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A Review of the Extremely Structural Properties of Carbon Nanotubes, Synthesis and Purification Methods

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Abstract: Carbon nanotubes (CNTs), also known as Bucky tubes, are a class of nanomaterials consisting of a two-dimensional hexagonal lattice of carbon atoms that bend in one direction and combine to form hollow cylinders. Carbon nanotubes are cylindrical isotropic forms of carbon, between Fullerene (0-dimensional) and Graphene (2-dimensional), and technologies are now available for mass production of nanotubes, including electric arc discharge, laser ablation, chemical vapor deposition (CVD) and high-pressure carbon monoxide disproportionation (HiPCO), consisting of a single layer of carbon atoms (graphene). The pieces are rolled up to make up. They can be single-walled carbon nanotubes (SWCNT) with a diameter of less than 1 nanometre (nm) or multi-walled carbon nanotubes (MWCNT), consisting of several concentrically interconnected nanotubes with a diameter of more than 100 nm, which can reach lengths of a few micrometers or even millimeters. Furthermore, as one-dimensional nanomaterials, these cylindrical carbon molecules have excellent mechanical stiffness and tensile strength due to the nanostructure of carbon nanotubes and the strength of the interatomic bonding. Carbon nanotubes also have certain chemical stability, high electrical conductivity, and excellent thermal conductivity, so carbon nanotubes have a promising future and will be widely used in alloy reinforcement materials, load material electrodes, conductive films, etc.

Keywords: Carbon Nanotubes, Preparation Methods, Modification Methods, One-Dimensional Nanomaterials, Properties

1. A Brief History of Carbon Nanotubes

Carbon nanotubes were officially recognized and named in 1991, and before that, they had been discovered in some studies and subsequently manufactured, but they did not attract attention at the time, and they were not regarded as a new form of carbon while ignoring their importance [1]. In 1890, it was discovered that carbon-containing gases could decompose on hotter surfaces to form filament-shaped carbon. In 1953, when CO and Fe_3O_4 reacted at high temperatures, a filamentous structure similar to carbon nanotubes was also discovered. Since the 50s of the 20th century, carbon deposition in petrochemical plants and cold nuclear reactors has become a major problem, that is, the accumulation of carbon filaments in this process has gradually been paid attention to. In order to inhibit the growth of carbon filaments, many studies have been conducted on its growth mechanism. In these carbon filaments obtained by organic catalytic pyrolysis, carbon nanotube-like structures have been found. In the late 70s of the 20th century, New Zealand scientists discovered that when an electrical spark is generated between two graphite electrodes, small fibrous clumps form on the surface of the electrodes [2]. Electron diffraction measurements revealed that the walls were composed of carbon arranged like graphite. In fact, the protection of multi-walled carbon nanotubes has been observed [15]. In 1991, Lijima, an electron microscopy expert at the basic research laboratory of NEC Corporation in Japan, was examining spherical carbon molecules generated in graphite arc equipment under a high-resolution transmission electron microscope when he accidentally discovered that tubular coaxial nanotubes were composed of carbon molecules, now known as "carbon nanotubes", or carbon nanotubes, also known as buckle tubes. In 1993, S. Lijima et al. and D. S. Bethune et al. simultaneously reported that by adding a certain catalyst to the graphite electrode by arcing, carbon nanotubes

with only one wall, that is, single-walled carbon nanotubes, could be obtained. In 1997, A. C. Dillon et al. reported that hollow tubes of graphene nanotubes could store and stabilize hydrogen molecules, which attracted widespread attention. Related experimental studies and theoretical calculations have also been carried out [12]. It is speculated that the hydrogen storage capacity of graphene nanotubes can reach 10% (mass ratio). In addition, carbon nanotubes can also be used to store other gases, such as methane.

