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Use of Graphene in Future Semiconductor Devices



Abstract:

Graphene is one of the most promising materials today, attracting the attention of several experts across diverse disciplines such as Photonics, Energy, Composites, and Electronics. This carbon allotrope has garnered interest since 2010, when the Nobel Prize in Physics was awarded for pioneering research on 2D graphene. The creation of nanomaterials with graphene has unique characteristics, and interest in graphene among researchers is fast increasing. The planet's most tenuous element is poised to instigate a revolution that will impact every aspect of human existence. The extraordinary features of graphene and its vast potential have generated significant excitement for this two-dimensional, one-atom-thick substance. This work aims to elucidate Graphene, focusing on its structure and stability. Its distinctive features provide a competitive advantage over comparable materials. It is anticipated that it will become ubiquitous in our future lives. The varied properties of graphene have made it highly sought after for several innovative applications in the industry. Extensive research on graphene focuses on biomedical applications because to its distinctive electrical and mechanical characteristics, making it a formidable contender. We introduce some uses of graphene anticipated to effect significant transformation imminently.

Keywords: *Graphene, Properties, 2-Dimensional, Atomic Structure, Composites, Extrinsic, Semiconductors.*

Introduction

Graphene has exceptional characteristics and holds significant promise. This promising material will provide new opportunities and markets, and its influence may be comparable to that of the Industrial Revolution. Its true potential is seen when used in a transformative capacity or to enhance an existing material. Its extensive array of superlatives makes it ideal for many applications. It is very flexible and lightweight, but much stronger than steel. It is translucent but has thermal and electrical conductivity. It is the premier two-dimensional material globally. Monolayer Graphene is far thinner than a single strand of human hair and is anticipated to transform consumer electronics, water, and healthcare sectors. Research on graphene is significantly influencing several sectors, including defense, energy, electronics, medicine, transportation, and desalination, among others. This document is structured as follows. We will first examine the atomic structure of graphene, followed by a comparison with similar materials. The stability of two-dimensional graphene is further elucidated, followed by prospective uses of this remarkable material. Structure similar to graphite, although its thickness is just one atom. A million graphene layers constitute a graphite crystal. Graphene has carbon atoms that are sp² hybridized. The interatomic spacing between carbon atoms in graphene is 0.142 nm. Graphene is defined as a two-dimensional substance, exemplified by layers of Molybdenum disulfide (MoS₂) and Boron nitride (BN), both of which have been synthesized since 2004.

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Graphene has no energy band gap between the valence and conduction bands. There exists a zero band gap with little overlap between the valence band and the conduction band. Owing to the pronounced ambipolar electric field effect, the charge carrier concentration is 10^{13} cm^{-2} , with mobilities of $10,000 \text{ cm}^2 \text{ s}^{-1}$ at ambient temperature.

In 2010, physicists Andre Geim and Konstantin Novoselov were awarded the Nobel Prize in Physics at the University of Manchester for their work on the two-dimensional substance graphene. Graphene is poised to transform the 21st century. Graphene has several prospective uses, including supercapacitors for energy storage, imaging technology, and graphene touch screens. It will be used in communication. Graphene may serve as a substitute for ITO.

Pencil contains the graphene, when we written with pencil on paper then graphite is cleaved into thin layers. A small fraction of these thin layers which has one atom thick and sp^2 bounded between carbon atoms called graphene. It is a plane monolayer of carbon atoms highly packed into a 2-D honeycomb lattice. [8].

It accepts that “graphene is the thinnest and strongest material”. There are two type of bond one is σ and other is π but, the σ bond is stronger than π bond. The sp^2 hybridized is presented by carbon bonds, where the in-plane σ c-c bond is one of the strongest bond in materials and out of the plane π bond, which contributes to a at least one covalent bond of electrons is responsible for the electron conduction of graphene and provides the weak interaction among graphene layers or between graphene and substrate. At the room temperature it's thermal conductivity is $\sim 5000 \text{ W mK}^{-1}$ for a single layer sheet.

Due to absorption of $\sim 2.3\%$ of visible light, graphene is highly transparent. Graphene has excellent mechanical strength due to σ c-c bond. The breaking strength of the graphene is 42 Nm^{-1} and Young's Modulus is $\sim 0.999 \text{ TPa}$. [10]

Resistivity of graphene sheet is $10^{-6} \Omega \text{ cm}$, which is less than the resistivity of the silver, the lowest resistivity substance known at room temperature.

