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Research Progress in The Preparation of Graphene by Oxidation-Reduction Method

Xingyu Yi

School of Chemistry and Chemical Engineering, Chongqing Technology of University, Banan 400054, Chongqing, China

Abstract: Graphene represents a monolayer carbon material with a hexagonal honeycomb lattice. It has high conductivity, high specific surface area and excellent thermal and mechanical properties. Such outstanding properties enable its wide-ranging applications in sensing, membrane technology, biomedical engineering, and other advanced fields. In this paper, the research progress of graphene prepared by oxidation-reduction method is systematically reviewed, covering the development from classical oxidation methods to modern improved processes. The effects of different types of reduction methods on the structure and properties of the products are analyzed. Finally, the main problems and future development directions are summarized.

Keywords: Graphene; Oxidation-reduction method; Preparation methods.

1. Introduction

Following the successful isolation of single-layer graphene via mechanical exfoliation by Geim and Novoselov [1] in 2004, this two-dimensional crystal material composed of carbon atoms has rapidly become a research hotspot of materials due to its excellent optical properties, electrical conductivity, mechanical properties, and thermal properties [2-5]. Nevertheless, mechanical exfoliation suffers from low efficiency and is limited to laboratory-scale preparation, which cannot meet the needs of large-scale industrial production. Therefore, researchers are committed to exploring efficient, low-cost, and industrialized methods for preparing graphene to promote its industrialization from the laboratory. 'Top-down' and 'bottom-up' preparation methods of graphene are divided into two categories. The top-down strategy involves breaking interlayer van der Waals interactions in graphite via physical or chemical methods, from which graphene is stripped. The main methods are oxidation-reduction method, liquid-phase exfoliation, and exfoliation. The bottom-up strategy, by contrast, starts with carbon atoms, which are induced to spontaneously assemble into the six-membered honeycomb lattice of graphene on a substrate through chemical reactions or atomic arrangement processes. Key techniques in this category include chemical vapor deposition (CVD), SiC epitaxial growth, and organic synthesis-based assembly.

Out of diverse graphene manufacturing strategies, redox preparation stands out for scalable industrial manufacture owing to its low raw-material cost, high product output and uncomplicated operating workflows. The method consists of two core stages: oxidation and reduction. First, natural graphite is oxidized to graphene oxide (GO) using natural graphite as the raw material; subsequently, GO is reduced to reduced graphene oxide (rGO). The reduction process mainly includes three approaches: chemical reduction, thermal reduction, and electrochemical reduction. Chemical reduction involves adding a reducing agent to a GO dispersion to generate rGO via chemical reactions [6-7]. Thermal reduction achieves interlayer exfoliation to obtain rGO by heating GO in a specific environment [8-9]. In the electrochemical reduction method, GO is coated on a conductive substrate or placed in an electrolyte, and a current is applied to remove oxygen-containing functional groups on the GO surface via electrochemical reactions, yielding rGO [10-11].

However, the redox method still faces several practical challenges. On the one hand, the use of strong oxidants destroys the sp^2 covalent bonds in the graphene layer and introduces oxygen-containing functional groups (e.g., carboxyl (-COOH) and hydroxyl (-OH)) into the originally continuous lattice. This results in the fracture of π-bonds and defects in the σ-bond skeleton, severely degrading the material's excellent electrical conductivity and mechanical properties. On the other hand, pollutants generated during the reduction process pose hidden risks to the environment. Therefore, developing strategies to reduce pollution and achieve green production while preserving the inherent advantages of the redox method has become a critical research focus.

In this paper, the research progress of graphene prepared via the oxidation-reduction method is systematically reviewed, covering developments from classical oxidation protocols to modern improved processes. The effects of different reduction strategies on the structure and properties of the resulting products are analyzed. Finally, the main challenges and future research directions are summarized.

2. Preparation of Graphene Oxide in Oxidation Stage

Graphene oxide (GO) is a layered carbon material derived from graphite oxidation using strong oxidants and concentrated sulfuric acid. In this process, acid species (such as HSO_4^-) intercalate into the graphite galleries to expand the interlayer spacing. Concurrently, the oxidant functionalizes the graphite surface, introducing a large number of oxygen-containing groups, mainly including -COOH, -OH, and -C(O)CH. These functional groups enlarge interlayer distance from ~0.335 nm to 0.7–1.2 nm [12-14], weakening interlayer forces and enabling GO exfoliation. This weakens the van der Waals forces between adjacent layers, making it easier to obtain single- or multi-layer GO sheets. Currently, the classical GO preparation methods include the Brodie method, the Staudenmaier method, the Hofmann method, the traditional Hummers method, and the modified Hummers method.

