Progress on preparation of graphene and its application

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Abstract: Graphene is a kind of new material with special chemical structure and excellent physical properties, demonstrating great application prospects in the fields of electronics, physics and chemistry. In this paper, some preparation methods of graphene were reviewed, and the advantages and disadvantages of these methods were analyzed, and the newest applications and development prospects of graphene were reviewed.

1. Introduction
Graphene, the parent of all graphitic forms (Figure 1), has become one of the most exciting topics of research in the last three to four years. Graphene is a one-atom-thick planar sheet of sp2-bonded carbon atoms densely packed in a honeycomb crystal lattice. It is the mother element of some carbon allotropes, including graphite, carbon nanotubes, and fullerenes [1]. Research on graphene has been successfully capitalized after its discovery in 2004 by Novoselov et al. at The University of Manchester [2]. This revolutionary discovery has added a new dimension of research in the fields of physics, chemistry, biotechnology, and materials science. The “thinnest” known material graphene exhibits excellent electrical conductivity, mechanical flexibility, optical transparency, thermal conductivity, and low coefficient of thermal expansion behavior [3]. The unique features of graphene have attracted tremendous interest both in academics and industry.

FIGURE 1 Graphene: the parent of all graphitic forms [4]

2. Graphene Synthesis Methods
To date, several techniques have been established for graphene synthesis. However, mechanical cleaving (exfoliation) (Novoselov et al. 2004) [2], chemical exfoliation (Allen et al. 2010; Viculis et al. 2003)[5, 6], chemical synthesis (Park and Ruoff 2009)[7], and thermal chemical vapor deposition (CVD) (Reina et al. 2009) synthesis are the most commonly used methods today[8]. Some other techniques are also reported such as unzipping nanotube (Jiao et al. 2010; Kosynkin et al. 2009; Jiao et al. 2009) and microwave synthesis (Xin et al. 2010)[9-12]; however, those techniques need to be...
explored more extensively. An overview of graphene synthesis techniques is shown in the flow chart in Figure 2.

![Graphene Synthesis Methods Flowchart](image)

**FIGURE 2 Different graphene synthesis methods**

2.1 Micromechanical Exfoliation
Micromechanical exfoliation is the first recognized method of graphene synthesis. Novoselov et al. (2004) used adhesive tape to produce a single graphene layer by a mechanical cleaving technique from 1-mm-thick HOPG [2]. Micromechanical exfoliation can be used to generate "high quality" graphene that is electrically isolated for fundamental studies of transport physics and other properties, but does not yet appear to be scalable to large area. It typically produces graphene "particles" with lateral dimensions on the order of tens to hundreds of micrometers.

While mechanical cleavage of graphene layers from a graphite crystal has afforded the study of the properties of single-layer graphene or bilayer graphene, the method is not suitable for large scale synthesis of single-layer graphene or of few-layer graphene.

2.2 Chemical Vapor Deposition (CVD)
Chemical vapor deposition is a chemical process by which a substrate is exposed to thermally decomposed precursors and the desired product deposited onto the substrate surface at high temperature Because the high temperature is not desired in many cases, plasma-assisted decomposition and reaction may lower the process temperature[13].

When a thermal CVD process involves chemical reactions of the reacting gases by generating plasma* inside a vacuum chamber, which leads to the deposition of thin film on the substrate surface, the process is known as plasma-enhanced chemical vapor deposition (PECVD). The plasma can be generated inside a PECVD system using RF (AC frequency), microwave, and inductive coupling (electrical currents produced by electromagnetic induction) PECVD has a wide range of advantages over other conventional CVD methods. By this technique, a process can be carried out at relatively low temperature compared to the other thermal CVD processes; hence, it is more feasible for industrial-scale applications [14].

2.3 Chemical synthesis: graphene from reduced graphene oxide
Chemical synthesis is the first method that demonstrated graphene synthesis by a chemical route. In the year 1962, Boehm et al first demonstrated monolayer flakes of reduced graphene oxide, which was recently acknowledged by the graphene inventor Andre Geim. The method involves the synthesis of a graphite oxide (GO) by oxidation of graphite, dispersing the flakes by sonication, and reducing it back to graphene[15]. There are three popular methods available for GO synthesis: the Brodie method (Brodie 1860) [15], Staudenmaier method (Staudenmaier 1898) [16], and Hummers and Offeman method (Hummers and Offeman 1958) [17]. All three methods involve oxidation of graphite using strong acids and oxidants. Brodie and Staudenmaier used a combination of potassium chlorate (KClO3) with nitric acid (HNO3) to oxidize graphite, and the Hummers method involves treatment of graphite with potassium permanganate (KMnO4) and sulfuric acid (H2SO4). Graphite salts made by intercalating graphite with strong acids such as H2SO4, HNO3 or HClO4 have also been used as precursors for the subsequent oxidation to GO.
2.4 Organic Synthesis
Synthetic organic chemists attempt to prepare graphene with full controllability by another strategy, in which certain type of graphene sheets can be synthesized by organic reactions. In organic chemistry, polycyclic aromatic hydrocarbons are considered as two-dimensional graphene segments composed of all-sp2 carbons. Pioneering contributions to the synthesis of polycyclic aromatic hydrocarbons were made by Scholl and Clar in the first half of the 20th century [18].

3. Applications of graphene
The fascinating of properties graphene and their derivatives enable them to be used in many potential applications [15-19].

3.1 Hydrogen storage material
Hydrogen has high energy density by mass. Therefore, it is considered as a key energy carriers. For practical applications, storage of hydrogen requires high gravimetric and volumetric densities, fast reaction kinetics, a low adsorption temperature, good reversibility, and low cost. The most common methods of storing hydrogen are in the form of gas in pressurized cylinders, cryogenic liquid, or as adsorbed gas in solid materials. Currently, the high temperature dissolution of hydrogen in metal hydrides poses a problem. Therefore, storage of hydrogen in materials by chemical process is indeed a safer method. Graphene can be an ideal material for hydrogen storage owing to the light weight, high surface area, and chemical stability. Hydrogen can be chemically stored in graphene by physisorption or chemisorption.

3.2 Energy storage devices
Graphene is a promising electrode material due to its high theoretical surface area and electron transferability along its 2-D surface. Graphene based electrodes are used as rechargeable lithium-ion batteries and electrochemical double-layer capacitors. Graphene nanocomposites can form a conducting 3-D network due to the uniform dispersion of silicon particles and reconstitution of graphene platelets, which are important aspects for the high storage capacities.

3.3 Memory and Photovoltaic Devices
Graphene-related nanomaterials have also been used in memory devices, transparent electrodes, electron acceptors, and light adsorbers because of their good electronic properties, transparency, and large specific surface area.

3.4 Transparent Conductive Films
Graphene materials are promising candidates for transparent conductive films because of their high carrier mobility, electrical conductivity, and optical transmittance in the visible range of the spectrum. Graphene-base transparent conductive films have been used as electrodes for dye-sensitized solar cells, liquid crystal devices, and organic light-emitting diodes.

4. Conclusions and Perspective
In this article, the preparation and applications of graphene have been reviewed. Preparation of high quality graphene materials in a cost-effective manner and on the desired scale is essential for many applications. Since new methods to synthesize graphene keep getting more and more interesting, we hope to see a solution that provides not just a fair balance between scalability and quality, but the best of both. The aim of this article is to provide an insight into graphene synthesis technology by providing an introduction and comparative study. Future efforts for graphene and n-layer graphene such as achieving desired surface functionalization and e.g., the "cutting" or preparation into desired shapes, could generate novel structures with many applications.
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