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Synthesis and Characterization of Graphene Based Nanomaterials for Energy Applications

Dhananjay S. Rakshe[1*], P. William[2], M.A. Jawale[2], A.B. Pawar[3], Sachin K. Korde[4], Neeta Deshpande[5]

[1] *Department of Computer Engineering, Pravara Rural Engineering College, SPPU, Pune, India*
[2] *Department of Information Technology, Sanjivani College of Engineering, SPPU, Pune, India*
[3] *Department of Computer Engineering, Sanjivani College of Engineering, SPPU, Pune, India*
[4] *Department of Information Technology, Pravara Rural Engineering College, SPPU, Pune, India*
[5] *Department of Computer Engineering, R H Sapat College of Engineering, Management Studies and Research, SPPU, Pune, India*

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Due to the one-of-a-kind and one-of-a-kind qualities that it possesses, graphene is an appealing soft substance that may be utilized in a variety of applications. This review focuses on two significant issues that need to be resolved to make use of the notable properties of nanostructures based on graphene: The creation of graphene-based nanostructures with various well-defined structural variations is the initial of these problems, and effectively utilizing graphene-based nanoparticles as functional nanostructures in important idea or technologies is the second of these problems. Before the distinctive qualities of graphene-based nanoparticles can be completely exploited, each of these challenges must be resolved. In this critical analysis from the chemical and nanomaterials viewpoints, we provide a quick summary of recent significant developments in the creation of graphene-based nanomaterials. In this study, we also cover the synthesis, characterization, and applications of graphene nanomaterials in the disciplines of both energy and environmental pollution rehabilitation, including solar cells, lithium-ion batteries, supercapacitors, and the adsorption and degradation of pollutants from huge quantities of the aqueous medium. There is also a discussion of the most significant challenges and opportunities in the research materials.

Keywords: Nanomaterials, Graphene, Synthesis, Characteristics, Energy-Related Applications.

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1. INTRODUCTION

Since the awarding of the Nobel Prize in Physics in 2010 for "groundbreaking experiments relating the two-dimensional (2D) substance graphene," graphene, which is one of the carbon allotropes, has garnered a growing amount of attention from the scientific world. Since that time, the number of scientific papers and patents that discuss the synthesis and applications of graphene and graphene-based nanomaterials has experienced a rapid increase and is continuing to rise [1]. Nanomaterials based on graphene have been shown to have distinctive properties, and new methods have been uncovered that are both straightforward and effective for the production of graphene-based nanocomposites that may be utilized in a wide variety of contexts. It is intended that the production of graphene and materials based on graphene be controlled in such a way as to bestow qualities for certain applications. This would make it possible to use graphene-based materials. It is common knowledge that two primary methods can be utilized in the production of graphene. The terms "bottom-up" and "top-down" relate to these two approaches, correspondingly. In top-down approaches, stacked graphite layers are separated to create individual graphene sheets, although, in bottom-up approaches, graphene is synthesized from various types of carbon. Bottom-up techniques are known as "bottom-up" techniques. Graphene or highly oriented pyrolytic graphite rods or graphite foils are used as substrates in an aquatic or non-aqueous liquid electrolyte to electrochemically exfoliate graphene into graphite. Graphene can be made in this way. Finally, we discovered an inexpensive and simple electrolytic method for producing graphene by electrochemically peeling away graphene filaments in acidic solutions [2]. This method can be used to produce graphene. By altering the electrochemical settings, researchers were able to investigate both the exfoliation and oxidation levels of graphene flakes as well as their size. In images obtained using scanning electron microscopy (SEM), it can be seen that it is possible to observe the nanosheets, which are very thin and crumpled, and which are placed haphazardly and overlap with one another [3]. Fig. 1 represents the summary of graphene's contribution to numerous applications and areas.

For the investigation of contaminants, several compounds made from graphene have been developed as sensors. These treatments not only improve the inherent properties of graphene but also modify the surfaces of the graphene layers by adding certain oh groups or other helpful nanomaterials. As a result, these investigations have improved knowledge and practical use of graphene-based nanomaterials across several scientific fields. Scientists have investigated the toxicity of graphene sheets, but we think that any potential biohazards are outweighed by the material's intriguing features. Additionally, we think that shortly, any cytotoxicity that may exist can be minimized or eliminated [4].

