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What is graphene?

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Abstract: Graphene is a monolayer of carbon allotrope that has honeycomb connections. The scientists have brought graphene to their focus. A large amount of scientific paper has already been written related to this issue. In this paper, I try to write a simple review of graphene and discuss it. I will focus on main concepts of graphene such as history, prospective of graphene, its grandeur, properties (including its optical, electronic, and mechanical properties) of graphene, its economic landscape, and finally the defection of graphene and its impact on semiconductors and mechanical behavior of graphene will be discussed.

Keywords: carbon, graphite, graphene, grandeur, defect

Introduction

Carbon is one of the most useful elements in the world that makes all basis of organic chemistry. Carbon has different physical properties and these properties are related to its dimensionality. Graphene is one of the most famous carbon allotropes that role a key point in electronic properties. Graphene has a carbon honeycomb structure and it looks hexagonal in shape (A. H. Castro Neto f. G., 2009). The atomic thickness of graphene is 0,345 nm and it is the thinnest and strongest materials in the universe until now. We can say that graphene is a million times thinner than a human hair but 200 times stronger than steel and it is harder than diamond. It has optical, electrical, mechanical, and thermal properties.

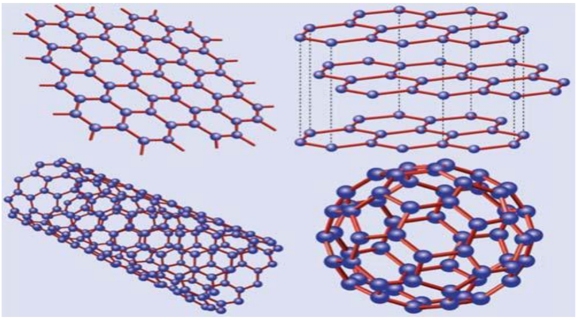

Figure 1. Graphene (top left) is a honeycomb lattice of carbon atoms. Graphite (top right) can be viewed as a stack of graphene layers. Carbon nanotubes are rolled-up cylinders of graphene (bottom left). Fullerenes (C_{60}) are molecules consisting of wrapped graphene by the introduction of pentagons on the hexagonal lattice (A. H. Castro Neto F. G., 2009).

The above figure shows us a different type of graphene. We can say about 2D materials including graphene that they are single atomic crystals, where 100 layers of them make a thin film of 3D materials. Finally, we can say that graphene is the mother of most carbon allotropes.

History of graphene

The earlier attempt to isolate graphene concentrated on chemical exfoliation and graphene separated by its layers intervening of atoms and molecules (Novoselov, 2009).
Graphite oxide thermally has a high lamellar structure where it focused by Benjamin Collins Brodie in 1859.
Graphene is made out of carbon atoms that have a honeycomb structure where it made from hexagons graphite, a three-dimensional _3D_ allotrope of carbon, became widely known after the invention of the pencil in 1564. Graphene was invented from graphite after 440 years since graphite inventions. Indeed, when a person wants to press a pencil to a piece of paper. In fact, he made graphene by his hand. The first person who wrote about the graphene band structure in 1964 was P. R. Wallace and he showed the unusual behavior semi-metallic of this material (A. H. Castro Neto F. G., 2009).
The first stable graphene was demonstrated by Novosolev from Manchester University in 2004 and two years later the first graphene products released in 2006 by Princeton University with the cooperation of Vorbeck Materials. Vor-inks became the first screen-printable graphene ink in the world (Hasan, 2018).

The Prospects of Graphene

Graphene is wildly used by researchers in the lab every day and there is a lot of paper that publish in this direction and all of them focus on different usages of graphene in the electronic equipment, economy, and bioscience and commercial market. We never forget that there is a lot of project around the world which they focus on graphene and its structure that will use in the many parts of technology and it will pave the way for good and luxurious life to the mankind in the next days.
We know more about atomic plane materials because of its bulk crystals but we don't know about graphene and its one

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atomic thick material until 2004. We can make 2D crystals by two principles. In the first method, we can mechanically split strong layered materials into a small individual atomic plane. In the second principle instead of cleaving graphite, we use an automatic method of employing, for example, ultrasonic cleaving. So, we can make by second principle polycrystalline films and composite materials.