2. Classification of Carbon Nanotubes

Carbon nanotubes can be considered as rolled graphene sheets, so using the number of graphene sheets as a basis for classification, they can be split into: single-walled carbon nanotubes and multi-walled carbon nanotubes. The individual layers between the lamellar structures are easily the centre of capture for a variety of defects, so that the walls of multi-walled tubes are often suofugai by small pore defects [3]. Compared with multi-walled tubes, single-walled tubes have a smaller distribution area of diameters, fewer defects, and higher homogeneity. The typical diameter of single-walled tubes is 0.6-2nm, the innermost layer of multi-walled tubes can be up to 0.4 nm thick and the thickest layer can reach hundreds of nanometers, but most typical diameters are between 2 nm and 100 nm. Furthermore, for single-walled carbon nanotubes, the synthesis requires a catalyst. Batch synthesis is difficult because it requires proper control of growth and atmospheric conditions. Not completely dispersed and form a bundled structure. The resistivity is always in the range of 10^{-4}——10^{-3}, and the purity is relatively poor. [5, 10] Typical SWCNT content is about 30-50 wt% in chemical vapor deposition (CVD) prepared samples. However, high purities of up to 80% have been reported using the arc discharge synthesis method. Defects are more likely during functionalization. Characterization and evaluation are easy. It twists easily and is more flexible. For multi-walled carbon nanotubes, they can be produced without a catalyst [12]. Batch synthesis is easy. Evenly dispersed, there's no obvious bundle formation. The resistivity is usually high in the 1.8×10−5–6.1×10−5 Ω·m purity. Typical MWCNT content in CVD-prepared samples is about 35-90 wt%. Defects are less likely, especially when synthesized by arc discharge, which has a very complex structure and cannot be easily twisted.

Carbon nanotubes are classified according to their structural characteristics and can be divided into three types: handrail nanotubes, herringbone nanotubes, and chiral nanotubes [11]. The helicity and electrical properties of carbon nanotubes are largely determined by the chirality index (n,m) of carbon nanotubes, usually n>=m. For details, when n = m, carbon nanotubes are called armchair-shaped nanotubes, and the chiral angle (helix angle) is 30°; When n>m=0, carbon nanotubes are called zigzag nanotubes, and the chiral angle (helix angle) is 0°; When n>m≠0, it is called chiral carbon nanotubes.

The conductivity of carbon nanotubes can also be regarded as a major criterion for their classification, and can be divided into according to their different conductive properties,

metallic carbon nanotubes and semiconducting carbon nanotubes: when n-m=3k (k is an integer), carbon nanotubes are metallic; when n-m=3k±1, carbon nanotubes are Nanotubes are semiconducting [6, 14].

Another more commonly used classification method is whether its tube wall contains defects, which can be divided into perfect carbon nanotubes and defective carbon nanotubes.

In addition, the uniformity of the shape of carbon nanotubes and the overall shape can also be used for classification, which can be divided into straight tube type, carbon nanotube bundle, Y type, snake type, etc.

Tube wall defects also have a certain influence on the mechanical properties of carbon nanotubes, and based on this, it is helpful to further understand carbon nanotubes and their composites. Due to the limitations of the carbon nanotube manufacturing process and the imperfection of the process, carbon nanotubes contain a large number of various defects, such as atomic vacancy defects (single or polyatomic vacancies) and Stone-Thrower-Wales (STW) type defects.

3. Preparation Method of Carbon Nanotubes

At present, the major synthesis methods for synthesizing carbon nanotubes are arc discharge, catalytic cracking, chemical vapor deposition, laser ablation, solid phase pyrolysis, laser method, and so on. Among them, the catalytic cracking method has the advantages of simple methods, is easy to control the conditions, and can be produced in large quantities, so this method is also the main method for the preparation of carbon nanotubes. However, the crude carbon nanotubes produced by catalytic cracking usually contain catalyst carriers, such as SiO_2 and Al_2O_3, which need to be separated and purified to obtain pure carbon nanotubes. This increases the number of intermediate steps and production costs and reduces the yield.

Other methods to obtain carbon nanotubes include the spontaneous formation of carbon nanotubes by the exothermic reaction of cesium with nanoporous amorphous carbon at a lower temperature of 50 °C; and the discovery of carbon nanotubes in the soot from the combustion of acetylene and benzene in low-pressure flames; the synthesis of carbon nanotubes as well as onion-like structures by electrolysis which uses molten alkali metal halides as the electrolyte, graphite rods as electrodes in an argon atmosphere; and the preparation of the alloys Fe-Ni-C, Al_2O_3 by powder metallurgy [7]. Fullerenes and monolayers of carbon nanotubes were found in the micropores of the alloys Fe-Ni-C and Fe-Ni-Co-C.

