The Application and Future Trend of Carbon Nanotubes Based on the Development and Properties

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Abstract: Moore's Law, as the most important and wildly followed laws in the semiconductor industry, seems to approach its end. In this situation, many measures have been taken to change this trend, including finding new and better materials. A hot new material, the carbon nanotubes (CNTs), have attracted many researches. As a one-dimensional material, carbon nanotubes have excellent Young's modulus, electrical conductivity, optical conductivity, etc. These excellent properties can be used in the semiconductor industry and some other areas. In this paper, chemical structure, physical, chemical and electrical properties of carbon nanotubes are introduced. Its commonly used preparation methods and doping strategies are also presented. Some current applications including sensors, electronic devices and biomedicine and development owing to these properties will also be shown to the readers. Certain future possible applications and develop directions will also be discussed. Although there are many shortages and challenges scientists are facing, such as the cost, the quality, the toxicity and so on, CNTs remain a promising material due to its excellent properties. This article gathers these current applications for readers to get some further knowledge about this hot material as well as attract more people to relevant research work.

Keywords: Carbon Nanotubes, Semiconductor, Biomedicine, Sensors.

1. Introduction

At the end of the twentieth century, due to the further reduction of the feature size of chips, a series of marginal effects and quantum effects continued to appear as a single semiconductor device approach to the atomic size, which brought many side effects to the performance of the product. In addition, smaller and smaller fabrication dimensions also bring great challenges to fabrication steps such as lithography and doping. Many factors have made Moore's Law of doubling the number of transistors that can be accommodated on an integrated circuit and doubling the performance per 18 months that the related semiconductor industry begins to fail.

To this end, relevant practitioners have begun to explore ways to further break through the limitations from various aspects. These ways can mainly be divided into two types, more Moore and the more than Moore. Among them, there is an exploration of new device structures and layouts, such as the Fin Field-Effect Transistor (FinFET), gate-all-around Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) and other emerging device structures. There are also explorations of new semiconductor materials, such as indium phosphide, arsenic gallium nitride and other new semiconductor materials. In addition, some one-dimensional and two-dimensional materials have also entered the field of vision of industrial researchers due to their excellent electrical and optical properties.

Among the new material exploration, carbon element, as an element in the same main group as silicon element, have also begun to be studied by the semiconductor industry. As the fourth main group element, carbon element has relatively stable chemical and physical properties like silicon element, and the method of obtaining it from nature is relatively simple, and it also has corresponding advantages in electrical and optical properties. This allows the C element to stand out from the multitude of possible sub-materials. C also has many structures, among which carbon nanotubes are one of them. As a one-dimensional material, carbon nanotubes (CNTs) have excellent Young's modulus, electrical conductivity, optical conductivity, etc. There are three typical SWNTs chiral structures that have been proposed, the type of chair, the zig-zag-type and the helical type., The

electronic behavior of SWNTs will change between semiconductors and metals due to these three distinct types. By changing the amount or the type of different CNTs, scientists can reach the properties of a CNTs device they want. Nowadays, there are several primary techniques for creating CNTs: the chemical vapor deposition (CVD), the laser ablation method, the electric arc method, catalytic decomposition and the laser deposition method. Meanwhile, some new technology such as the Self-assembly technology emerge though they are not mature yet.

In this paper, the author collects some of nowadays applications and researches to help the reader get some further knowledge about this hot material, and further looks forward to the possible potential applications of CNT in the future from the development history and related properties of CNTs.

2. Structure

A carbon nanotube is a needle-shaped structure made solely of carbon atoms that has a graphitic structure along its long axis, which means that the carbon nanotube can be regarded as a kind of one-dimensional material [1,2]. One or more cylindrical shells of graphitic sheets may make up a nanotube. Consequently, the carbon nanotube may be thought of as tubular graphite microcrystals [2]. The single-walled nanotube (SWNTs) and multi-walled nanotube (MWNTs) are two different types of carbon nanotubes which depend on the wall. In MWNTs, one tube is positioned within the other, which feature two or more concentric tubes. The properties of a SWNT depend on the direction where the hexagons are positioned with respect to the tube axis. Nowadays, three typical SWNT structures—the armchair-type, the zigzag-type, and the helical-type—have been proposed and these three different types will cause the electronic behavior of SWNTs to vary from semiconductors to metals by changing the amount or the type of different CNTs, scientists can reach the properties of a CNT device they want [3].

3. Properties

3.1 Physical properties

High tensile strength, low weight, and other outstanding physical characteristics are all possessed by carbon nanotubes [4]. With excellent Young's moduli (as high as 1 TPa) and outstanding tensile strengths (as high as 63 GPa), it is one of the toughest and strongest fibres known to humankind.[1]. This surpasses the tensile strength of sturdy industrial polymers by several orders of magnitude.

