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Graphene and its Enhance Useful Applications

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ABSTRACT

Graphene, a two-dimensional, single-layered sheet of sp2 hybridized carbon atoms. Graphene has mechanical, thermal, electrochemical and electronic properties these exceptional properties have opened up new opportunities for the application of this nanomaterial in the future. This review article aims to present an overview of the new research in applications of graphene.

KEYWORDS Graphene, field emission, sensors, energy storage, super capacitor, bio applications, energy technology and nanotechnology.

INTRODUCTION

In 1859 Benjamin Collins Brodie was aware of the highly lamellar structure of thermally reduced graphite oxide.[1]The structure of graphite was solved in 1916[2] by the related method of powder diffraction,[3]It was studied in detail by V. Kohlschütter and P. Haenni in 1918, who also described the properties of graphite oxide paper.[4] Its structure was determined from single-crystal diffraction in 1924.[5]

The theory of graphene was first explored by P. R. Wallace in 1947 as a starting point for understanding the electronic properties of 3D graphite. The emergent massless Dirac equation was first pointed out by Gordon Walter Semenoff and David P. DeVincenzo and Eugene J. Mele.[6] Semenoff emphasized the occurrence in a magnetic field of an electronic Landau level precisely at the Dirac point. This level is responsible for the anomalous integer quantum Hall effect[7-9]. Starting in the 1970s single layers of graphite were grown epitaxially on top of other materials [10]. This "epitaxial graphene" consists of a single-atom-thick hexagonal lattice of sp2-bonded carbon atoms, as in free-standing graphene. However, there is significant charge transfer from the substrate to the epitaxial graphene, and, in some cases, hybridization between the d-orbitals of the substrate atoms and π orbitals of graphene, which significantly alters the electronic structure of epitaxial graphene.

Single layers of graphite were also observed by transmission electron microscopy within bulk materials, in particular inside soot obtained by chemical exfoliation. Efforts to make thin films of graphite by mechanical exfoliation started in 199[11], but nothing thinner than 50 to 100 layers was produced before 2004.

Graphene is the first stable two-dimensional crystal [12], discovered in 2004. Graphene is pure carbon in the form of a very thin, nearly transparent sheet, one atom thick. It is remarkably strong for its very low weight (100 times stronger than steel) [13] and it conducts heat and electricity with great efficiency. While scientists had theorized about graphene for decades, it was first produced in the lab in 2004[14]. Because it is virtually two-dimensional, it interacts oddly with light and with other materials.

An ideal graphene sheet consists entirely of sp2-hybridized carbon atoms due to this reason graphene have emerged as a "shining star" in materials science[15]. When sp2-carbon atoms are arranged into two-dimensional fused hexagons, they form a single-atom-thick allotrope of carbon called graphene[16].

Technically, graphene is a crystalline allotrope of carbon with 2-dimensional properties. In graphene, carbon atoms are densely packed in a regular sp2-bonded atomic-scale hexagonal pattern. Graphene can be described as a one-atom thick layer of graphite. It is the basic structural element of other 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. Graphene research has expanded quickly since the substance was first isolated in 2004. Research was informed by theoretical descriptions of graphene's composition, structure and properties, which had all been calculated decades earlier. High-quality graphene also proved to be surprisingly easy to isolate, making more research possible. Andre Geim and Konstantin Novoselov at the University of Manchester won the Nobel Prize in Physics in 2010 "for groundbreaking experiments regarding the two-dimensional material graphene"[17].

Properties of Graphene:

1. Structure

The atomic structure of isolated, single-layer graphene was studied by transmission electron microscopy (TEM) on sheets of graphene suspended between bars of a metallic grid[18]. Electron diffraction patterns showed the expected honeycomb lattice. Suspended graphene also showed "rippling" of the flat sheet, with amplitude of about one nanometer. These ripples may be intrinsic to the material as a result of the instability of two-dimensional crystals[19-20] or may originate from the ubiquitous dirt seen in all TEM images of graphene. Atomic resolution real-space images of isolated, single-layer graphene on SiO_2 substrates are available via scanning tunneling microscopy. Photoresist residue, which must be removed to obtain atomic-resolution images, may be the "adsorbates" observed in TEM images, and may explain the observed rippling. Rippling on SiO_2 is caused by conformation of graphene to the underlying SiO_2 and is not intrinsic[20].

