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An introduction to synthesis and applications of graphene: A noble 2D nanomaterial

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Abstract
Graphene, 2D nano material exhibits a number of outstanding physical, mechanical and electronic properties which make it attractive for various applications. The wider use of graphene will require processes that produce this material in a very controllable manner.

Keywords: graphene, synthesis, applications, 2D nano material

1. Introduction
Graphene, the "wonder material", is the well-publicized and latest invented allotrope of carbon which is made up of a single atom thick carbon atom layer in a honeycomb-like hexagonal lattice. It has amazing properties as the lightest & strongest material, compared with its ability to conduct heat and electricity better than anything else.
Sheets of grapheme are bonded by loose bond in graphite. If these bonds are broken, the hexagonal sheets can be isolated to form graphene.
Graphene has a different structure from three dimensional diamond. It is the basic building block for various graphitic materials. It consists of sp^2 bonded carbon atoms, which are tightly packed into one atom thick layer of honeycomb lattice. It can be considered like different arrangements of benzene rings deductively extending in two dimensions [1].

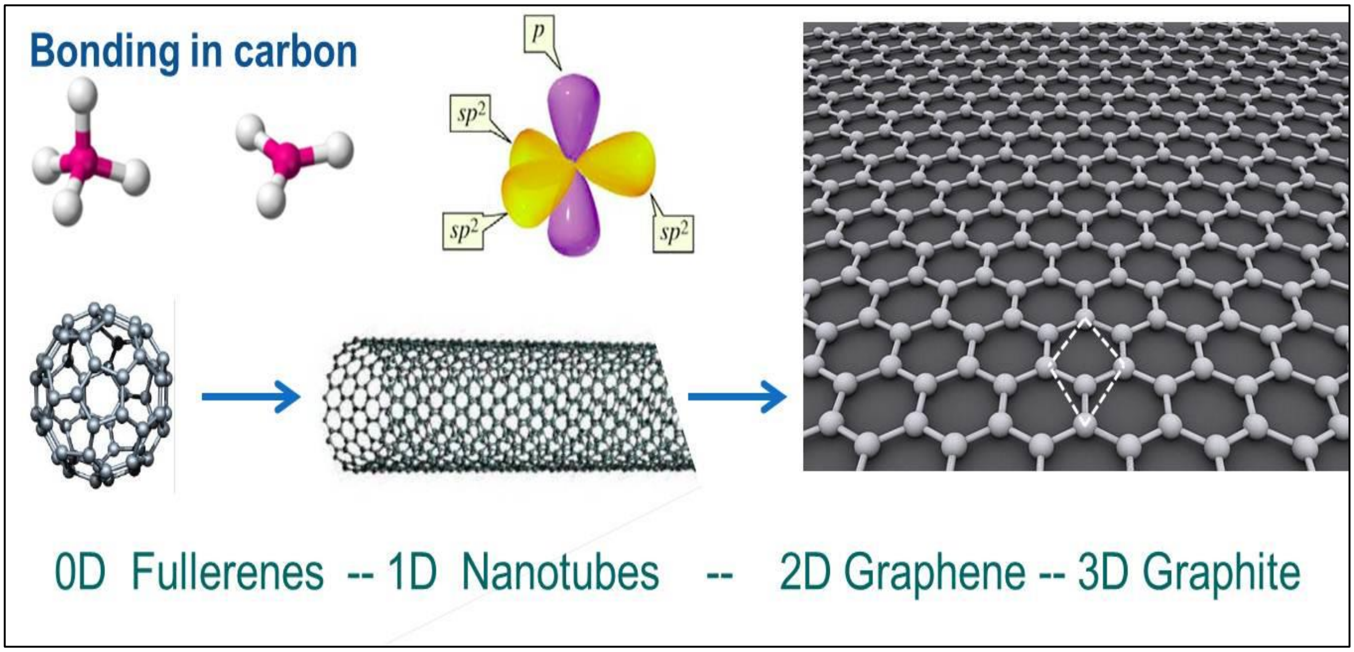

Fig 1

Different arrangements of benzene rings in two dimensions results graphenes having various morphologies and different covalent bonding with other atoms result in different modifications of sheets and existence of graphene with various properties [2].
So it is mandatory to synthesize the graphene in a controllable manner for practical applications. Various methods used for synthesis of graphene are summarized below:

- Electrochemical exfoliation
- Chemical exfoliation
- Epitaxial growth
- Chemical vapor deposition

1. **Electrochemical Exfoliation-** In this method graphite rods are utilized as positive electrode and as carbon source. The anode (graphite rod) and cathode (platinum wire) are placed at the bottom and top of electrochemical cell, respectively having aqueous solution of protonic acid as an electrolyte. The exfoliation process is ignited via application of certain voltage through electodes. The obtained water soluble graphene flakes are ultrasonicated, washed, dried and collected [3, 4].

