APPLICATIONS OF NANO CARBON ANALOGUES

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Introduction

Among these breakthroughs, the applications of nano carbon analogues stand out as a pivotal and burgeoning field. Nanocarbon analogues, including materials such as graphene, carbon nanotubes, and fullerenes, exhibit extraordinary properties at the nanoscale, offering an array of innovative applications across industries. These remarkable materials hold immense potential to revolutionize fields ranging from electronics and energy to medicine and materials engineering. In this exploration, we delve into the multifaceted applications that harness the unique attributes of nano carbon analogues, shaping the landscape of modern technology and scientific progress.

Applications of Fullerenes

1. Organic Photovoltaics (OPV)

Fullerene has a role in organic photovoltaics, where it helps make efficient solar cells. In the best-performing solar cells using a mix of materials, fullerene is used as n-type semiconductors, that accept electrons. It is used along with p-type semiconductors that are electron donors, often a substance like polythiophene. These materials are mixed together to form the active layer of the solar cell, and this mixture is called a bulk heterojunction. Fullerenes are either used directly or modified to make them dissolve more easily. The main derivative used in solar cells isC60, but C70 has been found to be 25% more efficient. Other derivatives like C60 PCBB can increase efficiency by over 40% compared to C60 PCBM. A record efficiency of 4.4% was achieved in 2005 using a fullerene derivative, highlighting how the active layer's properties impact performance. Fullerenes are the preferred n-type material, making up to 75% of the activelayer's weight. Solar cell efficiency is consistently rising, hinting at potential commercial use soon. Polymer transistors, like Organic Field Effect Transistors (OFETs) and photodetectors, are performing better, partly due to the interaction between OFETs and OPVs (organic photovoltaics). The top OFETs use fullerenes like C60, C70, and C84 as n-type semiconductors. Among these, C84-based fullerene OFETs have higher mobility and stability compared to C60 and C70. While more research is required, the realm of polymer electronics is expanding for bothfullerenes and single-walled carbon nanotubes, displaying promising advancements.

2. Antioxidants and Biopharmaceuticals

Fullerenes act as potent antioxidants, rapidly reacting with harmful free radicals that often cause cell damage. They hold significant potential for health, personal care, and various non-physiological applications where preventing oxidative damage is crucial. Major pharmaceutical companies are investigating fullerenes for controlling neurological damage in diseases like Alzheimer's and ALS. They are also being developed for atherosclerosis, photodynamic therapy, and anti-viral treatments. Fullerenes are exceptional at neutralizing free radicals, outperforming even Vitamin E by 100 times. They dissolve well in almond oil, making them suitable for ocular tissue toxicity testing without adverse effects.

3. Additives

As Polymer Additives

Fullerenes and fullerenic black display chemical reactivity and can be incorporated into polymer frameworks, resulting in novel copolymers possessing distinct physical and mechanical attributes. Additionally, they can be introduced to form composites. Extensive research has explored the utilization of fullerenes as additives in polymers, aiming to alter physical traits and enhance performance qualities.

As a Catalyst

The fullerene has a strong capacity to receive and transfer hydrogen atoms. This ability enables processes like hydrogenation (adding hydrogen) and hydrodealkylations (removing alkyl groups using hydrogen). Also efficient at facilitating the transformation of methane into more complex hydrocarbons with larger molecular structures. The substance prevents or suppresses the formation of coke (solid carbon deposits) during chemical reactions, which is beneficial for maintaining reaction efficiency and avoiding undesirable byproducts.

4. Water Purification

Fullerenes, due to their structure and electron configuration, can efficiently catalyze the production of singlet oxygen—a highly reactive and powerful oxidizing agent. This singlet oxygen can selectively degrade organic pollutants present in water sources, breaking them down into harmless byproducts through oxidation processes. This innovative approach offers a promising solution for tackling persistent organic pollutants and ensuring cleaner water resources.

5. Biohazard Protection

Fullerenes, especially C60, exhibit notable antioxidant properties. They can scavenge free radicals and reactive oxygen species, which are implicated in various health issues and the deterioration of materials. This property makes fullerenes valuable in protecting against biohazards, including harmful effects caused by exposure to radiation, toxins, and pollutants. When incorporated into protective materials, such as clothing, coatings, or filters, fullerenes can mitigate the damaging effects of biohazards by neutralizing harmful agents and preventing their interaction with biological systems.

