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# Synthesis, Characterization and Application of Graphene : A Review

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**Abstract**

Graphene is a single-layer, two-dimensional carbon honeycomb nanomaterial. Due to its excellent thermal conductivity, mechanical strength, current density, electron mobility and surface area Graphene and graphene oxide are widely used in material science, bio-medicine technology and other fields. Graphene oxide as precursor of graphene has been synthesized from coal via Exfoliation and Cleavage, Arc discharge, chemical vapour deposition (CVD), oxidation-cum-extraction (OCE), chemical leaching, template synthesis, chemical oxidation-reduction, thermal treatment and dielectric-barrier discharge (DBD) plasma are a few of the experimental techniques. Hummer's Method is used in the commercial synthesis of graphene oxide. Characterization of graphene oxide produced was conducted through several analysis such as X-Ray Diffraction analysis, Fourier Tr,ansform Infra Red (FTIR), UV-Visible Spectrophotometry and SEM EDS. This paper summarized the utilization of graphene across a range of fields, encompassing environment, energy, biomedical applications, sensors, bio-sensors, and heat sinks.

**Key words: Graphene, coal, synthesis, Hummer's Method, Characterization**

## 1. Introduction

Over recent years there is an interest in utilizing graphene as a next-generation electronic material. Graphene, characterized by a one-atom-thick planar sheet of sp2-bonded carbon atoms densely packed in a honeycomb crystal lattice, has attracted attention owing to its outstanding properties. **(Chen et al., 2008)**

Graphene have better physical properties compared to other materials, such as high thermal conductivity (5000 $Wm^{-1}$ $K^{-1}$) high electron mobility (250,000 $cm^2V^{-1}$ $s^{-1}$), high Young modulus values (1.0 TPa), large surface area (2630 $m^2$ $g^{-1}$),10 and better electrical conductivity and optical transmittance. **(Bahadır et al., 2016)**
Graphene is also known to be a zero-bandgap semiconductor; therefore, the band gap can be tuned through simple physicochemical processes. Owing to its exciting properties, study on graphene and its derivatives in the field of materials science and condensed-matter physics has generated immense attention over the past few years with various applications including membranes **(scott et al., 2008)** ,nanoelectronics, Li-ion batteries, electrodes, supercapacitors, sensors, drug delivery , etc.
Due to its exciting properties, the great attention has been developed to the study of graphene and its derivatives in the field of materials science and condensed-matter physics over the past few years. This paper summarize the applications such as ranging from membranes, nanoelectronics, Li-ion batteries, electrodes, supercapacitors, sensors, to drug delivery. **(Zhuang, et al., 2008)**

Graphene, obtained through the micromechanical cleavage of graphite, demonstrated high purity and quality, although it was time-consuming and unsuitable for mass-scale production. Recently, several other techniques have been introduced for the fabrication and synthesis of graphene. These methods include epitaxial growth through chemical vapor deposition on a copper (Cu) substrate, epitaxial growth by thermally depositing Si atoms from a SiC surface, colloidal suspension from graphite oxide, and several other innovative approaches.

In the context of energy storage applications, the corrosion behavior and electrical conductivity stand out as the two primary properties requiring consideration. Numerous types of steel necessitate surface modifications to boost their electrical conductivity while upholding high corrosion resistance for prolonged service. Consequently, various coating systems have been explored to enhance steel performance in energy storage applications. Examples include polymer-based coatings, multilayer coatings, and ceramic-based coatings **(Paul E et al.,2004)** Regarding polymer coatings, they tend to initiate microcracks in mechanical structures, diminishing their reliability, thereby emphasizing the search for alternatives suitable for long-term applications. **(Hamed et al., 2013)**

