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Application and development prospects of nanomaterials in multiple fields

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Abstract. Nanomaterials have unique structures and characteristics that allow them to exhibit far superior or new properties in many aspects than conventional materials. With the continuous progress in materials science research, the manufacturing and processing technologies of nanomaterials have also been fully developed in recent years. Nanomaterials of different types, structures, and compositions have been applied in many fields, such as construction, energy, environmental protection, and electronics, providing new ideas for solving many problems. In this paper, we first review the basic definition and properties of nanomaterials, then analyze and discuss the cases of nanomaterials already in use or promising design solutions in medicine, solar energy and textiles. This paper also summarize their advantages and manufacturing difficulties. All of these areas have mature nanomaterial products in use, and they provide ideas for further research and development in the future.

Keywords: nanomaterial, drug delivery, fluorescent labeling and imaging, solar energy, textile.

1. Introduction

Nanomaterials consist of structural units in the size range of 1-100 nm, and the special properties brought about at this size have attracted much attention in new materials research. Various types of nanomaterials developed based on these special properties have shown practical functions and room for development in the fields of medicine, solar energy, and textiles.

In the field of medicine, drug carriers made with nanomaterials can transport drugs to the desired part of the human body and release the drug amount on demand through special control to achieve localized, timed and quantitative drug use. Early diagnosis of diseases such as cancer can also be achieved by labeling and imaging with nano-fluorescent reagents.

In the field of solar energy, specially structured nanomaterials can enhance the efficiency of electron transport in solar cells, which in turn can improve the efficiency of photoelectric conversion.

In the field of textiles, functional fabrics developed in combination with nanomaterials can be used to make UV-protective and antibacterial apparel that protects the wearer from harmful elements in certain environments.

The development of materials science has promoted the development and application of many emerging advanced nanomaterials, and it is crucial to review these existing application examples and draw from them the future directions of nanomaterial development. The purpose of this paper is to

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summarize the application examples of nanomaterials technology in various fields, provide an overview, and explore the development direction of nanomaterials, with a view to providing a certain reference basis for related industries and research.

2. Nanomaterial

2.1. Concept of nanomaterials

Nanomaterials are usually defined as materials consisting of elementary units with dimensions of 1 to 100 nm in at least one dimension. It can be classified into four categories: low-dimensional nanomaterials containing nanotubes, nanopowders, and nanowires; surface nanomaterials with solid surface structures prepared by various surface treatment techniques such as laser treatment, deposition, and surface mechanical grinding, as a way to improve surface properties; and bulk nanomaterials consisting of structural units with nanoscale dimensions, such as composite nanomaterials and multiphase nanomaterials [1].

Materials that have nanostructures can have many properties that are different from those of conventional materials, including thermo-physical, mechanical, electronic, or optical properties. One reason is the increase in relative surface area. Compared to conventional forms of materials, nanomaterials have a much larger surface area to volume ratio, which greatly affects their chemical reactivity and strength. Another point is that with the new quantum effects that arise at the nanoscale, the material will have new properties in magnetism, optics, and electricity. because these properties of the material will be more affected by quantum effects at that scale [2].

2.2. Properties of nanomaterials

New materials developed based on nanotechnology can have new and useful properties. As the ultra-small particles that make up these new materials, the special properties of nanoparticles allow them to play a unique role in a variety of fields, serving as carriers for the transport of drugs in the human body, enhancing the conversion efficiency of solar energy systems, and strengthening the robustness of materials. These wonderful properties are obtained by the distinctive reactions of these particles when they interact with their surroundings. Properties such as electrical conductivity, elasticity, and strength can be further adapted to the needs of the application scenario by changing the shape and order of the internal structure of the nanomaterial [3].

The rise in health awareness has led to the constant pursuit of more effective medical treatments, and the use of nanomaterials has made it possible to precisely control the release of drugs in the human body and to diagnose and monitor diseases at an early stage. The demand for cleaner energy is also a common concern for all mankind. Solar cells rely on nanomaterials to achieve improved performance. Climate change and epidemics in recent years have made people pay more attention to the protection against harmful factors in the environment, and various new types of textiles made of nanomaterials have come into being. These three fields, namely medicine, solar energy and textiles, have all achieved breakthroughs and improvements through the unique properties of nanomaterials, meeting the development needs of modern society. These application cases, as representatives, can show the great potential of nanomaterials.

