the amount of surface imperfections in the structure. For this method, a low-pressure, empty chamber operating between 50 and 700 mbar that contains inert gas is located at an experiment facility [9]. A constant current of 50 to 100 A with an output voltage of 20V is applied to two carbon rods positioned end to end at a distance of just a few millimeters. This will generate a high temperature that will cause the negative electrode to sublimate. The periphery is covered with a hard gray shell of carbon that remains. It condenses into chamber soot at the chamber walls and cathode soot on the cathode. Carbon nanotubes with one or more walls can be produced from the soft, dark-colored inner core, cathode soot, and chamber soot. In the carbon nanotube production process using arc discharge, there are two different methods. Synthesis can be accomplished either with or without the aid of a catalyst. The catalyzer is not needed in the production of the MWNTs. The catalyzer is needed in the production of the SWNTs.

A quartz tube which holds a piece of pure graphite is heated to 1200ºC in an Ar environment [10]. Using a laser is meant to evaporate the graphite. For produce the SWNTs, the laser technique is necessary in order to add the metal particles as catalysts on the surface of the graphite. Studies have shown that the laser power has an effect on the diameter of nanotubes. The diameter of the tubes decreased as the laser pulse power rose. This technique has a high potential to produce a large amount of high quality and high purify single walled carbon nanotubes. Laser ablation works with a similar principle as the arc discharge process. However, when the laser is focused on metal particles, the catalysts within the particles supply the necessary energy. The primary benefits of this method are high yield and low levels of metallic contaminants. When the tube is closed, all of the metal particles have a propensity to evaporate from the end. This technique results in carbon nanotubes with branched structures rather than straight.

2.3. Applications in Biosensors

Carbon nanotubes have unique chemical and physical characteristics that make them useful in a variety of biosensors. These biosensors may be categorized into three groups which include electrochemical biosensors, field-effect-based biosensors, and optical biosensors.

The first kind of sensor may be an electrochemical one. They are relatively simple, low cost with high portability, electrochemical sensors are still used today. The most widely utilized type of electrochemical sensors are electrochemical enzyme sensors. It is because they have the ability to detect glucose. The enzyme sensors which based on carbon nanotubes have been reported in some conditions such as glucose detection. The simplest method for securing the enzymes to the carbon nanotube surfaces is absorption. On the electrode surfaces, carbon nanotubes may be produced instantly and have the ability to absorb enzymes prior to depositing. Carbon nanotubes in ionic liquids are dissolved. Then these mixtures are applied to the electrode. Then, techniques like ionic attraction, covalent bonding, or adsorption, could be used to achieve the attachment of the enzymes.

Field-effect transistors are widely used microelectronic devices. It is usually made of three electrodes and one semiconductor channel. Due to the high electric conductivity and high surface area, the CNT-based field-effect biosensors are considered as the research hotspot in recent years. The carbon nanotubes, which are used in the field-effect biosensors, are mostly SWNTs, making them appropriate for the formation of semiconductor channels. The CVD method is the most commonly used method for producing CNT-based field-effect sensors.

CNTs have been reported to improve the performance of optical biosensors. The physical and luminous characteristics of carbon nanotubes make them a popular material for biosensors. Different optical and electronic properties can be obtained by attempting to use different preparation methods. This results in the diversity of chirality. It also makes the multichannel sensing platform comes to be possible. By monitor the signal in different wavelength, CNT-based biosensors can detect the polyanalyte at the same time. Every carbon nanotube has its specific probe for DNA detection. By monitoring the signals in channels with different wavelengths, they can detect the multiple targets in one sample. Furthermore, the multiplex sensor array based on carbon nanotubes which has different chirality is also reported.

3. Conclusion

CNTs, as a novel functional material, have played an important role in the modification of biosensors. In this work, carbon nanotubes are outlined in detail including the preparation methods and performance. The applications of CNTs in electrochemical biosensors, field effect based biosensors, and optical biosensors are introduced.

Although there are many studies on CNTs, there is still much work to be done before CNT-based biosensors can enter the market. Improving portability is the future consideration for this type of biosensors. Improving sensitivity and reducing costs are also needed to be considered. Obtaining high flexibility and improving wearing comfortability in CNT-based biosensors are also the problems which is worth exploring.

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