* jay.rakshe@gmail.com

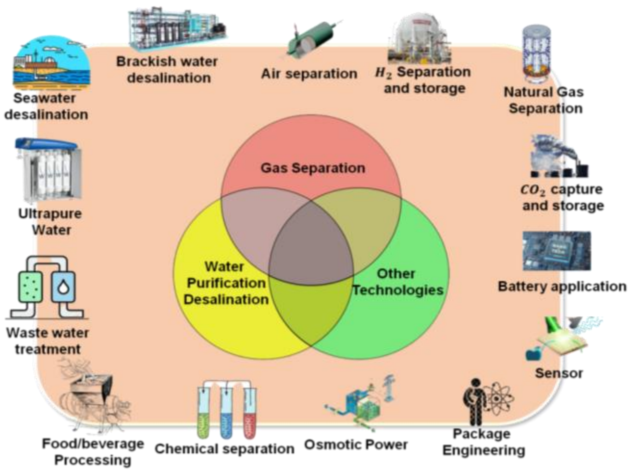

Fig. 1 – A summary of graphene's contribution to numerous applications and areas

The remaining part of this research is divided into 5 parts, section 2 – synthesis of nanomaterials based on graphene, section 3 – characterization of nanomaterials based on graphene, section 4 – Graphene-based nanomaterials in energy-related applications, section 4 – Environmental applications for graphene-based nanomaterials, section 5 – conclusion

2. SYNTHESIS OF NANOMATERIALS BASED ON GRAPHENE

Ever since micromechanical disintegration in 1999, numerous studies have been conducted on the production of graphene. To accomplish their many purposes, graphene-based nanoparticles must first be generated with controlled size, thickness, and shape. Consequently, developing effective techniques for their synthesizing is crucial. Up until now, the two primary ways for producing graphene from different sources of carbon have been "top - down" and "bottom - up".

2.1 Top-down Approach

To produce carbon, graphene materials, including 0D graphene sheets, 1D nanotechnology, and 3D graphite, can be used as a source of carbon and energy. The Staudemaier, Brodie, and Hummers technique for oxidizing exfoliation graphene is the most effective. The resultant graphene equivalents could be further expanded into one or maybe more multilayer graphene layers by quickly warming them, or they can be delaminated into single graphene oxide nanosheets by ultrasonic-assisted heating the others in an aqueous medium [5]. The controlled synthesis of graphene oxides has attracted a lot of research.

2.2 Bottom-up Method

Another essential technique for excellent control over the structure and shape of nanostructures is the bottom-up approach, which also commences with smaller organic molecules and contrasts with the top-down dosage, which also starts with graphite and provides a workable procedure for the widespread synthesis protocol [6]. It is widely known that vapor deposition can be used to catalyze the conversion of petroleum into graphitic compounds on metal surfaces (CVD). Large subdomains of single-crystalline graphite were effectively built on numerous metal substrates utilizing various CVD procedures using methane as the co-substrate. The Ni (111) layer, which has a secondary structure mismatch with the graphene, provides one of the finest substrates for depositing. Developing graphene on Ni film is said to have produced nanotubes with resistors of 280 $\Omega \cdot sq^{-1}$ (80 % transparent) and 770 $\Omega \cdot sq^{-1}$ (90 % transparent) [7]. Furthermore, CVD is the most desirable approach for making devices because of the precision at the graphene scale.

The CVD method still has a lot of trouble properly controlling the graphene's edge structure and topology, though [8]. Fig. 1 represents the diagrammatic illustration of top-down and bottom-up methods for synthesizing graphene.