2.1. Brodie method

Brodie [15] first proposed the synthesis of GO using natural graphite, fuming nitric acid (HNO_3), potassium chlorate ($KClO_3$), and other raw materials. By generating oxychloride radicals (e.g., $ClO_2\cdot$) and reactive oxygen species, the carbon atoms between graphite layers are oxidized, introducing functional groups such as hydroxyl and epoxy groups.

2.2. Staudenmaier method and Hofmann method

The Staudenmaier method [16] builds upon the Brodie method by incorporating concentrated sulfuric acid. This approach yields GO with a higher degree of oxidation and a more uniform structure; however, it still releases toxic gases and involves greater operational hazards. The Hofmann method [17] employs a mixed acid system of 98 wt% concentrated sulfuric acid and 68 wt% concentrated nitric acid, with potassium chlorate as the oxidant. Compared to the Staudenmaier method, it requires milder and shorter reaction conditions, though the oxidation degree is slightly lower, and toxic gas emissions remain a concern.

2.3. The traditional Hummers method and the improved Hummers method.

The traditional Hummers method [18] uses natural graphite, concentrated H_2SO_4, sodium nitrate ($NaNO_3$), and potassium permanganate ($KMnO_4$) as raw materials. Compared with the Brodie and Staudenmaier methods, it features a shorter reaction cycle and does not produce toxic gases. However, the method also has notable drawbacks: concentrated H_2SO_4 and $KMnO_4$ are highly corrosive; simultaneously, the introduction of a large number of oxygen-containing functional groups disrupts the conjugated structure of graphene and reduces its electrical conductivity. To address these issues, researchers have conducted extensive optimization and improvement of the preparation process. By adjusting reaction conditions and reagent systems, process safety has been effectively enhanced [19-20], the reaction cycle has been shortened, and the structure and properties of graphene oxide have been improved [21-22].Since 2010, many improved protocols have been proposed, mainly removing toxic sodium nitrate and optimizing the ratio of oxidants. Research has shown that simply adjusting the dosage of potassium permanganate can realize an eco-friendly oxidation process without sodium nitrate. Subsequently, Chen et al. [23] further demonstrated that efficient and environmentally friendly GO synthesis can be achieved solely by adjusting the amount of $KMnO_4$, without using $NaNO_3$ at all. M. M. Khani et al. [24] explored a new approach using cyanuric chloride as an oxidant, while Zhang et al. [25] introduced innovations such as segmented sampling methods. Studies have also shown that a single concentration of H_2SO_4 cannot simultaneously achieve graphite intercalation and oxidation, and that $KMnO_4$ is an essential co-oxidant. Novel fabrication tactics centered on oxygen atom transfer together with continuous-flow synthesis have been put forward by multiple research teams, which realizes ultrafast, regulatable and environmentally benign GO synthesis finished in minutes. In general, GO preparation methods are evolving toward rational design, green efficiency, and mechanism-driven optimization.

Table 1. Comparison of advantages and disadvantages of five oxidation methods

method	advantage	disadvantage
Brodie	The degree of oxidation is high.	The reaction is violent and dangerous; long cycle, produ-ce toxic gases.
Staudenmaier	The oxidation efficiency is improved	Poor safety; the reaction is slow.
Hofmann	The steps are relatively simple, and the oxidation process is controllable.	The explosion risk is high; there are many defects in the product.
The traditional Hummers	The safety is greatly improved; the reaction time is short, the yield is high.	High temperature has the ris-k of explosion; metal ion residues require a lot of wash-ing
The improved Hummers	Higher safety; Homogeneous oxidation	The steps are slightly cumbersome; high requirements for operating accuracy.

3. Preparation of Reduced Graphene Oxide in Reduction Stage

The main reduction strategies for graphene oxide (GO) include chemical reduction, thermal reduction, electrochemical reduction, and green biological reduction.

Various reductants including hydrazine hydrate and ascorbic acid can strip oxygen-bearing functional moieties from GO sheets to form rGO via chemical reduction; by contrast, thermal treatment breaks these groups into CO and CO_2 gas under sudden or sustained high-temperature surroundings. Electrochemical reduction transfers electrons from the electrode to GO sheets under an applied cathodic electric field, directly reducing GO to rGO. Green biological reduction relies on biomolecules (e.g., polyphenols and metabolites) as electron donors to transfer electrons to GO, producing rGO under mild conditions.

