Graphene Properties, Applications and Synthesis

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Abstract: ***In this paper we demonstrate the capability of graphene in making energy efficient solar panels inexpensively. The main differences between the three traditional methods for the growth of graphene, i.e. Mechanical Exfoliation, Chemical Exfoliation and Chemical Vapour Deposition, are highlighted. Graphene solar cells are more efficient and provide more power output in less time. Where there is increase in population and insufficient power production in villages and small scale industries, graphene solar panel will be installed to gain additional power without any problem. Researchers and industrialists quote graphene as the nearby future for power supply.***

Keywords: Carbon, Graphene, CVD (Chemical Vapour Deposition), nanotechnology, Solar cell

1. Introduction

Graphene is best material for solar panel, because there are properties with many superlatives to its name. Graphene is an allotrope of carbon in the form of a two-dimensional, atomic-scale, hexagonal structure like honeycomb. It is single atom thick layer; it is the basic structural element of other allotropes, including graphite, carbon nanotubes and fullerenes. Graphene has many unusual properties. It is about 200 times stronger than the strongest steel. It also exhibit ~97.7% transmittance throughout the entire visible light spectrum from the ultraviolet (UV) region to the long wavelength infrared region (IR) [1]. We use graphene material made by carbon, because carbon is the base of graphene and this material is easily available on earth and it's bonding is very strong. Its sp^2 bonding is very strong and there is one free electron for other bonding that's why it is flexible.

To date, graphene electrodes have been applied for different types of solar cells, namely, solid-state solar cells, electrochemical solar cells, quantum dot solar cells (QDSCs), and polymer solar cells. The main advantages of applying graphene in different solar cells are: (i) it creates a window for inducing wide ranges (from UV to far IR regions) of photon energy inside the solar cells, (ii) it exhibits higher charge transfer (CT) kinetics at the interface of electrochemical hybrid cells, (iii) it manufactures a flexible device with robust architecture, and (iv) it provides greater heat dissipation. On the other hand, electro catalytic activities of graphene play a key role in enhancing the efficiency of electrochemical solar cells like dye-sensitized solar cells (DSSCs), where the liquid/ solid interface acts as a pathway for transferring electrons. However, the inert nature of the graphene basal plane often holds back CT at the graphene/liquid interface despite the high in-plane charge mobility, so enhancement in electro catalytic activities occurs only through the edge-planes. Hence, surface functionalization of graphene is required to improve in-plane CT and enhance application for electrochemical solar cells. [2]

2. Properties of Graphene

Graphene has specific surface area (SSA) of 2630 m^2/g. which is much larger than that reported to date for carbon black (typically smaller than 900 m^2/g) or for carbon nanotubes (CNTs), from ≈100 to 1000 m^2/g and is similar to activated carbon.[3]

Structural Properties

Graphene's hexagonal lattice can be regarded as two interleaving triangular lattices as shown in fig. 1. This perspective was successfully used to calculate the band structure for a single graphite layer using a tight-binding approximation.

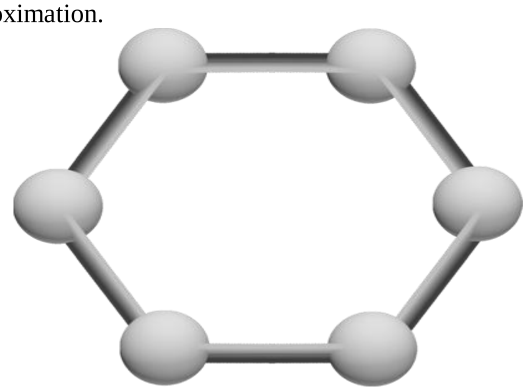

Figure: 1 Structure of Graphene

Chemical Properties

Graphene is the only form of carbon (or solid material) in which every atom is available for chemical reaction from both sides (due to the 2D structure). Atoms at the edges of a graphene sheet have special chemical reactivity. Graphene has the highest ratio of edge atoms of any allotrope. Defects within a sheet increase its chemical reactivity. Graphene is commonly modified with oxygen and nitrogen containing functional groups and analyzed by infrared spectroscopy and X-ray photoelectron spectroscopy. However, determination of structures of graphene with oxygen and nitrogen functional groups requires the structures to be well controlled. Single-layer graphene is a hundred times more chemically reactive than thicker sheets. [4]

Electronic Properties

More interesting is manipulating the flow of electron that carries electricity. Graphene is a zero-gap semiconductor, because its conduction and valence bands meet at the Dirac points. The Dirac points are six locations in momentum space, on the edge of the Brillouin zone, divided into two non-equivalent sets of three points.