## 2 Graphene synthesis

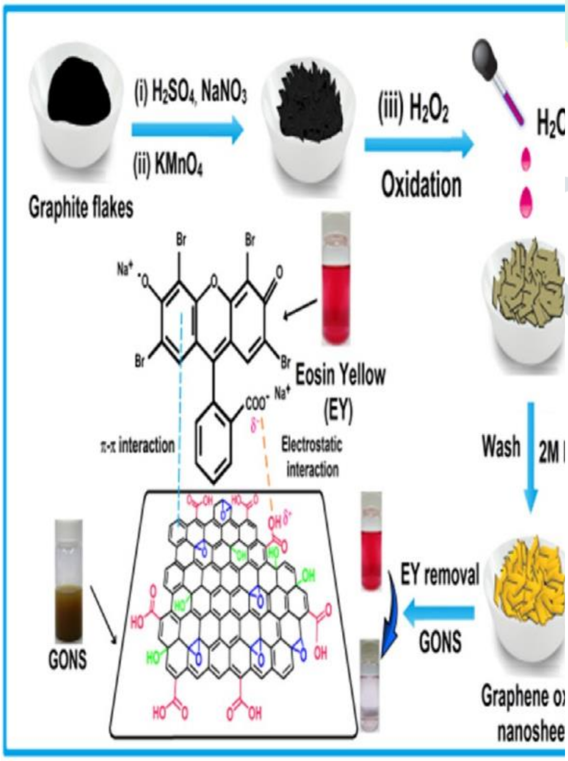


Fig 1 . Illustration for the synthesis of GONS P. (*P. Veerakumar et al., 2015*)

Graphene oxide, the oxygenated derivative of graphene, is characterized by its hydrophilic nature due to the presence of oxygenated functions, allowing it to disperse effectively in water. Additionally, these oxygenated functions play a crucial role in enhancing layer separation within graphene oxide.

Graphene synthesis can be achieved through various methods, including mechanical exfoliation, Hummers Method, arc-discharge, and chemical vapor deposition (CVD). Additional approaches, such as chemical reduction, sonochemicals, electrochemicals, and laser ablation, have also been developed for graphene synthesis **(Geetanjali et al., 2015).** These methods are evolving rapidly, incorporating diverse modifications to produce high-quality graphene. The quality of graphene is significantly influenced by the synthesis conditions and the careful selection of precursor chemicals.

### 2.1 Exfoliation Method

This method has two main branches scotch tape and liquid phase exfoliation.

The Scotch tape technique involves the successive peeling of multiple graphene layers adhering to the tape after extraction from graphite. Through iterative peeling, the number of graphene layers is progressively reduced. The removal of tape glue is facilitated by using commercial solvents like acetone. Ultimately, the tape is eliminated through an additional peeling process. This method is characterized by its simplicity, the high quality of the resulting graphene, but it lacks precise controllability and is limited in the quantity of graphene produced. **(Krane , Nils 2011)**

The Liquid Phase Exfoliation (LPT) technique involves dispersing graphite in an organic solvent with a surface energy similar to that of graphite. The solution undergoes sonication either in an ultrasound bath for several hundred hours or by applying a potential difference. **(Ching et al., 2011)** Following dispersion, the removal of thicker flakes is achieved through centrifugation of the solution. While the quality of the obtained graphene is comparable to the Scotch tape technique, the Liquid Phase Exfoliation method offers a significantly higher quantity of produced graphene with lower complexity.

### 2.2 Hummer's Method

Hummer's Method is used in the commercial synthesis of graphene oxide. Hummer's Method, renowned for its cost-effectiveness and high productivity. It involves incorporating graphite powder into sodium nitrate. In this process, concentrated sulfuric acid is introduced while stirring, and the addition of KMnO4 follows gradually. Maintaining a low temperature (below 20 °C) is crucial to prevent overheating and potential explosions. The stirring continues for 12 hours at a controlled temperature of 30°C. Subsequently, water is introduced under vigorous stirring to dilute the mixture. To ensure the thorough reaction with $KMnO_4$, the suspension undergoes treatment with a 30% $H_2O_2$ solution. The resulting mixture is then processed to obtain graphene oxide sheets through a series of steps involving washing with HCl and $H_2O$, followed by filtration and drying **(Shahriary et al., 2014)** .

### 2.3 Chemical Vapor Deposition (CVD) Method

Chemical Vapor Deposition (CVD) stands out as a highly effective method for synthesizing structural mono or few-layer graphene, offering the advantage of obtaining large-area graphene by exposing precursors to high temperatures. The key components of a typical CVD instrument include a tube furnace, gas flow system, tail gas treatment, and substrate, as depicted in Figure . The substrate choice plays a crucial role in facilitating graphene synthesis, with commonly used materials being nickel (Ni) or copper (Cu).