6. Automobiles

The use of fullerene black and rubber compounds enhances the strength and resilience of the vehicle's components. It can withstand wear, stress, and environmental factors better than traditional materials, leading to longer-lasting vehicle parts. Heat build-up can be an issue, especially in areas where friction or energy transfer generates excess heat. Fullerens and fullerene black have properties that can dissipate heat efficiently, contributing to better temperature regulation within the vehicle. Vehicles using these compounds may require less energy to operate and travel the same distance compared to vehicles using traditional materials. This can lead to cost savings for vehicle owners and a reduction in fuel consumption.

7. Medical Field

As MRI Contrast agent

Magnetic Resonance Imaging (MRI) is a widely used medical imaging technique that provides detailed images of the internal structures of the body. Contrast agents are substances introduced into the body before an MRI scan to enhance the visibility of certain tissues or organs. These agents alter the magnetic properties of the surrounding tissues, making them more distinguishable in the resulting MRI images. Fullerenes, due to their unique properties, are used as an MRI contrast agent. Fullerenes have high electron spin and nuclear spin relaxation rates, which can lead to enhanced image contrast in MRI scans. Properly designed fullerene-based nanoparticles can exhibit good biocompatibility, reducing the risk of adverse reactions when introduce into the body. Fullerenes can be functionalized with specific molecules that enable them to target particular tissues or cells. This offers the possibility of targeted imaging, and enhances diagnostic accuracy. Some fullerene-based nanoparticles have shown extended circulation time in the bloodstream, allowing for a longer window of time for imaging procedures.

Drug Delivery System

The water-soluble cationic fullerene known as tetra(piperazino) fullerene epoxide (TPFE) has found use in delivering DNA and siRNA precisely to the lungs. Effective treatment for lung-related diseases necessitates targeted delivery of active agents to specific organ locations. However, challenges arise due to the accumulation of micrometer-sized carriers in the lungs, potentially causing embolization and inflammation. To address this, size-controlled carrier vehicles have been created utilizing TPFE. In the bloodstream, TPFE and siRNA aggregate with plasma proteins, forming micrometer-sized particles. These particles block lung capillaries,releasing siRNA into lung cells. Once siRNA delivery is achieved, the particles swiftly exit the lungs.

Applications Of Carbon Nanotubes (Cnt)

1. Field Emission

Electron field emission materials for technological applications like displays, electron microscopes, and microwave amplifiers. For effective use, these materials need low-emission

threshold fields and high stability at high current densities. Carbon nanotubes (CNTs) have proven promising due to their small size, structural integrity, conductivity, and stability. CNTs possess lower threshold fields compared to conventional emitters, with Single-Walled Nanotubes (SWNTs) offering higher current density and longer lifetimes. SWNTs have shown stable emission at substantial current densities, making them appealing for applications such as microwave amplifiers. However, the emission site density of CNTs remains a challenge for high-resolution displays.

1.1 Cathode Ray Lighting Element

The creation of cathode ray lighting elements utilizing carbon nanotubes (CNTs) as field emitters has been pioneered by the Japanese company Ise Electronic Co. These elements adopt a triode-type design, where nanotubes are screen-printed onto metal plates. To enhance color production, a phosphor screen is incorporated onto the inner surface of a glass plate. The resulting phosphor screens exhibit higher luminance compared to traditional thermionic Cathode Ray Tube (CRT) lighting elements, leading to improvements in lighting intensity and efficiency.

1.2 Flat Panel Display

Innovative matrix-addressable diode flat panel displays have been developed, leveraging carbon nanotubes as electron emitters. An example from Northwestern University features nanotube-epoxy stripes on the cathode glass plate and phosphor-coated Indium-Tin-Oxide (ITO) stripes on the anode plate. Pixels are formed at the intersections of cathode and anode stripes. Samsung has also introduced a 4.5-inch diode-type field emission display, incorporating single-walled nanotube (SWNT) stripes on the cathode and phosphor-coated ITO stripes on the anode, arranged perpendicular to the cathode stripes.