3. CHARACTERISTICS OF NANOMATERIALS USING GRAPHENE

Spectral, morphological, and mechanical techniques were used to characterize the produced "films of GO/PEO and rGO/PEO nanocomposites with varying weight percentages of Graphene Oxide (GO) and reduced Graphene Oxide (rGO)". Examining the FT-IR spectrum of graphene nanoplatelets, polymers, and rGO/PEO composites were done using an FT-IR analyzer (Bruker Vertex 70). By combining and pulverizing the materials with KBr powder in a crusher and pestle, the powdery materials were turned into KBr disks for FT-IR characterization. The mix was pressed into discs using a machine. For both the monomer and composites, nanosheets were utilized. In the FT-IR, film and test discs were becoming suitable, and measurements were done in the 400-4000 cm^{-1} wavelength range. Bruker's Software OPUS 6.0 was used for the statistical studies, which used the rubber band method to change the baseline while deleting the CO_2 and H_2O traces. "The XRD patterns of the various nanomaterials were gathered using a JDX-3532 (JEOL Japan) X-ray diffractometer with a frequency of 1.54 Å" and a dispersion aspect (2) range of 0° to 70°. "One square-inch polymeric sample was progressively placed into the necessary standard glass beaker and exposed to the X-ray production chamber. The nanocomposites' morphology was examined using FE-SEM. The FE-SEM pictures were captured using a JEOL JSM-5910 transmission electron microscope (Japan). Before the neutrons were pushed at 10 kV using a tungsten halogen electron source to capture the TEM micrograph, the materials were placed on sample stubs, coated with gold, or otherwise examined [9]. "To get topographical information, surface profilometry was applied to the surface. Nitrogen was used to heat the substance at a rate of 10 °C per minute, with the temperature range set at 30 to 700 °C.

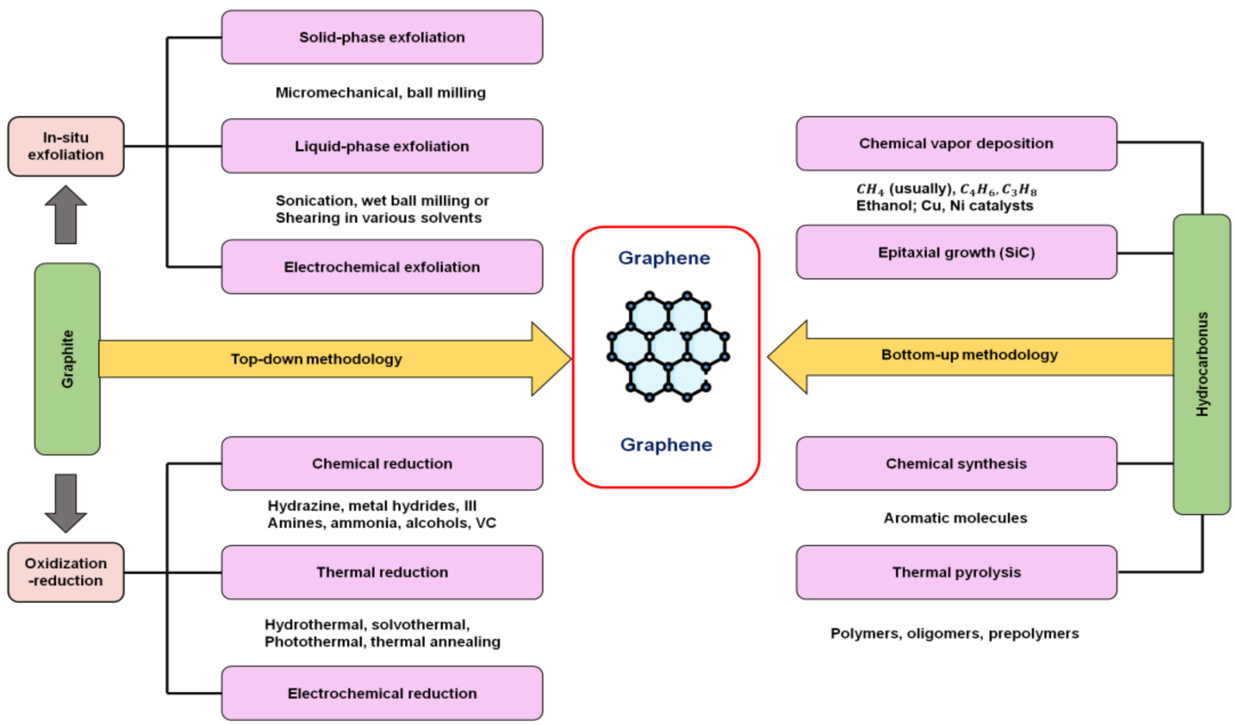

Fig. 2 – Diagrammatic illustration of top-down and bottom-up methods for synthesizing graphene

