Review On: Synthesis Approaches and Applications of Graphene and Its Derivatives

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***Abstract*: Graphene is a two-dimensional (2D) sheet of sp^2-hybridized carbon atoms packed into a honeycomb lattice. Now a days, graphene has been called a wonder material in the field of research. Since the few-layer graphene was exfoliated from graphite, graphene and its derivatives have showed promise in domains such as materials science, physics, chemistry, biology, and others. Graphene and its derivatives have some unique features that have prompted a lot of attention in a variety of industries. Graphene oxide, reduced graphene oxide, graphone, graphyne, graphdiyne, and fluorographene are all graphene derivatives. A comprehensive review of the many synthesis approaches and applications of graphene and its derivatives has been described in this article.**

Keywords: Graphene, graphene derivatives, fluorographene, synthesis approaches, honeycomb lattice.

1. Introduction:

Graphene has been one of the most fascinating carbon nanomaterials since its successful separation from graphite in 2004 [1]. Andre Geim and Konstantin Novoselov's discovery of graphene in 2004 aroused a worldwide interest in the material's potential applications [1, 2]. Graphene is made up of pure carbon atoms that are interconnected by van der Waals forces and are covalently bonded in the same plane. Although graphene is largely made up of pure carbon, the electrochemical characteristics of its edge and basal plane differ [2, 3]. The number of graphene-related research articles and patents has skyrocketed in the previous five years, showing that graphene is entering a new era, and numbers are expected to continue to increase in the next years [3, 4]. As a result, commercial-scale graphene production is expected to meet projected market demand in the near future.

There are now two types of graphene synthesis approaches: top-down and bottom-up. The top-down approach involves breaking down the structure of a precursor, such as graphite, and then separating the interlayers to generate graphene sheets. This method includes mechanical exfoliation, oxidation–reduction of GO, and arc discharge. Bottom-up processes like as chemical vapour deposition, epitaxial growth, and total organic synthesis, on the other hand, synthesize graphene on a substrate employing carbon source gas [2-5].

