Recent Trends and Synthesis Methods of Graphene Oxide: A Short Review

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Abstract

Graphene oxide (GO) is a compound that consists of carbon, oxygen, and hydrogen atoms. It is derived from graphene, which is a single layer of carbon atoms arranged in a hexagonal lattice. Graphene oxide has oxygen-containing groups (such as hydroxyl and epoxide groups) attached to the graphene sheets, which make it hydrophilic and easily dispersible in water. It has gained significant attention in various fields due to its unique properties, including its mechanical strength, conductivity, and potential applications in electronics, energy storage, biomedicine, and environmental remediation. GO is a carbon structure that is layered and has oxygen-containing functional groups (=O, -OH, -O-, -COOH) affixed to both layer sides and plane edges. GO may have a single layer or multilayer structure, much like any other 2D carbon material. In the present review we discussed the various synthesis methods and applications of GO in different domain in brief.

Keywords: Graphene oxide, carbon atoms, energy storage, functional groups, synthesis methods.

Introduction

The oxidized version of graphene, known as graphene oxide (GO), is made up of a single layer of carbon atoms organized in a hexagonal lattice. In contrast to pristine graphene, which is made entirely of carbon, graphene oxide has a variety of functional groups that incorporate oxygen, including carboxyl, hydroxyl, epoxide, and carbonyl groups [1, 2]. These oxygen groups are added during the oxidation process, which modifies graphene's electrical characteristics and turns it from a conductor to an insulator or semiconductor. Atoms of carbon, oxygen, and hydrogen make up the molecule known as graphene oxide. It comes from graphene, a single layer of hexagonally organized carbon atoms. Because graphene oxide has groups that contain oxygen like the hydroxyl and epoxide groups linked to its sheets, it is hydrophilic and readily soluble in aqueous solutions [3, 4]. The oxidation process introduces defects into the graphene lattice, which are sites for functional groups. These defects disrupt the sp^2 hybridized carbon network, creating regions of sp^3 hybridization. Because of its special qualities such as its mechanical strength, electrical conductivity, and possible uses in electronics, energy storage, biomedicine, and environmental remediation it has drawn a lot of interest from a variety of industries [4-6]. Because oxygen groups disturb the π-conjugated structure, GO is typically a type of insulator. But based on the level of oxidation and the particular functional groups present, it may display semiconducting characteristics. It is possible to substantially convert GO back to rGO, which has its conductivity restored but still contains some of the functional groups that give it its distinctive characteristics, by lowering GO (removing certain oxygen groups). GO consists of multiple layers of graphene, with an interlayer spacing that is larger than that of graphite due to the presence of oxygen groups [7]. Fig. 1 reveals the structure of graphene oxide.

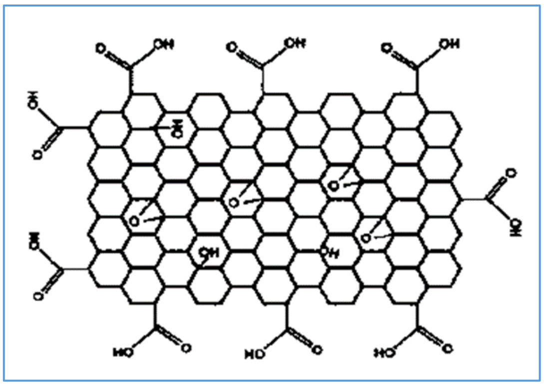

Figure 1: Structure of graphene oxide

This structure allows for the easy intercalation of molecules and ions, which is useful in many applications. Graphene oxide is a promising material due to its unique combination of properties, including tunable electrical characteristics, high surface area, and chemical versatility, positioning it for a wide range of applications in electronics, environmental science, and biomedical fields [7-9]. Hence the present research papers is discussed the brief information of graphene oxide based applications or trends and synthesis methods in brief.