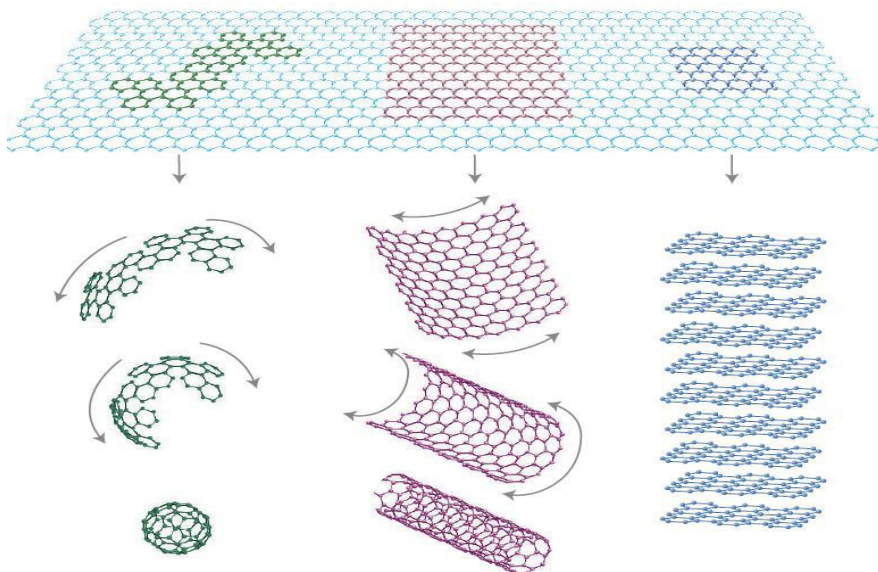


Figure 2:- C60 fullerene molecules, carbon nano tubes, and graphite can all be thought of as being formed from graphene sheets, *i.e.* one atom thin layer of carbon atoms arranged in a honeycomb lattice

A semiconductor has 6eV energy band gap and a metal has overlapping between conduction band and valence band whereas graphene has 0eV energy band gap so graphene is also called semimetal. The energy band gap in graphene is zero at room temperature, so it has high conductivity as silver.

Atomic Structure of Graphene

A monolayer of graphene is shown as a hexagonal two-dimensional array of carbon atoms exhibiting sp^2 hybridization, whereas diamond and amorphous carbon demonstrate sp^3 hybridization. A solitary carbon atom has four valence electrons and a total of six electrons, arranged as $1s^2, 2s^2$, as seen in Fig 1 (a). In sp^3 hybridization, the 2s orbital combines with three 2p orbitals to generate four sp^3 orbitals. In sp^2 bonding, three out of four valence electrons engage in the formation of in-plane covalent σ bonds. The fourth one does not participate in covalent bonding; instead, it facilitates the creation of an out-of-plane π band between adjacent carbon atoms.

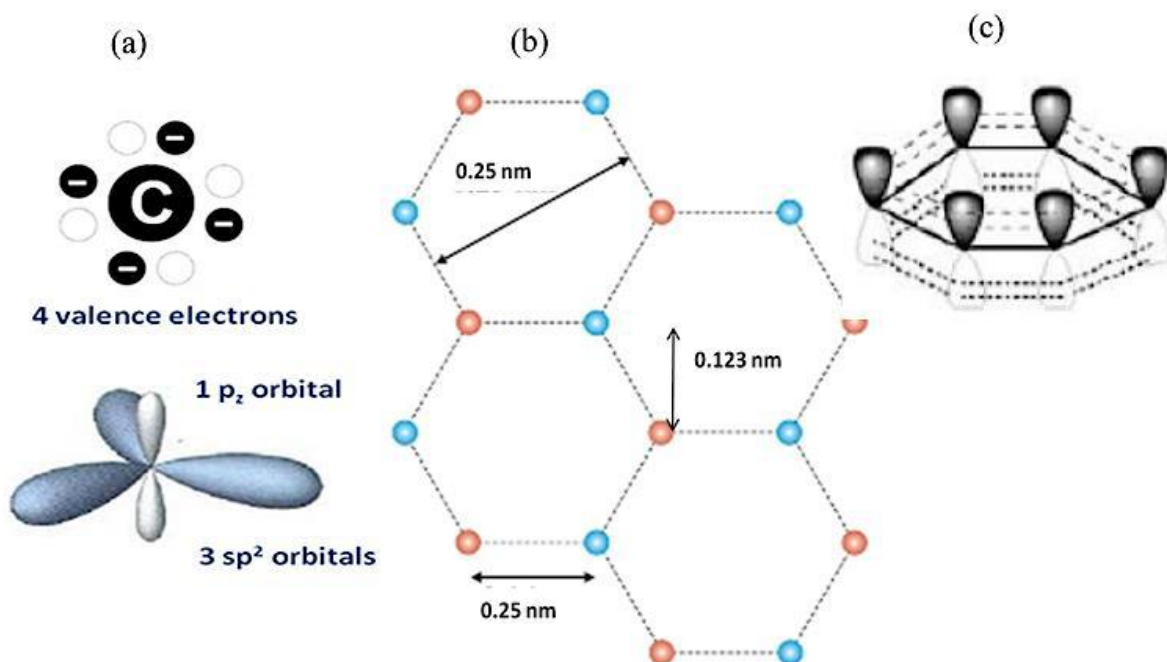


Fig 1: (a) Carbon atom and sp^2 hybridization. (b) Schematic of C- atoms in hexagonal lattice in graphene showing distance between neighboring carbons. (c) Schematic diagrams of formation of sp^2 hybridization in graphene, showing π and σ bonds