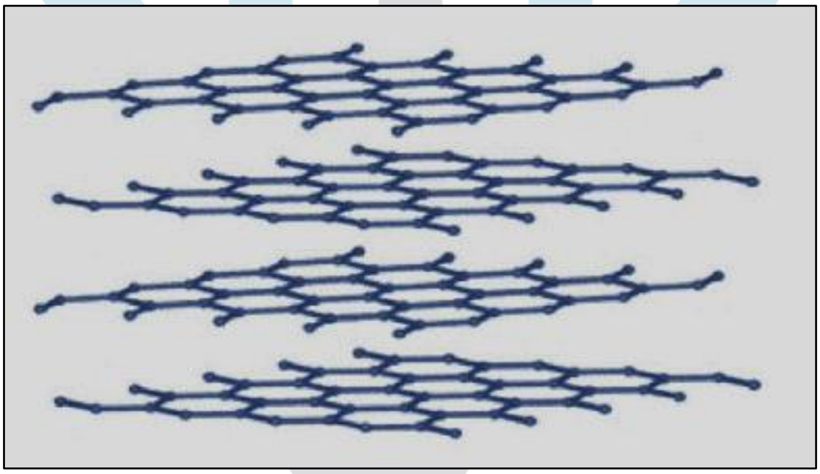

Figure 1 Structure of graphite

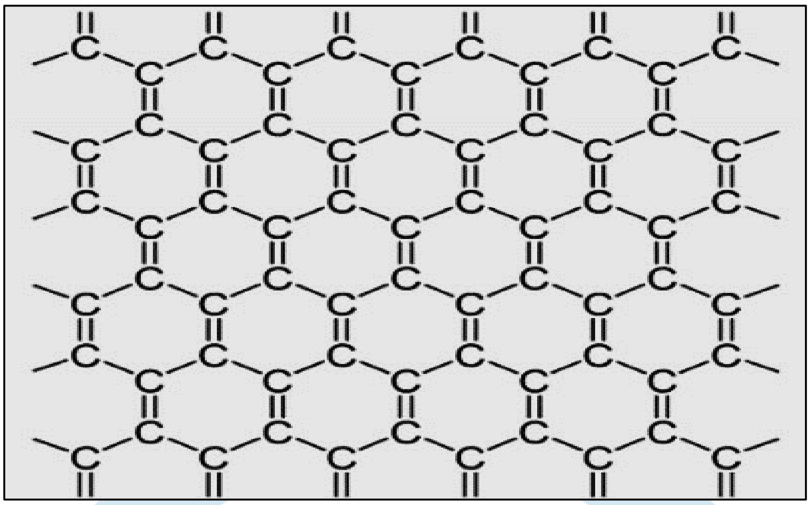

Figure 2 Structure of graphene

Figure 1 and Figure 2 shows the structure of graphite and graphene respectively. Graphene is a two-dimensional carbon atom sheet with sp^2 hybridization resulting from the mixing of the s, px, and py orbitals. Each carbon atom's remaining pz orbital produces π bonds with three surrounding carbon atoms, known as the valence band, and a band of empty π^* orbitals, known as the conduction band [6]. Graphene is a semiconductor with a narrow band gap [7]. At ambient temperature, the electron mobility of graphene was found to be as high as 15,000 $cm^2V^{-1}s^{-1}$, with very little temperature dependence and no effective mass for the charge carriers [8]. Graphene is applied as a temperature sensor, a thermoelectric sensor, and a thermal biosensor in energy management systems due to its exceptional thermal properties [9].

In order to be employed in industry, graphene must be produced at a cost that is competitive with current materials. The development of synthesis techniques that are cost-effective, highly predictable, and scalable, as well as high product yield and quality, is a critical concern. As a result, the following discussion of synthesis methods concentrates on these features.

2. Synthesis Approaches of Graphene and Its Derivatives:

Graphene could be synthesised using both bottom-up and top-down approaches. Figure 3 revels different synthesis approaches of graphene.

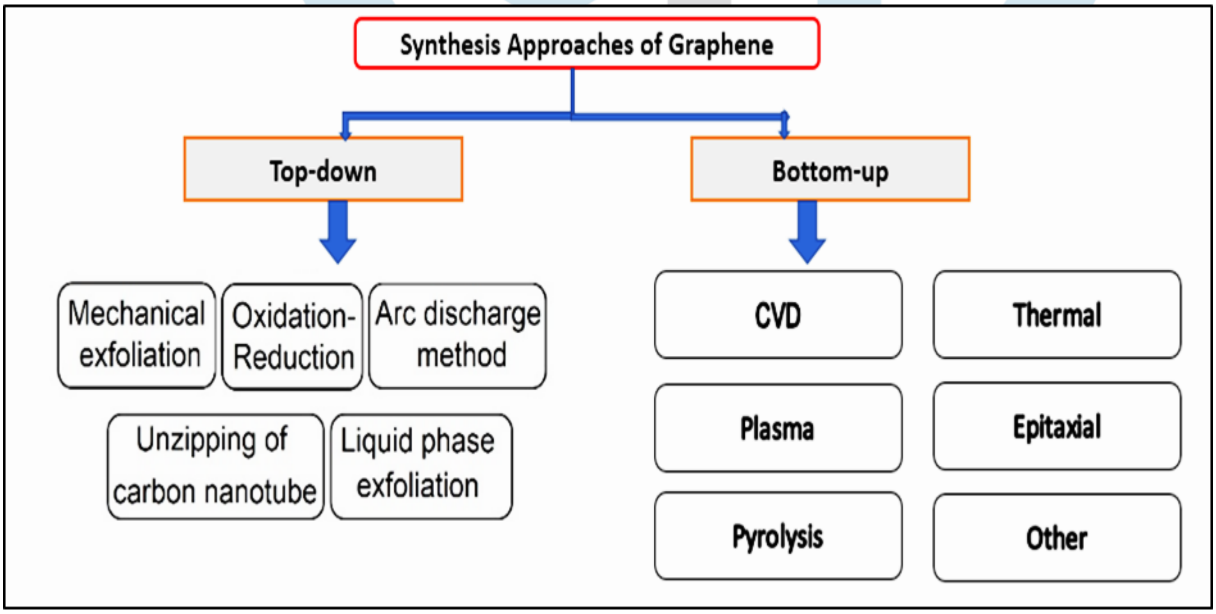

Figure 3 Different synthesis approaches of graphene

Any approach for producing or extracting graphene, depending on the required size, purity, and efflorescence of the individual result, is referred to as graphene synthesis.

2.1 Chemical Vapor Deposition (CVD):

CVD is a potential technology for the cost-effective production of graphene that can create vast areas of graphene. In this method, hydrocarbon gaseous species are fed into the reactor and pass through a hot zone, where they degrade into carbon radicals and deposit as single layer graphene on the metal surface. During this procedure, the metal surface works as a catalyst and controls the graphene deposition mechanism, which is important in the synthesis of pure graphene [10, 11].

