A review of applications and future prospects of nanotechnology

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Abstract. At the beginning of the 21st century, human beings entered the era of nanotechnology, and more scientists began to pay attention to and engage in the research of nanotechnology in different fields. This article introduces the origin and development history of nanotechnology and reviews its applications in energy equipment, environmental protection, and medical treatment, which reflect the importance of nanotechnology for human production and life based on existing literature and data. It can be seen that nanotechnology is a very promising technology that has made great achievements in the fields of energy equipment, medicine, environmental protection, and so on. At the same time, in the application and development of nanotechnology, there are not only safety risks in the use process but also opportunities to create new technologies and new materials. So, nanotechnology, as a relatively young technology, still has gaps or little research in some research fields, such as the emerging green nanotechnology, the precise control of nanostructures by self-assembly technology, and the way to industrial production, which will also become a hot trend in nanotechnology research in the future.

Keywords: Nanotechnology, Nanomaterials, Self-assembly, Toxicity.

1. Introduction

Nanotechnology is a typical emerging convergence technology. It is the ability to convert the nanoscience theory to useful applications by observing, measuring, manipulating, assembling, controlling, and manufacturing matter at the nanometer scale, and the atoms are arranged at the scale of 1-100 nanometers [1]. Due to the breakthroughs in different areas of nanotechnology in recent years, the transformation to industrial production has been achieved, and nanotechnology is also considered to have great prospect [2]. At present, scientists are trying to achieve minimization at the scale of nanomaterials to improve device performance for related applications. D. F. Jaramillo-Cabanzo et al. emphasized that the small size of one-dimensional nanostructures can lead to excellent electrical conductivity [3]. Chen H used the STM tip to fold and unfold graphene nanoisland along an arbitrarily chosen direction; this is the first atomic-scale and smallest scale graphene folding in the world, and they tried to use the structure of graphene to build heterojunction devices so as to achieve a leap in quantum device performance [4]. As a result, scientists use the continuous breakthrough of nanotechnology in the scale to improve the performance of its applications in different fields, which is conducive to improving the efficiency of devices, human life satisfaction, medical level, economic benefit and so on. The main research topic of this paper is to review the relevant application fields, development, and future prospects of nanotechnology. This paper mainly uses the literature research method to read and summarize the relevant literature. On this basis, the author introduces the application of nanotechnology in energy devices, medicine, environmental protection, and other areas that are more extensive and worthy of development and research in the future. At the same time, it also emphasizes the importance of paying attention to the existing risks of nanotechnology and its solutions. Therefore, the study of this paper is a summary of the important development fields of nanotechnology, which is conducive to people's comprehensive and systematic understanding of the history, recent development, and future development prospects of nanotechnology, and provides feasible directions for the improvement and development of nanotechnology research in the future.

2. History of nanotechnology development

In 1959, Feynman delivered the prophetic speech There's Plenty of Room at the Bottom at the annual banquet of the American Physical Society, which can be seen as the beginning of the history of nanotechnology. He mentioned the possibility of miniaturization at the atomic level as well as top-down and bottom-up approaches to nanomaterial synthesis. Fifteen years later, in 1974, Japanese scientist Norio Taniguchi first used the term "nanotechnology" to describe precision machining in a paper,which was about the concept of nanoscale technology. In 1981, one of the scientists at International Business Machines Corporation (IBM) invented the forementioned Scanning Tunneling Microscope(STM), which was a very important breakthrough in the further development of nanotechnology and nanoscience. A few years later, in 1989, another scientific team from IBM managed to align 35 atoms of xenon in the form of the letters IBM [5]. Additionally, during the period of 1985-1991, scientists discovered C60 buckyball (Fullerene) and carbon nanotubes, which are now widely used in electronic information materials, energy storage materials, medicine, and other fields. In the 2000s, after scientists discovered graphene in 2004, carbon-based materials became the backbone of almost every field of science and engineering [1]. The history of nanotechnology is shown in Figure 1.