3.2 Chemical properties

The chemical properties of carbon nanotube are similar to those of carbon, which is chemically stable. Additionally, due to its great biocompatibility, chemical inertness, and extensive antibacterial and antifungal capabilities, it may be employed in a variety of unique applications. such as biomedicine and some bio-sensors. [4].

3.3 Electrical properties

Carbon nanotubes have extremely low electrical resistivities, which can be as low as 5.1 mU cm for a multi-walled carbon nanotube with a 9.1 nm diameter and are usually between 1 and 10 mU cm. This can be lower than many metal materials [5].

4. Preparation

4.1 Preparation

Sumio Iijima's work published in Nature in 1991 sparked a surge in interest in carbon nanotubes. Iijima was utilising high resolution transmission electron microscopy (HRTEM) to look at carbon nanotubes made after graphite was arc-vaporized in helium. Single-walled nanotubes may be created catalytically, much like multi-walled nanotubes, it was demonstrated in 1996 [1].

Nowadays, there are several primary techniques for creating CNTs: the chemical vapor deposition(CVD), the laser ablation method, the electric arc method, catalytic decomposition and the laser deposition method and so on. Among them, the CVD, arc discharge and laser ablation are in common use [4].

Methane, ethylene, and other hydrocarbon sources are used in the chemical vapour deposition process. Typical Chemical vapor deposition use two or more gaseous feedstocks to introduce into the reaction chamber, where they chemically react with each other to form CNTs that are deposited on the wafer surface. The formation of both MWNTs and SWNTs is accomplished by the arc discharge process, which employs the high temperature required for the evaporation of carbon atoms into a plasma. For MWNT, the presence of a catalytic agent is optional, but for the manufacture of individual SWNT, a catalytic agent is necessary, such as cobalt, yttrium, nickel, iron, etc. In the laser ablation, a long quartz tube with a graphite target in the centre is placed in a heating furnace. When the furnace reaches a specific temperature, an inert gas is pushed into the tube and a laser beam is directed at the graphite target. Under the influence of laser radiation, gaseous carbon is produced. Gaseous carbon and catalyst particles are transformed into CNTs by the catalyst when they are transported by a gas stream from a high temperature region to a low temperature region.

4.2 Doping

Doping is a necessary process in the semiconductor area, which is a key process to fabricated the p-n junction, transistor and other structures. As a highly expected material, scientists have studied a lot on how to dope the carbon nanotubes.

4.2.1 P-type doping

The oxygen and water deposited on the surface of the SWNTs will act as an electron acceptor against the SWNTs, giving them a positive charge, which causes the SWNTs-TFTs (thin film transistors) to display p-type semiconducting properties in typical cases [6]. Therefore, researchers can even get a p-type carbon nanotubes without doping, though this is not stable.

To get a stable P-type CNT, some III A groups elements such as Boron, Indium, Gallium are always used for doping in the fabrication of P-type carbon nanotubes.

4.2.2 N-type doping

To get a N-type CNT, elements of V A or VI A groups can be used for doping, such as nitrogen, phosphorus, etc.

Certain metal elements from the I A groups have been employed in some studies to dope N-type carbon nanotubes too. As an illustration, Y Abiko and his group successfully created stable n-type TFTs using Cs that was encased in SWNT. Through the use of doping techniques, they discovered that the n-type characteristic is stable even in water and at high temperatures [6].

5. Discussion

5.1 Advantages

Because of its outstanding qualities, including its small weight, high tensile strength, and quick electron transfer kinetics, carbon nanotubes can be added to the device to improve conductivity, reduce weight as well as enhance strength.

Moreover, its excellent biocompatibility aids in the immobilisation of proteins. Carbon nanotubes have a vast surface area, are chemically inert, have antibacterial and antifungal characteristics, and may be changed with functional groups, making them suitable as protein carriers. In several biosensor applications, carbon nanotubes are incredibly appealing due to all these qualities. [4].

5.2 Disadvantages

The corresponding preparation methods or conditions such as how to prepare the CNTs on a large scale and ensure the quality of each products remain a great challenge. For instance, the paper claims

that agglomeration of the CNTs, which is a frequent issue caused by the tiny size of the CNTs, makes it difficult to achieve the necessary features of a CNTs device [7,8]. In terms of the price, unpurified SWNT samples are priced at roughly $5 per gram, whereas purified SWNTs are priced around $50 per gram. In contrast, the price of gold is presently around $10.00 per gram. [1].