1.3 Gas Discharge Tubes in Telecom Network

Gas discharge tube protectors, using noble gas-filled ceramic cases with parallel electrodes, are an established method to guard circuits against transient over-voltages. These protectors create plasma breakdown during high voltages, short-circuiting the system and shielding components from damage. They are used in telecom network devices for lightning and power faults. New prototype protectors employ carbon nanotube-coated electrodes, offering better reliability and performance. The nanotube-based protectors exhibit improved breakdown voltage stability and lower breakdown voltage compared to commercial products, making them attractive for advanced telecom networks like ADSL.

2. Energy Storage

Carbon nanotubes are under investigation for their potential in energy generation and storage. Their unique attributes include compact dimensions, a smooth surface structure, and precise surface specificity, as their structure exposes only the basal graphite planes.

2.1 Electrochemical Intercalation of Carbon Nanotubes with Lithium

Rechargeable lithium batteries operate via the electrochemical intercalation and de-intercalation of lithium between two electrodes. Leading lithium batteries use transition metal oxides for cathodes and carbon materials for anodes, aiming for high-energy capacity, rapid charging, and extended cycle life. Carbon nanotubes (CNTs) have raised speculation about their potential for achieving higher lithium (Li) capacity by fully utilizing all interstitial sites within their structure. The exact Li ion positions in intercalated SWNTs remain uncertain, but it's suggested they occupy interstitial sites between SWNTs. The potential of CNTs as battery electrodes, marked byhigh capacity and performance under high current rates, merits further investigation, although theobserved voltage hysteresis needs addressing.

2.2 Hydrogen Storage

CNTs possess a high surface area, along with the ability to adsorb hydrogen molecules onto theirsurfaces. This property makes them potential candidates for compact and efficient hydrogen storage systems, which are crucial for various applications like fuel cells and clean energy technologies. The adsorption of hydrogen onto CNTs can occur through physisorption, where hydrogen molecules adhere to the CNT surface due to van der Waals forces. This adsorption process is reversible and can occur at relatively low temperatures and pressures, making it suitable for practical applications. Functionalization and doping of CNTs can potentially increasetheir hydrogen storage capacity and improve adsorption kinetics. Achieving high hydrogenstorage capacity while maintaining reversible adsorption-desorption cycles, improving adsorption kinetics, and addressing safety concerns related to hydrogen release are areas of ongoing research.

3. Filled Composite

CNTs can enhance the strength and performance of lightweight materials. They have the potential to be utilized in a variety of products, from sports equipment like tennis rackets to critical components in spacecraft and aircraft. Notably, NASA is investing significantly indeveloping CNT-based composites for futuristic missions, exemplified by their interest in Mars exploration. This indicates the broad range of applications where CNTs are being explored for their ability to contribute to stronger, lighter, and more durable structural materials and filled composites.

4. Nanoprobes And Sensors

The small and uniform dimensions of nanotubes offer diverse applications due to their high conductivity, mechanical strength, and flexibility. Nanotubes hold promise as nanoprobes in various fields, including high-resolution imaging, nano-lithography, nanoelectrodes, drug delivery, sensors, and field emitters. Single multi-walled nanotubes (MWNTs) attached to scanning probe microscope tips enable high-resolution imaging, particularly for deep surface cracks and biological molecules like DNA. While challenges exist in attaching individual

nanotubes to probes, successful growth onto silicon tips using CVD has shown potential for enhancing probe stability and performance.

5. Templates

Carbon nanotubes (CNTs) provide a distinctive avenue for crafting one-dimensional nanostructures by using their narrow, straight channels to host external materials. Initial calculations suggested that capillary forces could confine gases and liquids within CNTs, sparking the concept of producing nanowires. The first practical validation occurred in 1993 when molten lead was solidified within multi-walled nanotubes (MWNTs), generating wires as minute as 1.2nm in diameter. Following this breakthrough, subsequent exploration has encompassed the infusion of CNTs with an array of materials, spanning metals and ceramics, to craft nanowires with assorted structures and compositions.