The mechanical characteristics of the nanocomposites were assessed using a Universal Testing Machine (UTM; Model: M350/500, Testometric UK). The test was carried out at room temperature with a crosshead rate of 1 mm per minute and an initial gauge length of 39 mm. To determine elastic modulus, compressive strength, and break elongation the gathered data was assessed [10].

4. GRAPHENE-BASED NANOMATERIALS IN ENERGY-RELATED APPLICATIONS

Due to its distinctive one-atom-thick layer 2D framework, and excellent properties of big surface area, nanomaterials are arising as a particular activated carbon for use in devices for energy storage such as superconductors, photovoltaic panels, and lithium batteries [11].

4.1 Application in Lithium-Ion Batteries

In today's world, recharged "Lithium-Ion Batteries (LIBs)" are extensively used in portable gadgets. Therefore, as the lithium-ion deployment mechanism in the electrode completes the recharge of LIBs, tremendous effort is being made to enhance LIB performances, particularly their specific energy, excellent rate, and cycling reliability. The electrode materials have a significant impact on these features. Many workers are now considering other anode materials because the typically used graphite has a poor specific capacity. It has been found that compared to ordered graphitic carbons, disordered carbon exhibits a greater capacitance. It follows that arbitrarily organized graphene nanofibers should have a large specific surface area due to their ability to store lithium, especially when considering how simple it is to thermally enhance the properties of oxygen-containing structural features in the predecessor to graphene oxide.

Metal oxide nanoparticles, with their high specific capacities, are an attractive anode material. In contrast, the electrode gets pulverized during charge/discharge operations due to the substantial volume change, rendering the process largely irreversible. However, this limitation can be mitigated to some degree "by reducing the size of these materials to the nanoscale". "Recently, graphene-metal oxide hybrids used as active materials in LIBs have been reported" to have a high specific capacity and strong cycle performance. Most commonly found among the metal oxides are "Co_3O_4, NiO, Mn_3O_4, CuO, TiO_2, SnO_2, and $Co(OH)_2$". Electrodes for lithium storage and conductors of electricity, graphene nanosheets play dual roles in these hybrid materials. Further, the volume growth of SnO_2 nanoparticles following the injection of lithium is constrained by the surrounding graphene. Nonetheless, it is difficult to control the functioning of such a building. Simple solvothermal method for producing graphene oxide/MoO_2 composites [13]. "Reversible capacities of 720 mA h g^{-1} at a current density of 100 mA g^{-1} and 560 mA h g^{-1} at a high current density of 800 mA g^{-1} after 30 cycles" were observed in a MoO_2/graphene oxide composite containing 10 % graphene oxide.

