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# The Emerge of Graphene

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## Abstract

*Graphene is a two dimensional one atom thick building block of carbon allotrope. It is attracting enormous attention of scientists as it can be easily isolated by exfoliation of graphite, first time shown by Novoselov, Geim and co-workers in 2004. It bears exceptional characteristics such as charge transport, thermal, optical, and mechanical properties. Because of these exceptional properties scientists believe that it can be used for technological applications in many areas. Recent progress has shown that the graphene-based materials can have a profound impact on electronic and optoelectronic devices, photovoltaic cells, Transparent conducting electrodes, ultra filtration, chemical sensors, nanocomposites and energy storage. This paper discusses the relevant material properties, device physics, and some of the available results. Thus aim this article is to put review in brief to provide a comprehensive scientific progress of graphene to date and its future prospects in this rapidly emerging field.*

**Key Words:** Graphite; graphene; carbon allotrope; stability; strength; photovoltaic cells; Transparent conducting electrodes; ultrafiltration; chemical sensors; nanocomposites; energy storage

## 1. Introduction

Carbon is the key material for life and the basis of all organic chemistry too. Carbon based systems show an unlimited number of different structures with an equally large variety of physical properties because of the flexibility of its bonding. Dimensions of these structures have great impact on their physical properties. The systems with only carbon atoms play an important role since it is the basis for the understanding of the physical properties in other allotropes. Graphene is made out of carbon atoms arranged on a honeycomb structure made out of hexagons. It is a two-dimensional carbon allotrope as illustrated in figure 1. Fullerenes are molecules where carbon atoms are arranged spherically as shown in fig 1(b) can be thought as wrapped-up graphene. In spherical point of view, the fullerenes are treated as zero dimensional, 0D, objects. Further carbon nanotubes can be obtained by rolling graphene along a given direction and reconnecting the carbon bonds. Hence carbon nanotubes have only hexagons and can be thought of as one-dimensional, 1D, objects. Graphite, a three dimensional, 3D, allotrope of carbon, became widely known after the invention of the pencil in 1564 and its usefulness as an instrument for writing comes from the fact that graphite is made out of stacks of graphene layers that are weakly coupled by Van der Waals forces. Hence, when one presses a pencil against a sheet of paper, one is actually producing graphene stacks and, somewhere among them, there could be individual graphene layers. Although graphene is the mother for all these different allotropes and has been presumably produced every time someone writes with a pencil, it was only isolated 440 years after its invention. The reason is that, first, no one actually expected graphene to exist in the free state and, second, even with the benefit of hindsight, no experimental tools existed to search for one-atom-thick flakes among the pencil debris covering macroscopic areas. Graphene was eventually spotted due to the subtle optical effect it creates on top of a chosen $SiO_2$ substrate that allows its observation with an ordinary optical microscope. Hence, graphene is relatively straightforward to make, but not so easy to find.

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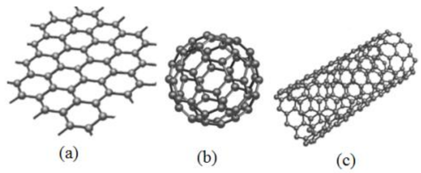


Fig. 1. Graphene structures - (a) Graphene layer (2D), (b) Graphene fullerenes (0D), (c) Graphene nanotube (1D).

Graphene has amazing properties and is a lightest and strongest material, compared with its ability to conduct heat and electricity better than anything else. Thus, it can be integrated into a huge number of applications. At initial stage it may be used to 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, we must understand the basic properties of the material.

## 2. Defining the graphene

Graphene is a thin single layer of carbon atoms that are bonded together in a hexagonal honeycomb lattice. It is an allotrope of carbon in the structure of a plane of sp2 bonded atoms with a molecule bond length of 0.142 nanometres. Graphite is nothing but layers of graphene piled on top of each other. Graphehe compound is one atom thick and hence lightest material with weight of 1 square meter is around 0.77 milligrams only. However, it is a strongest compound with a tensile stiffness of 15□ 107 psi. It is a best conductor of heat at room temperature and also the best conductor of electricity known. Its absorption power of white light is about $\pi\alpha \approx 2.3\%$ only and is potential suitable for use in spin transport. Carbon is the second most abundant mass within the human body and the fourth most abundant element in the universe which makes the carbon as the chemical basis for all known life on earth. Therefore, graphene becomes an ecologically friendly, sustainable solution for an almost limitless number of applications.