The studies of electronic properties of graphene focus on Dirac equation with some standard formalism of condensed matter to gain new physics so, these study of graphene led us to half-integer quantum Hall effect (QHE) and predict some phenomena like Klein tunneling, zitterbewegung, Schwinger production, supercritical atomic collapse and Casimir-like interactions between adsorbates on graphene (Geim, 2009).

Grandeur of Graphene

Graphene changes all the earlier landscapes with its unimaginable structure and shows that it has less speculative applications. As we look at graphene development in recent years, it will take place instead of Si in the electronic materials and will change most of our world landscapes in the next few years. Graphene has many usages in a different section of technology. For example, in the transmission electron microscopy (TEM). Graphene will offer a good possibility to extend high electron mobility transistors (HEMT) that has high usage in communication technologies (Geim, 2009).

At the end of graphene grandeur, I would like to say that recent studies about the graphene structure suggest to us about production cost of graphene sheets in large quantities that would be much lower than carbon nanotubes (Kaner, 2008).

Graphene properties

Carbon shows a lot of structures and a large number of different properties because of its flexibility bonding.

Graphene has different properties like optical properties, electrical properties, and mechanical properties.

In the first part of this section, I would like to focus on the optical properties of graphene and then I will explain the other parts.

The optical conductivity of graphene is constant and it is independent of energy. So, we can easily derive that optical conductivity is also independent of any parameters. The optical conductivity is very close to DC conductivity but it is not equal.

The optical properties of graphene are experimentally and theoretically depending on its local strain.

Graphene is a promising material with low resistance that use in many applications like touch screen, liquid crystal displays, organic light-emitting diodes, solar cell, computer.

Also, it is not imaginable to say that we will use in the future graphene and graphene oxide in other optical equipment where it will change our lives in many aspects that we had problems in recent years. Graphene has a very large Faraday rotation about 6 degrees and this specialty allows us to use it in magneto-optical devices (A. N. Grigorenko).

Second, the structure of flexibility reflects on graphene electronic properties. According to the graphene structure, the first Brillion zone (BZ) has two inequivalent Dirac point k and k` where the band crossing occurs there.

The charge carrier properties of graphene explain that graphene is zero-gap 2D semimetal carbon allotropes which have tiny overlap between valence and conductance and its charge carrier move under some condition (Xiao Huang, 2010).

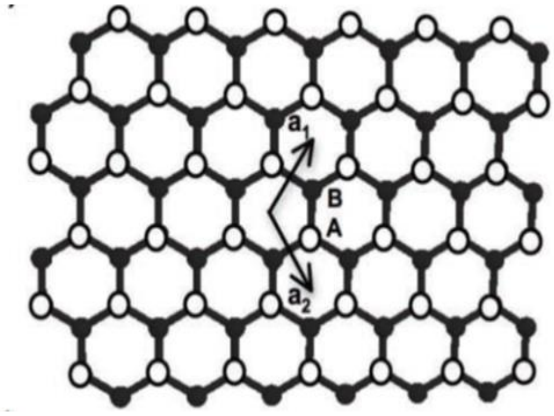

Figure2. Schematics of the crystal structure, Brillouin zone, and dispersion spectrum of graphene

Graphene ambipolar field effect and charge carriers can tune in both electrons and holes that show in figure 3.

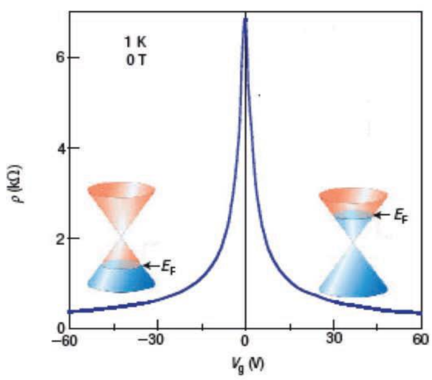

Figure3. Ambipolar electric field effect in monolayer graphene. The insets show that the changes in the position of the Fermi energy E_F with changing gate voltage V_g.