2.2 Arc Discharge Method (ADM):

Anode and cathode are submerged in a reaction chamber's gas or liquid media in the Arc discharge process. The medium dissociates during the passage of electricity, resulting in a high-temperature plasma, which is sufficient to sublime the precursor. Due to the use of vacuum, this approach is regarded to be costly. As a result, the use of air rather than the H_2/He medium is recommended to lower graphene synthesis costs [12].

2.3 Liquid Phase Exfoliation (LPE):

Exfoliation of graphite produces a steady dispersion of a single layer or a few layers of graphene in this top-down process. The primary steps in LPE are graphite dispersion in a suitable solvent, exfoliation, and purification of the final products. This process of exfoliation requires overcoming the van der Waals forces to separate graphene layers. As a result, the choice of solvent is critical. Surface energy, Hildebrand solubility, Hansen solubility parameters, and surface tension have all been taken into account when choosing a solvent [13, 14].

LPE is the most common process for manufacturing large amounts of two-dimensional (2D) materials like graphene while maintaining a reasonable balance of quality and cost, and it is now widely used in both academic and industrial settings [14].

2.4 Mechanical Exfoilation:

Mechanical energy is employed in the mechanical exfoliation procedure to break down these weak connections and separate the individual sheets. Exfoliation is a method of obtaining graphene layers by continuously peeling graphite layers. Although the mechanical exfoliation approach can produce monolayer to few-layer graphene, the probability of producing a comparable structure using this method is low [15, 16].

2.5 Oxidation-Reduction:

For large-scale graphene synthesis, oxidation reduction is a popular approach. The preparation procedure can be broken down into two parts: first, obtaining graphene oxide (GO) by combining a strong oxidant with acid-treated graphite; and second converting GO to reduction graphene oxide (RGO) by employing chemical reduction, thermal reduction, or catalytic reduction treatment techniques (rGO). Oxidation reduction is one of the most preferred processes for large-scale graphene preparation due to its easy preparation conditions, which are possible in the laboratory, easily available raw ingredients, and high yield [17].

2.6 Chemical exfoliation method:

In chemical exfoliation procedure, solution dispersed graphite is exfoliated by injecting large alkali ions between the graphite layers. Chemical synthesis is a procedure that involves synthesising graphite oxide, dispersing it in a solution, and then reducing it using hydrazine.

Chemical synthesis is one of the most effective methods for producing graphene. Producing colloidal suspension using a chemical process that modifies graphene from graphite and graphite intercalation compound. Exfoliation with chemicals is a two-step procedure. To enhance interlayer space, the interlayer van der Waals forces are first reduced. As a result, graphene-intercalated molecules are formed. After that, fast heating or sonication exfoliates graphene into single to few layers [18, 19].

3. Derivatives of graphene:

Derivatives of graphene have attracted much attention for the potential applications in various fields. Various forms of graphene derivatives are schematically presented in figure 4.