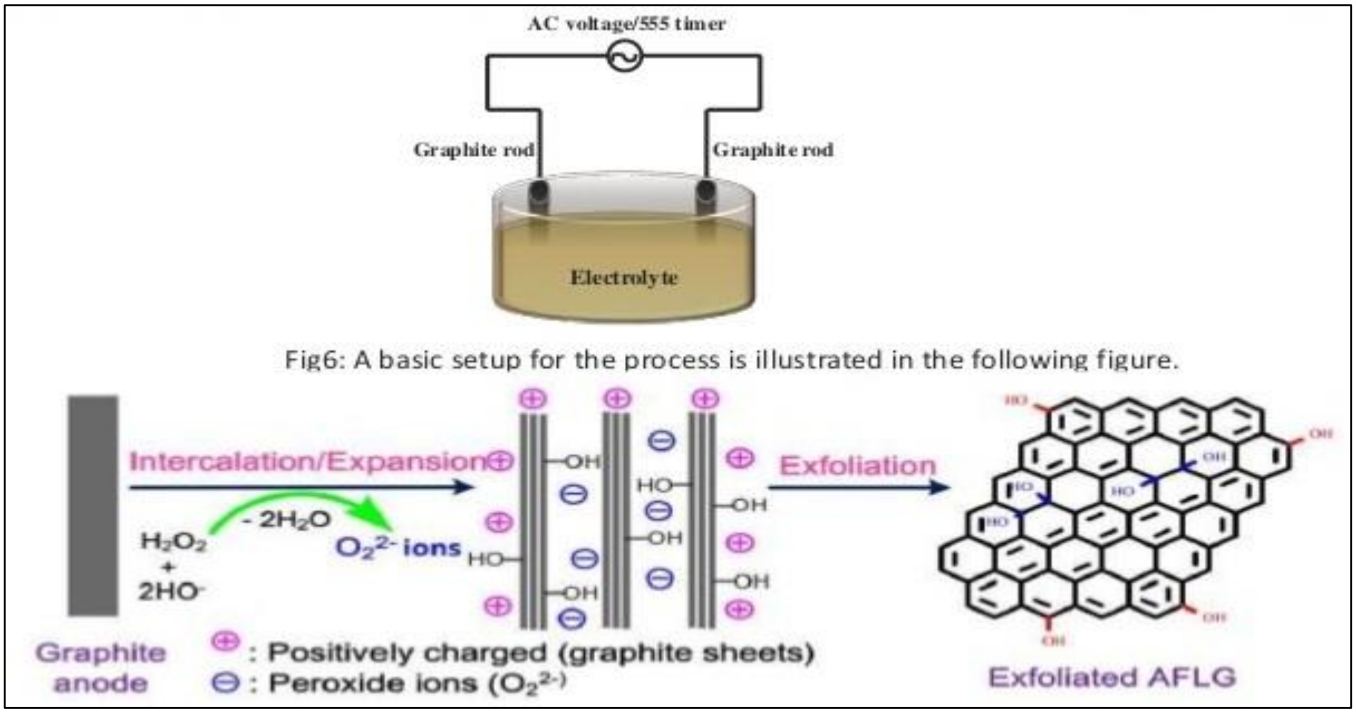

Fig 2

2. **Chemical Exfoliation–** In this method graphene is obtained by pre reduction of graphene oxide with sodium borohydride at almost 80ºC for 1 hour. After that aryl diazonium salt of sulfanilic acid was sulfonated in ice path for 2 hours. Finally the remaining oxygen functionality is being removed via post reduction with hydrazine at 100ºC for 24 hours [5].