The mechanism of graphene synthesis via CVD depends on the substrate **(Lavin-Lopez, M. P., et al., 2019)** employed, as illustrated in Figure 9b. When Ni is the substrate, carbon serves as the raw material, dissolving in Ni at elevated temperatures. The dissolved carbon is then separated and precipitated, resulting in graphene during controlled cooling. On the other hand, graphene synthesis on Cu substrate in CVD occurs when carbon directly deposits on the surface of Cu. Parameters such as C/H ratio, substrate quality, temperature, pressure, and oxygen on the substrate surface significantly influence the CVD graphene synthesis process.

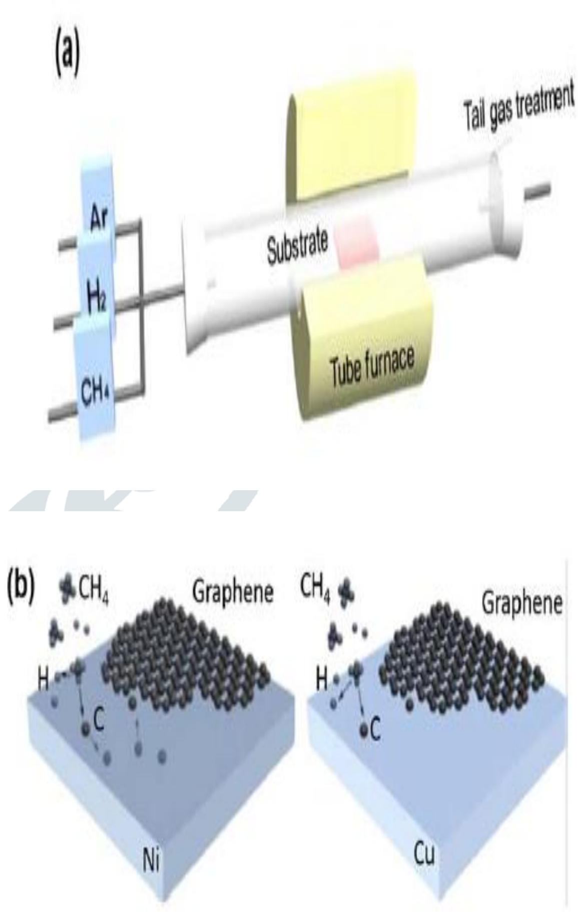


Fig 2 (a) CVD device (b) growth mechanism in CVD process (*Dasari et al., 2017*)

Optimizing the size and quality of graphene products through CVD is a challenging task due to the interdependence of numerous parameters. "Designs of experiments" method is used to assess the relative importance of parameters, revealing that temperature, time, rate of heating, and pre-annealing time significantly impact the quality of graphene products. **(Papon et al., 2017)**

Furthermore, emphasized that meticulous control of synthesis parameters can yield large-area, high-quality graphene, and large-sized graphene single crystals with diverse shapes and layers **(H.Liu, Hongtao, and Y. Liu., 2017).**

### 2.4 Plasma Enhanced Chemical Vapor Deposition Techniques

The advent of plasma-enhanced chemical vapor deposition (PECVD) for synthesizing graphene has paralleled the interest in exfoliation techniques. Some researchers introduced a direct current (dc) discharge PECVD method, utilizing Si wafers and various metal sheets (Ni, W, Mo) as substrates, along with a gas mixture of $CH_4$ and $H_2$ (0% to 25% CH4) at pressures ranging from 10 to 150 Torr. The resulting nanostructured graphite-like carbon (NG) film exhibited variable thickness across the substrate, attracting early attention in the field. (Obraztsov, A. N., et al., 2003)

The first report on single to few-layer graphene synthesis via PECVD emerged in 2004, employing a radio frequency PECVD system on diverse substrates such as Si, W, Mo, Zr, Ti, Hf, Nb, Ta, Cr, 304 stainless steel, $SiO_2$, and $Al_2O_3$. This method, conducted without special surface preparation or catalyst deposition, produced subnanometer-thick graphene sheets in a gas mixture of 5–100% $CH_4$ in $H_2$, with a total pressure of 12 Pa, at 900W power, and a substrate temperature of 680°C. **(Wang, J. J et al.,2004)**

A mechanism for graphene in PECVD chambers are suggesting that atomically thin graphene sheets are synthesized through a balance between deposition and etching, influenced by the surface diffusion of C-bearing growth species and atomic hydrogen, respectively. The vertical alignment of graphene sheets is attributed to the plasma electric field direction.