Synthesis methods of Graphene Oxide

GO is primarily synthesized through the chemical oxidation of graphite, with the Hummers method being the most widely adopted approach. In this method, graphite is treated with strong oxidizing agents such as potassium permanganate ($KMnO_4$) in the presence of concentrated sulfuric acid (H_2SO_4). The reaction typically occurs at low temperatures and leads to the formation of graphite oxide. The oxidized graphite is then exfoliated into single-layer graphene oxide sheets by stirring the mixture in water, which disrupts the van der Waals forces between the layers [9, 10]. This method is favored for its efficiency and relatively high yield, although it requires careful control to prevent the over-oxidation of the graphene structure. A variation of the Hummers method, known as the modified Hummers method, has been developed to address some of the limitations of the original technique. This modification often involves the addition of pre-oxidation steps or the use of different oxidizing agents, such as sodium nitrate ($NaNO_3$), to improve the oxidation process and reduce the formation of toxic by-products like nitrogen dioxide (NO_2) and dinitrogen tetroxide (N_2O_4). The modified method generally results in graphene oxide with fewer defects and a more controlled level of oxidation, which is beneficial for applications requiring specific electrical or mechanical properties. Beyond the Hummers and modified Hummers methods, other synthesis approaches include the Staudenmaier and Brodie methods [11-14]. The Staudenmaier method, an earlier technique, utilizes a mixture of concentrated nitric acid and sulfuric acid, with potassium chlorate ($KClO_3$) as the oxidizing agent. This method tends to produce GO with a higher degree of oxidation, but it also poses greater safety risks due to the potential for explosive reactions. The Brodie method, another historic approach, employs potassium chlorate and fuming nitric acid to oxidize graphite. While both the Staudenmaier and Brodie methods are less commonly used today, they remain important in understanding the evolution of graphene oxide synthesis techniques. Recent advancements in the synthesis of graphene oxide also explore greener and more sustainable methods, such as electrochemical oxidation and the use of environmentally friendly oxidants. These approaches aim to reduce the environmental impact of GO production while maintaining or enhancing the quality of the material. Electrochemical methods, for instance, use an electrical potential to oxidize graphite in an electrolyte solution, offering a cleaner alternative to chemical oxidation with fewer by-products. As research in this area continues, the synthesis of graphene oxide is expected to become more efficient, scalable, and environmentally sustainable [13-16]. Common synthesis methods for graphene oxide are illustrated in Fig. 2.

