Graphene oxide-polymer nanofibrous composites

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Abstract

Graphene oxide-polyvinyl alcohol (GO-PVS) nanofiber composites represent an attractive combination of materials science and physics. These advanced materials perfectly combine the remarkable properties of graphene oxide (GO) with the versatile and biophysical properties of polyvinyl alcohol (PVA). The synergistic interaction of these components has generated great interest in the fields of materials science and physics. This review highlights the complex manufacturing processes, unique properties, and rigorous electrical analyzes used to explore the fascinating world of GO-PVA nanofiber composites at the intersection of materials science and physics.

1. Introduction

Graphene oxide-polyvinyl alcohol (GO-PVA) nanofibrous composites represent class of materials that have garnered substantial interest in physics and materials science. These composites amalgamate properties of graphene oxide (GO) with flexibility and biocompatibility of polyvinyl alcohol (PVA), offering a multifaceted platform for a myriad of applications.

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We made the Scanning electron microscopy (SEM) analysis of the GO-PVA nanofiber composite films. The SEM image featured in Figure 1 offers a glimpse into several key attributes evident in the illustrations. The SEM image uncovers the intricate nanofiber structure of the composite film. Furthermore, the SEM image provides insights into the diameter distribution of the nanofibers within the composite film. The surface topography and roughness of the GO-PVA nanofiber composite films are also discernible through SEM analysis.
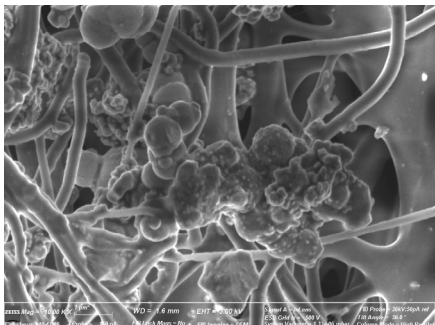

Figure 1. SEM image of the synthesized GO-PVA composite films.

The deposition protocol for GO-polymer nanocomposite should be optimized based on the specific application.

One of the aspects of interest in these composites is their electrical properties. GO-PVA nanofibrous composites exhibit remarkable electrical conductivity possibility. The unique two-dimensional structure of graphene oxide imparts excellent electron mobility, making these composites highly conductive. This opens up possibilities in the fields of flexible and transparent conductive materials, sensors, and energy storage systems.

Graphene is a two-dimensional, crystalline allotrope with a hexagonal lattice structure made from pure carbon atoms. They are best known for its unique properties containing high optical transparency, the best heat conductivity at room temperature and the ability to be flexible all within a strong, nano-sized material.

Graphene oxide (GO) happens to be a great precursor to obtaining graphene with higher yields and lower costs. To obtain GO, graphite oxide is first produced by utilizing graphite crystals that have been oxidized with strong oxidizing agents, such as sulfuric acid. Through sonication, graphite adopts oxygen-containing functional groups that allow the material to be dispersible in water while increasing interlayer distance.1 Then, graphite oxide can be exfoliated into either single or multilayers of oxygen-functionalized graphene oxide (GO). The difference between graphite oxide and GO are based on their different structures but chemical composition remains alike. GO is a single-layered material made of carbon, hydrogen and oxygen molecules, which ultimately becomes inexpensive yet abundant.

Graphene derivatives (GO, rGO, GQDs) have proven to be effective fillers in polymer nanocomposite materials thanks to their ideal material properties and dispersibility in polymer matrices, which has led to many applications. The tight packing of sp2 carbon atoms has been shown to serve as a near-perfect barrier to gas molecules, which demonstrates its use in packaging materials, protection for sensitive electronic devices, or even corrosion-resistant materials. For similar reasons, the fine-tuning of the filler content in nanocomposites can be used to adjust the selectivity of certain-sized molecules to generate superior membrane technologies. Furthermore, the unique hydrophilic, thermal, and electrical properties of GO can be taken advantage of in stimuli-responsive materials. This review aims to summarize the synthesis techniques, unique material properties (mechanical, electrical, thermal, etc.), and some representative applications (coating, membrane, anti-corrosion, and stimuli-responsiveness) of functional GO/rGO nanocomposite materials.