Application of Carbon Nanodots

1. Bio Sensing

Carbon dots (CDs) exhibit remarkable properties, such as water solubility, customizable surface modifications, non-toxicity, and multicolor fluorescence. These features make CDs versatile candidates for bio-sensing applications. They have been utilized to detect various analytes like glucose, phosphate, pH, metal ions, DNA, proteins, enzymes, and pathogens due to their excellent biocompatibility, cell permeability, and photo stability. For instance, researchers have developed fluorescent boronic acid-modified CDs for non-enzymatic blood glucose sensing. Glucose-induced covalent bonding between CDs and glucose molecules led to selective fluorescence quenching, enabling the detection of glucose in human serum. Fluorescence resonance energy transfer-based sensors have been designed for detecting substances like H2S and H2O2 in water samples, serum, and living cells. These sensors utilize the structural and spectral changes in CDs upon interaction with the target analytes, offering high sensitivity, selectivity, and cell permeability.

2. Bio Imaging

Favorable optical characteristics, chemical stability, and biocompatibility of CDs offer an appealing alternative to semiconductor quantum dots (QDs) and organic dyes. Notably, CDs are non-toxic and biocompatible, making them desirable for visualizing biological systems. In the realm of in vitro bio imaging, CDs have demonstrated significant potential. A study by Cao et al. employed surface-passivated CDs synthesized through laser ablation for cellular imaging. The water-soluble CDs exhibited strong fluorescence under various excitation conditions and were effectively used to label cell membranes and cytoplasm. Functionalized CDs have been explored for disease diagnosis and drug targeting, with transferrin-modified CDs showing enhanced targeting to tumor cells. Their biocompatibility and low toxicity suggest CDs could serve as

valuable contrast agents for in vivo applications, such as ZnS-doped CDs after being passivated with PEG1500N.

3. Environmental Monitoring

Their key advantages include high biocompatibility, adjustable fluorescence properties, substantial two-photon absorption capabilities, remarkable photostability, simple functionalization, cost-effectiveness, and scalable production. These attributes make CDs highly valuable for a range of applications, enabling the detection of various substances like Hg2+, Cu2+, Fe3+, Ag+, Pb2+, Sn2+, Cr(VI), and more through monitoring changes in their fluorescence intensity in response to external stimuli.

3.1 Cation detection

Divalent mercury ions (Hg2+), is crucial due to their high toxicity and potential harm to human health. Carbon dots (CDs) have shown promise in addressing this concern. Various studies have demonstrated their effectiveness in detecting Hg2+ ions with high sensitivity and selectivity. These efforts include using unmodified CDs, hydrothermally synthesized CNPs, and functionalized CDs, all achieving impressive detection limits, making CDs a promising tool for efficient and accurate Hg2+ ion detection.

3.2 Anion detection

Anion detection using carbon dots (CDs) has been explored in various studies. CDs have been utilized for detecting nitrite ions through chemiluminescence properties when exposed to peroxynitrous acid. Another approach involves functionalizing CDs with carboxyl groups to detect phosphate ions by leveraging the coordination of Eu3+ ions. Similarly, a fluorescent probefor fluoride ions (F-) detection was designed based on competitive ligand reactions between carboxylate groups on CDs and F- ions coordinated to Zr(H2O)2EDTA. CDs have also been applied for the detection of sulfide ions, where their electrochemical luminescence properties were used to create a rapid and selective sensor.

4. Food Quality Control

Food safety is crucial for human health, and recent years have seen growing concerns due to various food safety issues. To ensure food safety, accurate methods are needed to detect harmful substances in food. Tartrazine, a synthetic pigment used in foods, has raised health concerns, leading to the development of techniques to detect it, such as using fluorescent carbon dots (CDs) synthesized from aloe. CDs have also been employed to detect cysteine and Fe3+ ions through fluorescence quenching and recovery, glucose by quenching via hydrogen peroxide, and phytic acid through photoinduced electron transfer. Additionally, CDs have been utilized in a fluorescence resonance energy transfer sensor to determine vitamin B12 concentrations effectively.

