Fabrication and Development of 2D Material for Schottky Diode

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Abstract -In modern electronic applications, there is a growing requirement for Schottky diode materials that can maintain stable performance under varying temperature conditions, independent of other influencing parameters. Accordingly, material selection and fabrication processes must be carefully optimized. Several material systems have been explored for this purpose, including platinum–silicon (Pt–Si), palladium–gallium nitride (Pd–GaN), titanium–silicon carbide (Ti–SiC), gold–germanium (Au–Ge), and silver–indium phosphide (Ag–InP).

Recently, graphene, a two-dimensional semimetal with exceptional electrical and thermal properties, has emerged as a prominent material for Schottky diode fabrication. Graphene–silicon (graphene/Si) Schottky junctions are extensively utilized in applications such as photodetectors, communication systems, and solar cells. In this study, a graphene/n-type silicon (graphene/n-Si) junction is fabricated to investigate the electrical characteristics of the Schottky diode. Furthermore, the fabrication methodology and characterization of the graphene–Si Schottky diode are systematically presented.

Index Terms- Si, Schottky Diode, Graphene, Temperature, Pressure, 2D Material, Synthesis.

1. Introduction

This abstract outlines the fundamental concept of a Schottky diode formed by integrating graphene with n-type silicon (n-Si). The device is created at the interface of graphene and n-Si, establishing a metal–semiconductor junction. In this configuration, graphene—a two-dimensional form of carbon known for its outstanding electrical behaviour—functions as the conductive contact layer. The performance of the graphene–n-Si Schottky diode is influenced by the distinct properties of both materials. Graphene is characterized by high carrier mobility, remarkable mechanical durability, and optical transparency, whereas n-type silicon offers tuneable semiconducting properties through controlled doping. A key factor governing the diode's behaviour is the Schottky barrier height at the interface, which directly affects important electrical parameters such as forward voltage, rectification capability, and leakage current. This study introduces the graphene–n-Si Schottky diode as an emerging device with promising applications in modern electronics. Continued investigation is required to better understand its performance characteristics and optimize its design for uses in areas such as power devices, sensing technologies, and photovoltaic systems. By combining the advantageous features of graphene and silicon, this structure presents new opportunities for advanced electronic applications. With the rapid advancement of nanotechnology, nanomaterials are increasingly shaping the field of microelectronics. These materials, defined by their nanometre-scale dimensions, exhibit enhanced electrical properties, improved efficiency, and novel functionalities due to size reduction. Among them, graphene has gained significant attention because of its exceptional mechanical strength, superior electrical conductivity, and unique optical characteristics. Its low defect density further enhances its suitability for electronic applications. Graphene is widely utilized in various domains, including solar cells, sensors, and other electronic devices, where high performance is essential. This paper focuses on the synthesis techniques of graphene, examines its electrical properties, and presents experimental work carried out in the laboratory.

2. Methodology

The graphene is prepared by many methods such as Mechanical Exfoliation, Chemical Exfoliation, Chemical Synthesis, Pyrolysis, Electrochemical Method, Chemical Vapor Deposition, epitaxial Growth by reduction of Silicon carbide, Carbon tube nanotube unzipping, Liquid Phase exfoliation, Hummer’s methods (Fig.1)

