Graphene- The Revolutionary Wonder Material in Electronics

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Abstract

The recent discovery of Graphene has sparked much interest, thus far focused on the exceptional electronic structure of this particle, in which charge carriers mimic mass less relativistic particles. However in physical structure Graphene is one-atom-thick planar sheet of carbon atoms densely packed in a honeycomb crystal lattice, which is the thinnest material and also the strongest material ever measured. As a conductor of electricity it performs as well as copper, as a conductor of it out performs all other known materials. It is almost completely transparent, yet so dense that not even helium, the smallest gas atom, can pass through it. Carbon, the basis of known life on earth, has surprised the world once again. Graphene has emerged as an exotic material of the 21st century and has grabbed appreciable attention due to its exceptional optical, thermal and mechanical properties.

1. Introduction

Materials are the basis of almost all new discoveries in science. The development of new materials can lead to the uncovering of entire new fields of study, as well as new solutions to problems that may have been thought to be unsolvable. One such material is graphene, a deceptively simple arrangement of carbon atoms. This new material has a number of unique properties, which makes it interesting for both fundamental studies and future applications. The Nobel Prize in Physics for 2010 was awarded to Andre Geim and Konstantin Novoselov "for groundbreaking experiments regarding the two-dimensional material graphene".

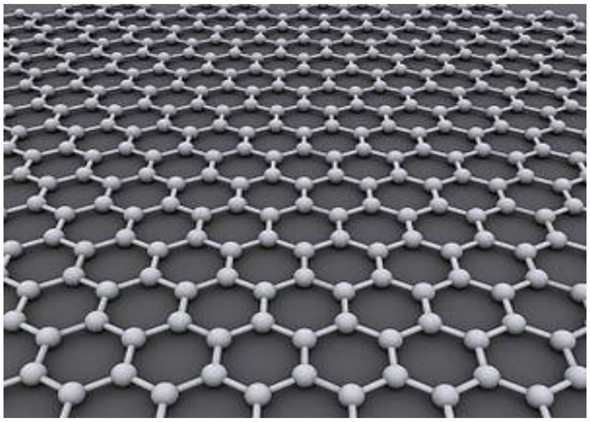

Fig: 1: Graphene is an Atomic-Scale Honeycomb Lattice Made of Carbon Atoms

Graphene is the name given to a flat monolayer of carbon atoms tightly packed into a two dimensional (2D) honeycomb lattice, and is a basic building block for graphitic materials of all other dimensionalities. Theoretically, graphene (or “2D graphite”) has been studied for sixty years, and is widely used for describing properties of various carbon-based materials. Forty years later, it was realized that graphene also provides an excellent condensed-matter analogue of (2+1)-dimensional quantum electrodynamics, which propelled graphene into a thriving theoretical toy model. On the other hand, although known as an integral part of 3D materials, graphene was presumed not to exist in the Free State, being described as an “academic” material and was believed to be unstable with respect to the formation of curved structures such as soot, fullerenes and nanotubes. Suddenly, the vintage model turned into reality, when free-standing graphene was unexpectedly found three years ago and especially when the follow-up experiments confirmed that its charge carriers were indeed mass-less Dirac fermions. So, the graphene “gold rush” has begun.

2. Structure of Graphene

Graphene is a single layer of carbon packed in a hexagonal (honeycomb) lattice, with a carbon-carbon distance of 0.142 nm. Although isolated graphene was reported for the first time only in 2004, the progress it made over these years is enormous, and it rightly has been dubbed "the wonder material". Graphene sheets stack to form graphite with an interplanar spacing of 0.335 nm, which means that a stack of three million sheets would be only one millimeter thick. Graphene is the basic structural element of some carbon allotropes including graphite, charcoal, carbon nanotubes and fullerenes. It can also be considered as an indefinitely large aromatic molecule, the limiting case of the family of flat polycyclic aromatic hydrocarbons.