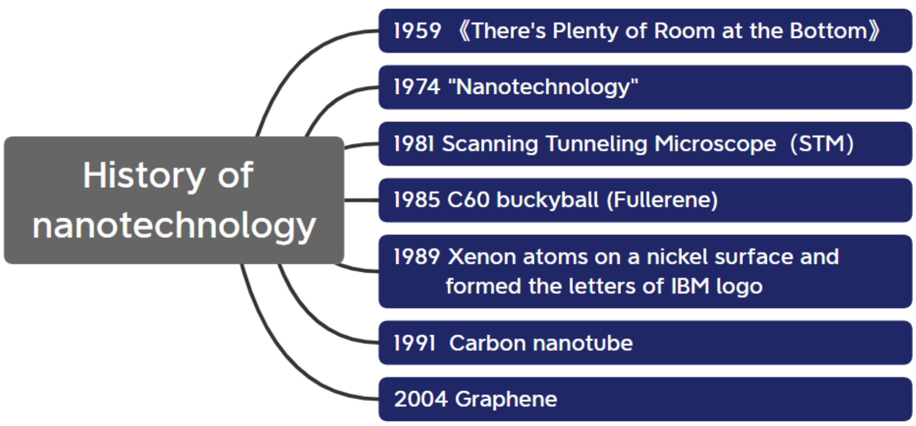

Figure 1. The history of nanotechnology.

3. Applications of nanotechnology in different fields

3.1. Energy device

So far, nanomaterials have been widely used in energy equipment; for example, a new type of solid electrolyte can be prepared by fixing the ionic liquid on the nanopore of the metal-organic skeleton, which can effectively improve the performance of lithium batteries [6]. High-performance anode materials for microbial fuel cells can be prepared using a corrosion-resistant composite made of polydimethylsiloxane doped with carbon nanofibers, which can improve surface electron transfer and electrochemical performance [7]. In addition, taking lithium-sulfur battery as an example, the morphology, surface area and surface modification of nanostructured carbonaceous additives have an impact on the performance of lithium-sulfur battery cathodes [8]. Moreover, nanotechnology is also utilized in the new photovoltaic solutions, where it can help perovskite solar cells get higher efficiency. For example, scientists can prepare perovskite films by adding nano-additives to the precursor solution of perovskite, so this method can passivate the surface of the perovskite film; the crystallinity and orientation of the film are also improved, which is very effective for improving the photoelectric conversion efficiency [9].

3.2. Medicine

Nanotechnology has gradually entered the field of modern medical technology and contributes to the search for new solutions for disease prevention, diagnosis, and treatment [5].

Nanotechnology can be used in cell mediated drug delivery, endogenous cell repair, and regenerative cell therapies, especially the use of stem cells and reprogrammed somatic cells as therapeutic agents. So many nanoscale technologies have been developed and implemented to modulate stem cell behavior for therapeutic applications [10]. Because of the unique properties of nanotechnology, it can provide new opportunities for cardiovascular tissue engineering, new nanomaterials can deliver drugs to the lesion site after intravascular administration and new nanotechnology can promote angiogenesis of vascular cells and accelerate wound healing [11]. This technique can effectively treat related cardiovascular diseases. In recent years, nanotechnology has also played an important role in promoting the regeneration of diabetic tissues and organs, which can provide an excellent and easy-to-control growth surface for the regeneration of cells and tissues. At the same time, the good histocompatibility of various nanoparticles reduces the transplant rejection of allogeneic cell tissues, bringing convenience to patients [12]. Besides, nanotechnology can also be applied to different virus detection methods.In particular, there is a new technology that can detect severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which causes coronavirus disease 19 (COVID-19) [5].

3.3. Environment protection

In addition to the mentioned improvements in device efficiency and the advancement of modern medicine, the application of nanotechnology can also lead to better environmental protection. At present, nanotechnology has a wide range of applications in detecting both water and air quality.