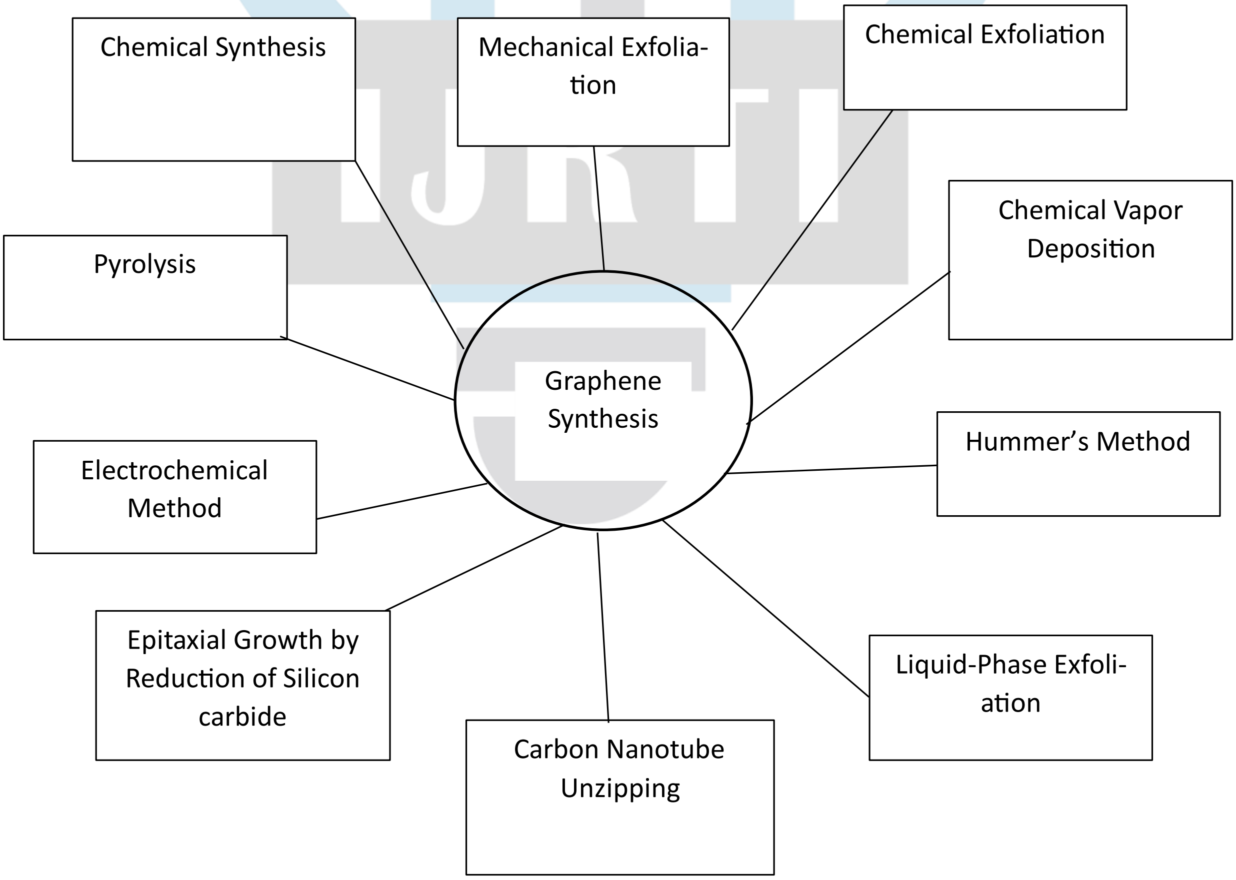
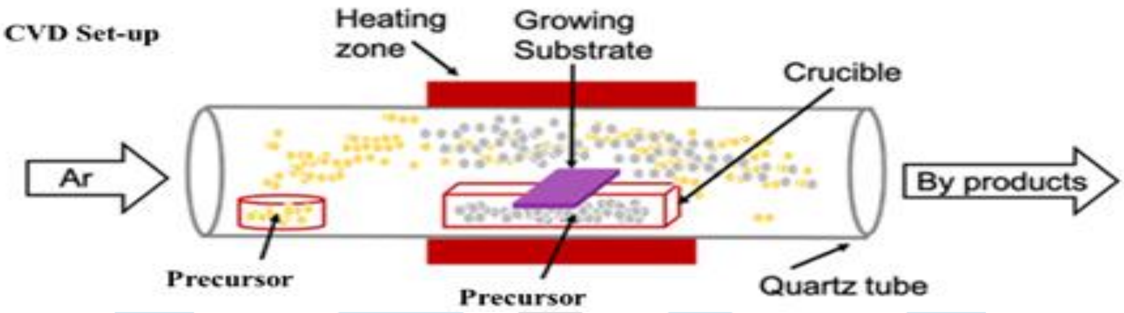


Fig. 1: Synthesis method of Graphene

2.1 Chemical Vapor Deposition

In the chemical vapor deposition technique, gaseous precursors are introduced into a reaction chamber where they decompose and deposit a thin film on a substrate. The process is carried out under controlled temperature and pressure conditions using a mixture of carrier gases. Typically, transition metals such as nickel (Ni) or copper (Cu) are used as substrates. Carbon atoms from gases like methane are deposited onto the substrate surface, while unwanted by products are removed from the chamber. Argon is often used along with methane to maintain a stable reaction environment.



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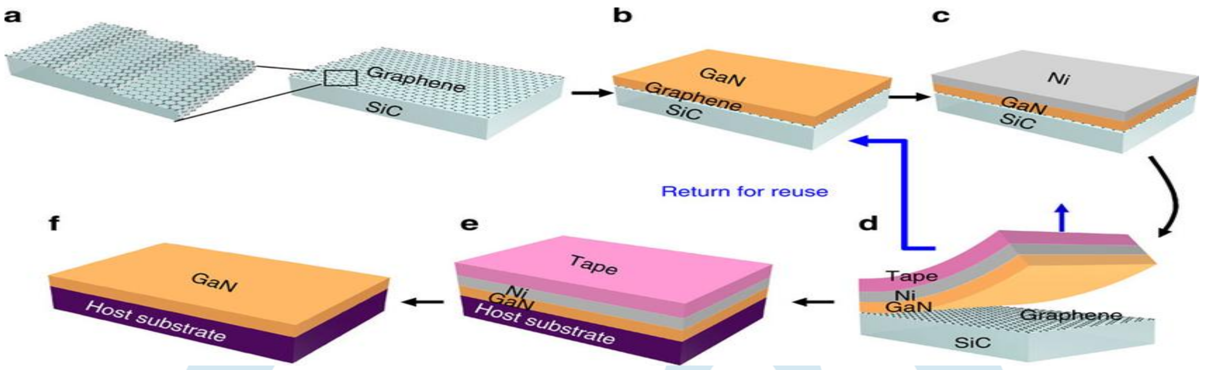
2.2 Mechanical Exfoliation