In addition, three additional methods for the preparation of carbon nanotubes are presented, the first being the arc discharge method, which is detailed over as two graphite rods connected to the power source that separates them by a number of millimeters. At 100 amperes, the carbon evaporates and a thermal plasma is formed; this method can easily produce single-walled cells, and ultramicroscopic networks with few structural defects and at a low cost; the drawback of

this method is that resulting carbon nanotubes are short and random in size and orientation; the second is the laser ablation method, which focuses on blasting graphite with intense laser pulses; using laser pulses instead of electricity to produce carbon nanotubes formed from carbon gas; and trying various conditions until conditions are encountered that produce a large number of carbon nanotubes [8]. This method results in better quality carbon nanotubes, higher yields, and narrower distribution than arc discharge. However, this method needs expensive lasers and high-power requirements, making it costly; the third method is chemical vapor deposition, which is detailed by placing the substrate in an oven, heating it to a high temperature, adding a carbon-containing gas for example methane (CH_3, etc.) slowly. With the gas decomposes, it releases carbon atoms, which are recombined in the form of NT. This approach is the easiest and best to expand to industrial mass production, with a simple process that produces carbon nanotubes of controlled diameter and considerable purity.

4. Purification of Carbon Nanotubes

Carbon nanotubes, which are divided into two categories: single-walled carbon nanotubes and multi-walled carbon nanotubes, and their properties are different, so their purification methods are also different; and because different preparation methods and experimental conditions attract different impurities, so the purification methods also vary according to the specific preparation methods [9]. So far, many kinds of purification methods have been proposed for carbon nanotubes, which can be roughly divided into physical methods, chemical methods, and integrated purification methods.

4.1. Physical Purification Method

4.1.1. Centrifugal Separation Method

As the size of impurities such as graphite particles, carbon nanoparticles, and amorphous carbon is larger than that of carbon nanotubes, they are deposited first by centrifugal force during centrifugal separation, while the smaller size carbon nanotubes are left in solution and thus separated. This removes nanospheres, metal nanoparticles, and other forms of carbon particles, but some approaches produce lower nanotube yields, especially after repeated centrifugation many times.

4.1.2. Electrophoretic Purification Method

Using the principle of electrophoresis, the CNTs prepared by the conventional arc discharge method are first fully dispersed in an isopropanol solution, centrifuged to remove the larger fragments, and then two coplanar aluminum electrodes with a spacing of 0.4mm are placed in a vessel filled with the dispersion. Since CNTs are electrically anisotropic, when an alternating electric field of 2.5×10^3 V.cm^{-1} is applied between the two aluminum electrodes, the CNTs will move towards the cathode under the action of the electric field and arrange themselves in a regular direction along the electric field. Calculations show that CNTs migrate in the electric field at a rate greater than 5×10^{-5} cm^2.V^{-1}.S^{-1}.

The method separates CNTs from other impurity particles depending on the electrophoretic rate, and the resulting CNTs are not damaged. The researchers also believe that the electrophoretic method offers the possibility of selecting and manipulating single carbon nanotubes.

4.1.3. Filtration Purification Method

Carbon nanotubes can be present as dynamically stable casting dispersions in solutions with surface activity in aqueous solutions [13]. This technique is usually applied in combination of oxidation. Products with acidic decomposition have very high solubility in alkaline solutions, while CNTs are insoluble, separated using an alkaline solution with pH 11 and filtered using a 3-5 micron filter, usually under vacuum. The filtration method is simple and effective, which can remove nanospheres, metal nanoparticles, polyatomic carbon, and fullerenes without destroying the sample, but the method is costly.

4.1.4. Ultrasonication

Carbon nanotubes are suspended in a solution of distilled water, toluene, or acid and sonicated for 5-30 minutes. This separates the carbon nanotubes from the attached particles, producing a scattered of the nanotubes and other particles for better centrifugation. The separation of particles is highly dependent on the surfactants, solvents, and reagents used. Solvents have an impact on the stability of the dispersion tubes in the system.