Furthermore, for a variety of reasons—including the fact that their toxicity profile for human cells has not yet been adequately addressed—CNTs cannot replace or compete with the antibacterial materials now in use (such as polymers and Ag-NPs). They take a long time to make and cost a lot of money, and mass manufacturing is still exceedingly difficult.

6. Applications

There are so many practical or possible applications of carbon nanotubes. In this article, the author will list three main applications, the sensors, the electronic devices and the biomedicine. And also show some possible directions and developments on these aspects.

6.1 Sensors

Carbon nanotubes can be used in different kinds of sensor thanks to the above-mentioned exceptional properties.

For instance, there are several standard ways for detecting gases, but each one needs large instruments and trained personnel to operate. Because they are far more affordable, lighter, and easier to carry, compact size sensors are a great option. In terms of sensitivity and selectivity, carbon nanotubes serve as the sensing surface in gas sensors, giving them a significant edge.

Because of their superior electromechanical qualities, carbon nanotubes may also be employed in piezoelectric sensors. According to study done by Park et al. in 2019, the sensor made using carbon nanotubes is very sensitive, biocompatible, simple to build, small, flexible, and affordable.[9]

6.2 Electronic devices

The excellent electronic properties help the carbon nanotubes become a promising material in some electronic devices such as the lithium-ion battery, the electric double-layer capacitor (EDLC), MOSFET, flexible TFT, memory and so on.

Carbon nanotubes have great mechanical qualities, a high surface-to-volume ratio, and a few electrical characteristics, such as high conductivity and high energy density, that make them potentially suitable as anode materials [3]. In this situation, electrically conductive carbon nanotubes can be utilised as an addition in the electrode of an EDLC due to its robust electrical and mechanical qualities. Comparing the electrodes with carbon black to those with carbon nanotubes has revealed the latter to have a higher capacity at current densities [4,10]

6.3 Biomedicine

Carbon nanotubes are mostly used in the biomedical fields of drug targeting, cancer detection and therapy, antibacterial and antifungal medicines, and so forth.[4]

Both drug targeting and controlled drug release employ MWNTs. Carbon nanotubes are used in the delivery of medication because of their hydrophobic qualities, which enable them to remain in the circulatory system for an extended period of time. Carbon nanotubes have been employed for targeted and controlled drug administration because to the wide range of stimuli they can manage, including magnetic stimuli, electric stimuli, temperature changes, and many more. Various biomolecules, including as proteins, DNA, RNA, immunoactive substances, and lectins, are transported via carbon nanotubes [4].

Researchers have also found that carbon nanotubes has great antibacterial potential [4]. In a number of methods, carbon nanotubes can exhibit antibacterial properties. Carbon nanotubes have an antibacterial activity, however the precise mechanism behind this feature is yet unknown. Carbon nanotubes can affect the surface of microorganisms in a number of ways, such as by altering the

integrity of the membrane by developing intimate associations with the membrane surfaces or by inducing a specific generation that results in DNA damage and cell death.

6.4 The future development

Though there is a lot of practical applications in certain areas that have been studied, some specific issues remain to be addressed. In view of the preparation problems, continuous study on the corresponding preparation methods or conditions such as how to prepare the CNTs on a large scale and ensure the quality of each products remain a great challenge. The Self-assembly technology seems to be able to improve this situation but it is not mature yet. For the application of materials, to change the current predicament that the performance of auxiliary materials is not prominent enough, research may focus how to improve the method of adding or the amount used. For biomedical applications, research on how to reduce the toxicity of CNTs for disease detection, condition monitoring and disease treatment in biology and even human body is a huge challenge. Above all are the current predicaments, but also directions that scientists can strive to improve.

7. Conclusions

This paper briefly introduces the chemical structure, physical, chemical and electrical properties of carbon nanotubes. Its commonly used preparation methods and doping strategies are also presented. of nowadays hot material, the carbon nanotubes. After a brief understanding of these, the author shows some current developments and applications in the sensors, the electronic devices and the biomedicine areas owing to these properties. At the end of this article, some possible applications in these aspects and other areas are also showed too. Although there is no evidence shows CNTs can fundamentally solve the problem of Moore's law failure, it can alleviate this to some extent and lead to some new opportunities to the development of some similar materials in the semiconductor industry. At the same time, research on carbon nanotubes has further deepened people's understanding of this material, providing a basis for carbon nanotubes to play a role in other fields This paper aims at helping the readers who know little about the carbon nanotubes but are curious about this new hot material to gain some knowledge and to clarify the development history of carbon nanotubes. However, this paper focuses on just three main areas with concise elaborations, aimed at attract more people to pay attention and invest in related industries

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