Although water is vital for sustaining life, it is highly vulnerable to contamination due to uncontrolled agricultural and industrial activities. In the past decades, due to the rapid development of industrialization, a large amount of industrial wastewater has been produced. Take China as an example. A large amount of wastewater has been discharged into rivers, lakes, and coastal areas, resulting in the water bodies of China's seven major river basins being polluted to varying degrees [13]. Therefore, any form of water reuse or recycling will help mitigate this phenomenon, and nanotechnology has been very effective in wastewater treatment. For heavy metal pollution in industrial wastewater, magnetite nanomaterials were used because iron oxide nanoparticles are widely used to separate heavy metal ions from water due to their special properties [14]. Nanotechnology can also be used for air pollution control and purification. Recent developments in nanotechnology allow for the preparation of nanomaterials with larger surface areas and excellent filtration, adsorption, and photocatalytic properties, so they can be used mainly for air purification. For instance, menbranes/filters made from electrospun nanofibers are used for filtrating PM 2.5 because of their filtration efficacy and low pressure drop. In order to improve the filtration efficiency, the most common method is to increase the polarity and surface electrostatic charges of the polymers. In addition, adding some active components to the polymers used to make filters can also improve their different functions, such as using the magnetic properties of metal oxide nanoparticles to adsorb dust in the air [15].

4. Future prospects and safety issues

4.1. Future prospects

It is not surprising that the use of nanostructured materials has been raising health and environmental safety concerns, favoring the expansion of a sub-field dedicated to green and safe-by-design solutions [16]. Nowadays, green nanotechnology is becoming increasingly important. Green nanotechnology relies on the principles of green chemistry towards a sustainable design, manufacture, use, and end-of-life of nanomaterials. For example, it has also been applied to the coatings industry through the replacement of toxic compounds, or they can be controlled or released over time [16].

Besides, the most perspective area of nanotechnology is self-assembly as well [5]. Self-assembly refers to the process in which a disordered system is formed into an organized structure by the interaction of individual components (attraction and repulsion, or spontaneous formation of chemical bonds) without external intervention. So as an important part of nanotechnology, the principle of self-assembly can be applied in different areas, such as optoelectronics, biopharmaceutical, biosensor and so on. Therefore, it is an important research topic in the field of nanomaterials science to manufacture a series of new nano materials by nano self-assembly technology.

Nowadays, with the rapid development of science and technology, nanomaterials with a single structure can no longer satisfy the needs of production in society. Compared with single nanomaterials, nanomaterials with controllable size and uniform morphology formed based on self-assembly technology show enhanced integration properties among multiple components, which greatly promotes the practical application of nanomaterials. So far, researchers have used materials such as metals, semiconductors, oxides, inorganic salts and polymers to precisely control a series of ordered and fine nanoassemblies through a "bottom-up" approach. In the future, people will focus more on how to improve the structural precision regulation and mass production of nano self-assembly technology. Because this technology can control the properties of nanostructures at the macroscopic level, it will not only be beneficial for the development of targeted drugs but also enable the development of CNT-based electronic devices and be increasingly used in energy and environmental remediation applications [5]. In addition, with the considerable investment in the research and development of nanotechnology products, if the technology of industrial scale-up of nanotechnology in materials is realized, the related products manufactured under nanotechnology can be produced in large quantities, which will give the nano industry great economic benefits in the future [2]. Therefore, the search for inexpensive but high-performance new materials to replace the traditional expensive materials is crucial to the realization of this technology, and the high price of raw materials cannot support the high volume manufacturing at the beginning of industrial production.

4.2. Safety issues of nanotechnology

Safety in nano-technology is a very important theme that needs to be addressed in order to determine the boundary between adverse and normal.