The mobility in graphene tells us about high carrier density in electrically and chemically doped devices and the electronic properties of graphene also explain the quantum hall effect (QHE) at room temperature.

Third, the mechanical properties of graphene include Young's modulus and fracture strength study by molecular dynamics. The Youngs modulus experimentally investigates with force-displacement by atomic force microscopic (AFM) on graphene tranches. Also, the elastic properties of graphene were measured by nanoindentation by using an (AFM) in recent years (By Yanwu Zhu, 2010).

Theoretically, some work investigates the mechanical properties of zigzag graphene and armchair graphene nanoribbons. We can study the elastic deformation of functionalized graphene sheets (FGS) and reduced graphene oxide (RGO) by AFM (Xiao Huang, 2010).

Application of Graphene

Graphene has many applications in different parts of our life like technology, economy, biomedical science, electronic equipment, analyzing water, etc. so, in this part shortly I will explain some of them.

The carrier in graphene is bipolar with electrons and holes that can be tuned by an electrical field. Graphene transistors that now we can fabricate in some companies, has electrical properties. Also, high-frequency graphene field-effect transistors (FET) using top gate geometry and a new type of single-electron transistors (SET) that have a base of graphene quantum dots made by beam lithography reported recently. Look Figure 4 for graphene-based SET.

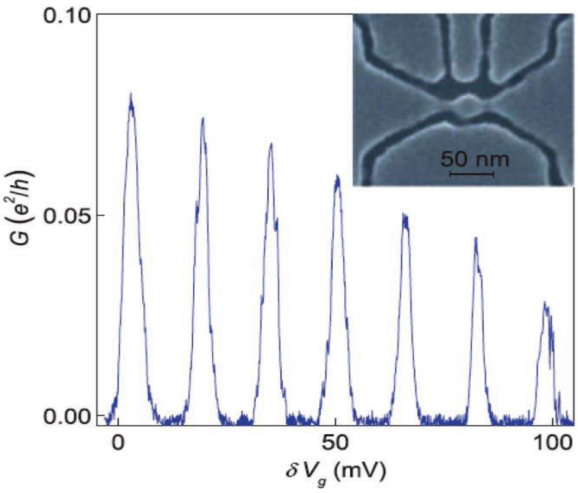

Figure 4. A graphene-based. Conductance G of a device with the central island of 250 nm in diameter and distant side gates as a function of V_g in the vicinity of + 15 V; T = 0.3 K. The inset shows one of the smaller devices illustrating the high-resolution lithography “that allows features down to 10 nm.

The graphene bipolar characteristics make its carrier sensitive for doping electrically and chemically and graphene oxide is also a good sensor.

Graphene with high carrier mobility, high electrical conductivity, and high optical transmittance is shown that it has transparent conductivity films (TCFs) characteristics (Gunho Jo, 2012). Scientists also find many ways to obtain graphene and graphene oxide from (TCFs).

Graphene electrodes use for purposes of recharging batteries and making electrochemical double capacitors. Also, we can study hydrogen storage, fuel cells, and solar cells by using graphene materials. The properties of elastic modulus, tensile strength, electrical conductivity, and thermal stability were improved by graphene polymer nano compositions (By Yanwu Zhu, 2010).

The application of graphene in the oil and gas industry use just for a few years. Graphene application in oil and gas industries can use in many sections like drilling, lubrication, de-salination, anti-corrosion coatings, cement-ing, oil-water separation, oil spill cleanup, and emulsion (Neil Neuberger, 2018).

Graphene is used in the water filtration system for purification of water as it allows water to pass through the system, not other liquids and gases. It is also in medical sensors, drug delivery, and cancer therapy. However, its toxicity profile must investigate before clinical use.

Graphene has a good potential to use as a replacement of indium tin oxide in LCD panels and also it can also use in other sections like ultracapacitors for energy storage and nanoelectromechanical systems (Meindl, 2009).