3.1. Chemical reduction method

Chemical reduction employs reducing agents to remove oxygen-containing functional groups from the GO surface, thereby restoring graphene's conjugated structure. This method is relatively simple to operate, features mild reaction conditions, and yields significant reduction effects, making it a widely used strategy in laboratory research. In 2007, Stankovich et al. [26] first reduced graphene oxide using hydrazine hydrate, confirming the feasibility of chemical reduction. Follow-up investigations confirmed sodium borohydride displays favorable deoxygenation capacity. To improve reduction quality, hydroiodic acid has been proven to provide the highest C/O ratio among common reductants. Chen et al. [27] combined hydrazine hydrate reduction with microwave radiation, which greatly shortened the reaction time. Thereafter, research on chemical reduction continued to deepen, focusing on mechanism elucidation and process optimization. Common chemical reductants include

hydroiodic acid and sodium borohydride. Studies indicate that hydroiodic acid usually provides higher reduction efficiency than sodium borohydride. Guo et al. [28] further expanded the reducing agent system, using sodium borohydride, hydrazine hydrate, and thiourea to prepare B-rGO, N-rGO, and N/S-rGO, respectively, and compared them with commercial rGO (C-rGO). As shown in Figure 1, all samples exhibited different degrees of lamellar agglomeration, among which N/S-rGO showed the most severe agglomeration and the poorest stability. By contrast, N-rGO showed the best comprehensive stability, while B-rGO performance fluctuated significantly. Subsequently, Chudziak et al. [29] further expanded the reducing agent system, systematically comparing the reduction efficiency and product intrinsic properties of hydrazine hydrate, sodium borohydride, ascorbic acid, and sodium dithionite. The results indicated that the reduction ability of the agents followed the order: sodium dithionite > hydrazine hydrate > ascorbic acid > sodium borohydride. Meanwhile, Joshi et al. [30] proposed a new method for the efficient reduction of GO using Al-assisted HI at room temperature. The effects of single HI reduction and HI-Al composite reduction were systematically compared. Figure 2. illustrates the preparation process. The results show that Al-assisted reduction can significantly improve the reduction efficiency. The C/O ratio of HI-Al rGO reaches 6.1, which is much higher than that of the single HI reduction product. Zhu et al. [31] prepared rGO via four routes: vitamin C chemical reduction, rapid thermal reduction, slow thermal reduction, and VC-assisted rapid thermal reduction. Figure 3. presents the corresponding preparation processes. The results indicate that rapid thermal reduction enables lamellar expansion and exfoliation, yielding flake-like rGO with a high reduction degree and optimal electrical conductivity.

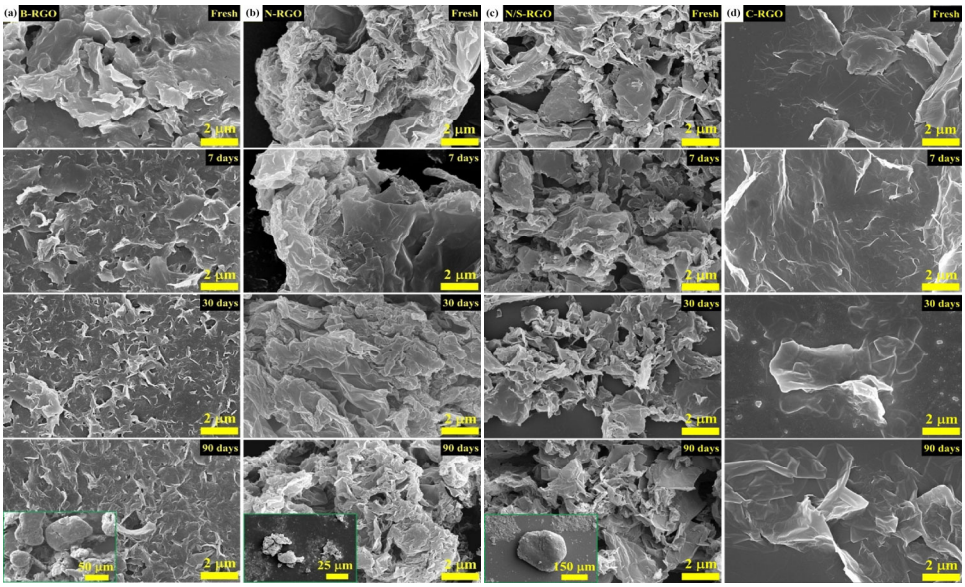


Figure 1. SEM images of rGO samples at different time periods : (a) B-rGO ; (b) NR-rGO ; (c) N / S-rGO ; (d) C-rGO [28]