Mechanical exfoliation involves peeling thin layers from bulk graphite using adhesive tape. The tape is pressed onto graphite for a few seconds and then removed, carrying thin graphite layers with it. These layers are subsequently transferred onto a silicon dioxide/silicon (SiO_2/Si) substrate. This method is simple and produces high-quality graphene, although it is not suitable for large-scale production.

Image show Scotch-tape–based micromechanical cleavage for graphene

2.3 Epitaxial Growth of Graphene on Silicon Carbide

In this method, graphene is formed by heating silicon carbide (SiC) at high temperatures. During heating, silicon atoms sublimate from the surface, leaving behind carbon atoms that rearrange to form graphene layers. The thickness and quality of graphene can be controlled by carefully regulating temperature and pressure conditions.



https://www.google.com/search/ Epitaxial Growth of Graphene on SiC

2.4 Chemical Synthesis

Graphene can also be synthesized through chemical processes such as arc discharge. In this technique, graphite is exposed to high temperatures in the presence of gases like hydrogen, resulting in the formation of graphene nanosheets. Rapid heating under controlled atmospheric conditions facilitates the breakdown of graphite into graphene structures.

2.5 Hummer's Method

Hummer's method is a widely used chemical approach for producing graphene oxide (GO). In this process, graphite is oxidized using strong oxidizing agents such as sulfuric acid (H_2SO_4) and potassium permanganate ($KMnO_4$), often in the presence of sodium nitrate ($NaNO_3$). The reaction is carried out with continuous stirring for several hours. Hydrogen peroxide (H_2O_2) is then added to stop the reaction. The resulting graphene oxide is washed to remove impurities. Ultrasonication is commonly applied to enhance exfoliation and improve dispersion stability.

2.6 Carbon nanotube Unzipping

This technique involves converting carbon nanotubes into graphene sheets. Single-walled carbon nanotubes (SWCNTs) are treated with chemical agents such as tetrachloropalladate ions ($PdCl_4^{2-}$), which act as "chemical scissors" to cut and open the nanotubes along their length, producing graphene-like structures.

2.7 Liquid-Phase Exfoliation

In liquid-phase exfoliation, bulk graphite is dispersed in a suitable solvent and subjected to ultrasonic energy. This process breaks down large graphite flakes into thinner graphene layers in multiple stages:

2. Initial fragmentation of large flakes along specific directions.
3. Formation of cracks and penetration of solvent molecules between layers.
4. Final separation into thin graphene sheets.

2.8 Pyrolysis

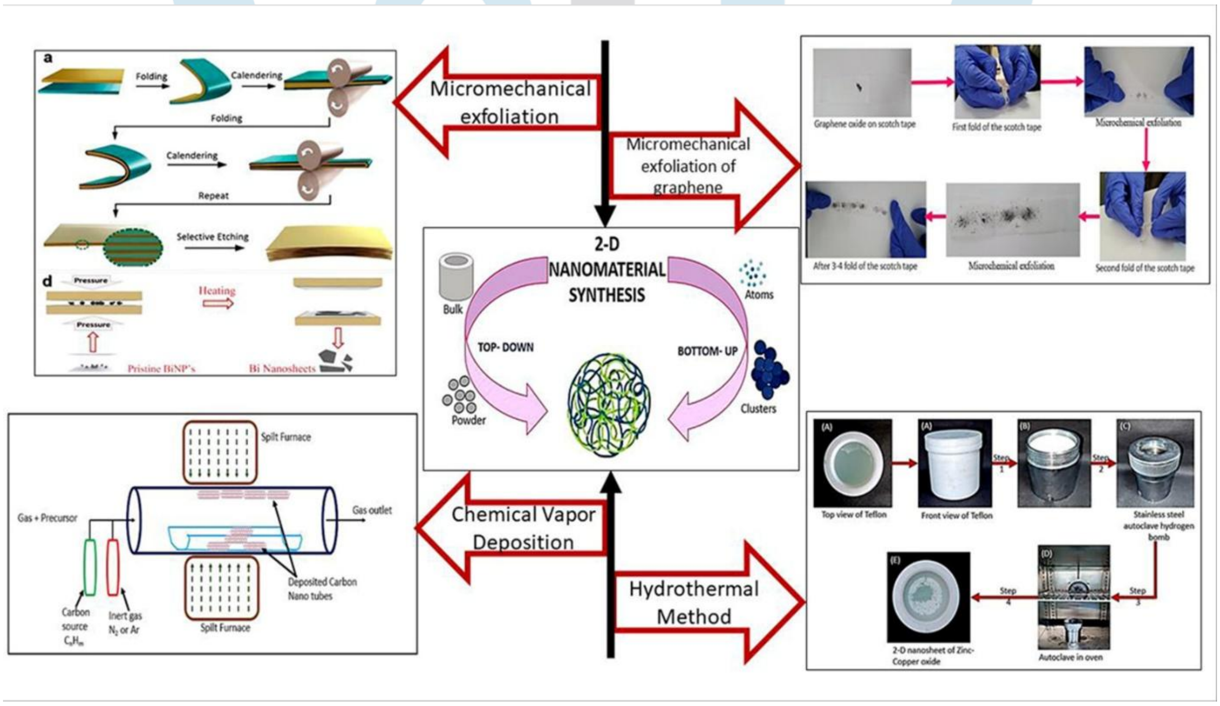
Pyrolysis involves the thermal decomposition of materials in an oxygen-free environment. At high temperatures, precursor materials break down into simpler substances, resulting in the formation of graphene along with other recoverable products.