4.1.5. Spatial Exclusion Chromatography

Space exclusion chromatography (SEC) is also known as gel permeation chromatography. The method is based on differences in the size and shape of the specimen molecules to achieve separation. The filler used in this method is a gel, the pore size of which should be comparable to the size of the specimen being separated [6]. For those molecules that are too large (e.g. carbon nanotubes) they cannot enter the pores and are repelled, so they are the first to flow out as the mobile phase moves; small molecules can enter large and small pores without being repelled at all and are the last to flow out; medium-sized molecules can enter larger pores but are repelled by smaller pores and so flow out between the two cases. As the size of carbon nanotubes and other impurities are different, this method can effectively separate single-walled or multi-walled carbon nanotubes from other impurities.

4.2. Chemical Purification Methods

Carbon nanotubes have high structural stability and are resistant to strong acids and bases, while other impurities, such as graphite particles, carbon nanoparticles, and fullerenes, are far less stable than carbon nanotubes [8]. The metal catalyst particles can be removed with acids (e.g. hydrochloric acid, hydrofluoric acid, etc.) and the other carbon components can be removed with oxidants, taking advantage of the high stability of carbon nanotubes and their resistance to oxidation. The commonly used oxidation methods are vapor phase oxidation and liquid phase oxidation, also known as dry and wet methods.

4.2.1. Vapour Phase Oxidation Purification Method

The gas phase oxidation method mainly uses air or oxygen to oxidize samples containing carbon nanotubes for the purpose of purification, which does not require special experimental equipment, and the reaction conditions are easy to control. However, the oxidation time of the gas phase oxidation method is difficult to control, and the oxygen in the oxidation process has local inhomogeneity, and the yield is low [10]. Gas phase oxidation purification method: oxygen oxidation method, air oxidation method, CO_2 oxidation method, H_2S-O_2 oxidation method, gold powder catalytic O_2 oxidation method. The disadvantage of this method is that the ends of the carbon nanotubes are often opened, cutting the carbon nanotubes, destroying the surface structure, and introducing oxygen-containing functional groups (-OH, -C = O, and -COOH) on the carbon nanotubes, the metal particles cannot be removed directly and further acid treatment is required [11].

4.2.2. Liquid Phase Oxidation Purification Method

The liquid phase oxidation method uses oxidizing acids to treat the crude product by oxidizing the carbon particles while dissolving off the metal catalyst particles with acid. Usually, the acid treatment will remove the metal catalyst and some fullerenes to obtain pure carbon nanotubes. Although the liquid phase oxidation method removes the by-products, it changes the surface structure of the carbon nanotubes, resulting in the production of many acidic functional groups (-COO, >C=0, -COH, etc.) on the surface of the carbon nanotubes. This is unfavorable for the application of carbon nanotubes in electricity, mechanics, and materials science, but favorable for the application of carbon nanotubes in chemistry, especially in the field of multiphase catalysis, because with these functional groups on the surface of carbon nanotubes, it is more favorable for surface modification with metals. Commonly used oxidizing acid solutions include nitric acid, mixed acids, potassium dichromate, and potassium permanganate in sulphuric acid solution. Liquid phase oxidation purification methods: nitric acid oxidation, mixed acid oxidation, potassium dichromate oxidation, potassium permanganate oxidation.

4.2.3. Electrochemical Oxidation Method

This method involves immersing the carbon nanotube electrode in 0.2 M high-pressure sodium in 3 solutions or 0.2 M hydrochloric acid (with N blowing 2 for 20 minutes prior to use) with a potential cycling between +1.00 and +2.00 V and a scan rate of 50 mV s^{-1}. Carbon nanotubes with fewer defects show a higher electrochemical oxidation resistance than those with more defects. Suitable for purifying CNT arrays without disrupting their alignment.

4.2.4. Microwave Purification Method

Carbon nanotubes are sonicated and then diluted in sodium hydroxide3 (or other acids). Microwaves are heated to 100-200 W and microwaves are warmed to ~200°C within 30 min. This removes amorphous carbon, metals, and other nanoparticles with no known negative effects [1].

