



Review

From graphene aerogels to efficient energy storage: current developments and future prospects

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ABSTRACT

Graphene aerogels are more versatile than two-dimensional graphene due to their higher specific surface areas and mechanical stability. Due to restricted surface polarity and electron transport, graphene aerogels perform poorly electrochemically. Graphene composite aerogels are lightweight and porous in three dimensions. Graphene or graphene compounds materials maintain flexibility, electrical conductivity, and mechanical durability, making them useful in many applications. These materials have good chemical absorption, thermal resistance, and electrical conductivity. Engineers and researchers focus on supercapacitors for their durability, power density, and ability to withstand several charge and discharge cycles. Graphene's high electrical conductivity, large surface area, steady temperature, and excellent mechanical and chemical qualities benefit supercapacitors. One-layer graphene is unusual because of its hexagonal carbon atoms. The graphene's lattice structure and pores are of great interest because they improve cycle stability, electron transit, and performance. Graphene supercapacitors employ composite aerogels or three-dimensional networks as electrodes. This article covers three-dimensional graphene aerogel basics, production methods, and explains how graphene composite aerogel structural modification improves battery and supercapacitor performance. The three-dimensional porous structure of graphene aerogels can hold metal, bimetal, and nonmetal compounds and atoms. Conductivity, adsorption, and redox are improved by graphene composite aerogels' microstructure, pore characteristics, phase composition, and lattice structures. This investigation underscores the potential of graphene aerogel composites as promising candidates for advanced energy storage systems, offering significant advancements in battery and supercapacitor technologies. Moreover, the tunability of their surface chemistry provides opportunities for enhanced ion diffusion and charge storage capabilities. This article contributes valuable insights for the development of efficient and sustainable energy storage solutions in the pursuit of a cleaner and robust energy landscape.

1. Introduction

Graphene has generated significant interest since its discovery in 2004 due to its exceptional mechanical, electrical, and thermal characteristics [1]. Its high strength/strain-to-failure [2], huge surface area

[3], and chemical stability [4] have led to specific applications. These attributes have also been employed in the progress of nanoelectronics [5,6], energy storage [7,8], sensors [9,10], catalysis [11], and biomedicine [12]. The outcomes of these applications have yielded favorable results. Nevertheless, the characteristics like mechanical strength,

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electrical and thermal conductivity, structural integrity, interfacial adhesion and electrochemical performance of the composites formed by enclosing graphene within polymers frequently fall short of the expectations set by theoretical models [13–22]. The insufficiency of graphene dispersion inside the polymeric matrix is believed to be accountable for the aforementioned events. The formation of an agglomeration occurred due to the π - π stacking interactions between the sheets of graphene. To fully harness the potential of graphene, it is necessary to enhance various techniques for constructing three-dimensional structures using this two-dimensional material, tailored to specific applications. Therefore, it is imperative to design and research materials made of graphene with a three-dimensional structure. The materials encompass hydrogels, aerogels, and sheets with macropores.

The highly favorable characteristics of a specific category of these formations, known as aerogels, have sparked the interest of several scientists [23–33]. These materials exhibit superior electrical conductivity compared to distributed graphene sheets [34,35]. Graphene Aerogels (GA) can achieve densities comparable to that of air, potentially making graphene a feasible substitute for the exceedingly scarce and expensive element helium [36]. Aerogels are a type of porous nanomaterials that utilize air as a solvent rather than water or other conventional wet gel components. These materials possess a substantial pore volume, an extensive surface area, and the capacity to customize the surface area. The end products undergo drying by freezing or supercritical drying following the synthesis of molecular components into aerogels utilizing sol-gel methods. Aerogels have low values for thermal conductivity, refractive index, dielectric constant, and density at room temperature [37]. Furthermore, their porosity level is significantly elevated, varying between 90 % and 99 %. Hence, they may be applied

in several domains such as electronics, catalysis, and Cerenkov detectors [38]. Carbon aerogels, in particular, distinguish themselves within the aerogel group because of their exceptional adaptability, enabling them to fulfill a wide range of functions [39,40]. Micropores are linked to the internal arrangement of particles, while macropores and mesopores are linked to the arrangement between particles [41]. Hence, the composition and morphology of the precursor nanoparticles employed in the synthesis of carbon aerogels can influence the porosity of the aerogels. Graphene oxide (GO) possesses inherent reactivity and exhibits excellent solubility in water, rendering it a very attractive precursor substance for the fabrication of three-dimensional graphene architectures. Fig. 1 depicts the overview of GCA and applications in batteries and supercapacitors.