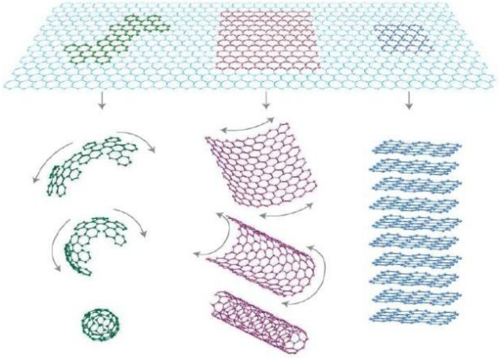

Fig: 2. Structure of Graphene

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The single layer of carbon is what we call graphene. Graphene and Graphite are the two dimensional sp2 hybridized forms of carbon found in pencil lead. Graphite is a layered material formed by stacks 41 of graphene sheets separated by 0.3 nm and held together by weak vander Waals forces. The weak interaction between the sheets allows them to slide relatively easily across one another. This gives pencils their writing ability and graphite its lubricating properties, however the nature of this interaction between layers is not entirely understood. A single 2-D sheet of graphene is a hexagonal structure with each atom forming 3 bonds with each of its nearest neighbors. These are known as the sigma bonds oriented towards these neighboring atoms and formed from 3 of the valence electrons. These covalent carbon-carbon bonds are nearly equivalent to the bonds holding diamond together giving graphene similar mechanical and thermal properties as diamond. The fourth valence electron does not participate in covalent bonding. It is in the 2pz state oriented perpendicular to the sheet of graphite and forms a conducting sigma bond. The remarkable electronic properties of carbon nanotubes are a direct consequence of the peculiar band structure of graphene, a zero band gap semiconductor with 2 linearly dispersing bands that touch at the corners of the first Brillion zone. Bulk graphite has been studied for decades but until recently there were no experiments on graphene. This was due to the difficulty in separating and isolating single layers of graphene for study.

3. Synthesis of Graphene

In 2004, Andre Geim and Knowstantin Novolselov came up with an ingenious method after years of effort to isolate monolayer graphene flakes. As discovered in more detail later, they developed the ‘scotch tap’ or ‘drawing method’ which relies on taking a large crystal of graphite and peeling the crystal repeatedly by using an adhesive tape to generate a large number of thin crystals. Soon after, a group headed by Philip Kim at Columbia University in the US confirmed the existence of graphene using the same drawing tecknique, while Walt de Heer and Clair Berger at Georgia Tech developed an epitaxial growth process that may be suitable for mass-producing graphene for industrial applications.

In 2008, graphene produced by exfoliation was one of the most expensive materials on Earth, with a sample that can be placed at the cross-section of a human hair costing more than $1000 as of April 2008. Since then, exfoliation procedures have been scaled up, and now companies sell graphene in large quantities. On the other hand, the price of epitaxial graphene on SiC is dominated by the substrate price, which is approximately $100/cm2 as of 2009. Even cheaper graphene has been produced by transfer from nickel by Korean researchers, with wafer sizes up to 30 inches reported. [22]

In 2011, the institute of Electronic Materials Technology and Department of Physics, Warsaw University announced a joint development of acquisition technology of large pieces of graphene with the best quality so far. In April, the same year, Polish scientist with support from Polish Ministry of Economy began the procedure for granting a potent to their discovery around the world [22]. Some methods of production of graphene are: Drawing method, Thermal decomposition on SiC, Graphite oxide reduction, Chemical vapour deposition.

4. Properties

Graphene’s unique properties arise from the collective behavior of electrons. Through the investigation of pristine graphene many charming properties were discovered in the past few years including extremely high charge (electrons and holes) mobility with 2.3% absorption of visible light, thermal conductivity, quantum hall effect etc.

5. Applications

For many years it was believed that carbon nanotubes would create a revolution in nano-electronics because of their microscopic dimension and very low electrical resistance. These hopes however have not yet come to fruition because of various difficulties. These include producing nanotubes with well-defined sizes, the high resistance at the connection between nanotubes and the metal contacts that connect them to circuits and the difficulty of integrating nanotubes into electronic devices on a mass-production scale.