3. Application of nanomaterials in Medical

3.1. Drug delivery

The drug carriers made of nanomaterials can transport the drug to the needed part of the body in a certain way and make it release a certain amount at a specific time in a physically or chemically controlled way, thus being able to locate, time and quantify the therapeutic effect of the drug inside the body. Nanomaterial carriers are usually made of polymeric materials, and their main forms are nanoparticles, nanomicelles, nanocapsules, nanoemulsions, etc. They are combined with drug molecules by physical wrapping, adsorption, or chemical bonding. These carriers require

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biodegradability and biocompatibility with very low or no toxicity to the human body, such that some of the copolymers constituting the carriers can be degraded into substances that are normally degraded, such as water and fat, and can have a long circulation time in the human body.

Examples of nanomaterials, such as functional nanoparticles and synthetic biomolecules, have already been used. Synthetic gold nanoparticles (GNs) of specific shapes and structures conjugated with other materials can be used for drug delivery, and genetic nanomaterials such as DNA and RNA can be introduced into cells for cell therapy. Small molecules or ions can easily pass through the lipid bilayer membranes of cells, but larger nanomaterials require complex chemical surface modification to be effectively absorbed through cellular endocytosis. Lipids, polymers, and other nanocarriers have been developed to facilitate the endocytosis process. However, these nanomaterials are often not exposed to the cell interior and remain in liposomal vesicles. The development of nanomaterials that can be truly internalized effectively and accurately by cells still faces difficulties [4].

Controlled drug delivery to a target can be achieved based on the sensitivity of the nanocarrier to factors such as temperature, pH, and light. Taking light triggering as an example, light has many desirable properties as a stimulus for a triggerable drug delivery system. Using changes in wavelength, adjustments in radiation intensity and time allow for spatial and temporal control. Organic nanomaterials are heavily used in this field because they are chemically modified with easy-to-use photoreactive groups, have high drug loading, and are often biodegradable. Such externally triggerable systems can provide flexibility in application scenarios where drug effects fluctuate with patient needs [5].

3.2. Fluorescent labeling

For the study of many complex problems in biology, the use of markers and stains has brought significant positive effects, and fluorescent labeling and imaging of biomolecules have been an extremely important research tool in biological studies. Parameters such as fluorescence intensity, emission spectra, excitation spectra, fluorescence lifetimes, etc., can be used as monitoring of the situation around the molecule. Recent developments in materials science have led to new achievements such as nano-sized fluorescent imaging agents, which break the limitations of traditional approaches such as low photobleaching threshold and poor photochemical stability [6].

Nanoparticles (NPs) constitute a brighter and more photostable fluorescent imaging agent. Each nanoparticle can carry a large number of fluorescent species, and the particle matrix isolates these fluorescent species from the biological environment. NPs need to have the necessary surface modifications and bioconjugation to be able to label living cells or access them for in vivo or in vitro imaging [7].

NPs are usually defined as materials with sizes between 1-100 nm. Microscopic effects such as quantum size effects, surface effects and macroscopic quantum tunneling effects occur when materials are in this size range, invalidating the governing rules at the macroscopic level. The nanoscale size will allow them to produce high signal-to-noise ratios and signal amplification, greatly improving response times and analytical sensitivity. At the same time, such a small size also keeps mechanical interference to living cells to a minimum, revealing excellent spatial resolution and selectivity. The robust stability to photobleaching, good biocompatibility, and low cytotoxicity make NPs ideal for bio analysis [8].

For diseases such as cancer, the main means of examination are MRI and CT, but these modalities need to detect symptoms only when there are obvious lesions in the body parts, resulting in missing the best time for treatment. Using fluorescent nanomaterials to mark the organism, imaging is faster and the image resolution is higher, enabling more effective diagnosis of early cancer and avoiding radiation damage to the human body. Because of the ability to passively accumulate at the tumor site, GNs possessing many optical properties are more suitable for early cancer diagnosis than small drug molecules. Fluorescence imaging of MCF-7 tumor-bearing mice was performed with ultra-small GNs modified with glutathione (GSH) and small dye molecules IRDye 800CW, respectively, and the results showed that ultra-small GNs are more effective fluorescent reagents and are also cleared from normal tissue soon after imaging [9].

4. Application of nanomaterials in solar energy

Renewable energy represented by solar energy has gradually replaced traditional energy sources such as fossil fuels. As the use of solar energy continues to increase, how to further improve the photovoltaic conversion efficiency of solar energy devices has been the focus of attention today. Nanomaterials play a key role in addressing this issue.