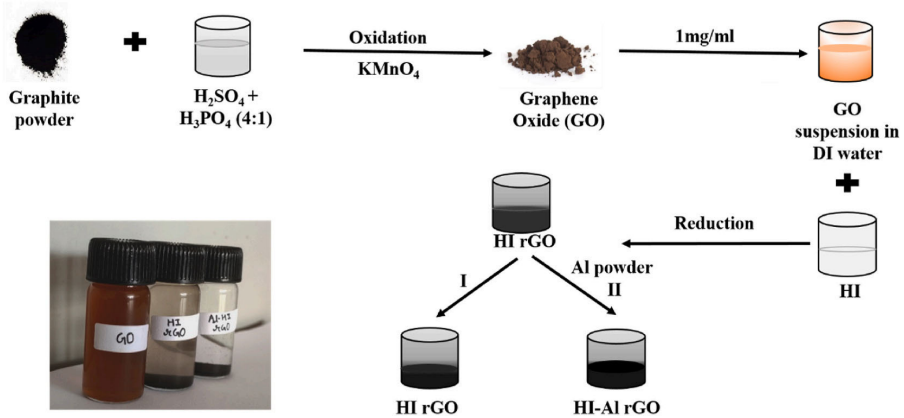


Figure 2. Syntheses of GO, HI-reduced rGO and Al-assisted HI-reduced rGO [30]

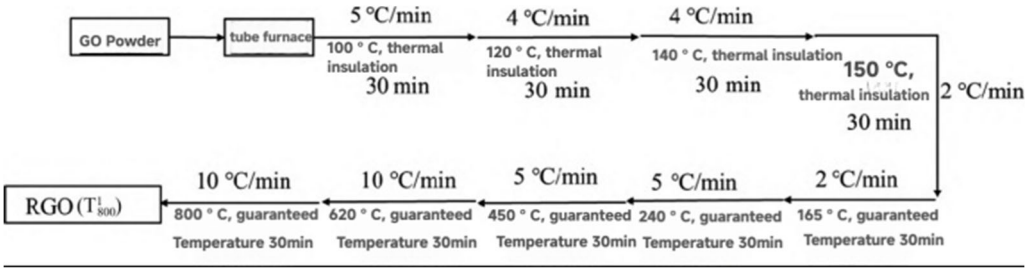


Figure 3. Preparation process of rGO (T^{l}_{800}) [31]

In summary, chemical reduction is suitable for batch production due to its simple operation, mild conditions, and low cost. However, the reduction reaction is often incomplete, resulting in insufficient electrical conductivity and structural integrity of the obtained rGO. Additionally, traditional reducing agents pose significant concerns regarding high toxicity, residual contaminants, and environmental risks.

3.2. Thermal reduction method

The thermal reduction method is a typical strategy for deoxidizing and reducing graphene oxide via high-temperature treatment. Thermal energy drives the removal of oxygen-containing functional groups from the GO surface in the form of gaseous products, restoring the sp^2 conjugated network of graphene. This approach has been widely used in the preparation of reduced graphene oxide. Boehm et al. [32] introduced a reducing agent to assist heating and succeeded in obtaining nanoscale carbon thin films. Novel preparation routes toward rGO keep emerging, and one feasible scheme relies on quick thermal expansion to realize layered exfoliation of graphene oxide. Building on this, Liu et al. [33] first proposed a two-step heat treatment method for preparing rGO. Liu Jinxin et al. [34] synthesized rGO/NiO composites via a one-step hydrothermal method. Electrochemical tests showed that the specific capacitance of the composites reached 1100 F/g at a current density of 0.5 A/g, and remained at 969 F/g at 10 A/g, demonstrating excellent rate performance and cycling stability. And there are studies showing that high-temperature annealing (850–1000 °C) is widely used to adjust the microstructure and performance of thermally reduced graphene oxide. Based on the study of single high-temperature annealing, Aditya et al. [35] further proposed a stepwise reduction strategy and prepared rGO using a microwave-assisted high-temperature two-step thermal reduction method (MSTR). As shown in Figure 4, the first step involves treating GO with 900 W microwave irradiation for a short period; the second step is further high-temperature annealing in a nitrogen atmosphere at 500–800 °C. This method is green, efficient, and operationally simple. Wang et al. [36] prepared α-Fe_2O_3/rGO composites via a hydrothermal method, with the preparation process illustrated in Figure 5. The results show that α-Fe_2O_3 nanoparticles (particle size ≈ 60 nm) are densely and uniformly distributed on the graphene sheet surface, effectively increasing the specific surface area.