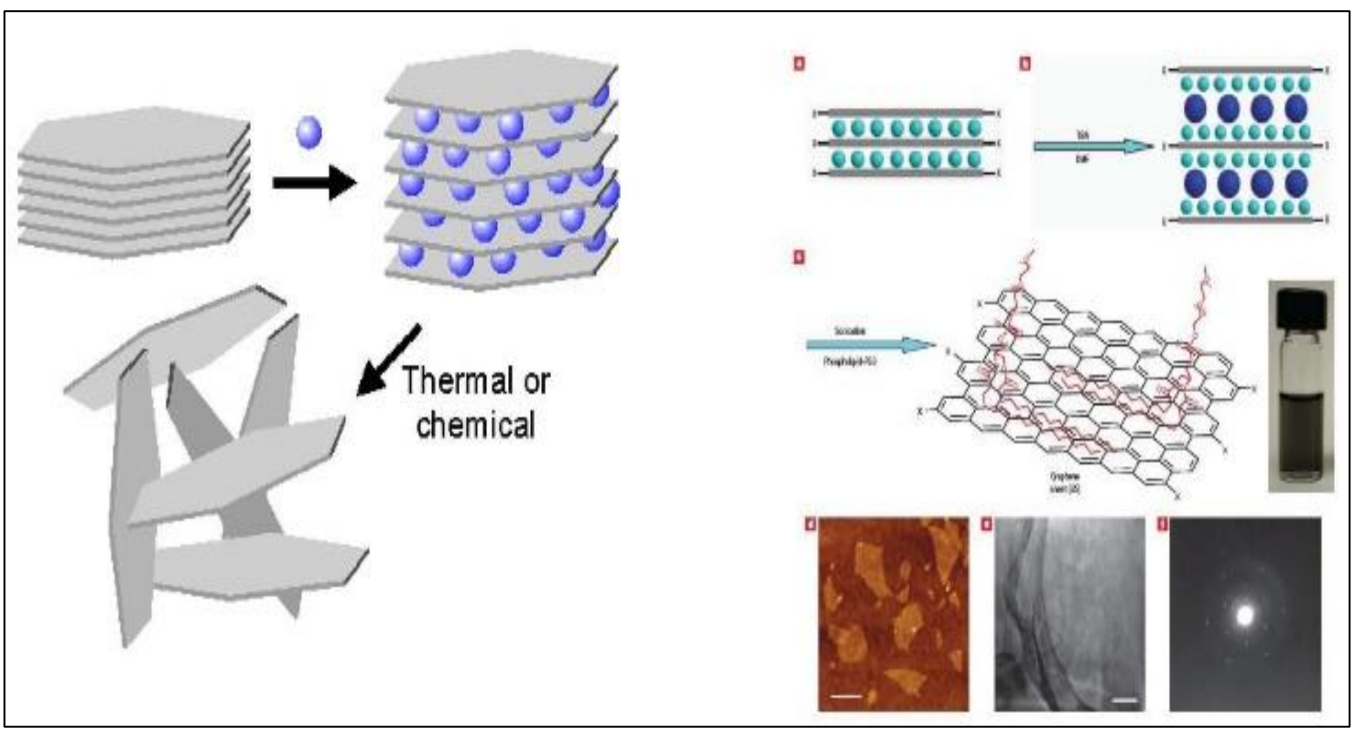

Fig 3

3. **Epitaxial Growth (Thermal Decomposition) –** In this method SiC substrate is heated at a temperature around 1200ºC. Ultra high vacuum is provided to hinder the uniform growth of multilayer graphene and favors only bilayer. The Silicon atoms are evaporated due to thermionic emission leaving behind only carbon atoms on the remaining substrate. Accumulating carbon layers on substrate are controlled by controlling temperature and pressure [6].