The principle of solar power generation is to use the photoelectric effect of semiconductors in solar cells. When a semiconductor PN junction is irradiated by sunlight, it will form a hole-electron pair after absorbing photons of sufficient energy. Under the action of the electric field of the PN junction, electrons flow from the p region to the n region and holes flow from the n region to the p region, forming an electric current when the circuit is connected. Enhancing the efficiency of electron transport in this process can effectively improve the utilization of solar energy.

Titanium dioxide (TiO_2) nanomaterials have good stability and excellent optics and electricity, which have great promise for solar energy applications, but they have inherent limitations such as sensitivity to UV light only and poor charge transport due to a wide band gap. Core-shell structured nanomaterials are capable of integrating individual components into a functional system, and this design is expected to overcome the performance limitations of TiO_2 materials themselves, such as facilitating electron transport in the TiO_2 shell through a conductive core, but for practical applications, a fast and simple method for large-scale synthesis of core-shell structured TiO_2 nanomaterials is still lacking [10].

Photocatalysts with hollow nanostructures are also one of the strategies to achieve efficient utilization of solar energy. The hollow structure allows the light to enter and reflect several times, which enhances the light utilization. Moreover, the nanoparticles of hollow photocatalysts have a high surface area, a short path, and a large number of active sites, which enable them to promote charge separation effectively. Based on these characteristics, the hollow nanostructured materials can generate a large amount of photogenerated charges and bring excellent photocatalytic ability. To realize such photocatalysts for large-scale applications requires the ability to fabricate large-scale hollow-structured nanomaterials with uniform size and stable structure, and the hard template method is a feasible fabrication method with low cost and simple operation, but lacks sufficient stability. The realization of large-scale etching of hollow structures is still a problem to be solved [11].

5. Application of nanomaterials in textile

5.1. UV protection textile

UV radiation promotes vitamin D synthesis and calcium absorption in the body, but the harmful part of it is one of the major physical carcinogens in the natural environment. Excessive exposure to UV radiation can accelerate skin aging and induce harmful effects such as skin cancer. Various types of UV protective textiles have been used to protect the wearer from the more intense UV radiation. Due to the limitations of conventional textiles in terms of protective properties, various nanomaterials have been used in the development of UV protective textiles. In addition to providing better durability, nanomaterials with large specific surface areas can also enhance UV-blocking properties at very low concentrations [12].

Metal oxide nanoparticles such as magnetite nanoparticles, titanium dioxide nanoparticles, zinc oxide (ZnO) nanoparticles and cerium nanoparticles are able to successfully block the UV radiation. Factors affecting the UV-blocking properties are particle size, phase composition, surface properties, crystallinity and crystal structure. The in situ preparation of ZnO nanoparticles on modified cotton fabrics enabled the development of multifunctional fabrics that exhibited excellent UV protection and substantial antimicrobial effects after 100 wear cycles and 20 wash cycles [13].

5.2. Antibacterial textile

The large surface area of conventional textile materials and their ability to retain moisture create good conditions for the growth of microorganisms. The growth of harmful bacteria can cause damage to textile materials and, in more serious cases, can endanger the health of the wearer, for example by causing skin infections or allergic reactions. Nanomaterials can be used to develop functional smart textiles with antibacterial properties [14].

Silver nanoparticles (AgNPs) have been used as antimicrobial agents in textile fabrics, health care products, cosmetics, coatings and wound dressings due to their effective bactericidal effect. TiO_2 is particularly attractive in terms of photocatalytic bactericidal activity because of its lower cost, natural abundance, and better chemical stability. To achieve antimicrobial inactivation in visible light, TiO_2 NPs can be doped with metallic and nonmetallic elements, modified with carbonaceous nanomaterials, coupled with other metal oxide semiconductors, or deposited on fibrous materials [15].

The green approach of synthesizing ZnO NPs using plant extracts has attracted a lot of attention due to its environmental benefits, lack of toxicity, and low cost. ZnO NPs synthesized in this way provide a greater antimicrobial effect than chemically synthesized ZnO NPs. The antibacterial mechanism relies on photocatalysis, formation of reactive oxygen species, and direct interaction of the nanoparticles with the bacterial surface. The NPs synthesized by this method are non-toxic and skin-compatible and suitable for the preparation of antimicrobial textiles. However, for now, there are few studies on the comfort and antimicrobial durability of such NPs, and more research efforts need to be conducted in the future [16].