4.2 Application as Supercapacitor Materials

It is common to practice dividing supercapacitors into two broad categories, electromechanical double-layer capacitors (EDLCs) and supercapacitors, based on their underlying charge storage methods. The available surface of graphite particles as capacitor conductors is not dependent on pore dispersion in the solid state, in contrast to conventional high-surface-area materials such as carbon materials and nanotubes. Electron-doped graphite oxide capacitors (EDLCs) utilize graphene materials produced through the thermal treatment of graphite oxide. As an electrolyte, H_2SO_4 aqueous solution yielded graphene capacitance values of 117 and 100 $F \cdot g^{-1}$ at 100 and 1000 $mV \cdot s^{-1}$ scan speeds, respectively. Specific capacitance and electrochemical stability of graphene sheets generated in Chen's group by exfoliating and reducing graphite oxide in a low-temperature plasma were exceptional. As a supercapacitor, it seems to reason that graphene with fewer aggregations, fewer layers, and a larger effective surface area would function better. This has led to a great deal of interest in the chemical transformation of graphene from the part of a variety of research institutions. The extremely large surface area of chemical activation is provided by its stiff, highly porous; however, the efficiency of superconductors employing graphite as an electrode depends on the flexibility of graphene layers. Two different types of bifunctional graphene nanosheets are produced by the thermal exfoliating of graphite at room temperature in oxygen and elevated temperatures in nitrogen. The specific capacitance of the first functionalized graphene was found to be substantially higher than that of the second. Quick redox processes for the pseudo capacitance can be introduced by oxygen-containing groups on the surface of this functionalized graphene, such as hydroxyl, carboxyl, and epoxy groups. The electrolyte solution can reach the sheet surfaces of the multilayered graphene film thanks to the film's highly open pore shape, and the film also serves as an excellent "spacer" to prevent the graphene layers from stacking back up.

The as-prepared film displayed a specific capacitance in an aqueous solution of 215 $F \cdot g^{-1}$. Recently, a straightforward CVD method using ethanol as the carbon source to create a porous 3D graphene network has been published in Fig. 3.

5. ENVIRONMENTAL APPLICATIONS FOR GRAPHENE-BASED NANOMATERIALS

Another important topic that requires considerable consideration in scientific research is environmental pollution repair. As economies have grown and industrial activity has risen over the past few decades, so too has water pollution from heavy metal ions and toxic organic chemicals. Graphene-based nanomaterials have been the subject of several studies due to "their high specific surface area, which would allow for sufficient contact area for pollutants". This has led to their potential use in "the high-performance removal of a variety of organic and inorganic pollutants from aqueous solutions, including by adsorption to lower concentration, decomposition to less toxic molecules, and reduction to low-valent species". In other words, adsorbents, photo degradants, and photo reductants made from graphene have all found applications in the cleanup of polluted environments.

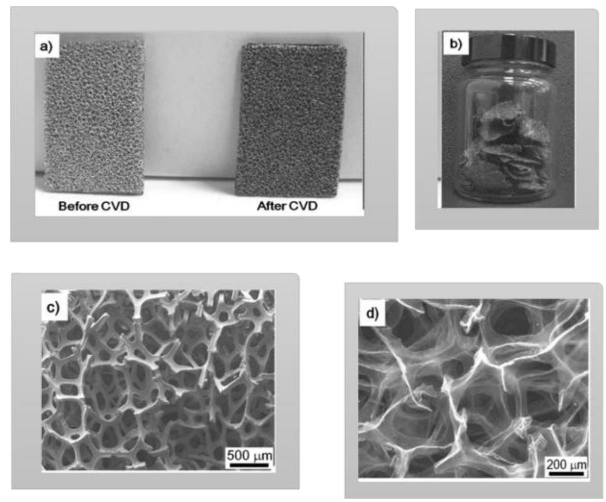

Fig. 3 – Images of Ni foam (before and after graphene growth) and ~0.1 g 3D graphene networks produced in a single CVD procedure. SEM pictures of (c) 3D graphene networks developed on Ni foam following CVD, and (d) 3D graphene networks after Ni foam has been removed

Application in the removal of pollutants from aqueous solutions as adsorbents: Graphene's high surface area makes it a promising adsorbent for a wide range of pollutants. For instance, by utilizing ultrasonication and centrifugation, graphene nanosheets with one or a few layers were extracted from a 1-methyl-2-pyrrolidinone (NMP) mixture. A maximum adsorption capacity of 35 mg g^{-1} was achieved when the NMP was used to remove fluoride from aqueous solutions. To better disperse graphene in aqueous solutions, many researchers have used modified graphene as an adsorbent for pollutant removal. "Several heavy metal ions, such as Pb(II), Cd(II), Co(II), and U," have been reported to be strongly adsorbed to the few-layered graphene oxide developed by Wang's group (VI). Maximum adsorption capabilities were determined to be "842 $mg \cdot g^{-1}$ for Pb(II), 106.3 $mg \cdot g^{-1}$ for Cd(II), 68.2 $mg \cdot g^{-1}$ for Co(II), and 97.5 $mg \cdot g^{-1}$ for U(VI)", according to their research. All of these values are much higher than those found in any other adsorbents.