Optical Properties

As a general rule, the thinner something is, the more likely it is to be transparent. As you might expect, super thin graphene, being only one atom thick is almost completely transparent. Graphene's ability to absorb a rather large 2.3% of white light is also a unique and interesting property especially considering that it is only 1 atom thick. Adding another layer of graphene increases the amount of white light absorbed by approximately the same value (2.3%).

Strength

Graphene has a breaking strength of 42N/m. Steel has a breaking strength in the range of 250-1200 MPa= 0.25-1.2x109 N/m2. Thus graphene is more than 100 times stronger than the strongest steel.

3. Application of Graphene

Graphene, the well-publicized and now famous two-dimensional carbon allotrope, is as versatile a material as any discovered on Earth. It's amazing properties as the lightest and strongest material, compared with its ability to conduct heat and electricity better than anything else, means that it can be integrated into a huge number of applications. Initially this will mean that graphene is used to help improve the performance and efficiency of current materials and substances, but in the future it will also be developed in conjunction with other two-dimensional (2D) crystals to create some even more amazing compounds to suit an even wider range of applications. To understand the potential applications of graphene, you must first gain an understanding of the basic properties of the material. [3]

Optical Electronic

One particular area in which we will soon begin to see graphene used on a commercial scale is that in optoelectronics; specifically touch screens, liquid crystal displays (LCD) and organic light emitting diodes (OLEDs). For a material to be able to be used in optoelectronic applications, Graphene is an almost completely transparent material and is able to optically transmit up to 97.7% of light. [3] It is also highly conductive. Currently the most widely used material is indium tin oxide (ITO), and the development of manufacture of ITO over the last few decades time has resulted in a material that is able to perform very well in this application.

Ultra filtration

Another standout property of graphene is that while it allows water to pass through it, it is almost completely impervious to liquids and gases (even relatively small helium molecules). This means that 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 1 single atom thick and can also be developed as a barrier that electronically measures strain and pressures between the two substances.

Photovoltaic Cell

Offering very low levels of light absorption (at around 2.7% of white light) whilst also offering high electron mobility means that graphene can be used as an alternative to silicon or ITO in the manufacture of photovoltaic cells. Silicon is currently widely used in the production of photovoltaic cells, but while silicon cells are very expensive to produce, graphene based cells are potentially much less so. When materials such as silicon turn light into electricity it produces a photon for every electron produced, meaning that a lot of potential energy is lost as heat. Recently published research has proved that when graphene absorbs a photon, it actually generates multiple electrons.

Energy Storage

One area of research that is being very highly studied is energy storage. While all areas of electronics have been advancing over a very fast rate over the last few decades the problem has always been storing the energy in batteries and capacitors when it is not being used. These energy storage solutions have been developing at a much slower rate. The problem is this: a battery can potentially hold a lot of energy, but it can take a long time to charge, a capacitor, on the other hand, can be charged very quickly, but can't hold that much energy (comparatively speaking). The solution is to develop energy storage components such as either a super capacitor or a battery that is able to provide both of these positive characteristics without compromise.

4. An Overview of Graphene Synthesis

The basic building blocks of all the carbon nanostructures are single graphitic layers, which are covalently sp^2 bonded carbon atoms that exist in a hexagonal honeycomb lattice (Fig. 2), which forms 3D bulk graphite, when the layers of single honeycomb graphitic lattices are stacked and bonded by a weak van der Waals force. The single graphite layer, when forms a sphere is known as zero dimensional fullerene, when rolled up with respect to its axis forms a one-dimensional cylindrical structure, called the carbon nanotubes, and when it exhibits a planar 2D structure from one to few layers stacked to each other, called graphene. [2] One graphitic layer is known as single-layer graphene and correspondingly 2 and 3 graphitic layers are known as bi layer and tri layer graphene, respectively. More than 5 layers up to 10 layers graphene is generally called as few-layer graphene and; 20 to 30 layered graphene is characterized as multilayer graphene or thick graphene or nano crystalline thin graphite. This section overviews the major and most popular graphene synthesis process, including exfoliation, chemical synthesis, thermal chemical vapor deposition (CVD), and epitaxial increase in concert with a brief discussion of their feasibility for applications in solar energy devices.