Graphene can self-repair holes in its sheets, when exposed to molecules containing carbon, such as hydrocarbons. Bombarded with pure carbon atoms, the atoms perfectly align into hexagons, completely filling the holes[21].

2.Chemical

Graphene is the only form of carbon (and generally all solid materials) in which each single atom is in exposure for chemical reaction from two sides (due to the 2D structure). It is known that carbon atoms at the edge of graphene sheets have special chemical reactivity, and graphene has the highest ratio of edgy carbons (in comparison with similar materials such as carbon nanotubes). In addition, various types of defects within the sheet, which are very common, increase the chemical reactivity[22]. The onset temperature of reaction between the basal plane of single-layer graphene and oxygen gas is below 260 °C [23] and the graphene burns at very low temperature (e.g., 350 °C)[24]. In fact, graphene is chemically the most reactive form of carbon, owing to the lateral availability of carbon atoms. 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 oxygenand nitrogen containing functional groups is a difficult task unless the structures are well controlled[25].

3. Physical
The carbon–carbon bond length in graphene is about 0.142 nanometers. Graphene sheets stack to form graphite with an interplanar spacing of 0.335 nm[26].

4. Electronic
Graphene is a semi-metal or zero-gap semiconductor. Four electronic properties separate it from other condensed matter systems.Electrons propagating through graphene's honeycomb lattice effectively lose their mass, producing quasi-particles that are described by a 2D analogue of the Dirac equation rather than the Schrödinger equation for spin-1/2 particles[27].

4. Optical
Graphene's unique optical properties produce an unexpectedly high opacity for an atomic monolayer in vacuum, absorbing $\pi\alpha \approx 2.3\%$ of white light, where α is the fine-structure constant.[This is a consequence of the "unusual low-energy electronic structure of monolayer graphene that features electron and hole conical bands meeting each other at the Dirac point... [which] is qualitatively different from more common quadratic massive bands"[28] Based on the Slonczewski–Weiss–McClure (SWMcC) band model of graphite, the interatomic distance, hopping value and frequency cancel when optical conductance is calculated using Fresnel equations in the thin-film limit. Although confirmed experimentally, the measurement is not precise enough to improve on other techniques for determining the fine-structure constant [29].

5. Thermal
Graphene is a perfect thermal conductor. Its thermal conductivity was measured recently at room temperature and it is much higher than the value observed in all the other carbon structures as carbon nanotubes, graphite and diamond (> 5000 W/m/K). The ballistic thermal conductance of graphene is isotropic, i.e. same in all directions. Similarly to all the other physical properties of this material, its 2 dimensional structure make it particularly special. Graphite, the 3 D version of graphene, shows a thermal conductivity about 5 times smaller (1000 Wm-1K-1). The phenomenon is governed by the presence of elastic waves propagating in the graphene lattice, called phonons. The study of thermal conductivity in graphene may have important implications in graphene-based electronic devices. As devices continue to shrink and circuit density increases, high thermal conductivity, which is essential for dissipating heat efficiently to keep electronics cool, plays an increasingly larger role in device reliability[30].

APPLICATIONS

1. Optical Electronics
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, it must be able to transmit more than 90% of light and also offer electrical conductive properties exceeding 1 x 106 Ω1m1 and therefore low electrical resistance. Graphene is an almost completely transparent material and is able to optically transmit up to 97.7% of light. It is also highly conductive, as we have previously mentioned and so it would work very well in optoelectronic applications such as LCD touch screens for smart phones, tablet and desktop computers and televisions [31].