High-temperature heat treatment is simple, fast, and requires no large amounts of reagents, making it suitable for large-scale preparation. However, high temperatures can easily cause lamellar wrinkling, restacking, or even structural damage, while the degree of reduction is difficult to control. Both the heating rate and the atmosphere exert a significant influence on the product, resulting in poor batch-to-batch stability, high energy consumption, and demanding equipment requirements.

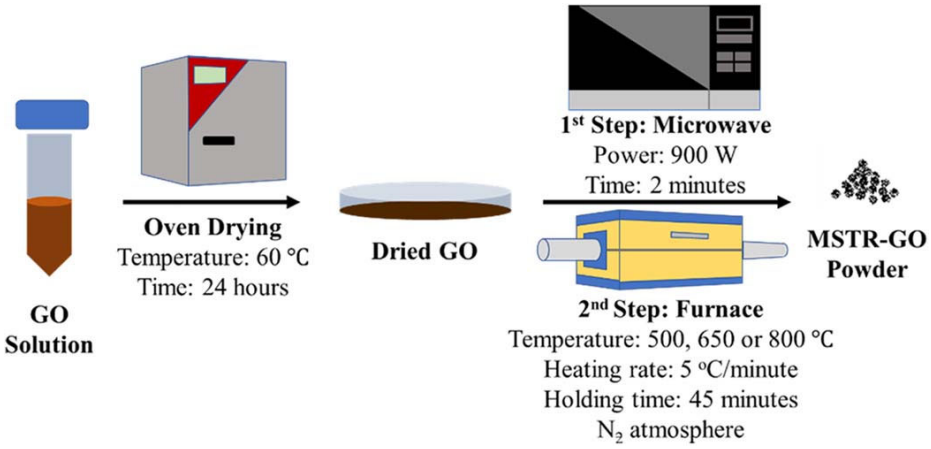


Figure 4. MSTR reduction process [35]

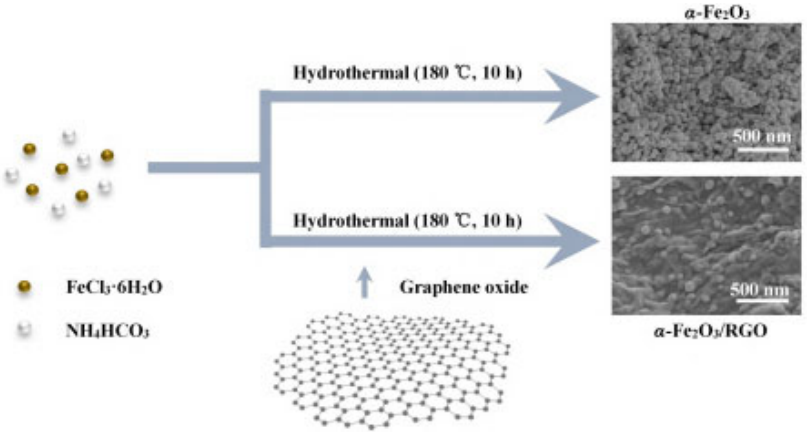


Figure 5. Preparation flow chart ofα-Fe2O3 andα-Fe2O3 / rGO [36]

3.3. Electrochemical reduction

The electrochemical reduction method has emerged as an important green technology for preparing high-performance reduced graphene oxide (rGO). In 2009, Shao et al. [37] and Ramesha [38] demonstrated that GO can be efficiently reduced and its conductivity restored under mild applied potentials. Bikkarolla et al. [39] found that partially reduced GO exhibits significant catalytic activity toward the oxygen reduction reaction. And Some studies have realized direct electrochemical reduction of GO on conductive substrates such as copper electrodes. Marrani et al. [40] focused on the key role of electrolyte media in GO reduction, comparing aqueous and non-aqueous systems. Their results showed that non-aqueous electrolytes achieve a higher reduction degree, a lower oxygen-to-carbon ratio (0.20), and yield electrochemically reduced GO (erGO) with controllable defects and better quality. Building on this, Beladi-Mousavi et al. [41] further overcame the limitations of traditional electrode-dependent methods by developing a new bipolar electrochemical approach for quasi-two-dimensional, electrode-free reduction. This strategy enables one-step controllable GO reduction without direct electrode contact, and the device schematic is shown in Figure 6. Some researchers have proposed a mediator-assisted electrochemical strategy has been developed to enable efficient bulk-phase GO reduction in aqueous media, overcoming the limitation of conventional electrode-only reactions.