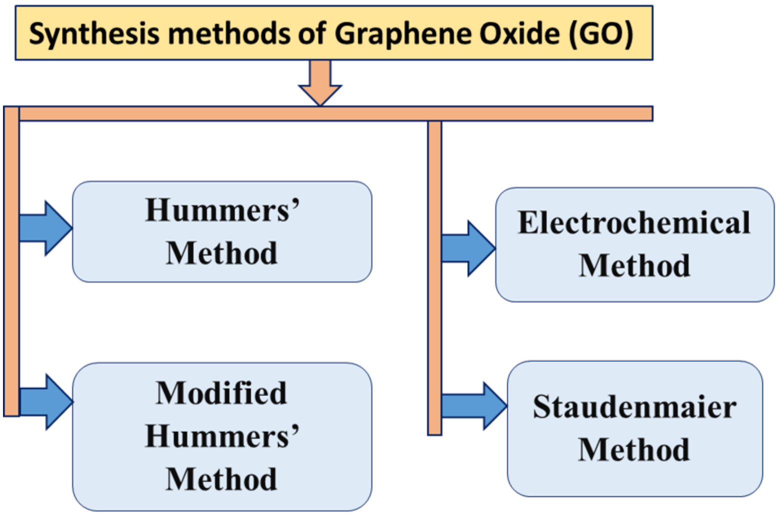

Figure 2: Common synthesis methods for graphene oxide

Applications of Graphene Oxide

Graphene oxide has found a wide range of applications across various fields due to its unique properties, such as high surface area, mechanical strength, and the presence of oxygen-containing functional groups. In energy storage, GO is used in batteries and supercapacitors, where its excellent electrical conductivity and large surface area improve electrode performance, leading to devices with higher capacity and faster charge-discharge rates. In environmental applications, GO serves as an effective material for water purification, capable of removing heavy metals, organic pollutants, and pathogens through adsorption and filtration processes [17, 18]. Its barrier properties are also leveraged in gas separation membranes. In the biomedical field, GO's biocompatibility and ease of functionalization make it ideal for drug delivery systems, biosensors, and tissue engineering. It can be used to target specific cells for drug delivery or to create scaffolds for tissue regeneration. Additionally, GO is being explored for its antibacterial properties in developing coatings for medical devices and implants, preventing infections [19, 20]. In electronics, GO is used in the development of flexible and transparent conductive films, which are essential components in flexible displays, wearable devices, and sensors [21, 22]. Furthermore, GO's catalytic properties are harnessed in catalysis and sensing applications, where it serves as a platform for immobilizing catalysts or enhancing sensor sensitivity. The versatility of graphene oxide makes it a valuable material in a diverse array of technological applications [22-25]. Fig. 3 shows different applications of graphene oxide.

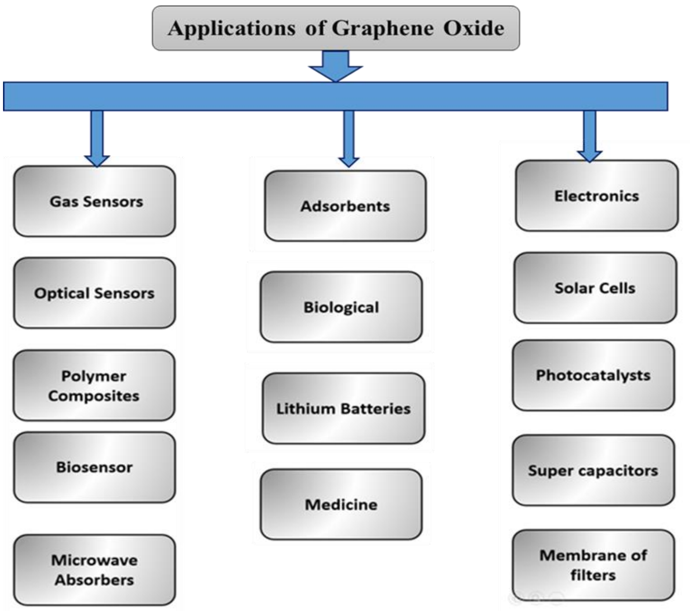

Figure 3: Applications of graphene oxide

Literature survey

Sharma N, et al. (2017) prepared GO by exfoliation of graphite using modified Hummer's method. Authors reported that, by this method crystalline structure GO and rGO were obtained. In Raman excitation peaks were obtained for two laser wavelengths 532 and 785 nm. The synthesized nanoparticles of GO and rGO were used for gas sensing application. The outcomes demonstrate that functional groups containing oxygen are removed from GO by reduction using hydrazine hydrate, as verified by FTIR and TGA measurements. A rise in crystallinity is seen in XRD between GO and rGO, indicating the re-formation of the sp^2 network in rGO. The decreased graphene oxide surface exhibits greater corrugation and sensitivity than the graphene oxide surface, according to FESEM pictures. GO and rGO both had linear I–V characteristics. Both GO and rGO have the potential to be effective gas sensing materials, according to the results of this experiment [26].

Mascarenhas FC, et al. (2020) synthesized graphene oxide using Indian gooseberry (amla) extract by green reduction method. Indian gooseberry extract has been successfully used as a reducing agent in a hydrothermal autoclave to decrease GO, and its properties have been compared to those of rGO reduced by hydrazine hydrate. An array of characterisation techniques, including XRD, Raman, FTIR, XPS, and UV-VIS spectroscopy, have validated the reduction of GO to rGO. The elimination of some oxygen functional groups is confirmed by a decrease in the FTIR spectra's peak strength. Author reported the gas sensing applications of synthesized GO. The maximum sensitivity was recorded to ammonia gas. Sensitivity of rGO-G has increased with higher concentration and about 5% sensitivity is achieved for 3 ppm concentration of ammonia [27].