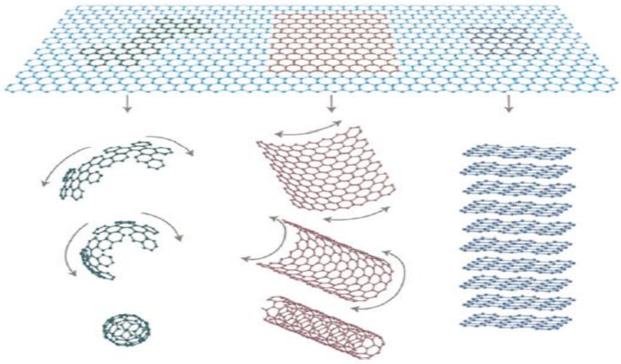

Figure 2: Structure of Graphene Synthesis [5]

5. Mechanical Exfoliation

In 2004, Andre Geim and Konstantin Novoselov of University of Manchester, UK won a Nobel Prize in Physics for isolating 1-carbon atom thick graphene sheets. To separate the graphene sheets from graphite flakes they used Scotch Tape. To visualize the graphene, they stuck the tape on a silicon wafer and examined the wafer under an optical microscope. Thin films of graphene are transparent to the naked eye which is why it is believed they will play an important role in the next generation of extremely thin electronics. [6]

Procedure

1) Take the top piece of tape and gently pull it apart from the bottom.
2) Re-adhere the top piece to the bottom and pull apart again. Repeat this 4-5 more times with the same piece of tape.
3) Throw away the top piece of tape.
4) Get a fresh piece of tape, and repeat step 2. As you repeat this step, you'll note that the bottom piece of tape is gradually covered with a shiny-gray graphite "film."
5) Repeat step 4, until the "film" is a dull gray. This will likely take 4-5 pieces of tape, depending on the initial amount of graphite.
6) Next, adhere the sticky side of the bottom piece of tape to the shiny purple side of the silicon wafer piece. Press the tape firmly yet gently onto the wafer piece.
7) The silicon wafer can now be viewed under an optical microscope with at least a 100X objective.
8) The color and graphene thickness will vary depending on the microscope and thickness of the silicon dioxide, but Figure 3 represents an example sample.
9) The wafer can also be viewed under an electron microscope or atomic force microscope if one is readily available.

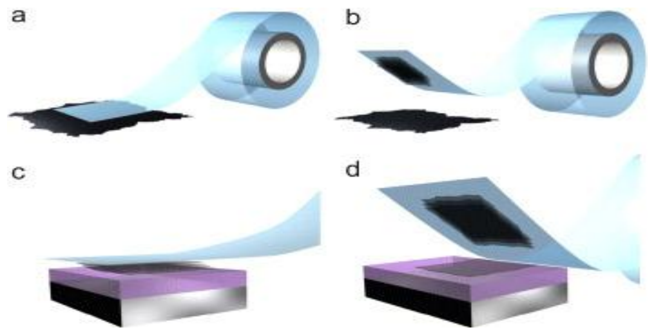

Figure 3: Mechanical Exfoliation using Scotch Tape [7]

Advantages
1) Safe and simple process.
2) Few layer graphene can be easily obtained.
3) The chances of impurity in the graphene so obtained are less.
4) Sample preparation is simplified.

Disadvantages
1) Requires skilled manual labour.
2) Yield obtained may not meet the requirements.

6. Chemical Exfoliation

In chemical exfoliation process, alkali metal ions were used to intercalate the bulk graphite structure to separate out graphene layers followed by the dispersion in a solution as shown in fig. 4. The main reasons for using alkali metals for intercalation reactions are as follows: (i) alkali metal ions can easily react with graphite and form intercalated structures, (ii) they also produce a series of intercalated compounds with different stoichiometric ratios of graphite to alkali metals, and (iii) alkali metals have their atomic radius smaller than the graphite interlayer distance and hence easily fit in the interlayer spacing during the intercalation reaction. [2] This can be obtained in a number of different ways: some methods are based on chemical modification of graphite (e.g. graphene oxide), followed by separation; others are based on directly intercalating small molecules between the layers (e.g. liquid-phase exfoliation).