Li-ion battery is the bone of handheld devices like telephone and day by day it requires more ability and has strong characteristics (Minghui Liang, 2009). To make stronger batteries we need good materials that have good stability. So, we use graphene-based materials to make good anode Li-ion batteries because, it has super electrical conductivity, high surface area, and chemical tolerance (Wonbong Choi, 2010). Graphene improves batteries like faster charging, high energy output, high cycle times, and larger lifetime.

Graphene also uses in other sections such as sea-water desalination, preparation of pure and ultra-pure water, biomedicine, biology, environmental protection and many others section that are important in our lives and this extensive usage of graphene predict that graphene and graphene oxide will play a good role in technology and economy (Na Song, 2018).

The economic landscape of graphene

The graphene market is not as much developed as other materials. The total size of graphene global marked including its applications and manufacturers were USD 24.5 million in 2015 but this change in 2020 and the size of the graphene market take a higher place of about USD 126 million.

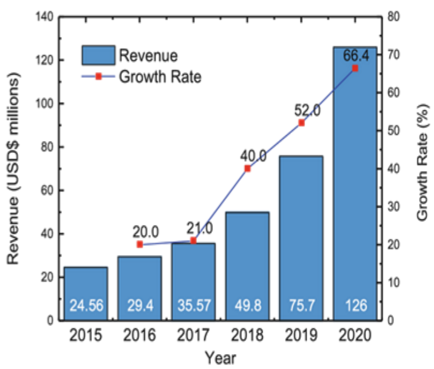

Figure 5. Show projected growth of the worldwide graphene industry from 2015 up to 2020 (Hu, Yang, & Hasan, 2019).

To understand the amount of investment for graphene manufacture around the world, look at the diagram in figure 6.

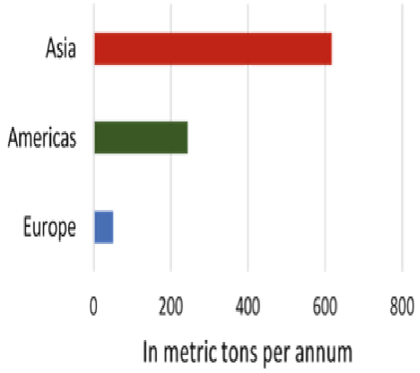

Figure 6. Graphene production capacities in 2015 (Hu, Yang, & Hasan, 2019).

The Asia Pacific is the fastest and largest area for graphene investment among other countries, this is because of being the large raw graphite capacity of China.

The growth of the graphene industry in Europe is now related to some researches in the universities. For example, the UK government invested GBP 100 million at the University of Manchester and GBP 20 million at the University of Cambridge. The European Union investigate Euro 1 billion for 10 years since 2011 for the project of

"Graphene Flagship Program" to understand and permute graphene and related 2D materials.

The graphene market was USD 8.75 million in 2016 and reached USD 38.5 million by 2020 (Hu, Yang, & Hasan, 2019).

Graphene defects

According to the second law of thermodynamics, there are a few disorders in crystalline materials, and such defects influence the properties of some materials. This defect can see in semiconductors or mechanical properties of some metals. Several experiments show that there are some native or physical defects in graphene. We can show the defects of graphene by using transmission electron microscopy (TEM) and scanning tunneling microscopy (STM) methods.

The intrinsic defects of materials have different dimensionality. Graphene material lattice can reconstruct by forming nonhexag-onal rings and this explains that simple defects in any materials especially in graphene materials are missing atom of its structure. Scientists can observe single vacancies (SV) of graphene materials experimentally by TEM and STM methods.

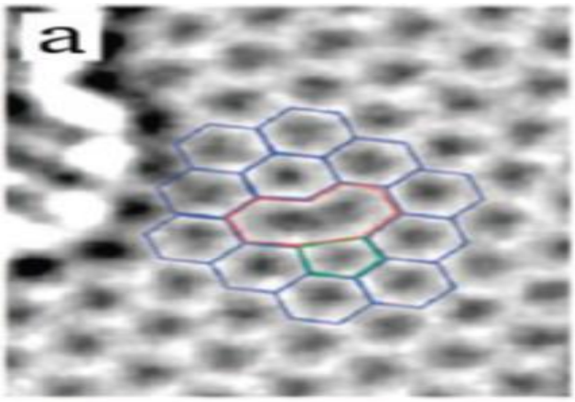

Figure 7. Single vacancy. As seen in an experimental TEM image (Florian Banhart, 2011).

