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Review Article

‘Graphene’ - The Nano Carbon Wonder!

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Abstract

The newer and exceptionally unique properties of a wonderful material called “graphene”, present in a simple mark of a pencil, has evoked a deluge of research interest internationally. But what is probably more unexpected is the news that it is not only just the thinnest of all possible materials, it is also extremely strong, stiff and conducts electrons faster at room temperature than any other substance. Researchers are delving fast to fabricate it into products such as super tough composites, ultra sensitive chemical detectors, sensors, smart displays, ultra -fast transistors, quantum- dot computers, These are used in bikes, tennis rackets and even living tissue engineering. solar cells and so on, the chemists are striving hard to synthesize it. It is no wonder that this innocuous material has become one of the hottest substances.

Keywords: Grapheme,Nanocarbons,chemical detectors, sensors, smart displays, quantum- dot computers.

Introduction

Inside every pencil, there is a novice smart star waiting to get out. To release it, just draw a line. The soft, silvery-grey form of pure carbon found in pencils consists of stacked-up sheets of interlinked carbon atoms separates out. These gossamer films of carbon just one atom thick is the material called ‘graphene’. It provides a rich possibilities of fundamental physics research and numerous practical applications The peculiar way that graphene conducts electricity opens up avenues into some of the weirder areas of quantum physics like ‘perfect quantum tunneling,’ one of the most exotic predictions of Quantum Electrodynamics. This phenomenon has been the exclusive preserve of astrophysics, confined to cosmology or high-energy physics, working with multimillion/billion dollar telescope or particle accelerators; but now it can be studied easily in laboratories with the help of this novel material. However, synthesis of its long sheets of desired shape and dimension is a difficult task. Graphene is presently 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 $1,000 (as of April 2008).[1]

While as of 2014, graphene is not used in commercial applications, many have been proposed and/or are under development, in areas including electronics, biological engineering, filtration, lightweight/strong composite materials, photovoltaics and energy storage.[12]Graphene is produced as a powder and as a dispersion in a polymer matrix, or adhesive, elastomer, oil and aqueous and non-aqueous solutions. The dispersion is stated by the manufacturer to be suitable for advanced composites,[13] paints and coatings, lubricants, oils and functional fluids, capacitors and batteries, thermal management applications, display materials and packaging, inks and 3D-printers’ materials, and barriers and films.[14]

Structure

Graphene is a one-atom-thick planar sheet of sp^2-bonded carbon atoms that are densely packed in a honeycomb crystal lattice. It can be viewed as an atomic-scale chicken wire made of carbon atoms and their bonds. The name comes from graphite + ene; graphite itself consists of many graphene sheets stacked together. The sheets are held together by weak, attractive intermolecular forces and vanderwaals forces. The feeble coupling between neighboring graphene sheets is what enables graphite to be broken so easily into minuscule wafers that make up the mark left on paper when someone writes with a pencil. The carbon-carbon bond length in graphene is approximately 1.42 Å. Planar graphene itself has been presumed not to exist in the free state, being unstable with respect to the formation of curved structures such as soot, fullerenes, bucky balls and nanotubes. Bucky balls and the many other nanotubular fullerenes can be thought of as graphene sheets wrapped up into atomic scale spheres, elongated spheroids and the like. Carbon nanotubes are essentially graphene sheets rolled into minute cylinders. [1]

History of Making Efforts

For years, attempts to make graphene ended in faliure. Single layers of graphite were previously (starting from the 1970s) grown epitaxially on top of other materials. 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 alter the electronic structure of the graphene.

In another method called chemical exfoliation was tried in which various molecules were inserted between the atomic planes of graphite to wedge the planes apart. The final product usually emerges as slurry of graphitic particles-not much different from wet soot. There have also been a number of efforts to make very thin films of graphite by mechanical exfoliation (starting from 1990 and continuing until after 2004) but nothing thinner than 50 to 100 layers was produced during these years.

Graphene was first isolated by the Manchester group of Andre Geim who in 2004 finally managed to extract single-atom-thick crystallites from bulk graphite by micromechanical cleavage. They simply stuck a flake of graphite debris onto plastic adhesive tape folded the sticky side of the tape over the flake in two .As the experimenters repeated the process, the resulting fragments grew thinner. Once the investigators had many thin fragments they meticulously examined the pieces and were astonished to find that some were only one atom thick. Even more unexpectedly, the newly identified bits of graphene turned out to have high crystal quality and to be chemically stable even at room temperature. They provided the first and unexpected proof for the existence of true (free-standing) 2D crystals. Previously, it was assumed that graphene cannot exist in the flat state and should scroll into nanotubes "to decrease the surface energy".[2]