6. Conclusion

The special properties of nanomaterials are derived from their large specific surface area and the various special effects that occur under their size. Nanomaterials developed on this basis have brought different solutions to problems and types of products to several fields. In the field of medicine, there are nano drug carriers for precise positioning, timing and dosing of drugs, and nano fluorescent markers for early diagnosis of cancer and other symptoms; in the field of solar energy, nanomaterials with special structural design can effectively improve the efficiency of photovoltaic conversion; in the field of textiles, UV-protective and antibacterial textiles made of nanomaterials can be used to produce functional clothing to protect the wearer in different environments. These cases reflect the excellent performance and wide range of applications of nanomaterials, but at the same time, it can be seen that many nanomaterials with desirable properties still have challenges in mass production. In future research and development of nanomaterials, in addition to performance, manufacturing technologies suitable for mass production should also be a focus of attention. Overall, the development of nanomaterials is quite promising and more research is needed to be put into it.

7. References

[1] Definition and classification of nanomaterials[J]. Light Metals,2020(05):20.
[2] Darweesh, H. H. M. (2018). Nanomaterials: Classification and Properties-Part I. Journal of Nanoscience, 1(1), 1-11.
[3] Bratovcic, A. (2019). Different applications of nanomaterials and their impact on the environment. SSRG International Journal of Material Science and Engineering, 5(1), 1-7.
[4] Kang, G., Carlson, D. W., Kang, T. H., Lee, S., Haward, S. J., Choi, I., ... & Chung, A. J. (2020). Intracellular nanomaterial delivery via spiral hydroporation. ACS nano, 14(3), 3048-3058.
[5] Liu, Q., Zhan, C., & Kohane, D. S. (2017). Phototriggered drug delivery using inorganic nanomaterials. Bioconjugate chemistry, 28(1), 98-104.
[6] Wang, F., Tan, W. B., Zhang, Y., Fan, X., & Wang, M. (2005). Luminescent nanomaterials for biological labelling. Nanotechnology, 17(1), R1.
[7] Peng, H. S., & Chiu, D. T. (2015). Soft fluorescent nanomaterials for biological and biomedical imaging. Chemical Society Reviews, 44(14), 4699-4722.
[8] Yao, J., Yang, M., & Duan, Y. (2014). Chemistry, biology, and medicine of fluorescent

DOI: 10.54254/2755-2721/23/20230618

nanomaterials and related systems: new insights into biosensing, bioimaging, genomics, diagnostics, and therapy. Chemical reviews, 114(12), 6130-6178.

[9] Fan, M., Han, Y., Gao, S., Yan, H., Cao, L., Li, Z., ... & Zhang, J. (2020). Ultrasmall gold nanoparticles in cancer diagnosis and therapy. Theranostics, 10(11), 4944.

[10] Li, W., Elzatahry, A., Aldhayan, D., & Zhao, D. (2018). Core–shell structured titanium dioxide nanomaterials for solar energy utilization. Chemical Society Reviews, 47(22), 8203-8237.

[11] Fang, B., Xing, Z., Sun, D., Li, Z., & Zhou, W. (2022). Hollow semiconductor photocatalysts for solar energy conversion. Advanced Powder Materials, 1(2), 100021.

[12] Mondal, S. (2022). Nanomaterials for UV protective textiles. Journal of Industrial Textiles, 51(4_suppl), 5592S-5621S.

[13] Saleem, H., & Zaidi, S. J. (2020). Sustainable use of nanomaterials in textiles and their environmental impact. Materials, 13(22), 5134.

[14] Andra, S., Balu, S. K., Jeevanandam, J., & Muthalagu, M. (2021). Emerging nanomaterials for antibacterial textile fabrication. Naunyn-Schmiedeberg's Archives of Pharmacology, 394, 1355-1382.

[15] Díez-Pascual, A. M. (2020). Recent progress in antimicrobial nanomaterials. Nanomaterials, 10(11), 2315.

[16] Xu, J., Huang, Y., Zhu, S., Abbes, N., Jing, X., & Zhang, L. (2021). A review of the green synthesis of ZnO nanoparticles using plant extracts and their prospects for application in antibacterial textiles. Journal of Engineered Fibers and Fabrics, 16, 15589250211046242.