Variations of PECVD, such as microwave PECVD (MW-PECVD), demonstrated by synthesis on a stainless steel substrate, have further showcased the versatility of the method **(Yuan et al., 2009)** These adaptations exhibited high graphitization, excellent bio-sensing capabilities, and impressive growth rates, paving the way for potential applications. Future advancements in PECVD technology are anticipated to focus on enhancing control over graphene layer thickness and facilitating large-scale production, thereby expanding the range of practical applications.

### 2.5 Pyrolysis of Graphene

The solvothermal synthesis of graphene, utilizing a closed vessel under high pressure with a 1:1 molar ratio of ethanol and sodium, allows for the detachment of graphene sheets through sonication and subsequent pyrolysis of sodium ethoxide. **(Md Sajibul Alam et al., 2016)** Characterization through Raman spectroscopy and transmission electron microscopy (TEM) revealed graphene sheets with dimensions up to 10 µm, displaying a crystalline structure and defect-rich nature, as evidenced by a broad D-band and G-band with an intensity ratio of ~1.16 (IG/ID), indicative of single-layer defective graphene **(Choucair et al.,2009)**. Despite its cost-effectiveness and low-temperature requirements, the method has seen limited exploration due to the compromised graphene quality resulting from the presence of numerous defects.

### 2.6 Other Methods

Exploring diverse methods for graphene production, electron beam irradiation of PMMA nanofibers and the conversion of nanodiamond provide alternative routes beyond conventional approaches **(Subrahmanyam et al.,2009) Additionally**, the synthesis of graphene involves the unzipping of multi-walled carbon nanotubes (MWCNTs) through highly oxidative $KMnO_2$ and concentrated $H_2SO_4$ , as well as through laser irradiation **(Dmitry V., et al., 2009)** Li in liquid ammonia and plasma etching each contributing to the formation of graphene nanoribbons (GNRs) by opening up carbon nanotubes.

Moreover, arc discharge methods play a pivotal role in synthesizing boron- and nitrogen-doped graphene. Nitrogen-doped graphene sheets are obtained through arc discharge between carbon electrodes and pyridine or ammonia in the presence of nitrogen. **(Panchakarla, L. S., et al., 2009)** Meanwhile, boron-doped graphene sheets are synthesized by utilizing a hydrogen-diborane vapor mixture or boron-stuffed graphite electrodes [98]. These diverse techniques underscore the versatility in tailoring graphene properties, offering unique opportunities for advanced applications in materials science and beyond.

## 3 Characterization of Graphene

These characterization techniques play a crucial role in comprehensively assessing graphene properties, enabling the thorough examination of its morphology, structural integrity, quality, defect presence, and the number of layers.

### 3.1 Optical Microscopy

Additionally, optical microscopy provides valuable insights into the overall quality and uniformity of the graphene layers. This technique allows researchers to assess the presence of defects, wrinkles, and impurities within the graphene structure, contributing to a comprehensive characterization of the material. Moreover, optical microscopy is non-invasive, enabling repeated examinations of the same sample over time without causing any damage. This versatility makes it a preferred method for routine analysis and quality control in graphene research and production processes. Fig a shows the optical micrograph with different graphene layers of graphene on $SiO_2$/Si substrate.

### 3.2 Scanning Probe Microscopy

Furthermore, scanning probe microscopy not only provides high-resolution images of graphene structures but also allows for precise measurements of surface properties, such as roughness and height variations, at the nanoscale level. This capability is crucial for understanding the intricate details of graphene surfaces and interfaces. The combination of atomic force microscopy (AFM) and scanning tunneling microscopy (STM) offers a comprehensive approach to characterizing graphene, enabling researchers to investigate both the topographical features and electronic properties of this advanced nanomaterial with unparalleled precision. Fig b shows the AFM image of mechanically exfoliated graphene flake with atomic- level thickness. Fig c shows high contrast atomic resolution of obtained using STM for graphene hexagonal structure.

### 3.3 Scanning Electron Microscopy

Scanning electron microscopy (SEM) technique is used to determine surface morphology and number of layers of graphene. The high-resolution images obtained through SEM allow for the observation of features such as grain boundaries, defects, and the overall quality of graphene layers. This technique is particularly advantageous for its versatility in imaging a wide range of sample sizes and its ability to provide three-dimensional representations, enhancing the understanding of the spatial arrangement of graphene layers on the substrate. SEM, with its capability to capture fine details at the micro and nanoscale, plays a crucial role in the comprehensive characterization of graphene-based materials. Fig d shows a micrograph from SEM for mechanical exfoliated graphene layers.