Double vacancies (DV) occur by merging two SV or missing two atoms in graphene structure as shown in figure 8 in the below picture.

If graphene misses more than two DV through some methods then it will lead us to more defect configurations. If occur missing a large number of atoms from a small area due to the impact of ions, that time a reconstruction will require because of area surface reduction.

One dimensional defect occurs during the study of some experimental work of graphene. In fact, the line defect occurs when we want to separate two domains of lattice orientations with tilt axis to plane.

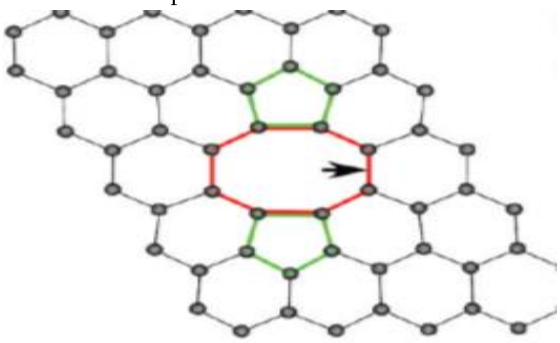

Figure 8. Atomic structures of reconstructed double vacancy defects in graphene as obtained from our DFT calculations (Florian Banhart, 2011).

Line defect frequently divided domain of different crystal orientation as shown in figure 9. Also, we can say that this defect is a line of reconstructed point with or without dangling bands.

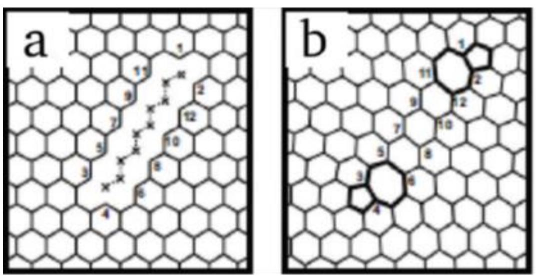

Figure 9. Line defect formation from aligned vacancy structures (Florian Banhart, 2011).

Defects of graphene strongly affect electronic properties and it will change the situation of the electronic structure of graphene. We are at the beginning study of graphene electronic properties and it will take time and need more experiments that show how much will this defect is on graphene electronic properties (Florian Banhart, 2011).
The tuning properties of graphene can be realized by several methods. For example, particle irradiation, thermal annealing, chemical reaction, and strain treatment (Gao Yang, 2018).

Conclusion

Graphene is a single monolayer carbon atom that arranges by a hexagonal lattice. It is carbon allotrope was extracted by Novosolov in 2004 at the University of Manchester. It is the thinnest and strongest material that has ever been discovered until now. It has a multi-field different electrical, optical and mechanical properties that attracted the scientists and expert's attention. Some world markets also have invested a big amount of money to develop some new unique products by utilizing the different specifications of graphene. From a mechanical point of view, it has the most strength and flexibility amongst most of the materials that have ever been discovered or as a manmade product found. This item also has shown the most electrical flexibility and conductivity. It also has properties of stretching of up to 20%.

Graphene has also high electrical current density millions of times than copper. The graphene's intrinsic mobility is 100 times that of silicon. It can be used in many ways like water purring, bioscience, nanotube, nanotechnology, and many other fields. It will take no longer that we produce and manufacture good equipment and products such as phones, computers, watches, nanomaterial and machinery, advanced model vehicles, and even supercapacitors using graphene and graphene batteries. We will prefer graphene and graphene oxide to other materials in the next generation of technology because of its good structures, multipurpose properties, and high flexibility. Now we are identifying the detailed structure and properties of graphene. In some cases we make some equipment applying graphene, but if we want to utilize much more from graphene materials and apply graphene to our products, let's wait no longer than a few years. Some projects are running on concentrating on graphene such as the "graphene flagship of Europe" that has a one billion budget. Passing time it will be more clear for us how graphene will change the industry and upcoming technology.

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