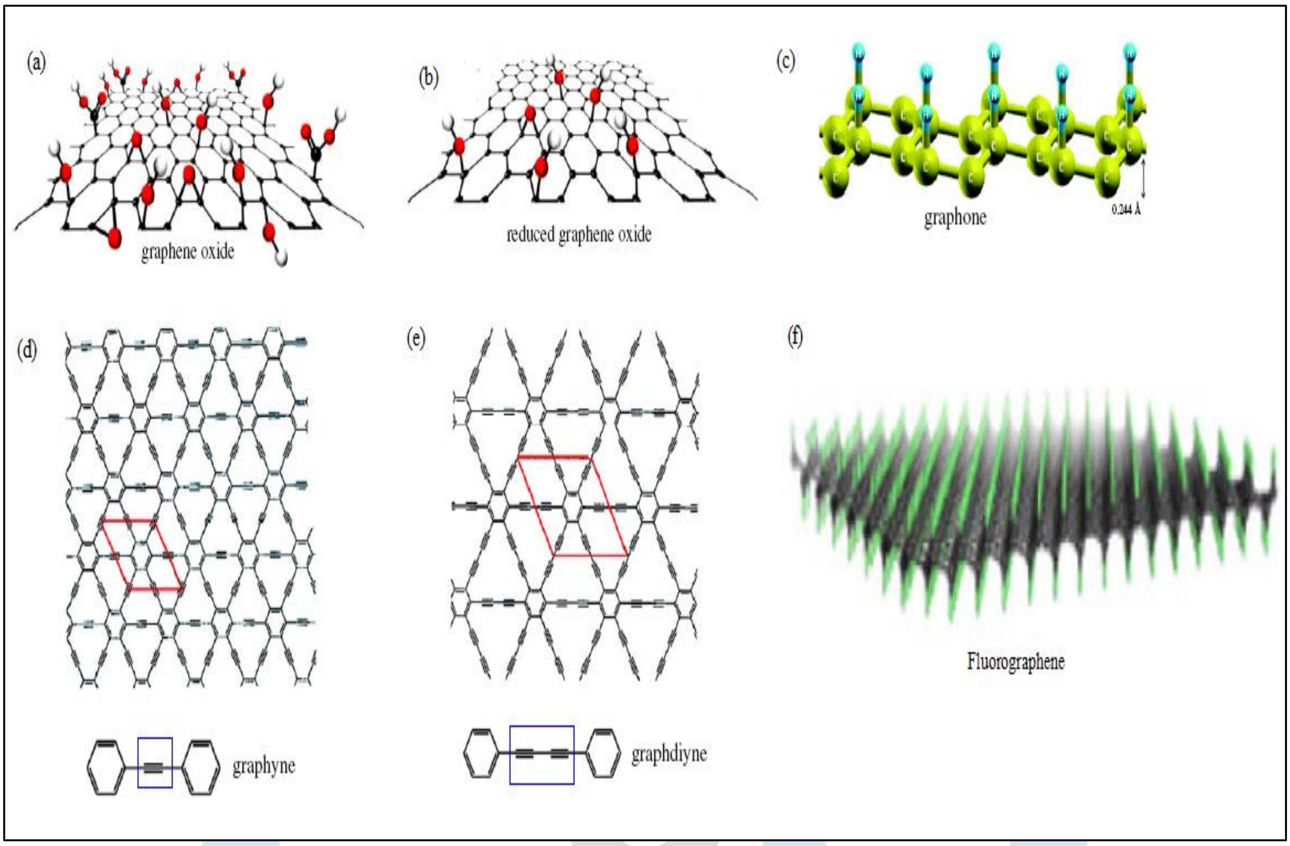

Figure 4 (a-f) Derivatives of grapheme

a) Graphene oxide: Graphene oxide (GO) is a remarkable physicochemical material with a small size, a large surface area, exceptional strength in a two-dimensional structure, and intriguing physicochemical characteristics among others derivatives of graphene. Hydrophilicity is a property of GO particles. In a wide range of concentrations, they produce stable aqueous dispersions [20, 21].

b) Reduced Graphene oxide:

Reduced graphene oxide (rGO) is an alternate version of graphene oxide that has been processed using a variety of processes, including chemical, thermal, and others, to reduce the quantity of oxygen in the material because oxygen makes GO more unstable. Reducing agents or thermal treatment can be used to remove certain oxygen-based groups, resulting in rGO. The rGO is a fascinating member of the graphene family since it is the only type, along with GO, that can be scaled up and made on a kg scale [22-24].

c) Graphone: Graphone is a half-hydrogenated graphene. The structure of graphone is illustrated as trigonal adsorption of hydrogen atoms on graphene. Graphone has been examined in a number of studies that investigate band gap modulation, ferromagnetism, antiferromagnetism, spin orbit coupling, structure, and thermal stability. A semi hydrogenated derivative of graphene which they called graphone [25].

Graphone is a graphene sheet with 50% hydrogenation and stoichiometry C_2H. Additionally, the hydrogen atoms are only on one side of the carbon sheet, resulting in a mixture of hybridized sp^2 and sp^3 carbon atoms. Upon geometry relaxation, it was found that graphone has a somewhat zigzag shape [26, 27].

d) Graphyne:

Graphynes are novel star carbon isomers made up of sp- and sp^2-hybrid carbon atoms with two-dimensional 2D layered in-plane porous geometries. These unusual topological and electronic structures, as well as their high charge mobility and good electronic transport capabilities, are the outcome of these unique qualities. The number of acetylenic chains between neighbouring benzene rings in a graphynes unit can be given a general term of graphyne [27, 28].

e) Graphdiyne:

Graphdiyne, a two-dimensional periodic carbon allotrope, differs significantly from graphene's hybridised orbital, which contains only single or double bonds. Graphdiyne is made up of two carbon atoms that are triple and double bound. It's a type of two self-doped non-equivalent distorted Dirac cone material with superior electronic characteristics to graphene, according to research [28 -30].

f) Fluorographene:

Fluorographene, a two-dimensional stoichiometric graphene derivative, has piqued the scientific community's interest due to its amazing physical and chemical properties. The electrical and optical characteristics of fluorinated graphenes are greatly affected by the insertion of fluorine atoms into the carbon lattice and the C/F (C sp^2/sp^3) ratio [31].