### 3.4 High Resolution Transmission Electron Microscopy (HRTEM)

In High-Resolution Transmission Electron Microscopy (HRTEM), similar to SEM, an electron beam is employed for structural characterizations, but in this case, the beam is transmitted through the ultrathin sample. HRTEM enables the acquisition of atomic-resolution images, providing an unparalleled level of detail in the examination of graphene structures. Figure fig (e) showcases the precise atomic arrangement of the graphene structure and its interfaces, highlighting the capability of HRTEM in offering insights at the atomic scale for comprehensive graphene characterization.

### 3.5 Raman spectroscopy

Furthermore, Raman spectroscopy plays a pivotal role in graphene characterization due to its non destructive nature and its ability to provide valuable bonding information. The distinctive fingerprints of graphene in Raman spectra offer insights into various aspects of the material, including its quality, number of layers, induced strain, presence of defects, and lattice mismatch. The characteristic D-band, G-band, and 2D band positions at approximately 1350 $cm^{-1}$, 1580 $cm^{-1}$, and 2690 $cm^{-1}$, respectively, in the Raman spectra of monolayer graphene, serve as key indicators. Figure 14(f) illustrates the Raman spectra of different graphene layers on $SiO_2$/Si substrate, showcasing the effectiveness of Raman spectroscopy in elucidating graphene properties with a laser power of approximately 532 nm.

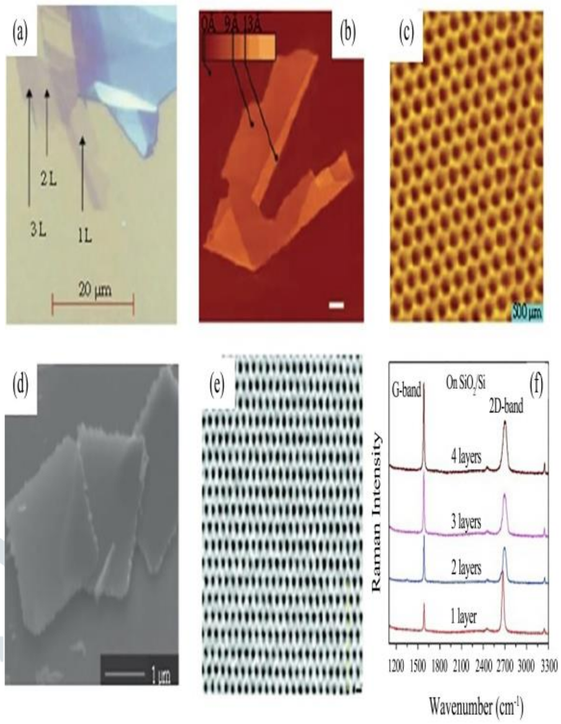


Fig 3 (a) Optical micrograph showing single-(1L), bi-(2L), and trilayer (3L) graphene on $SiO_2$/Si Substrate *(Park J.S et al 2009)*; (b) AFM image of mechanically exfoliated graphene (Scale bar is 1 μm) (*Novoselov et al., 2005*); (c) STM micrograph showing atomic resolution of graphene with hexagonal close-packed lattice structure (*Luican et al., 2009*); (d) SEM micrograph showing exfoliated graphene layers (*Zhang et al,2005*); (e) The hexagonal honeycomb lattice of SLG under HRTEM (Scale bar is 0.2 nm) (*Huang et al., 2011*); (f) Raman spectra of one to four layers of graphene on $SiO_2$/Si substrate (*Wang et al., 2008*).

## 4 Applications of Graphene

### 4.1 Graphene Field Emission (FE)

Developing efficient field emission (FE) displays using graphene involves creating structures that capitalize on high field enhancement. While many graphene synthesis methods result in flat layers on substrates, **(Eda et al.,2008)** have addressed this challenge by fabricating a graphene/polymer composite thin film. This film, synthesized from graphene derived from graphite oxide (GO) dissolved in polystyrene, exhibited improved field emission characteristics. The orientation of graphene sheets in the composite films was manipulated by adjusting spin coating speeds, with the best field emission observed at 600 rpm, yielding a turn-on electric field (Eto) of approximately 4 V/µm and a field enhancement factor (β) of around 1200.