Graphene oxides have excellent antibacterial properties. Graphene and its derivatives are beneficial for their wound healing and antiinfective characteristics. Also, GO can be doped with silver and some other materials to enhance its antibacterial effects. The antibacterial activity of fiber containing GO and RGO is also greatly enhanced against some bacteria such as *Escherichia coli*, *Staphylococcus aureus*, etc. Electrospun gelatin/CS/HA nanofibrous incorporating either GO or RGO show good antibacterial properties and protein adsorption capabilities [29]. The presence of GO within the PLA/PU nanocomposite enhances antibacterial activity against gram-positive *Staphylococcus aureus* and gram-negative *Escherichia coli*. The addition of GO actually inhibited the attachment and proliferation of bacterial cells, thus resulting in a PLA/PU/GO composite with good antibacterial activity and suggesting that such a nanocomposite can be used as good material for TE [30]. The incorporation of GO in PLA/PU can reduce the growth of bacteria up to 100% within 24 h.

It has been proven that most GO and derivatives are cytocompatible in vitro and in vivo. However, the physicochemical properties of 2D materials, such as structure, shape, size, surface functionality, concentration, and aggregation state have an essential impact on cellular behavior. Graphene, with its sharp edge properties, has the potential to cause cell damage during the penetration of cell membranes. Its aggregation can also lead to cytotoxicity.

Graphene at the nanoscale, when <100 nm, results in cytotoxicity, inflammation, and even genotoxicity (due to facing less steric hindrance). In contrast, graphene with functionalized groups (i.e., GO, FGO such as the amine group, and rGO) is easily internalized by cells (especially in nano sizes), in addition to causing more irregular cell membrane perturbation. GO and its derivatives have been ascertained to have specific antibacterial properties, which are also emphasized in tissue engineering

applications. The antibacterial activity of GO is related to various mechanisms, including membrane stress, oxidative stress, entrapment, the basal plane, and the photothermal effect. GO has sharp edges that damage the cell membrane, meaning it could, in turn, lead to bacterial cell mortality via the membrane stress mechanism. The structure of GO allows it to act as an electron acceptor; thus, in the vicinity of bacteria, the abstraction of electrons within the membrane occurs, compromising membrane integrity and killing bacterial cells (particularly *P. aeruginosa* and *S. aureus*). GO and rGO, owing to the existence of functionalized groups, can alter the partial pressure of intracellular oxygen, which results in oxidative damage that destroys the bacterial cell internal composition, particularly *E. coli*, through the deactivation of their proteins and lipids, which eventually leads to cell death. GO has illustrated synergistic effects with laser energy; hence, it has been used for photothermal therapy, directly enhancing its antibacterial activity. Another fascinating property that GOBMs possess is antioxidant activity, and sp2 carbons play an essential role in scavenging radicals by radical adduct formation and electron transfer. Because of this characteristic, these biomaterials can effectively scavenge radicals and protect cells from high levels of oxidative stress. Graphene, being nonbiodegradable (except FGO), presents serious concerns for potential toxicity, immune response, and environmental hazards. It is reported that GO is susceptible to biodegradation by oxidative attack through hydrogen peroxide and horseradish peroxidase. Therefore, many attempts, such as the fabrication of nanocomposites, have been carried out to accelerate GO biodegradation, as the degradation rate of biomaterials (i.e., scaffold) must be compatible with the rate of tissues and organs.

The distinctive properties of graphene are derived from its particular crystal lattice structure. Within this, the bonding between each carbon atom is hybridized sp2 with the addition of π orbitals. In each unit cell of graphene, two π orbitals exist that are dispersed to form two π bonds, both of which could be known as bonding and antibonding [12]. This arranged lattice is a fundamental building block for all graphitic materials in various dimensions, namely (1) zero-dimensional (0D), e.g., carbon dot, fullerenes and nanodiamonds; (2) rolled one-dimensional (1D), e.g., carbon nanotubes; (3) two-dimensional (2D), e.g., graphene and GO; and (4) stacked three-dimensional (3D), e.g., graphite [13]. The graphene family structure also results in an exceptional surface-to-volume ratio, high intrinsic mobility, unparalleled thermal conductivity, and excellent electrical, optoelectronic, and mechanical properties that have paved the way due to being attractive technological tools [12][14]. Graphene is renowned as one of the most robust materials known to humans, and it is found to be 200 times stronger than steel [15]. In GO, hydrogen bonding forms between hydroxyl and epoxy groups and weak interactions with other groups. The existence of the carboxylic acid group offers a negative surface