4.2.5. Integrated Purification Methods

Chemical purification methods in the oxidation of other impurities at the same time, there is a considerable part of the carbon nanotube wall and tube ends are also oxidized away, the residual carbon nanotubes either tube diameter or tube length are smaller than the state before the purification, its structure has been more damaged; physical purification method in the purification process to avoid damage to carbon nanotubes [10], but because carbon nanotubes and most of the impurities are carbon, in the physical properties of However, since carbon nanotubes and most of the impurities are carbon, there is not much difference in physical properties, so it is difficult to obtain high purity carbon nanotubes. Both have their advantages and disadvantages. This has led to the use of a combination of Physico-chemical methods [5]. The combined method is a purification process that combines the advantages of chemical methods for efficient separation and physical methods that do not destroy the structure of the carbon nanotubes while minimizing the damage to the carbon nanotubes while making the separation as efficient as possible. Integrated purification methods: (1) combination of acid treatment and electrophoresis (2) combination of microporous filtration and electrolysis (3) combination of gas phase oxidation, acid treatment, and microporous filtration (4) combination of acid treatment and centrifugal separation (5) combination of extraction, acid treatment, and freezing.

5. Structure and Properties of Carbon Nanotubes

The structure of pure carbon nanotubes is completely composed of carbon, which can be understood as a tubular shell formed by graphene sheets composed of benzene-type rings of hexagonal carbon atoms. Graphene sheets are honeycomb lattice-derived, cylinders without any gaps, representing the individual atomic layers of crystalline graphite. MWCNT is a concentric cylinder rolled into a pile of graphene sheets. Each nanotube is a single molecule made up of millions of atoms, tens of micrometers in length and extremely small in diameter, only 0.7 nanometers. The single-walled carbon nanotube contains only 10 atoms on its circumference, and the tube is also only one atom thick. Nanotubes typically have a large aspect ratio (i.e., the ratio of length to diameter) of about 1000, so they can be considered as one-dimensional structures [8]. MWCNTs are larger and consist of a large number of single-walled tubes, which are stacked one by one inside. The name MWCNT can only be used to weigh nanostructures with an outer diameter of less than 15 nanometers, and structures beyond this range are called carbon nanofibers. Carbon nanotubes differ from carbon fiber in that carbon fiber is not a single molecule, but a chain of graphite flakes stacked on top of each other.

Except for the two different structures mentioned above, there are three other types of carbon nanotubes. These carbon nanotubes are armrest carbon nanotubes, herringbone carbon nanotubes, and chiral carbon nanotubes [13]. The different

places between these carbon nanotubes depend on the structure of the graphite formation, i.e. how it is "rolled up" during creation. The choice of the rolling axis relative to the hexagonal network of graphene sheets and the radius, of the closed cylinder is based on which different types of SWCNTs are generated.

In addition, carbon nanotubes have adsorption properties. Various gases can be stored, e.g. hydrogen. Once inside atoms and molecules, they cannot re-enter the outside, as the ends of the tubes are sealed and pass through the graphene plane of the cylinder, which they cannot, as the carbon lattice is too narrow for most atoms and carbon nanotubes create capillary effects. The carbon nanotubes are open-ended and attract liquid substances and molten metals.

Carbon nanotubes are 50-100 times stronger than the best steel and are six times denser than ordinary steel. This means that a carbon nanotube-based material with the same volume will be ten times stronger. Carbon nanotubes are highly refractory, with a maximum specific surface area of up to 2,600 m^2/g. In addition, carbon nanotubes are quite flexible. They can be stretched, compressed, twisted, etc. There is no need to worry about damaging them in any way [2, 4]. They are similar to hard rubber tubes and will not tear or break under all kinds of mechanical loads. However, not only do they not rupture or fracture under mechanical stresses beyond the critical nanotubes, they just rebuild, while maintaining high strength, flexibility, other mechanical and electrical properties, high abrasion resistance, reusable strain (tens of thousands of twisting/untwisting cycles, compression/stretching per minute) without affecting the strength of the nanotubes, their electrical conductivity, and thermal conductivity. No signs of deformation or wear.