A single-layer graphene film has been prepared using the electrophoretic deposition (EPD) method **(Wu et al.,2009).** Dispersing graphene films obtained through graphite exfoliation in isopropyl alcohol, they deposited the solution onto indium tin oxide (ITO) coated glass substrates via EPD. The resulting graphene cathodes demonstrated a low turn-on electric field (Eto) of 2.3 V/µm and a high field enhancement factor (β) of approximately 3700. While these methods have shown promise for flexible substrates, achieving the high field emission currents (in the order of mA-A) required for demanding applications may pose challenges.

### 4.2 Graphene Based Gas and Bio Sensors

In addition to its versatility, graphene's application in sensors, particularly gas and biosensors, capitalizes on its operational principle rooted in the modulation of electrical conductivity (σ). This modulation occurs due to the adsorption of molecules on the graphene surface, leading to changes in carrier concentration. The remarkable sensitivity of graphene-based sensors extends to the detection of single atoms or molecules, facilitated by several key properties. Firstly, graphene's two-dimensional (2D) nature exposes all carbon atoms to the analyte, enhancing interaction **(Schedin et al., 2007).** Secondly, its high conductivity coupled with low Johnson noise allows even slight changes in carrier concentration to result in significant variations in electrical conductivity. Thirdly, the presence of very few crystal defects ensures minimal noise caused by thermal switching **(Dresselhaus, M. S., and G. Dresselhaus., 1981)** . Lastly, four-probe measurements on single crystal graphene devices with ohmic electrical contacts and low resistance further contribute to the precision of the sensor measurements.

Furthermore, expanding beyond gas sensing, has showcased graphene's effectiveness in biosensing, particularly in glucose detection **(Shan et al..2009)** Utilizing glucose oxidase (GOD) as an enzyme model, they developed a novel electrochemical biosensor comprising polyvinylpyrrolidone-protected graphene, polyethylenimine-functionalized ionic liquid, and GOD. The sensor demonstrated direct electron transfer of GOD, highlighting graphene's potential for fabricating glucose sensors. Their study reported a linear response up to 14 mM of glucose, indicating the applicability of graphene in glucose biosensing.

In addition to glucose detection, superior effectiveness of graphene-based biosensors compared to carbon nanotubes (CNTs) in detecting catecholamine neurotransmitters like dopamine and serotonin. The graphene electrodes exhibited enhanced biosensing performance, particularly in the presence of common interfering agents such as ascorbic acid and serotonin, showcasing graphene's advantage over CNTs in neurotransmitter detection.

In another study a nano composite film sensing platform, based on Nafion graphene, was employed for the determination of $Cd^{2+}$ through anodic stripping voltammetry (ASV). This nano composite film, leveraging the advantages of graphene and the cationic exchange capacity of Nafion, demonstrated heightened sensitivity in $Cd^{2+}$ assays. Given the detrimental health effects associated with cadmium exposure, the study explores graphene's potential for sensing cadmium, offering a valuable application in monitoring environmental and industrial settings. **(Li et al., 2009)**

Moreover, recent research has highlighted concerns about the potential negative impact of lithographic steps, whether photo or e-beam, during the preparation of graphene on the sensing properties. Residual polymers left on the graphene surface after such lithographic processes can adversely affect the sensing performance. There is a cleaning process to eliminate contamination on the sensor device structure, allowing for the intrinsic chemical response of graphene-based sensors. The contamination layer was effectively removed through a high-temperature cleaning process conducted in a reducing ($H_2$/Ar) atmosphere, emphasizing the importance of addressing surface cleanliness in graphene-based sensor fabrication **(Dan et al., 2009).**

For the majority of gas and bioelectronic sensor applications, graphene synthesized through various methods has been deposited on Si or Si/$SiO_2$ substrates, and electrical contacts were prepared with materials such as Au/Ti or other metals that offer good adhesion and ohmic contact with graphene. This standardized approach facilitates consistent and reliable sensor performance across different studies.