The problem that prevented graphene from initially being available for developmental research in commercial uses was that the creation of high quality graphene was a very expensive and complex process. It is a chemical vapor disposition method which involves the use of toxic chemicals such as Platinum, Nickel or Titanium Carbide to ethylene or benzene are exposed at high temperatures to grow graphene as a monolayer by. Also, it was previously impossible to grow graphene layers, at large scale, using crystalline epitaxy on anything other than a metallic substrate. Therefore, it was difficult to separate the graphene layers from its metallic substrate without damage which limited its uses in electronic sector.

Knowing the importance and extraordinary properties of graphene, people were tried to produce its layers in large amount in simple way but they were not succeeded unit a revolution is occurred in this area by the discovery made by [1] using a piece of graphite and a scotch tape. They way of producing the graphene using this simple technique revolutionized the way we look at potential limits of our abilities.

## 3. Graphene properties

Basically, graphene is a single atomic layer of graphite. Graphite is an abundant mineral which is an allotrope of carbon that is made up of very tightly bonded carbon atoms organized into a hexagonal lattice. The sp2 hybridization structure of graphene makes it very special. It is a very thin atomic thickness of about 0.345Nm. These properties enhance the strength, electricity and heat conduction as well as many others of graphene. Let us review these properties one by one.

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2.1 Stability of graphene structure

Previously it was believed that two dimensional compounds could not exist due to thermal instability when separated. It is found that graphene is quite stable and is 2D. Initially, scientists could not understand its secrete and took time to found the correct reason. The research revealed that the carbon-carbon bonds in graphene are so small in length and hence so strong in strength which makes the graphene structure quite stable.

2.2 Electronic Properties

Zero-overlap semimetal with both holes and electrons as charge carriers with very high electrical conductivity is a most useful property of the graphene. We know that carbon atom has six electrons in total; two in inner shell and four in the outer shell. Therefore, the four electrons in the outer shell are available for chemical bonding. However in graphene, each carbon atom is connected to three other carbon atoms on the two dimensional plane leaving one electron free in the third dimension for electronic conduction. Such highly mobile electrons are called pi (□) and obviously are located above and below the graphene sheet. These pi orbitals overlap with each other and help to enhance the carbon-carbon bonding in third dimension. In this way the electronic properties of graphene are controlled by the bonding and anti-bonding of these pi orbitals. It is found that the electrons and holes which act as charge carriers have zero mass at the Dirac points. This happens because the energy-movement relation is linear for low energies near the six individual corners of the Brillouin zone. Such electrons and holes are known as Dirac fermions or Graphinos and the six corners of the Brillouin zone are known as Dirac points. Due to the zero density of states at the Dirac points, the electronic conductivity is actually very low. However, the Fermi level can be changed by doping with electrons or holes to create which is potentially better at electrical conductivity than other conductors like copper or aluminum at room temperatures.

2.3 Mechanical strength

The inherent strength is one of the outstanding properties of the graphene the bond length in the graphene is only 0.142 nm and is very short indicating it is very strong. Thus the graphene is a strongest material ever discovered. Its tensile strength is about $1.3\times10^{11}$ Pascal whereas of the steel is about $4\times10^{8}$ Pascal. It proves that how the graphene is very useful in strength. Another property of the graphene is the light weight. The weight of one square metre of graphene sheet is about 0.77 milligram whereas the weight of a thin paper of same size is roughly about 1000 time more. Another important property of the graphene is its elasticity which makes it special again. Graphene regains its original shape after removing the tensile strain. Thus, as far as concerning the mechanical properties, the graphene material is very important, however the current task is to reduce the cost of production and complexity.