First of all, it is true that there are some unknown or known safety issues with the application of nanotechnology. For the environment, there are also negative environmental impacts from nanotechnology, such as the difficulty of removing graphene from waste due to its toxicity, and the fire risk of nanocomposite graphene due to its thermal conductivity and flame retardancy [17]. For instance, in the use of nanoparticles for water purification mentioned earlier in this essay, as nanoparticles adsorb toxic substances, will they react with toxic substances after the completion of the adsorption process and release secondary toxic substances? Also, this question is worth considering when it comes to air purification. The current way to address such risks is to find a secondary detection method that can identify toxins produced by the nanoparticles during the purification process and filter the nanoparticles with residual toxins. At the same time, some common nanomaterials have biological toxicity. Especially, the extremely small size of nanoparticles makes it difficult for them to be further decomposed, and as the decomposition spreads into the atmosphere, oceans, and soil, natural ecosystems will be destroyed.

As the creators of nanotechnology, human beings are also very concerned about the risks and hazards of nanotechnology to their own lives and health. There are three basic ways to expose humans to nanoparticles: inhalation, ingestion, and adsorption [17]. As we all know, nanotechnology stretches the limits of medical technology, but it also poses safety risks. For example, common medical nanotitanium oxide material has been used in orthopedics, medical imaging, and tumor treatment because of its excellent properties. However, according to relevant research data in recent years, nanotitanium oxide particles have cytotoxicity and phototoxicity, and they will produce adverse biological reactions in the human body once they enter it [18]. So nanotoxicology research is very important to solve the safety problems of nanotechnology by obtaining nanotoxicological profiles at the molecular, cellular, and organ levels. Specifically, through the characterization of nanomaterials, scientists can obtain the causal relationship between the physical and chemical properties of nanomaterials and their toxicity, as well as the appropriate classification of nanomaterials. It is also very important for nanomaterial risk assessment to have an in-depth understanding of cellular uptake, trafficking, and toxicity mechanisms [19]. This is very useful for analyzing the toxicity of nanomaterials and finding corresponding methods to reduce the toxicity. Additionally, the core principle of solving the safety risks of nanomaterials is no harm. When nanomaterials are used in the human body as medical materials or in close contact with human beings as common materials in life, a large number of biological experiments should be done to ensure that human harm and material loss are avoided or reduced to the greatest extent.

On the one hand, in order to solve these issues, humans should properly handle nanomaterials with biological toxicity, effectively remove toxic nanoparticles before releasing them into the natural environment, and treat toxic nanoparticles without toxicity or reduce their toxicity. On the other hand, the government should set up a nanotechnology risk assessment system. They could set a standard for toxicity permitted by nanotechnology and strictly prohibit the use of products that exceed this standard to protect the environment and human health. At the same time, it also provides guidelines for assessing the toxicity of nanoparticles, helping people to treat, repair, and prevent the risks and harm caused by nanotechnology.

5. Conclusion

This review introduces the history and applications of nanotechnology in three significant fields and highlights the importance of nanotechnology in production and life. Although the application of green nanotechnology and self-assembly technology will become a trend in future research, the safety issues about the toxicity of nanomaterials themselves and the toxicity caused by reactions during use are currently unresolved. In conclusion, although there are still some safety problems in nanotechnology today, it is indeed a very promising technology that is not only widely used in energy devices, medicine, and environmental protection but has also achieved great success in these fields. For some areas that are currently less involved in nanotechnology,the author believes it will become the trend of its development and achieve advanced research results in the future. This article also has some shortcomings, such as a lack of data to support the conclusion and an introduction to the application field that is not comprehensive enough. In order to solve these problems, the author can try to do experiments in the future to get accurate data and pay attention to the latest research articles on nanotechnology in different fields.

Acknowledgment

Firstly, I would like to show my deepest gratitude to my professors at this international conference, who have introduced me to much knowledge about nanotechnology and the relative principles of molecular engineering. Mastering relevant knowledge is very important for me to complete this thesis. Further, I would like to thank my parents and all my family members for their encouragement and support. They provided a quiet environment for me to write my thesis and tried not to disturb me. Without all their enlightening instructions and impressive kindness, I could not have completed my thesis.

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