Along with its derivatives, particularly graphene oxide (GO) and reduced graphene oxide (rGO), graphene materials have been studied in various fields due to the presence of aromatic ring, free π- π* electron and reactive functional groups. A number of comprehensive reviews have documented the remarkable performance of graphene materials.

During the oxidation process, defects, impurities, structural disorder, wrinkle, crack, fragmentation, and other structural characteristics may arise, affecting the electrical, optical, and adsorption properties of GO. As a result, reduced graphene oxide (rGO), a graphene derivative, can be generated from GO. To convert GO to rGO, chemical or physical reduction might be used. During the reduction process, the oxygenous functional groups in GO are eliminated, leaving rGO with a carbon to oxygen ratio [32].

4. Applications of Graphene and Its Derivatives:

The use of graphene and its derivatives has proliferated in a variety of fields due to their excellent versatile features. Figure 5 depicts some of the promising areas where graphene and its derivatives are being used in pictorial form.

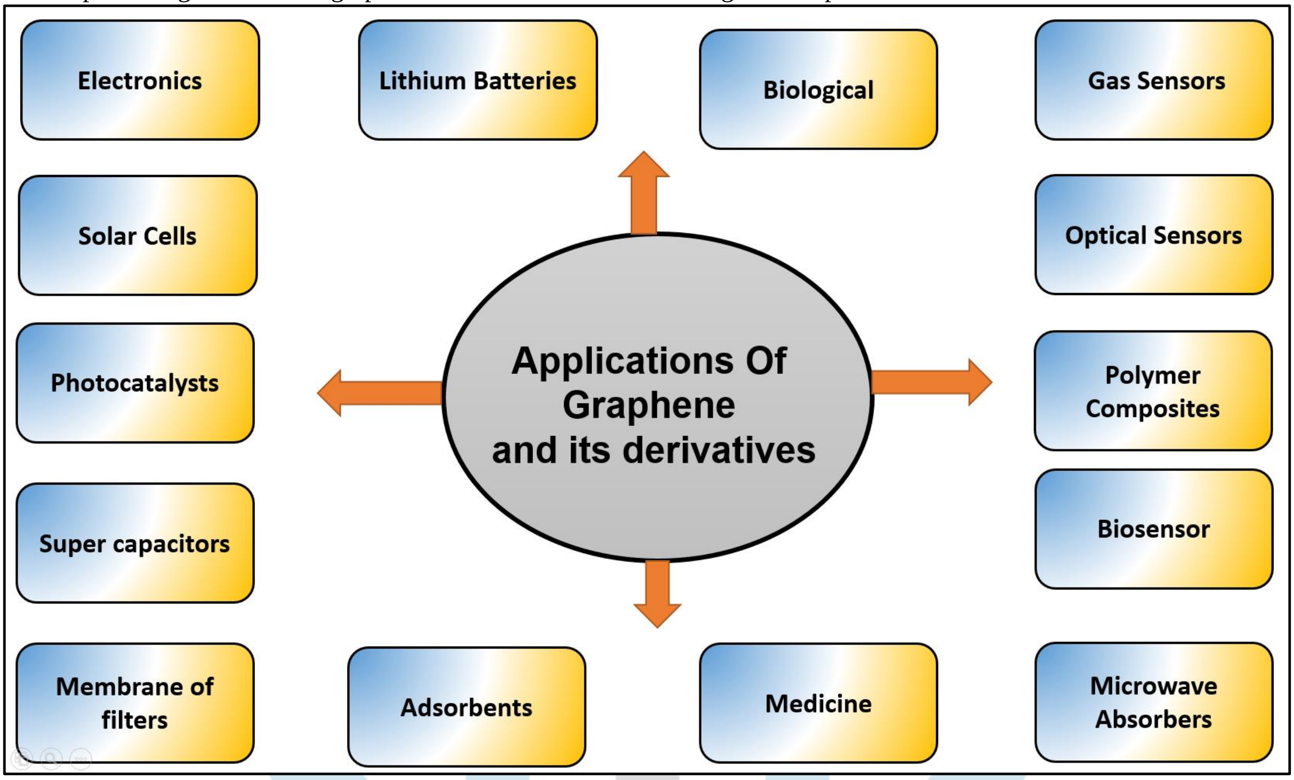

Figure 5 Schematic diagram of applications of graphene and its derivatives

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