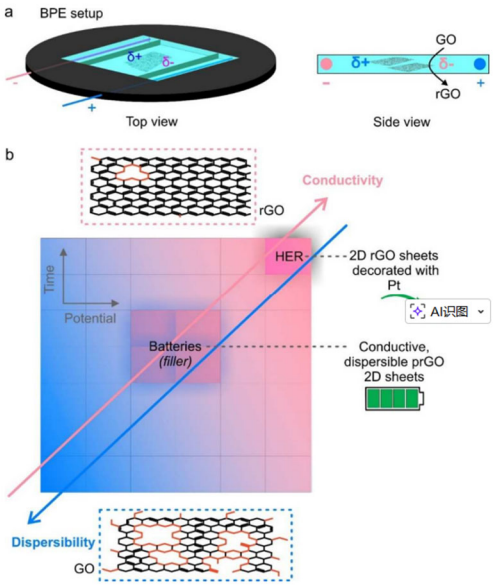


Figure 6. Bipolar electrochemical device schematic + principle model [41]

In summary, electrochemical reduction is a green process with controllable reduction degrees. However, its reduction efficiency is highly dependent on the composition of the electrode material and electrolyte, which limits its scalability and makes large-scale mass production challenging.

3.4. Green biological reduction method

Compared with chemical reduction, the green biological reduction method offers distinct advantages, including low carbon footprint, good biocompatibility, and sustainability as a preparation technology for reduced graphene oxide (rGO). This method is mainly divided into two categories: plant

extract-mediated reduction and microbial reduction. For plant extract reduction, the polyphenolic components of eucalyptus bark water extract can effectively remove oxygen-containing functional groups from GO. In addition, extracts from clove, white mulberry, and black grape have also demonstrated reduction capabilities. Fatimah et al. [42] first verified the reduction efficiency of Annona spinosa leaf extract. Podder et al. [43] expanded the green reduction system by using pigeonpea leaf extract to achieve mild GO reduction at atmospheric pressure. Studies have shown that pigeonpea leaf extract can effectively restore the conjugated structure of graphene and successfully prepare rGO. In terms of microbial reduction, several microbial strains, such as Escherichia coli, Lactobacillus plantarum, and Lactococcus lactis, can achieve green GO reduction under mild conditions. Among them, Lactococcus lactis shows the highest reduction efficiency. And certain lysine-producing bacteria can reduce GO indirectly by secreting reducing substances, requiring no direct contact between the microbes and GO.

In summary, bioreduction is green and safe, with mild conditions, no toxic by-products, and no residual reagents. However, it suffers from slow reaction rates, limited reduction degrees, difficulties in controlling biomass composition and reaction conditions, and poor product stability. These challenges make it difficult to efficiently prepare high-quality rGO.

Table 2. Comparison of advantages and disadvantages of four reduction methods

method	advantage	disadvantage
chemical reduction	It is easy to operate and can be batch processed.	Some of the reducing agentsare more toxic and affect the performance.
thermal reduction	The reaction is fast, and the product defects are easy to repair.	High energy consumption, high temperature may introduce structural defects.
electrochemical reduction	The reaction is mild and controllable.	Mass production remains challenging.
Green biological reduction	Environmentally friendly, non-toxic, good biocompatibility	The reduction time is longer and the yield is lower.

4. Conclusion and Foresight

The redox method is a relatively mature and widely used route in the preparation of graphene. This route can realize the effective exfoliation of graphene sheets and restore its conjugated structure and electrical conductivity to a certain extent, which can meet the basic requirements of most composite materials, energy storage devices, catalysis applications, and other related fields.

However, there are still some outstanding bottlenecks in this method: 1) the oxidation process causes significant damage to the carbon skeleton, and it is difficult to achieve complete repair of defects; 2) the reaction controllability is poor, and the stability of the key parameters of the batch product is insufficient; 3) The traditional reducing agent has high efficiency but is toxic and easy to remain, while the green reducing agent is safe but the reduction is not complete; 4) In large-scale production, the separation and purification of products are difficult, the production of acid-containing wastewater is large, and the treatment cost is high. In view of the above problems, the future preparation of graphene can be developed in the following four aspects: 1) Stepwise oxidation and synergistic reduction, supplemented by carbon-based repair agents to fill the defect sites; 2) Build an online measurement and control system, use continuous flow micro-reaction, standardize raw material pretreatment, and optimize process parameters based on machine learning; 3) Develop a composite green reduction system, supplemented by electrochemical and photocatalytic reduction, taking into account the reduction effect and no residual characteristics; 4) Optimize the washing and drying process, recycle waste acid, and improve the economy and continuity of the process.

References

[1] Novoselov, K. S., Geim, A. K., Morozov, S. V., et al. (2004). Electric field effect in atomically thin carbon films. Science, 306(5696), 666-669.