The σ bonds resemble the bonds that constitute diamond, exhibiting greater strength. They serve as the foundation of the distinctive hexagonal configuration. They have comparable exceptional mechanical characteristics to graphene, similar to those of diamond [1,2]. The π linked electrons facilitate conductivity and regulate graphene's interactions with both itself and its external environment. A single layer of graphene has a lattice constant characterized by a closest neighbor interatomic distance of [3]. The interaction between charge carriers in graphene (electrons) and its honeycomb lattice causes the electrons to behave as massless particles. Unlike non-relativistic particles that adhere to the Schrödinger equation, electrons in graphene exhibit relativistic behavior, according to the Dirac equation, and are classified as Dirac fermions (distinct from high-energy, electrically neutral particles such as neutrinos). This phenomenon is ascribed to the linear band structure next to the six corner points (Dirac points, where the conduction and valence bands converge) of the hexagonal Brillouin zone, as seen

in Fig. 2. The energy-momentum relationship in graphene is linear, resulting in electrons possessing zero effective mass. The remarkable electrical characteristics of graphene are a direct result of its zero-gap semimetal structure.

Properties Of Graphene

Graphene has several properties, including mechanical, electrical, electronic, optical, magnetic, and ferroelectric characteristics.

A. Mechanical Characteristics

- a) Graphene is among the strongest materials. It has a tiny layer, nevertheless this single layer is more robust than steel.
- b) In graphene, the σ link exists between the two carbon atoms, and the σ bond is stronger than the π bond; so, graphene is stronger than steel.
- b) Its thickness is much smaller than that of one million graphene layers, which is equivalent to the thickness of human hair.
- d) The tensile strength of graphene may be enhanced by using GO/PI, CRGO/PRA, and ODA-GO/PI.
- e) Graphene is lightweight due to its monolayer atomic structure.

B. Electrical Properties

Silver (Ag) has superior conductivity relative to other materials; nevertheless, graphene possesses even greater conductivity than silver. The electron conductivity of graphene is $10^6 \Omega \text{ cm}^{-1}$. Graphene has a zero energy band gap, allowing electrons to transition effortlessly from the valence band to the conduction band. In contrast, an insulator exhibits a 6 eV energy band gap, while a semiconductor has an approximate 1 eV energy band gap.

Biomedical

Graphene-based materials such as Graphene Oxide, few-layer Graphene flakes, and virgin Graphene. Graphene has adaptable, distinctive, and diversified characteristics that may be innovatively used in the biomedical business. Graphene uses include biological agents (antimicrobials), tissue engineering, sensors, and transport systems. Research is now underway to produce groundbreaking and new medical devices that will substantially improve healthcare, recognizing the promising and advantageous features of graphene.



Fig. 5: Biomedical Applications of Graphene

Graphene has the potential to revolutionize Next-Gen Electronics with flexible phones, accelerated semiconductors, and transistors, as seen in Fig. 6. Research is now focused on addressing the obstacles associated with the use of graphene in transistors and elucidating the advantages over ordinary silicon [16,17]. Wearable and flexible electronic devices use the distinctive mechanical features and conductivity of graphene. This remarkable material may transform a smartphone into a wrist-worn device or enable the creation of a rollable tablet. Contemporary touch displays for tablets and smartphones may be significantly enhanced with the use of graphene as a coating. Its ability to conduct electricity at ambient temperature and its monolayer thickness have catalyzed research into its potential use as a semiconductor. Graphene can significantly enhance the speed of computers by improving their circuits.

Conclusion

Graphene, with its remarkable mechanical, thermal, optical, and electrical capabilities, has garnered the attention of a growing number of researchers across several disciplines, including flexible electronics and composites. There has been fast advancement in the functionalization and production methods for graphene and its derivatives. These have shown significant promise in numerous domains, including catalysis, sensors, energy technology, composite materials, nanoelectronics, and biomedicine. Graphene-based membranes have facilitated advancements in separation membranes and filtration owing to their distinctive features. These represent very hopeful and significant advancements in the fields of conversion, energy storage, proton conductors, water desalination, and membrane separation. The quantity of patents and publications concerning graphene and graphene-derived materials is swiftly escalating. Indeed, it is unfeasible to adequately address the many capabilities of graphene inside a single study. This article presents many modern uses of graphene currently under investigation and inquiry. The achievement to far has been remarkable; yet, it is evident that a sustainable, environmentally friendly, large-scale, and cost-effective manufacturing plan for high-quality graphene is necessary. Additional issues include comprehending the toxicity of Graphene and Graphene Oxide (made by Graphene Oxidation) at both in vivo and in vitro levels. A systematic standardized investigation is essential to address safety concerns prior to advancing to large-scale development.

We have concentrated on the outstanding and fast progress in the applications of Graphene and have chosen evaluated the current research fields.

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