2.9 Chemical Exfoliation

In this method, graphite is chemically treated to separate it into individual graphene layers. The process produces dispersed graphene flakes in a solution, which remain stable under controlled conditions. It is a relatively simple and scalable approach for graphene production.

2.10 Electro Chemical Exfoliation Method

Electrochemical exfoliation uses an electrochemical setup where a graphite rod acts as the anode and a platinum wire serves as the cathode. Both electrodes are immersed in an electrolyte solution, typically sulfuric acid (H_2SO_4), and a voltage of around 10–12 V is applied. This causes the graphite to exfoliate, releasing graphene layers into the solution. The graphene can then be collected through filtration for further use.



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3 Fabrication Process

To develop graphene-based Schottky junctions, a silicon wafer coated with a 20 nm thick SiO_2 layer was used as the substrate. Trenches were patterned into the oxide layer prior to transferring graphene, allowing direct access to the underlying n-type silicon. The exposed silicon regions inside the trenches were cleaned using a buffered oxide etch (BOE) solution composed of NH_4F and HF in a 6:1 ratio to remove any native oxide layer. Subsequently, graphene was transferred onto the prepared substrate using a dry transfer technique as reported by Petronel et al. Photolithography was then employed to pattern the graphene across both the trench region and the oxide surface. The active junction area was defined at the interface where graphene made direct contact with the exposed silicon within the trench. A schematic representation of the device structure is illustrated in Fig. 2.

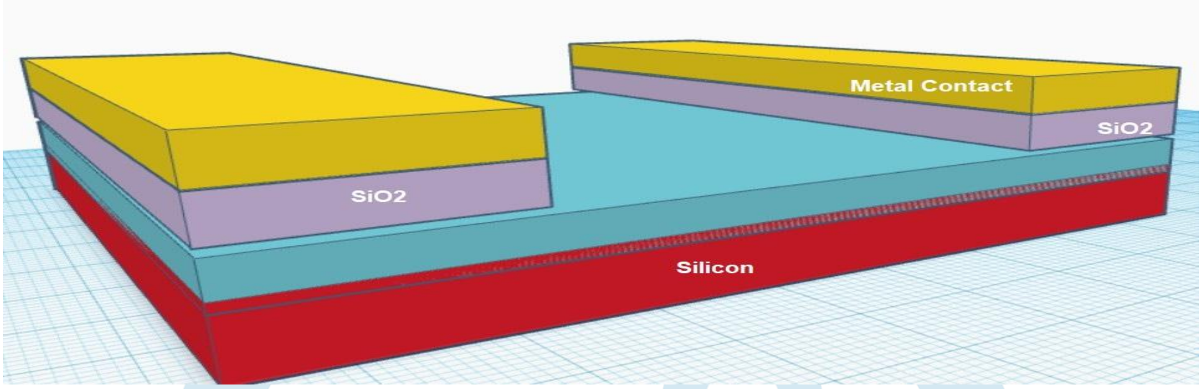

Fig:2 Graphene/n-Si Schottky junction (metal-semiconductor junction)

4 Conclusion

In this study, graphene was synthesized using the electrochemical exfoliation technique, followed by filtration to obtain usable material. The prepared graphene was then utilized to fabricate a metal–semiconductor junction with n-type silicon. Future work will focus on analysing the electrical characteristics of the fabricated graphene/n-Si Schottky diode. Additionally, a comparative study will be conducted to evaluate its performance against conventional metal–semiconductor junctions.

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