2.4 Optical properties

A single layer of graphene sheet absorbs 2.3% of incident white light. It is a unique and interesting property as only one atom thick layer is exposed. This is due to its above mentioned electronic property in which the charge carriers, electrons as well as holes, act as mass-less charge carriers with very high mobility. If we add another layer of the graphene, its absorption power of light becomes twice as that of the single layer. It is also found that if we increase the intensity of light continuously, a point will reach the absorption of light does not increase. This is called saturation point of intensity of light. Further increase in intensity causes decrease in absorption of light. This is an important characteristic regarding the mode-locking of fiber lasers. Thus, using the property of existence of saturation point in the intensity of light in absorption in graphene layer, full-band mode locking can be achieved in fiber lasers.

Thus these exciting properties of graphene produce large chances of its applications. But before the graphene is heavily integrated into different areas from kitchen appliances to space research we have to spend more time to understand the amazing material. However, few applications which are always in discussion of researcher are quoted below.

## 4. Graphene Applications

It is lightest and strongest material compared with its ability to conduct heat and electricity. Graphene is used to help improve the performance of electricity of current materials and substances. In feature it can be used to develop conjunction with other 2-dimensionalcrystals to suit wide range of applications. Mechanical exfoliation is the process of dissecting graphite layer by layer until a single layer remained. Since, graphene is one atomic thick then it is possible to create materials by interjecting the graphene with other compounds which are one atomic thick. These can be used to form layers one above other with potentially more applicant. Other two dimensional crystals such as boron nitride, tantalum sulphide can be used in combination with other crystals for limitless applications. The only problem with graphene is that it is a great conductor having no band gap. Therefore, it cannot be switched off. So in the future a band gap needs to be created so on to use it in electronic circuits.

3.1 Biological engineering

Graphene having a large surface area, high conductivity, thinness and strength it would be best to use it in bioelectric sensor devices. It can also be used to monitor things such as glucose levels, haemoglobin levels, cholesterol and even DNA sequencing. In the future, we may even see toxic graphene able to be used as antibiotic or anticancer treatment and drug delivery [2].

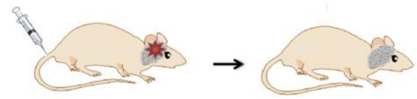

Fig. 2. Use of graphene in drug delivery.

3.2 Electronics

Graphene has a high carrier mobility, as well as low noise. Therefore, it can be used as the channel in a field effect transistor. In 2008, the smallest transistor of one atom thick and 10 atoms wide is made of graphene [3]. In 2009, researchers demonstrated four different types of logic gates, each composed of a single graphene transistor [4]. In February 2010, researchers announced transistors with an on/off rate of 100 gigahertz, far exceeding the rates of previous attempts, and exceeding the speed of silicon transistors with an equal gate length. In November 2011, researchers used 3d printing as a method for fabricating graphene devices [5]. In 2013, researchers demonstrated graphene's high mobility in a detector that allows broad band frequency selectivity ranging from the THz to IR region (0.76–33 THz)[6]. Further in the same year researchers reported the creation of transistors printed on flexible plastic that operate at 25 gigahertz, sufficient for communications circuits and that can be fabricated at scale. The researchers first fabricate the non graphene containing structures—the electrodes and gates—on plastic sheets. Separately, they grow large graphene sheets on metal, then peel it off and transfer it to the plastic. Finally, they top the sheet with a waterproof layer. The devices work after being soaked in water, and are flexible enough to be folded.

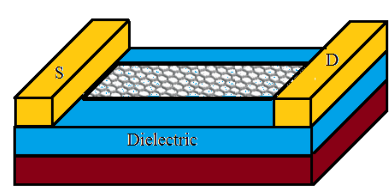


Fig. 3. Use of graphene in transistors.

3.3 Transparent conducting electrodes

One area in which graphene can widely be used in optoelectronics. It can be used in touchsreens, liquid crystal displays, and organic light emitting diodes. It is an almost completely transparent material and is able to transmit up to 98% of light. It can also work in displays of tablets, computers and televisions. Currently most common and widely used material is indium tin oxide. Graphene is also able to match the properties indium tin oxide. Graphene displays additional properties so it can replace indium tin oxide. High tensile strength and flexibility enables it to be used in the above applications.