Beyond experimental studies, numerous theoretical reports have contributed to understanding the sensing properties of graphene. These theoretical investigations delve into the impact of gas or biomolecule absorption on graphene's mobility, the charge transfer dynamics between molecules and the graphene surface, and the potential effects of doping graphene for enhanced sensing capabilities. These theoretical insights complement experimental findings, providing a comprehensive understanding of the underlying mechanisms governing graphene-based sensor behavior **(Zhang et al., 2009).**

### 4.3 Field Effect Transistors (FET)

Graphene's potential application in Field-Effect Transistors (FETs) became apparent when Novoselov et al. first reported electric field effects in graphene in 2004. In their groundbreaking work, they observed ambipolar characteristics in graphene-based FETs, with electron and hole concentrations reaching 10^13 sq-cm and mobilities up to ~10,000 sq-cm/V-s at room temperature. However, to be suitable for transistor applications, graphene needs to adopt a quasi-one-dimensional (1D) structure with narrow widths and atomically smooth edges. This structural transformation is achieved by forming graphene nanoribbons (GNRs), predicted to exhibit band gaps conducive to room temperature FET applications. GNRs not only provide 2D confinement due to their structure but also further confine electrons through width quantization in the ky direction.

The width confinement in GNRs leads to the splitting of the original 2D energy dispersion of graphene into various 1D modes. Depending on boundary conditions, some of these 1D modes may not pass through the intersection point of the conduction and valence bands. Consequently, quasi-1D GNRs transform into semiconductors with finite energy band gaps, enhancing their utility in FET applications. Researchers have successfully introduced band gaps of up to 400 meV by patterning graphene into GNRs, as demonstrated in Fig 4 depicting GNR FETs fabricated on $SiO_2$/Si substrates. This advancement showcases the potential of GNRs in achieving efficient switching speed and high carrier mobility in FETs.

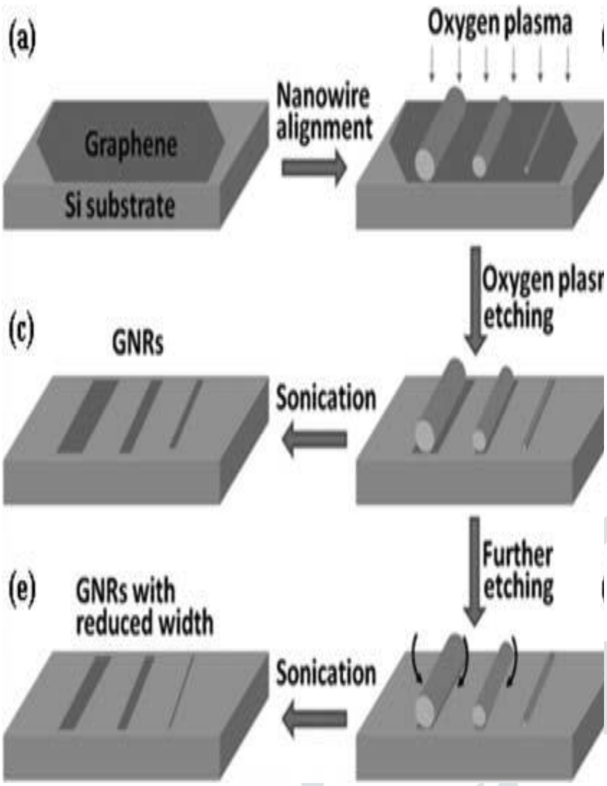


Fig 4. (a–f) Schematic fabrication process to obtain GNRs by oxygen plasma etch with a nanowire etch mask. (*Bai et al., 2009*)

While chemical routes have successfully produced graphene nanoribbons (GNRs) with widths in the range of 10 to 15 nm, a more advanced fabrication process, as illustrated in Fig using the nanowire etch mask technique, has enabled the creation of GNRs with widths as narrow as 6 nm. Chen et al. conducted studies on the Field-Effect Transistor (FET) properties of GNRs, examining how their width influences resistivity. Their experiments revealed that as the width of GNRs decreased, resistivity increased, a phenomenon attributed to the presence of edge states. Additionally, the electrical current noise in GNR devices at low frequencies was observed to be predominantly influenced by 1/f noise.

Beyond experimental investigations, numerous theoretical studies have delved into predicting the performance of GNR FETs. These studies have explored various factors such as edge roughness, chirality, chemical doping, carrier scattering, and contact effects. Additionally, different models have been developed to provide insights into the performance of GNR FETs **(Zhao et al., 2009).** Theoretical investigations not only enhance our understanding of the characteristics of GNR-based FETs but also serve as valuable tools for designing efficient devices. These studies contribute to the ongoing exploration and optimization of graphene nanoribbon-based transistors for diverse applications in electronics.