Walt de Heer argues that with graphene we will be able to avoid all of these problems. Graphene is useful in so many areas, that it is hard to pick and choose. Physicist like them because they are a playground for understanding how electrons behave when graphene get confined in two-dimension. Biologists are interested in using them as a way of probing biological systems. Graphene can be either metals or semiconductors and their electrical properties can rival or even exceed the best metals or semiconductors known. Because of this engineers are interested in using them as building blocks for smaller transistors. Material scientists want to mix graphene into more traditional substances to create hybrid materials that are much stronger or are conducting, while still being malleable.[3] Some major applications of graphene are Graphene Transistors, Graphene Nanoribbons, Transparent Conducting Electrodes, Ultracapacitors, OPV Solar Cell, Integrated Circuits, Graphene Biodevices.

Graphene Transistor

Owing to its high carrier mobility and saturation velocity, graphene has attracted enormous attention in recent years. Graphene – a sheet of carbon just one atom thick- shows great promise for use in electronic devices because electrons can move through it at extremely high speeds. This is because; they behave like relativistic particles with no rest mass. This, and other unusual physical and mechanical properties, means that the wonder material could replace silicon as the electronic material of choice and might be used to make faster transistors than any that exist today.

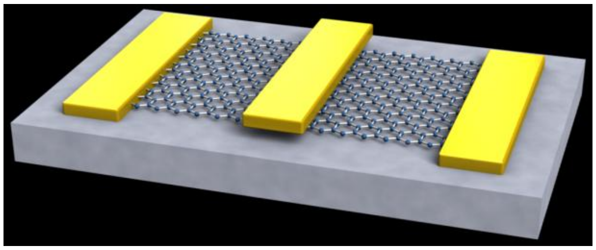

Fig: 4: Graphene Transistor

Graphene Biodevices

These devices are based upon graphene's large surface area and the fact that molecules that are sensetive to particular diseases can attach to the carbon atoms in graphene. For example, researchers have found that graphene; strands of DNA and fluorescent molecules can be combined to diagnose diseases. A sensor is formed by attaching fluorescent molecules to single strand DNA and then attaching the DNA to graphene. When an identical single strand DNA combines with the strand on the graphene a double strand DNA it formed that floats off from the graphene, increasing the fluorescent level. This method results in a sensor that can detect the same DNA for a particular disease in a sample.

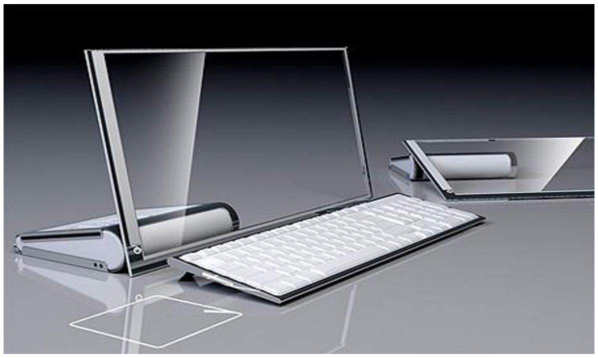

Fig: 3. Graphene Biodevices

Limitations

Despite so many fruitful promises in the field of electronics, the graphene based IC's; microprocessor, etc are unlikely to appear for the next 10-15 years. For more practical applications one would like to utilize the strong gate dependence of graphene for either sensing or transistor applications. One of the major problems lies in the production of high quality graphene having sufficient reproducibility. Also despite being almost similar to silicon-even a bit better in times of most of the characteristics graphene lacks the ability work as switch. Without this, a chip will draw electricity continuously, unable to turn off. Unfortunately, grephene has no bad gap and correspondingly resistivity changes are small. Therefore, a plagued by a low on/off ratio. However one way around this limitation, is to carve graphene into narrow ribbons. By shrinking the ribbons the momentum of charge carriers in the transverse direction becomes quantized which results in the opening of a band gap. This band gap is proportional to the width of the ribbon. This effect is pronounced in carbon nanotubes where a nanotube has a band gap proportional to its diameter. The opening of a fond gap in graphene ribbons has recently been observed in wide ribbon devices lithographically patterned from large graphene flakes and in narrow chemically synthesized graphene ribbons. [1]

6. Future Aspects

Despite the reigning optimism about graphene-based electronics, "graphenium" microprocessors are unlikely to appear for the next 20 years. In the meantime, one can certainly hope for many other graphene-based applications to come of age. In this respect, clear parallels with nanotubes allow a highly educated guess of what to expect soon.