[2] Bahrami, F., Malik, M. W., Van Loock, F., et al. (2023). Accurate determination of stiffness and strength of graphene via AFM-based membrane deflection. Measurement Science and Technology, 34(12), 125027.

[3] Zheng, L., Qi, A., Zhang, Z., et al. (2025). Ultrastrong graphene films through confined assembly for extreme environmental applications. CCS Chemistry, 7(12), 3823-3835.

[4] Mohammadi, R., Ghaderi, M. R., & Hajian, E. (2023). A molecular dynamics simulation study of in- and cross-plane thermal conductivity of bilayer graphene. Materials, 16(20), 6714.

[5] Han, X., Dai, Y. Y., Xie, Y. Z., et al. (2025). Electrically-driven polarized nano-light sources based on suspended graphene nanoscrolls. ACS Nano, 19(33), 30221-30232.

[6] Chudziak, T., Montes-García, V., Czepa, W., et al. (2023). A comparative investigation of the chemical reduction of graphene oxide for electrical engineering applications. Nanoscale, 15(44), 17765-17775.

[7] Abakumov, A. A., Bychko, I. B., Voitsihovska, O. O., et al. (2024). Tuning the surface area of reduced graphene oxide by modulating graphene oxide concentration during hydrazine reduction. Materials Letters, 354, 135417.

[8] Akbi, H., Mekki, A., Rafai, S., et al. (2022). Phenomenological description of the thermal reduction kinetics in graphene oxide films. Materials Chemistry and Physics, 277, 125477.

[9] Aukstakojyte, R., Gaidukevic, J., Niaura, G., et al. (2022). Structural control and electrical behavior of thermally reduced graphene oxide samples assisted with malonic acid and phosphorus pentoxide. Inorganics, 10(9), 142.

[10] Korkut, A. S., & Uralcan, B. (2023). Reduced graphene oxide/ionic liquid composites with tunable interlayer spacing for improved charge/discharge kinetics in supercapacitors. Nanotechnology, 34(23), 235402.

[11] Sun, X., Yang, N., Dong, H., et al. (2023). In-situ electrochemical synthesis of heteroatoms-doped reduced graphene oxide toward nonradical degradation of tetracycline. Chemical Engineering Journal, 471, 144834.

[12] Shaibu, O. S., & Obukohwo, O. A. (2024). Facile synthesis and optimization of graphene oxide reduction by annealing in hydrazine vapour in ambient air for potential application in perovskite solar cells. Science World Journal, 19(1), 194-199.

[13] PriyaDarshani, M., & Sharma, R. (2024). Controlling the bandgap of graphene oxide via varying KMnO4. Optical Materials, 147, 114634.

[14] Abed, W. A., & Jabr, L. A. R. (2025). Synthesis and physical characteristics of graphene oxide (GO) by modified hummers method. In AIP Conference Proceedings (Vol. 3318, No. 1, p. 060003). AIP Publishing LLC.

[15] Brodie, B. C. (1860). Sur le poids atomique du graphite. Annales de Chimie et de Physique, 59, 466-472.

[16] Staudenmaier, L. (1898). Verfahren zur darstellung der graphitsäure. Berichte der Deutschen Chemischen Gesellschaft, 31, 1481-1499.

[17] Hofmann, U., & König. (1937). Untersuchungen über graphitoxyd. Zeitschrift für anorganische und allgemeine Chemie, 234(4), 311-336.

[18] Hummers, W. S., & Offeman, R. E. (1958). Preparation of graphitic oxide. Journal of the American Chemical Society, 80(6), 1339-1349.

[19] Zhu, Y., Kong, G., Pan, Y., et al. (2022). An improved Hummers method to synthesize graphene oxide using much less concentrated sulfuric acid. Chinese Chemical Letters, 33(10), 4541-4544.

[20] Le, H. N., Dao, T. B. T., Do Nguyen, T., et al. (2024). Revisiting oxidation and reduction reactions for synthesizing a three-dimensional hydrogel of reduced graphene oxide. RSC Advances, 14(42), 30844-30858.

[21] Karnis, I., Krasanakis, F., Sygellou, L., et al. (2024). Varying the degree of oxidation of graphite: Effect of oxidation time and oxidant mass. Physical Chemistry Chemical Physics, 26(13), 10054-10068.

[22] Saxena, S., Kumar, A., Yadav, N., et al. (2025). Influence of oxidation time on defect density and crystallinity in graphene oxide synthesized via modified Hummer's method. The Journal of Physical Chemistry Letters, 16(42), 10932-10937.