In particular, graphene's mechanical strength and flexibility are advantageous compared to indium tin oxide, which is brittle. Graphene films may be deposited from solution over large areas. Researchers [7-10] have produced large area, continuous, transparent and highly conducting few layered graphene films by chemical vapor deposition and used as anodes for application in photovoltaic devices. A power conversion efficiency up to 1.71% was demonstrated, which is 55.2% of the PCE of a control device based on indium tin oxide [11]. Organic light emitting diodes with graphene anodes have been demonstrated [12]. The electronic and optical performance of graphene based devices are similar to devices made with indium tin oxide.

Fig. 4. Use of graphene in transparent touchscreens.

3.4 Ultrafiltration

Graphene can be used as a barrier between two substances since it allows water to pass through and is impervious to liquids and gases . A team of researchers in Columbia University have created monolayer graphene that has pore size of 5nm. So, graphene is developed to be used in water filtration systems, desalination systems etc [13].

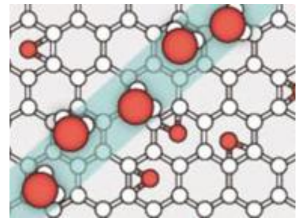

Fig. 5. Use of graphene in filtration.

3.5 Composite materials

Graphene is much stronger and also much lighter. So it can be used in aerospace engineering for the production of aircraft. It can replace steel in the structure of aircraft improving fuel efficiency. It could also be used to coat aircraft to prevent electrical damage resulting from lightening strikes. These can be used in body armor for military personnel and vehicles.

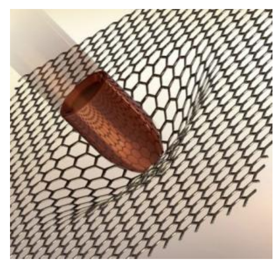

Fig. 6. Use of graphene in body armor.

3.6 Photovoltaic cells

Currently silicon cells are widely used but are expensive. In case graphene having low levels of light absorption and high electron mobility can be used. Further silicon is able to generate electricity from particular wavelength bands of light, while graphene is able to work on all wavelengths. It is flexible and thin. It can be used to recharge mobile phones, curtains to help power our home.

3.7 Energy Storage

Energy storage is one or area of research that is highly being studied. Today energy is stored in batteries and capacitors. Batteries can hold a lot of energy but take much time to charge. On the other hand capacitors take less time to charge but cannot store much energy. The solution is to develop a product that is able to provide both these positive characteristics. Graphene may be used develop such product. Also graphene is being studied to develop superconductors. These will be charged quickly and store a large amount of energy. In next 5 – 10 years graphene based micro-superconductors will likely to be developed. These can be used in smart phones, tablets, PCs, vehicles, etc.

3.8 Other applications

Some other applications of graphene in brief are as follows.

• In lubricant's field graphene can work a bets lubricant. It works better than traditional lubricants. A one atom thick layer of graphene in between a steel ball and steel disc lasted for 6,500 cycles. Traditional lubricants last 1,000 cycles.

• Graphene can be used as sound transducers. It provides relatively good frequency response, suggesting uses in audio speakers. Its light weight may make it suitable for microphones as well.

• Graphene can be used for waterproof coating. It could potentially usher in a new generation of waterproof devices whose chassis may not need to be sealed like today's devices.

• Graphene can be a coolant additive. Its high thermal conductivity suggests that it could be used as an additive in coolants. Preliminary research work showed that 5% graphene by volume can enhance the thermal conductivity of a base fluid by 86% [14]. Another application due to graphene's enhanced thermal conductivity was found in PCR.

• Graphene can be used for thermal management. In 2011, researchers reported that a three dimensional, vertically aligned, functionalized multilayer graphene architecture can be an approach for graphene based thermal interfacial materials (TIMs) with superior thermal conductivity and ultra low interfacial thermal resistance between graphene and composites can be utilized in thermal interface materials [15]. When one adds a a layer of graphene to each side of a copper film increases the metal's heat conducting properties up to 24%. This suggests the possibility of using them for semiconductor interconnects in computer chips. The thing is to mention that the improvement is the result of changes in copper's microstructure and not from graphene's independent action as an additional heat conducting channel.

It is proved that the exceptional properties of graphene such as electrical, thermal, mechanical, optical makes it very useful material for various engineering applications.

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