The most immediate application for graphene is probably its use in composite materials. Indeed, it has been demonstrated that a graphene powder of uncoagulated micron-size crystallites can be produced in a way scaleable to mass production. This allows conductive plastics at less than 1 volume percent filling, which in combination with low production costs makes graphene-based composite materials attractive for a variety of uses. However, it seems doubtful that such composites can match the mechanical strength of their nanotube counterparts because of much stronger entanglement in the latter case.

Another enticing possibility is the use of graphene powder in electric batteries that are already one of the main markets for graphite. An ultimately large surface-to-volume ratio and high conductivity provided by graphene powder can lead to improvements in batteries' efficiency, taking over from carbon nanofibres used in modern batteries. Carbon nanotubes have also been considered for this application but graphene powder has an important advantage of being cheap to produce.

One of the most promising applications for nanotubes is field emitters and, although there have been no reports yet about such use of graphene, thin graphite flakes were used in plasma displays (commercial prototypes) long before graphene was isolated, and many patents were filed on this subject. It is likely that graphene powder can offer even more superior emitting properties.

Carbon nanotubes were reported to be an excellent material for solid-state gas sensors but graphene offers clear advantages in this particular direction. Spin-valve and superconducting field-effect transistors are also obvious research targets, and recent reports describing a hysteretic magnetoresistance and substantial bipolar supercurrents prove graphene's major potential for these applications. An extremely weak spin-orbit coupling and the absence of hyperfine interaction in 12C-graphene make it an excellent if not ideal material for making spin qubits. This guarantees graphene-based quantum computation to become an active research area. Finally, we cannot omit mentioning hydrogen storage, which has been an active but controversial subject for nanotubes. It has already been suggested that graphene is capable of absorbing an ultimately large amount of hydrogen and experimental efforts in this direction are duly expected.

7. Conclusion

The field of graphene-related research has grown at a spectacular pace since single-layer flakes were first isolated in 2004. Graphene that began its journey as an exciting material for fundamental physics has now become the focus of efforts by scientists in a wide range of disciplines. Organic and material chemists are busily working on new route to produce high quality single layers, while engineers are designing novel devices to explore graphene's extraordinary properties. This review paper briefly discusses the significant structural attributes of graphene in association with other closely related carbon forms. Starting from its discovery the evolution in synthesizing process has been reviewed. Its unique characteristic properties those made it an extraordinary material has been highlighted. A wide range of utility in different sectors has been mentioned as well as giving idea of its future scopes and prospects. Reviewing the characteristic properties and utilitarian values of graphene it is very much clear that graphene is indeed a wonder material of present time and it holds great promises to become one of the primary materials of the times to come.

References

[1] Md. Nazre Imam- Medak College of Engineering & Technology- Graphene: The Futuristic Element, 2011. http://www.slideshare.net/imamnazre/graphene-the-futuristic-element

[2] Mandar M Deshmukh, Vibhor Singh- Graphene- an exciting two dimensional material for science and technology, 2011, Resonance 238-246

[3] Antonio Castro Neto, Francisco Guinea and Nuno Miguel Peres- Drawing conclusions from graphene, November, 2006

[4] Vincent C. Tung, Matthew J. Allen, Yang Yang and Richard B. Karner- High-throughout solution processing of large scale graphene, 2008, Nature Nanotechnology

[5] www.physorg.com

[6] www.nanowerk.com

[7] www.pubs.acs.org

[8] http://materialsforenergy.typepad.com/materials/2010/11/graphenethe-ultimate-ultracapacitor.html

[9] www.en.wikipedia.org