Gaikwad G, et al. (2017) synthesized (PANI/GO/ZnO) nanocomposites were successfully prepared by nanoemulsion method. According to the author, at room temperature, PANI nanofibers, PANI/GO, and PANI/GO/ZnO nanocomposites with varying ZnO and GO weight ratios demonstrated superior NH_3 selectivity and sensitivity. With a recovery time of about one minute and thirty seconds, the PANI/GO/ZnO nanocomposite demonstrated the best performance, responding to 1000 ppm NH3 at 80 ± 1 °C with a response of 5.706—10.3 times better than the PANI sensor. The current study intends to investigate how graphene oxide affects conducting polymer and metal oxide nonmaterial gas sensing characteristics. In order to do this, the gas sensing characteristics of PANI and its nanocomposite containing ZnO and GO were investigated at different temperatures and gas concentrations using the nanoemulsion method. A preference towards ammonia gas has been demonstrated by all produced nanocomposites [28].

Chung C, et al. (2013) conducted survey on optical biosensing performance of graphene oxide. The literature describes theoretically novel strategies that lack the need for GO colloidal suspensions, allowing GO to be integrated onto a solid phase and paving the way for their use in novel biosensing devices. Moreover, photoluminescent signals are utilized by the majority of GO-based biosensing devices. Nevertheless, significant advancements are also made in potent label-free optical methods that use GO in biosensing, namely those that make use of optical fibers, surface plasmon resonance, and surface enhanced Raman scattering. An important summary of these subjects is provided here, emphasizing the significance of GO's physicochemical characteristics. There are also new opportunities and problems identified in this fascinating sector [17].

Idumah CI, et al. (2022) carried out survey on polyaniline and graphene nanocomposites for supercapacitors. The new 2D material graphene, in accordance to the researchers, has exceptional properties and has been used in many potential applications, including supercapacitor devices, which have improved their capacitance, energy, and power densities through the use of graphene as the electrode material. This has led to the development of more effective energy storage devices. These devices store electrical energy using two different methods: reversible Faradic reactions or ion adsorption, which result in EDL-capacitance and pseudo-capacitance, respectively. It has been repeatedly demonstrated that a simultaneous function of these capacitances can enhance supercapacitors' overall performance. This can be accomplished by combining graphene with metal hydroxides or oxides or conductive polymers. Further study is necessary to enhance the interactions between these exceptional electrode materials' composite materials, which will optimize the pseudo-capacitance and improve supercapacitor performance [29].

Dong et al. (2012) generated Co_3O_4 nanowires on reduced graphene oxide (rGO) with better structural morphology, resulting in a high specific capacitance of 1100 Fg-1. By creating 3D extremely porous graphene foam, several intrinsic performance constraints in rGO—such as aggregation and stacking brought on by π-π interaction, interlayer contact resistance, defects, and chemical moieties—were addressed. The composite was created by growing Co_3O_4 nanowires on a graphene scaffold that were 200–300 nm thick and many micrometers long. At high current densities, the nanocomposite demonstrated exceptional capacitance retention for longer than 25000 seconds [30].

Kumar, R. et al. (2020) by depositing the thin film created a gas sensor based on graphene oxide (GO). The process of thermal evaporation was used to create the thin films. Three different doses of meta toluic acid (MTA) were utilized to functionalize GO. Using common instruments, the Graphene Oxide (GO) was characterized following functionalization. SEM was used to examine the surface morphology of both GO and functionalized GO. Two probe resistance measuring techniques were used to examine the gas sensing behavior of functionalized graphene oxide (GO) for varying ammonia gas concentrations. The repeatability of the sensor was also examined for a steady gas volume. The exhibited selectivity and extended stability of the functionalized graphene oxide (GO) suggest its potential application in ammonia gas sensors [31].

Conclusions and Future Scope

Graphene oxide is a versatile nanomaterial with significant potential across multiple applications. The synthesis methods, properties, and diverse functionalities of GO make it a subject of ongoing research. Continued exploration of GO's capabilities and improvements in synthesis techniques will likely lead to further advancements in its applications, particularly in electronics, environmental remediation, and energy storage technologies. Recent trends in the literature indicate a growing interest in hybrid materials that combine GO with other nanomaterials, such as metal nanoparticles, polymers, and other carbon-based materials. These hybrids aim to exploit the synergistic effects of the components to achieve superior performance in applications ranging from catalysis to sensors. Additionally, sustainability is becoming a key theme, with researchers increasingly focusing on the environmental impact of GO production and exploring ways to recycle or reuse GO-based materials.

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