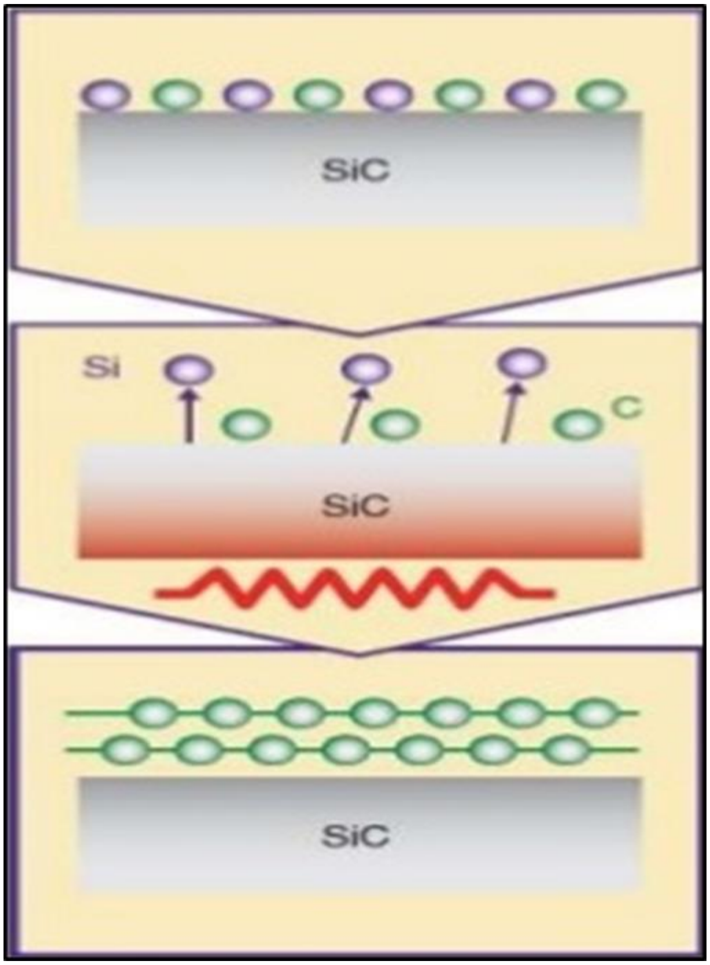

Fig 4

4. Chemical Vapor Deposition (CVD) – In CVD method graphene can be grown directly on a transition metal substrate via saturation of carbon through exposure to a hydrocarbon gas at high temperature. Normally nickel or copper films are used as a substrate with methane gas. When the substrate is cooled, carbon precipitates as mono- to multi-layer graphene sheets due to decreased solubility of carbon on the substrate [7, 8].

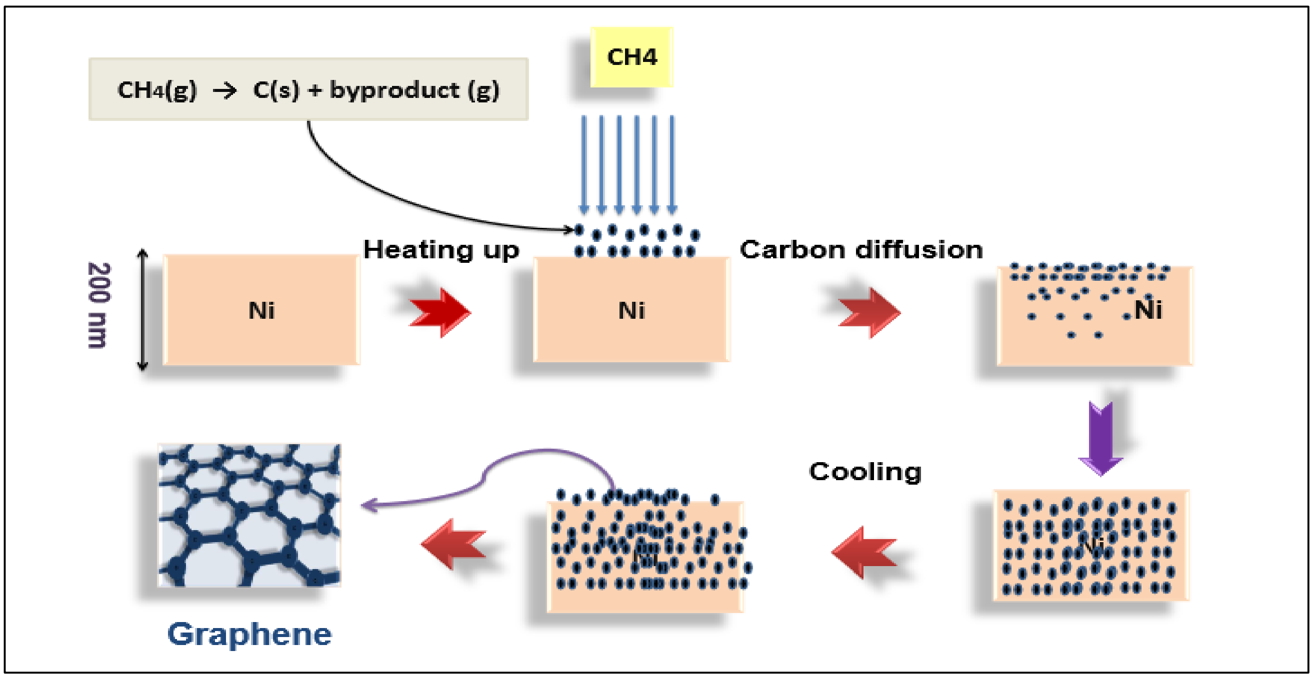

Fig 5

Physical Properties of Graphene

It is the thinnest possible material with density 0.77mg m^{-2}.

Strength – Graphene appears to be one of the strongest material ever tested with its breaking strength 42 Nm^{-1}. It is 200 times stronger than steel [9, 10].

Optical transparency – It is almost transparent with its ability to absorb 2.3% of light falling on it. This is a consequence of the unusual low energy electronic structure of monolayer grapheme [11].

Electric conductance- Electrical conductivity of graphene sheets is 10 times that of copper. Room temperature mobility is predicted to be as high as 200000 $cm^2 V^{-1}S^{-1}$ [12, 13, 14].