[23] Chen, J., Yao, B., Li, C., et al. (2013). An improved Hummers method for eco-friendly synthesis of graphene oxide. Carbon, 64, 225-229.

[24] Khani, M., Mehdipour, E., Faghani, A., et al. (2016). Preparation of graphene oxide by cyanuric chloride as an effective and non-corrosive oxidizing agent. RSC Advances, 6(116), 115055-115057.

[25] Zhang, H., Li, C., Xu, B., et al. (2023). Study on the structural characteristics and mechanism of GO prepared by improved Hummers method. Chemical Progress, EICSCD(5), 2606-2615.

[26] Stankovich, S., Dikin, D. A., Piner, R. D., et al. (2007). Synthesis of graphene-based nanosheets via chemical reduction of exfoliated graphite oxide. Carbon, 45(7), 1558-1565.

[27] Chen, W., Yan, L., & Bangal, P. R. (2010). Preparation of graphene by the rapid and mild thermal reduction of graphene oxide induced by microwaves. Carbon, 48(4), 1146-1152.

[28] Guo, N., Cui, Y., Lin, Y., et al. (2022). Comparison of performance stability of different chemically reduced graphene oxide under long-term preservation. Journal of Materials Science: Materials in Electronics, 33(23), 18294-18310.

[29] Chudziak, T., Montes-García, V., Czepa, W., et al. (2023). A comparative investigation of the chemical reduction of graphene oxide for electrical engineering applications. Nanoscale, 15(44), 17765-17775.

[30] Joshi, R., Dey, A., & Lahiri, I. (2022). Enhanced room-temperature reduction of graphene oxide using Al as a supplement in the liquid phase HI. Ceramics International, 48(23), 35896-35905.

[31] Zhu, Y., Zhang, H., Liang, F., et al. (2024). Controllable preparation and characterization of reduced graphene oxide. Materials Bulletin, (12), 56-61.

[32] Boehm, H. P., Clauss, A., Fischer, G., et al. (1962). Dünnste Kohlenstoff-Folien. Zeitschrift für Naturforschung B, 17(3), 150-153.

[33] Liu, Z., Diao, Z., Yuan, Y., et al. (2021). A two-step thermal treatment method to produce reduced graphene oxide with selectively increasing electrochemically active carbonyl group content for high-performance supercapacitor electrode. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 620, 126573.

[34] Liu, J., Sun, W., Xin, G., et al. (2024). Synthesis and electrochemical properties of reduced graphene oxide/NiO composites by hydrothermal method. Journal of Inner Mongolia University of Science and Technology, 43(4), 353-358.

[35] Aditya, D. M., & Hardiansyah, A. (2022). Spectroscopic studies on reduced graphene oxide behaviour in multi-step thermal reduction. Advances in Natural Sciences: Nanoscience and Nanotechnology, 13(1), 015008.

[36] Wang, H., Bao, S., Su, Z., et al. (2025). α-Fe_2O_3/(RGO). [Incomplete reference, only title fragment available], 42(1), 88-97.

[37] Shao, Y., Wang, J., Engelhard, M., et al. (2010). Facile and controllable electrochemical reduction of graphene oxide and its applications. Journal of Materials Chemistry, 20(4), 743-748.

[38] Ramesha, G. K., & Sampath, S. (2009). Electrochemical reduction of oriented graphene oxide films: An in situ Raman spectroelectrochemical study. The Journal of Physical Chemistry C, 113(19), 7985-7989.

[39] Bikkarolla, S. K., Cumpson, P., Joseph, P., et al. (2014). Oxygen reduction reaction by electrochemically reduced graphene oxide. Faraday Discussions, 173, 415-428.

[40] Marrani, A. G., Motta, A., Amato, F., et al. (2021). Effect of electrolytic medium on the electrochemical reduction of graphene oxide on Si (111) as probed by XPS. Nanomaterials, 12(1), 43.

[41] Beladi-Mousavi, S. M., Salinas, G., Antonatos, N., et al. (2022). Fine-tuning the functionality of reduced graphene oxide via bipolar electrochemistry in freestanding 2D reaction layers. Carbon, 191, 439-447.

[42] Fatimah, I., Fadillah, G., Rednasari, R. A., et al. (2022). Green reduction of graphene oxide using Annona muricata leaves extract for adsorption of methylene blue. Inorganic Chemistry Communications, 146, 110144.

[43] Podder, S., Dey, S., & Chatterjee, A. (2025). Facile and green synthesis of reduced graphene oxide using Cajanus cajan leaf extract and exploration of potential reducing phyto-constituents using quantum chemical calculations. Next Materials, 9, 101221.