6. Surface Modification of Carbon Nanotubes

6.1. Covalent Functionalization

Covalent chemical functionalization of carbon nanotubes began with the chemical cleavage of carbon nanotubes by oxidizing agents, and in 1994 Tsang et al. found that multi-walled carbon nanotubes could be cleaved by sonication in strong acids, resulting in open carbon nanotubes. In 1998, Liu et al. investigated the cutting of single-walled carbon nanotubes by using strong acid and ultrasound to obtain fullerene tubes with lengths ranging from 100 to 300 nm, followed by oxidation with concentrated sulfuric acid at a volume ratio of 4:1 and 30% hydrogen peroxide. 30% hydrogen peroxide obtains single-walled carbon nanotubes with shuttle groups at the end. [11, 12, 15] These truncated carbon nanotubes were monodispersed well in water. Later, attempts were made to functionalize the carbon nanotubes using other oxidants such as K_2CrO_2; O_sO_4; $KMnO_4$. The presence of reactive groups not only improves the hydrophilicity of carbon nanotubes, making them more soluble in polar solvents such as water but also provides a basis for carbon nanotubes to react with other substances or groups, thus providing a wide range of modifications to their surfaces.

6.2. Non-covalent Functionalization

Although the covalent functionalization of carbon nanotubes has made great progress in the dispersion and surface modification of carbon nanotubes, this type of functionalization method is to act directly with the graphite lattice structure of CNT, which can destroy the sP2 structure of the functionalization site of CNT, and the structure causes damage so that functionalized carbon nanotubes can be obtained with the structure intact. The sidewalls of carbon nanotubes consist of a lamellar structure of graphite with sP2 hybridization of carbon atoms forming highly delocalized π-electrons [9]. These π-electrons can be used to combine with other compounds containing π-electrons through π-π non-covalent bonding to give functionalized carbon nanotubes. Poly (m-phenylene vinylene) derivatives (poly p-phenylene vinylene co-2, 5-dioetoxv m-phenylenevinylene, PmPV for short) are a co-choked luminescent polymer, with which Curran et al. used multi-walled carbon nanotubes to form MWNTs-PmPV composites through π-π interactions. Star et al. conducted a functionalization study of SWNTs using PmPV.

The results showed that the average diameter of SWNTs bundles in the suspension decreased with increasing PmPV content, and the surface coverage of SWNTs became homogeneous. These results confirm that PmPV is entangled in the carbon nanoparticles through the π -π interactions on the carbon nanotubes.

6.3. Inorganic Nanoparticles Modified Carbon Nanotubes

After the organic functionalization of carbon nanotubes, the surface takes on a variety of reactive groups, but in order to guarantee their good dispersion in inorganic matrix media, it is often necessary to coat or fill the functionalized carbon nanotube surface with some inorganic nanoparticles to improve their; interfacial bonding with the matrix, so as to maximize the excellent performance of carbon nanotubes. At the same time, such inorganic particle-modified carbon nanotubes themselves have important applications in non-homogeneous catalysis, solar cells, luminescent materials, sensors, etc.

The acidified carbon nanotubes have reactive groups such as -OH and -COOH, which can "tether" metal ions or particles to the carbon tubes, thus enabling the encapsulation of inorganic particles on the surface of the carbon tubes [14]. The rutile phase TiO_2 particles were wrapped on the surface of carbon nanotubes in situ by hydrolysis in nitric acid solution. Liu et al. successfully wrapped $NiFe_2O_4$ nanoparticles on the surface of acid-treated carbon nanotubes by dropping NaOH solution into the mixture of acid-treated carbon nanotubes with Ni^{2+}, Fe^{3+} by hydrothermal treatment.