Thermal properties- Thermal conductivity of grapheme was measured to be between (4.84 +- 0.44) * 10^3 to (5.30 +- 0.48) * 10^3 $Wm^{-1}k^{-1}$ [15].

Graphene is different from others due to –

- Its unique structure
- All in one properties
- Low cost
- Most abundant element
- Simple fabrication techniques

It is chemically inert and possess high thermal stability. Graphene makes experiments possible that give new twists to the phenomenon in quantum physics.

In view of the amazing properties of graphene, it can be integrated into a huge number of applications [16-21] like-

- Biological engineering
- Mechanical engineering
- Optical electronics
- Ultra filtration
- Composite materials
- Photovoltaic cells
- Energy storage
- Super capacitors
- As a superconductivity material
- Solar cells
- Micro electronics
- Transparent conductivity electrode
- Solar cells
- Graphene biodevices

The applications of graphene in various fields of engineering have been summarized as below:

1. **Biological Engineering:** Graphene offers a large surface area, high electrical conductivity, strength and thinness. It can be very good material for the development of fast and efficient bio electric sensory devices. It can be able to monitor glucose levels, haemoglobin levels, cholesterol and DNA sequencing. A special type of toxic graphene can be engineered which may be used as an antibiotic or in anticancer treatment. Due to its capacity to molecular makeup and potential biocompatibility, it may be utilized in the process of tissue regeneration.
2. **Graphene electrodes for touch screens:** Indium tinoxide is being used as a transparent conductor in normal touch screens on table computers and smart phones as well as as an electrode in solar cells and OLEDs [22, 23]. Graphene due to its optical conductivity may be strong material for the replacement of Indium tinoxide. Graphene out performs ITO and other competing material with lower resistance and high transparency to electric current. In terms of potential real world electronic applications we can expect to see such devices as graphene based e-paper with ability to display interactive and updatable information. It can be possible to design flexible electronic devices including portable computers and televisions.
3. **Composite materials:** Aerospace engineers are using carbon fibre into the production of aircraft as it is very strong, stiff and light. Graphene can be integrated into epoxy plastics to create a material which can replace steel in the structure of aircraft and other devices. It can be used to coat aircraft surface material to prevent electrical damage because of lightning strikes.
4. **Ultrafiltration:** Graphene possess very special quality that while it allows water to pass through it but almost completely impervious for liquid and gas molecules. Graphene could be used as an ultra-filtration medium to act as a barrier between two substances. The benefit of using graphene is that it is only single atom thick and graphene filters have extremely small pore sizes, so the pressure during ultra-filtration is highly reduced. It is possible to develop water filteration systems using graphene for the desalination of water and efficient, economic bio fuel creation.
5. **Energy storage:** Energy storage has always been a problem in batteries and capacitors when they are not being used. The solutions have been developing at very slow rate as a battery can potentially hold a lot of energy but takes longer time to charge while a capacitor can be charged very quickly but can't hold that much energy. The solution is to develop such super capacitors or batteries which are able to provide both of these characteristics without any compromising. Graphene is being studied and developed in the manufacturing of super capacitors [24, 25]. which are able to store large amount of electricity. These micro super capacitors may be developed for use in low energy applications such as smart phones and portable computer devices and could be commercially available in few years.
6. **Transparent memory with graphene:** Researchers have got success in development of transparent flexible memory chips using silicon oxide. Two terminal transparent memory devices are being developed using graphene.
7. **Integrated circuits with graphene transistors:** Researchers have got success in designing a high speed graphene circuit. Although a graphene is not a natural semiconductor still graphene transistors have been operated at twice the speed of comparable silicon transistors.
8. **Photovoltaic cells:** Graphene offers very low levels of light absorption and shows high electron mobility so it can be used as an alternative to silicon or ITO in the manufacture of photovoltaic cells. Graphene based cells are potentially less expensive than silicon cells. When silicon turns light into electricity it absorbs a photon for every electron produce which means lot of potential energy is being lost as heat. Research has proved that graphene absorbs a photon and generates multiple electrons. Silicon is able to produce electricity from certain wavelength bands of light while graphene is able to work on all wavelengths. Being flexible and thin, graphene based photovoltaic cells may be used in clothing,

to help recharge our mobile phone and curtains to help power our home.

Conclusion

Graphene has been proved to be a novel and most promising nano material. It possesses various incredible properties. Many of them are still undiscovered. In this research article an attempt has been made to provide an overview of structure, synthesis and applications of this amazing nano material in various fields of science and engineering.

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