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. However, recent tests have shown that graphene is potentially able to match the properties of ITO. The fact that high quality graphene has a very high tensile strength, and is flexible with a bending radius of less than the required 5-10mm for rollable e-paper, makes it almost inevitable that it will soon become utilized in these aforementioned applications. In terms of potential real-world electronic applications we can eventually expect to see such devices as graphene based e-paper with the ability to display interactive and updatable information and flexible electronic devices including portable computers and televisions[32,33].

2. Biological Engineering
Bioengineering will certainly be a field in which graphene will become a vital part of in the future; though some obstacles need to be overcome before it can be used. Current estimations suggest that it will not be until 2030 when we will begin to see graphene widely used in biological applications as we still need to understand its biocompatibility. However, the properties that it displays suggest that it could revolutionize this area in a number of ways. With graphene offering a large surface area, high electrical conductivity, thinness and strength, it makes a good candidate for the development of fast and efficient bioelectric sensory devices, with the ability to monitor such things as glucose levels, haemoglobin levels, cholesterol and even DNA sequencing. Eventually we may even see engineered 'toxic' graphene that is able to be used as an antibiotic or even anticancer treatment. Also, due to its molecular make-up and potential biocompatibility, it could be utilised in the process of tissue regeneration & used in cancer therapy[34].

3. Ultrafiltration
Another standout property of graphene is that while it allows water to pass through it, it is almost completely impervious to liquids and gases. This means that graphene could be used as an ultrafiltration 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 2 substances (amongst many other variables). Graphene is much stronger and less brittle than aluminium oxide currently used in sub-100nm filtration applications. What does this mean? Well, it could mean that graphene is developed to be used in water filtration systems, desalination systems and efficient and economically more viable biofuel creation[17,34].

4. Composite Materials
Graphene is strong, stiff and very light. Currently, aerospace engineers are incorporating carbon fibre into the production of aircraft as it is also very strong and light. However, graphene is much stronger whilst being also much lighter. Ultimately it is expected that graphene is utilized to create a material that can replace steel in the structure of aircraft, improving fuel efficiency, range and reducing weight. Due to its electrical conductivity, it could even be used to coat aircraft surface material to prevent electrical damage resulting from lightning strikes. In this example, the same graphene coating could also be used to measure strain rate, notifying the pilot of any changes in the stress levels that the aircraft wings are under. These characteristics can also help in the development of high strength requirement applications such as body armour for military personnel and vehicles[31,32].

5. Photovoltaic Cells
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. Also, while silicon is able to generate electricity from certain wavelength bands of light, graphene is able to work on all wavelengths, meaning that graphene has the potential to be as efficient as, if not more efficient than silicon, ITO. Being flexible and thin means that graphene based photovoltaic cells could be used in clothing; to help recharge your mobile phone, or even used as retro-fitted photovoltaic window screens or curtains to help power your home[32,33].

6. 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. The solution is to develop energy storage components such as either a supercapacitor or a battery. Recently, to develope enhancing the capabilities of lithium ion batteries (by incorporating graphene as an anode) to offer much higher storage capacities with much better longevity and charge rate. Also, graphene is being studied and developed to be used in the manufacture of supercapacitors which are able to be charged very quickly, yet also be able to store a large amount of electricity. Graphene based micro-supercapacitors will likely be developed for use in low energy applications such as smart phones and portable computing devices and could potentially be commercially available within the next 5-10 years. Graphene-enhanced lithium ion batteries could be used in much higher energy usage applications such as electrically powered vehicles, or they can be used as lithium ion batteries are now, in smartphones, laptops and tablet PCs but at significantly lower levels of size and weight[31-35].

Conclusion:

Graphene is a cheap and multifunctional material with unique physical and chemical properties. Graphene-based nanomaterials these days have led to an explosive growth of the research works on their applications can be observed from the literature in the past few years, especially in the areas of biosensors, bioelectronics and energy storage etc. Owing to the progress in graphene, fabrication of water-soluble. Every property of graphene for the development and welfare of mankind and used in human life also used in biomedical applications still there is much to be done. For example, taking electrochemical sensing into consideration, there is an urgent need in this area to fabricate reliable, reproducible, and low-cost sensors with high detection sensitivity using well-defined graphene.

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