charge (hydrophilic section); therefore, GO has stability in different polar solutions (particularly water), while graphene is inclined to aggregation. Moreover, owing to free surface π electrons from unmodified graphene (hydrophobic section), GO has an amphiphilic structure that could act as a surfactant. Graphene is hydrophobic, and GO, in comparison with graphene, could be hydrophilic or hydrophobic depending on the chemical and functionalization of the surface chemistry. These characteristics make GO the most important derivative of graphene, which possesses an easy process and a high affinity to accommodate biomolecules. The enhancement of chemical reactivity and graphene stability in solution is intertwined with the presence of reactive oxygen functional groups. Disrupted sp2 reduces its mechanical, electrical, and thermal properties. Although rGO has less oxygen content, hydrophilic functional groups, or surface charge, through the modification of noncovalent interactions (e.g., van der Waals interactions and π–π stacking), the physical adsorption of both polymers and small biomolecules onto its basal plane is enhanced remarkably.

Graphene oxide is a derivative of graphene, consisting of carbon atoms organized into a two-dimensional hexagonal lattice, but with oxygen-containing functional groups. On the other hand, polyvinyl alcohol is a polymer known for its biocompatibility and ease of processing into nanofibrous structures. When these two materials are combined to form nanofibrous composites, several exciting electrical processes come into play:

●**Electrical Conductivity Enhancement:** The inclusion of graphene oxide within the PVA nanofibers significantly enhances charge transport and the development of conductive pathways within the composite.

●**Capacitive Behavior:** The high surface area and electrical conductivity of graphene oxide-polyvinyl alcohol nanofibrous composites as supercapacitors can store and release electrical energy efficiently, and advancements in energy storage technologies.

●**Sensors and Detectors:** The electrical conductivity and sensitivity of these composites make them ideal candidates for sensors and detectors.

●**Electromagnetic Interference (EMI) Shielding:** The excellent electrical properties of GO-PVA nanofibrous composites can protect sensitive components from external electromagnetic radiation.

●**Flexible Electronics:** The flexibility and mechanical properties of PVA make these composites suitable for flexible displays, electronic textiles and health monitoring devices.

●**Transparent Conductive Films:** GO-PVA composites can be processed into transparent conductive films, such as touchscreens, organic light-emitting diodes (OLEDs), and solar cells.

•**Energy Harvesting:** These composites can be used in energy harvesting devices, where they convert mechanical vibrations or thermal gradients into electrical energy.

2. Conclusion

In summary, the development of graphene oxide-polyvinyl alcohol (GO-PVA) nanofibrous composites has shown promising potential in the field of material science and physics, particularly in the context of enhancing electrical properties. This innovative composite material brings together the unique properties of graphene oxide and the versatile characteristics of polyvinyl alcohol, resulting in a multifunctional material with remarkable electrical attributes.

The incorporation of graphene oxide into PVA nanofibers potentially can significantly improve electrical conductivity. The high surface area and exceptional charge transport properties of graphene oxide play a pivotal role in changing the resistivity of the nanofibrous composites. Researchers have demonstrated that the electrical properties of GO-PVA nanofibrous composites can be tuned by controlling the graphene oxide content and the fabrication process. This tunability allows for the customization of electrical characteristics. The improved electrical properties of GO-PVA nanofibrous composites open doors to a wide range of applications, including sensors, energy storage devices, smart textiles, and electronic skin.

Future studies may focus on improving the dispersion of graphene oxide within the PVA matrix, investigating the long-term stability of electrical properties, and exploring more sophisticated fabrication techniques.

In conclusion, the development of graphene oxide-polyvinyl alcohol nanofibrous composites with enhanced electrical properties holds great promise for advancing both material science and physics. These composites offer a versatile platform for developing new materials and technologies that can revolutionize various industries, making strides toward more efficient, flexible, and responsive electronic devices and systems.

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