6. CONCLUSION

Graphene research, a special form of 2D carbon, has increased steadily since its discovery. Applications of modified graphene and graphene combined with other functional nanoparticles will be the focus of future research. Throughout this thorough analysis, new findings on the synthesis of substances derived from graphene and their applications to clean up environmental contamination were presented. Particular possibilities are described, including those found in solar cells, lithium-ion batteries, supercapacitors, and the adsorption and degradation of dangerous contaminants from large volumes of aqueous solutions. Compared to other nanostructures, graphene-based materials can be manufactured using "top-down" or "bottom-up" methods, and they have unique properties in the energy and environmental domains. There are still numerous problems in need of workable fixes. In practical applications, "top-down" synthesis frequently leads to a large number of flaws in the graphene framework, but "bottom-up" synthesis is difficult to adopt for mass production. Therefore, new techniques are required to mass-produce elevated graphene at an affordable price. Foremost, although graphene-based components are employed as electrode material for start charging transportation and collection in electrical gadgets, more research is required to address several critical issues, which include graphene morphological characteristics, deformities, hydroxyl group, and construction behavioral patterns among graphene and other fully functioning particles. Last but not least, even though bifunctional graphene-based nano systems have demonstrated promising results in the removal of a wide range of contaminants from the aqueous phase, preferential adsorbent for individual pollutants is hardly ever reported, and degradation reactions frequently focus on natural chemicals compared to other toxic environmental substances or increased metal ions. The lack of progress in research on the relationship between graphene-based nanoparticles and improved performance has also hampered the development of effective functional graphene-based materials. Although graphene-based nanostructures have the potential to play a significant contribution to the fight against environmental degradation, their use is now limited by their expensive production processes and low throughput. There is little doubt that these issues will be resolved as technology advances and that more useful materials based on graphene will soon be widely used.

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Синтез і характеристика наноматеріалів на основі графену для енергетичних застосувань

Dhananjay S. Rakshe[1], P. William[2], M.A. Jawale[2], A.B. Pawar[3], Sachin K. Korde[4], Neeta Deshpande[5]

[1] *Department of Computer Engineering, Pravara Rural Engineering College, SPPU, Pune, India*
[2] *Department of Information Technology, Sanjivani College of Engineering, SPPU, Pune, India*
[3] *Department of Computer Engineering, Sanjivani College of Engineering, SPPU, Pune, India*
[4] *Department of Information Technology, Pravara Rural Engineering College, SPPU, Pune, India*
[5] *Department of Computer Engineering, R H Sapat College of Engineering, Management Studies and Research, SPPU, Pune, India*

Завдяки унікальним властивостям графен є привабливою м’якою речовиною, яку можна використовувати в різних цілях. Цей огляд зосереджується на двох важливих проблемах, які необхідно вирішити, щоб використовувати властивості наноструктур на основі графену: формування наноструктур на основі графену з різними чітко визначеними структурними варіаціями та наночастинки на основі мікроорганізмів як функціональні наноструктури. Перш ніж можна буде повністю використати відмінні якості наночастинок на основі графену, потрібно вирішити кожну з цих проблем. У цьому критичному аналізі з точки зору хімії та наноматеріалів ми надаємо короткий підсумок останніх значних досягнень у створенні наноматеріалів на основі графену; охоплюємо синтез, характеристику та застосування графенових наноматеріалів у дисциплінах енергетики та реабілітації забруднення навколишнього середовища, включаючи сонячні елементи, літій-іонні батареї, суперконденсатори, а також адсорбцію та деградацію забруднювачів із величезних кількостей водне середовище. У матеріалах дослідження також обговорюються найбільш значущі виклики та можливості.

Ключові слова: Наноматеріали, Графен, Синтез, Характеристики, Енергетичні програми.