### 4.4 Transparent Electrodes

Indium tin oxide (ITO) is commonly used to create transparent conductive coatings for various applications, such as liquid crystal displays (LCDs), flat panel displays, touch panels, solar cells, and electromagnetic interference (EMI) shielding. However, the high cost, limited supply, and brittle nature of indium restrict its use on flexible substrates, driving the exploration for alternative materials that offer high transparency and conductivity in thin-film form. Graphene is emerging as a highly sought-after material for future optoelectronic devices, particularly for transparent electrodes in solar cells and LCD displays. The exceptional thermal, chemical, and mechanical stability of graphene, coupled with its high transparency and atomic layer thickness, positions it as an ideal candidate for transparent conducting electrode applications, making it a next-generation material for this purpose.

Graphene's qualities, including high hole transport mobility, large surface area, and inertness against oxygen and water, make it promising for various photovoltaic applications. Monolayer graphene is not only highly conductive but also highly transparent, absorbing only 2.3% of white light. An 80% transmittance from graphene grown on a 300 nm thick nickel layer, corresponding to 6 to 10 graphene layers **(K. Kim et al., 2009)**. By optimizing growth parameters, the transmittance increased to 93%, making the graphene film even thinner. However, ultraviolet/ozone etching to reduce thickness led to increased sheet resistance, attributed to the decreasing number of graphene layers.

Graphene-based transparent electrodes were applied in dye-sensitized solar cells (DSSCs). They employed a straightforward approach for fabricating graphene films from exfoliated graphite oxide, followed by thermal reduction. The resulting transparent electrodes exhibited 70% transparency over a broad wavelength range (1000 to 3000 nm) and good conductivity of 550 S/cm **(Wang et al., 2008)** . The DSSCs utilizing graphene electrodes demonstrated specific characteristics, including a short-circuit photocurrent density of 1.01 mA/cm², an open-circuit voltage of 0.7 V, a calculated filling factor of 0.36, and an overall power conversion efficiency of 0.26%. The lower efficiency was attributed to the perceived low quality of the graphene film used in the DSSC fabrication.

### 4.5 Battery

While graphite has traditionally served as the anode material in Li-ion batteries due to its reversibility and reasonable specific capacity, the quest for Li-ion batteries with higher energy density and durability has driven the exploration of new electrode materials. Among carbonaceous materials, graphene-based anodes have emerged as promising alternatives for Li-ion batteries. Graphene offers superior electrical conductivity compared to graphitic carbon, high surface area, and excellent chemical tolerance.

Researchers, such as have explored graphene nanosheets decorated with $SnO_2$ nanoparticles to enhance Li-ion battery performance. The preparation involved dispersing reduced graphene nanosheets in ethylene glycol and reassembling them in the presence of $SnO_2$ nanoparticles. This $SnO_2$/graphene hybrid exhibited a reversible capacity of 810 mAh/g, significantly improving cycling performance compared to bare $SnO_2$ nanoparticles **(Paek et al., 2013).**

A self-assembled $TiO_2$-graphene hybrid nanostructure used to enhance the high-rate performance of the electrochemical active material. Anionic sulfate surfactants were employed to stabilize graphene in aqueous solutions and facilitate the self-assembly of nanocrystalline $TiO_2$ with graphene. The resulting specific capacity of the $TiO_2$-functionalized graphene was 87 mAh/g, more than double the high-rate capacity (35 mAh/g) of control rutile $TiO_2$ **(Wang et al., 2009).**

While reports on the application of graphene as an electrode material in batteries exist, future research should focus on a deeper understanding of the electrochemical processes in these systems. Additionally, there is a need to explore and apply various graphene-based electrodes in Li-ion batteries for continued advancements in energy density and performance.

## Conclusion

The precursor graphite was successfully utilized to synthesize the GO. In addition, sodium borohydride and orange peel extract were employed in the reduction process to create graphene from GO. Characterization using FTIR and UV-Visible spectroscopy confirmed the formation of GO, while DLS analysis provided insights into the size distribution of nanosheets for both GO and graphene, signifying the production of graphene nanolayers. The XRD pattern further supported the synthesis of GO from the supplied coal. Nanostructured morphology of the graphene nanosheets was vividly revealed in SEM images. TGA study elucidated the thermal degradation of both GO and graphene, thereby affirming the development of nanosheets. The utilization of coal as a precursor presents a cost-effective and environmentally friendly approach for the synthesis of carbon nanomaterials.

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