Inorganic modification of carbon tube surfaces can also be achieved using chemical reactions between covalently functionalized carbon nanotubes and inorganic particles protected by organic compounds. Banerjee firstly acidified the surfaces of single-walled carbon nanotubes (SWNTs) to

produce multiple shuttle groups on the surface of carbon nanotubes and used the reactions between the shuttle groups and aminated TiO_2 particles to obtain TiO_2 particle-coated Ravindran et al. used organic matter containing luciferyl and terminal amine groups to stabilize the ZnS encapsulated particles. Ravindran et al. stabilized ZnS-encapsulated CdSe nanocrystals with organic matter containing luciferyl and terminal amine groups in the presence of a vinylcarbodiimide (EDC) dehydrating agent to the amine groups are coupled to the shuttle groups on the surface of the acid-treated carbon tubes, thereby allowing the semiconductor nanocrystals to attach to the unterminated ends of the carbon tubes. This heterogeneous connection can be used as a component of nanoelectronic and optoelectronic devices, etc [11]. Haremza et al. Haremza et al. achieved the attachment of CdSe nanocrystals to the surface of carbon tubes by the reaction of amine-functionalized CdSe nanocrystals with single-walled carbon nanotubes modified with phthalide halogen groups. The attachment of CdSe nanocrystals to the surface of carbon tubes was achieved by the reaction of amine-functionalized CdSe nanocrystals with single-walled carbon nanotubes modified with phthalide halide groups.

7. Applications of Carbon Nanotubes

Carbon nanotubes have excellent electrical, mechanical, and chemical properties. Incorporating carbon nanotubes into polymers, ceramics, or metal matrixes can significantly improve the physical properties of the subject material such as electrical and thermal conductivity. As a new material, carbon nanotubes are mainly used in the field of lithium battery materials and conductive plastics.

Carbon nanotubes have a hollow structure and can be used as a "storage" container for hydrogen [3]. The density of the hydrogen stored in them is even higher than that of liquid or solid hydrogen. When properly heated, this hydrogen can be slowly released. Such a storage device with a high storage density and a low specific gravity is the material of choice today. If cars were fuelled by hydrogen instead of petrol, and the exhaust gases from the tailpipe were only water vapor, then not only would the cars running down the road not cause air pollution, but they would also increase the humidity of the air. And if carbon nanotubes are used to store energy in portable form, they can be used directly as fuel for picnics. And hydrogen is an inexhaustible source of renewable energy.

If carbon nanotubes were added to ordinary metals and plastics, and the composite material was woven into threads and made into sports protection, such as leg guards for footballers, there would be no more injuries on the green field. If, for example, carbon nanotubes were used to make flat electron guns the size of fluorescent screens, they could be wall-mounted and even held in the hand like a book.

An analysis of the working principle of lithium-ion batteries shows that the positive and negative electrodes of the battery are constantly embedded and separated when the battery is being charged. Under normal circumstances, there is a very small gap between the diameter of the carbon nanotubes and the nanotubes, which provides a channel for the embedding and separation of lithium ions. According to scientific research, the nanotube material is characterized by a special structure of tubular molecules and the relatively small depth of embedding of lithium ions, which results in a large number of embedding positions, both in the hollow tube and in the small gaps between the layers of the nanotube. In this way, the charging and discharging capacity of the lithium-ion battery can be maximized.

In addition, carbon nanotubes have promising applications in the field of composite materials [7]. Recently, it has been reported that the tensile strength of carbon nanotube/polymer composites with 30% to 50% of the total volume of carbon nanotubes exceeds 1.2 GPa. It has also been reported that the volumetric conductivity of carbon nanotube/cellulose paper is 0.53 Ωcm, the shielding effectiveness in the range of 15 to 40 GHz exceeds 20 dB, and the absorption effectiveness of electromagnetic waves in the range of 30 to 40 GHz accounts for It is a good wave absorbing material.

8. Conclusion

At present, the synthesis and application of carbon nanotubes have become the frontier and hot spot of research in the materials science field. The synthesis and application of carbon nanotubes have become a frontier in materials science.

The use of carbon nanotubes in nanotechnology, and biotechnology How to achieve high dispersion of carbon nanotubes and improve their compatibility with other functional and structural materials through surface treatment has become a key factor in promoting the practical use of carbon nanotubes [8]. The research on how to achieve a high degree of dispersion of carbon nanotubes and improve their compatibility with other functional and structural materials through surface treatment has become a key issue in promoting the practical use of carbon nanotubes.

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