Moreover, GO is a highly commendable primary substance for the production of GA that incorporate graphene. This phenomenon arises due to the ability of oxygen groups situated at the basal and outer surfaces of the graphene molecule to establish covalent connections with a wide range of substances. As a result, new materials are created, each with the capability to be tailored to specific needs. The biopolymers are covalently immobilized onto GO sheets, which improves their biocompatibility without significantly changing their performance. Hydrothermal reduction or appropriate reducing chemicals can turn GO into a three-dimensional structure with sub-micron to micron pores via self-assembly [31]. Self-assembly may occur through π - π interactions between hydrophobic contacts and reduced sheets. Aerogel generated is often exceptionally delicate. A network of linked graphene sheets gives graphene aggregates extraordinary mechanical strength [42,43]. High-porosity GA lack density.

GA porousness, high specific capacitance, large surface areas, and

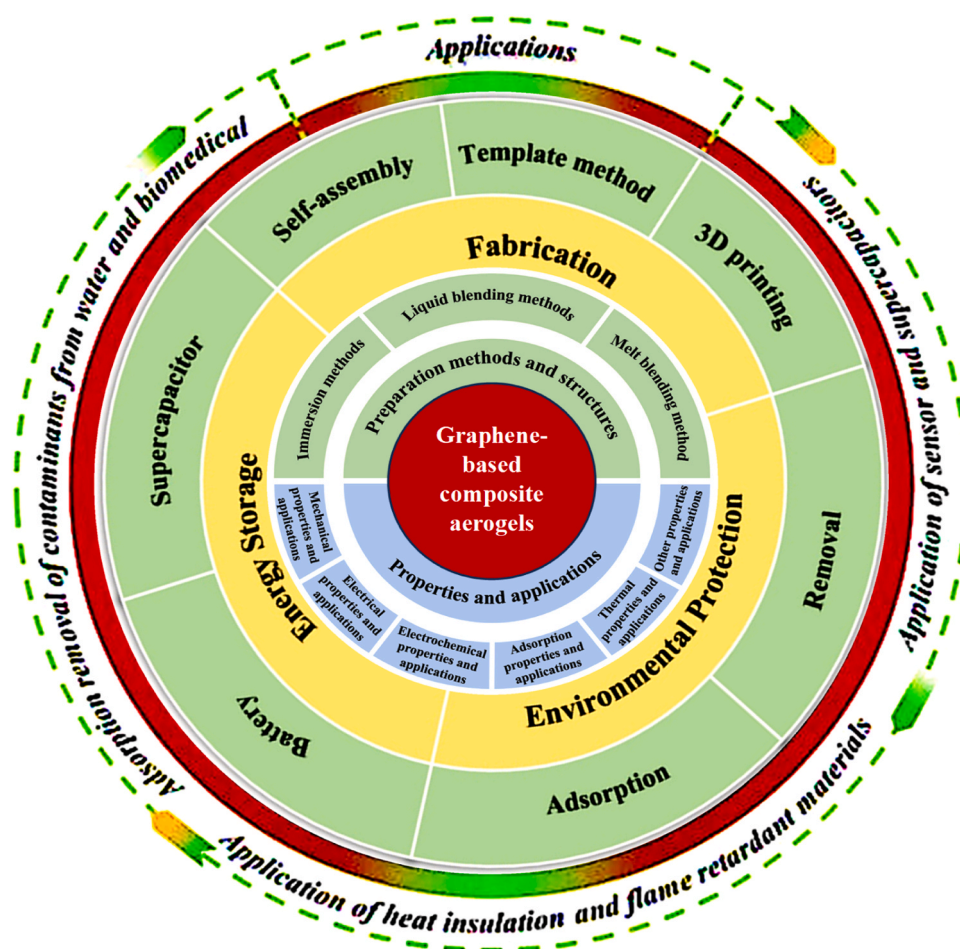


Fig. 1. Overview of GCA and applications in batteries and supercapacitors.