5. Explosive Screening

They offer a green alternative to quantum dots (QDs) and have gained traction in trace explosive detection. TNT, a worrisome environmental pollutant, prompted researchers to develop efficient platforms for detecting ultra-trace levels of TNT. N-rich CDs were synthesized and employed for both fluorescence and electrochemical detection of TNT, with impressive sensitivity and a linear range. Similarly, a fluorescence sensor using CDs capped by molecularly imprinted polymers showed selectivity and sensitivity for TNT detection, proving effective for real sample analysis. In the case of picric acid (TNP), CDs doped with rare earths and amorphous photoluminescent CDs were devised as selective and sensitive methods for detecting TNP, aiding in environmental and security applications.

Application of Graphene

Graphene holds promise in various applications, such as single-molecule gas sensing, biomedicaldevices, and optoelectronic devices.

1. Energy Storage

Lithium-ion batteries (LIBs) are favored for energy storage due to their extended cycle life, higher specific energy, and rechargeable nature, with graphene's outstanding properties like electrical conductivity, surface area, and stability making it a suitable energy storage material. However, conventional electrode materials like SnO_2, CO_3O_4, and others face limitations in practical use due to low electrical conductivity. Incorporating graphene-based materials has shown potential for enhancing capacity and cyclic performance. Graphene-enhanced materials, such as graphene-encapsulated CO_3O_4, Mn_3O_4, and Fe_3O_4, have demonstrated improved energy density, current density, and chemical stability in LIBs. Supercapacitors also benefit from graphene's high specific area, as demonstrated in graphene-hydrated RuO2 and nitrogen-doped graphene-based composites for enhanced capacitance and stability in supercapacitor applications. Additionally, graphene-modified materials have shown promise in thermal energy storage, with increased thermal conductivity observed in palmitic acid/GO composites.

2. Energy Conversion

Fuel cells offer high conversion efficiency and ease of use, with graphene replacing CNTs as a promising material for enhanced catalytic activities. Commonly, expensive materials like Pt, Au, and Ru are used for the cathode in fuel cells, with Pt being widely utilized despite its high cost and susceptibility to CO poisoning. Efforts to develop metal-free oxygen reduction reaction (ORR) catalysts led to the synthesis of Pt/graphene hybrids, such as PtNP/GNS composites, Pt- deposited GNS, and functionalized graphene sheets, which exhibited improved current density and ORR activity compared to conventional Pt-based catalysts. Doping and intercalation, like B and N doping and rGO/CNT hybrids, further enhanced the performance of graphene-based hybrid catalysts in fuel cells.

3. Graphene Based Conductors

Graphene exhibits remarkable electrical conductivity, surpassing copper due to its dual charge carrier behavior involving both electrons and holes. Research by Ivan et al. introduced graphene-based transparent conductors by intercalating few-layer graphene (FLG) with FeCl3, leading to alow sheet resistance of 8.8 Ω/sq, considerably below critical values for multi-layer and chemically derived graphene. Additionally, studies by Sajid et al. explore the application of graphene-based conductors as transmission lines, showing wave propagation characteristics akin to microstrip transmission lines and potential for planar antenna arrays.

Conclusion

As we conclude this exploration, it is evident that these nano carbon analogues have transcended traditional material limitations, ushering in a new era of innovation and discovery. Fullerenes, with their unique hollow structures and exceptional properties, have showcased potential in fields as diverse as drug delivery, electronics, and even energy storage. Carbon nanotubes, with their remarkable strength, electrical conductivity, and flexibility, have proven their worth in reinforcing materials, creating high-performance electronics, and revolutionizing medical applications. Carbon dots, the smallest of the nano carbon analogues, have emerged as versatile luminous nanoparticles with potential applications in imaging, sensing, and even disease diagnosis. And last but certainly not least, graphene, the two-dimensional wonder material, has disrupted numerous industries, enabling breakthroughs in electronics, energy storage, and composite materials. As these nano carbon analogues continue to be refined, explored, and integrated into various domains, the future holds the promise of more groundbreaking discoveries and practical applications. Their ability to transform conventional materials and reshape industries underscores the profound impact of nanotechnology on our modern world.The journey from laboratories to real-world applications has only just begun, and the tale of fullerene, carbon nanotubes, carbon dots, and graphene promises to be one of the most captivating chapters in the ongoing narrative of scientific progress.

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