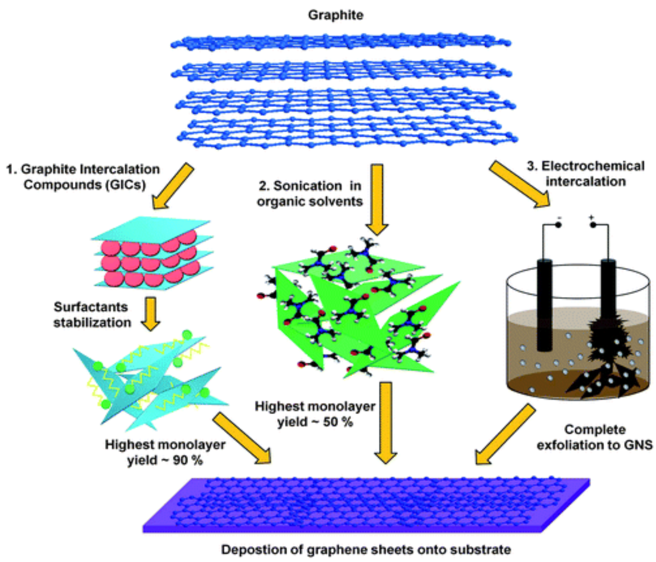

Figure 4: Chemical Exfoliation Process

Advantages

1) Suitable for large amount of graphene production.
2) High yield.
3) Scalable to industrial level.

Disadvantages

1) High Cost.
2) Defective Graphene.

7. Chemical Vapour Deposition (CVD)

The use of chemical vapor deposition (CVD) and other surface precipitation methods for the synthesis of graphene on transition metals has recently been reported. Fig. 5 shows the synthesis process of CVD. The advantage of these methods is that large graphene domains can be easily obtained. Most importantly, since some transition metals can be etched by acid solutions, graphene deposited on these materials can be easily transferred to other substrates. Thickness control of graphene during synthesis is an important step for future applications, and understanding this mechanism is critical. Although some reports claim that the thickness can be controlled, there remains a large degree of uncertainty. [9]

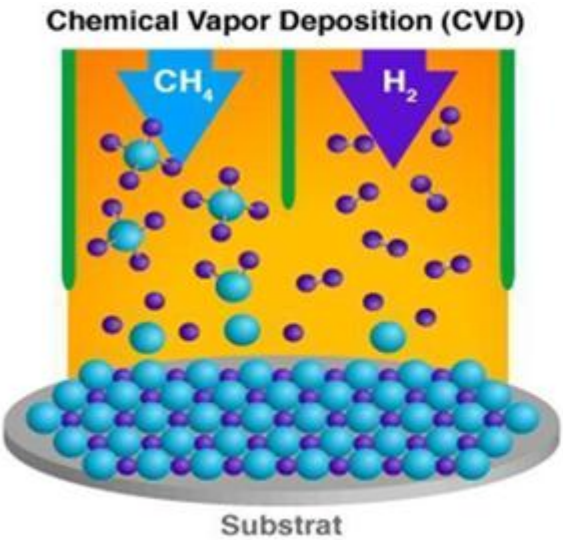

Figure 5: Chemical Vapour Depositions

Advantages

1) High quality, impervious, and harder graphene is obtained.
2) Producing large domains of graphene is easy.
3) High growth rates possible.

Disadvantages

1) High temperature leads to wrinkled graphene due to difference in coefficient of Thermal Expansion.
2) Complex process.
3) Difficulty in controlling the thickness in some cases.
4) Difficulty in transferring the film to other surface.

8. Conclusion

In this paper review and comparison has been given between chemical exfoliation, mechanical exfoliation and chemical vapour deposition. It is concluded that chemical vapour deposition is best among all these processes because large amount of graphene can only be formed by using CVD process. The main reason of selection of graphene is its inexpensiveness. Graphene is said to replace electronics and electricity in nearby future.

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