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Review

Green Nanomaterials for Smart Textiles Dedicated to Environmental and Biomedical Applications

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Abstract: Smart textiles recently reaped significant attention owing to their potential applications in various fields, such as environmental and biomedical monitoring. Integrating green nanomaterials into smart textiles can enhance their functionality and sustainability. This review will outline recent advancements in smart textiles incorporating green nanomaterials for environmental and biomedical applications. The article highlights green nanomaterials' synthesis, characterization, and applications in smart textile development. We discuss the challenges and limitations of using green nanomaterials in smart textiles and future perspectives for developing environmentally friendly and biocompatible smart textiles.

Keywords: green nanomaterials; smart textiles; environmental applications; biomedical applications; nanoparticles

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1. Introduction

Significant advances have been reported lately for smart textiles, alongside progress in materials science and nanotechnology [1]. Smart textiles, also named smart fabrics or e-textiles, are designed with integrated electronic components, sensors, and other technologies. These components can be used to monitor, transmit, and receive data, and can be embedded in textiles in various ways, such as by weaving or printing them directly onto the fabric [2]. Based on how they react to the environment, they can be classified into passive smart textiles (can sense the environment), active smart textiles (can sense and react to stimuli from the environment), and very smart textiles (can sense, react, and adapt their behaviour based on the received stimuli) [1,3]. Based on their functionality, smart textiles can also be classified into sensing, actuating, energy harvesting, and communicating [4]. Thus, smart textiles can be designed to detect and measure various physical and chemical parameters (i.e., temperature, pressure, humidity, and gas concentration), and can be employed in healthcare and environmental monitoring [5]. The actuating smart textiles can respond to external stimuli (i.e., heat or light) and change their properties or shape accordingly [6]. Smart textiles can also be designed to capture and store energy from external sources, such as sunlight or body heat, and use it to power other devices or sensors [7,8]. Finally, they can be designed to transmit and receive data wirelessly, allowing them to be integrated into more extensive networks or systems [9].

In the environmental sector, smart textiles can be used to monitor environmental conditions (i.e., temperature, humidity, and light). They can also be used in construction for indoor air quality monitoring and controlling heating and cooling systems [10].

In healthcare, smart textiles can be employed to monitor a range of health parameters (i.e., heart rate, respiration, and body temperature), and to deliver drugs or other therapeutic agents directly to the body. For example, smart textiles can be used as wearable sensors to the potential to revolutionize topics, from environmental science to medicine, due to their unique properties. The future potential for the development and commercialization of these materials is expansive and diverse.

Scientists are investigating textiles incorporating carbon-based nanomaterials or metal-organic frameworks (MOFs), which could effectively filter pollutants, contaminants, and pathogens from air and water. The objective is to develop wearable technology that promotes personal and environmental health [232,233]. It is possible to create personal energy harvesting and storage systems through the development of textiles that incorporate nanomaterials such as photovoltaic cells, thermoelectric devices, and piezoelectric materials. This will increase the energy efficiency of wearable technology and lessen our reliance on conventional energy sources [234]. Real-time health monitoring is one of the most promising uses for smart textiles based on nanomaterials. Sensors can be incorporated into these textiles to monitor physiological variables, including heart rate, body temperature, and blood oxygen levels. Future breakthroughs might include the ability to identify diseases [235]. Future smart textiles may contain nanoparticles that may securely transport and deliver medications or other therapies, which could revolutionize the way we handle a range of medical issues [236,237]. Nanomaterials have the potential to significantly enhance wound treatment. To encourage more rapid recovery, decrease the risk of infection, and even encourage tissue regeneration, smart fabrics may be developed [238]. Despite these promising customers, there are still barriers to be solved for the use of nanoparticles in smart textiles in the future. While many lab-scale demonstrations have been successful, scaling these processes for mass production remains a challenge. The efficacy of the nanoparticles and their related features must be maintained throughout the life cycle of the textile product, including through washing and use. To ensure the reliability and effectiveness of these materials, appropriate standards and regulations must be developed, as with any breakthrough technology. It is important to fully understand and control how nanomaterials interact with the environment and the human body. In order for the public to easily understand and accept these products, education and communication are essential. Issues and scepticism about the usage of nanoparticles may exist, and these must be properly addressed.

Nevertheless, there are still several challenges to be addressed in developing and implementing smart textiles incorporating green nanomaterials, such as those related to compatibility, cost, safety, and regulation. However, the growing interest and investment in this field suggest that we can expect continued progress in developing these innovative and sustainable textile products in the future. Consumer acceptance, legal issues, cost-effectiveness, and the scalability of production of nanomaterials, as well as the capacity to integrate nanoparticles into textiles without affecting their qualities, will be crucial to commercialization. Sustainability is an additional important aspect of commercialization. From production to disposal, the life cycle of these materials should be evaluated and optimized to reduce their environmental impact. For instance, biodegradable or recyclable nanomaterials could be investigated.

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