Exceptional Features of Graphene

Two features of graphene make it an exceptional material. First, it exhibits remarkably high quality-resulting from a combination of the purity of its carbon content and the orderliness of the lattice into which its carbon atoms are arranged. Investigators have so far failed to find a single atomic defect in graphene-say, a vacancy at some atomic position in the lattice or an atom out of place. That perfect crystalline order seems to stem from the strong yet highly flexible interatomic bonds, which create a substance harder than diamond yet allow the planes to bend when mechanical force is applied. The flexibility enables the structure to accommodate a good deal of deformation before its atoms must reshuffle to adjust to the strain. The quality of its crystal lattice is also responsible for the remarkably high electrical conductivity of graphene. Its electrons can travel without being scattered off course by lattice imperfections and foreign atoms.

The second exceptional feature of graphene is its conduction of electrons, perhaps “electric charge carriers” which move much faster and as if they had far less mass than do the electrons. That kind of interaction inside a solid, so far as anyone knows, is unique to graphene. The electrons in graphene behave like relativistic particles that have no rest mass and travel at about 10^6 metres per second. Although this is a factor of 300 slower than the speed of light in vacuum, it is still much faster than the speed of electrons in an ordinary conductor.

Interpretations of the Unique Behaviors

Electrons move virtually unimpeded through the highly regular atomic structure of graphene, reaching such great speeds that their behaviors cannot be described by “ordinary” quantum mechanics. The theory that applies instead is known as relativistic quantum mechanics, or quantum electrodynamics (QED), a theory whose distinctive predictions were thought , until now, to be observable only in black holes or high energy particle accelerators.

To appreciate the weird behavior of electrons in graphene, it may be useful to compare it with ordinary conductor. The ‘free electrons’ in a ordinary metal that make up an electric current, carries a unit negative charge. When electrons move through metal lattice they move against the positive field of the metal cation. Therefore, the moving electrons in electric conductor, which are called quasiparticles act as if they had a different mass than ordinary electrons. Astonishingly, however the charge carrying particles in graphene do not act like electrons at all but like another elementary particle- nearly mass less neutrino- carrying a negative charge. Theorists sometimes describe them as Dirac quasiparticles. In Spite of their scaled down speed than light, their behavior closely parallels the relativistic behavior of the neutrino.

The paradoxes of quantum electrodynamics often arise from the fact that relativistic particles are always accompanied by their antiparticles. The electron, for instance, pairs with an antiparticle called the positron, its mass is exactly the same as that of the electron, but its electric charge is positive. A particle-antiparticle pair can appear under relativistic conditions because it costs little energy for an extremely fast-moving high – energy object to create a pair of “virtual particles.” Oddly, the pair emerges directly from nothing from the vacuum. Why that happens is a consequence of one of the many versions of Heisenberg’s uncertainty principle in quantum mechanics: roughly speaking, the more precisely an event is specified in time, the less precise is the amount of energy associated with that event. Consequently, on extremely short timescales, energy can take on almost any value, because energy is equivalent to mass, according to Einstein’s famous formula $E=mc^2$, the energy equivalent to the mass of a particle and its antiparticle can appear out of nothing. For example, a virtual electron and a virtual positron can suddenly pop into existence by “borrowing” energy from the vacuum, provided the lifetimes of the virtual particles are so short that the energy deficit is paid back before it can be detected.[3]

Potential applications

Single molecule gas detection

Graphene makes an excellent sensor due to its 2D structure. The fact that its entire volume is exposed to its surrounding makes it very efficient to detect adsorbed molecules. Molecule detection is indirect: as a gas molecule adsorbs to the surface of graphene[11], the location of adsorption experiences a local change in electrical resistance. While this effect occurs in other materials, graphene is superior due to its high electrical conductivity (even when few carriers are present) and low noise which makes this change in resistance detectable.[4]

Graphene nanoribbons

Graphene nanoribbons (GNRs) are essentially single layers of graphene that are cut in a particular pattern to give it certain electrical properties. Depending on how the un-bonded edges are configured, they can either be in a Z (zigzag) or Armchair configuration. Their 2D structure, high electrical and thermal conductivity, and low noise also make GNRs a possible alternative to copper for integrated circuit interconnects. Some research is also being done to create quantum dots by changing the width of GNRs at select points along the ribbon, creating quantum confinement[5].

Ballistic transistors

Charge carriers in graphene move at high speed and lose relatively little energy to scattering or colliding with atoms in its crystal lattice. That property should make it possible to build so called ballistic transistors ultra high frequency devices that would respond much more quickly than existing transistors do the remarkable stability and electrical conductivity of graphene even at nanometer scales could enable the manufacture of individual transistors substantially less that 10 nanometers across and perhaps even as small as a single benzene ring. In the long run, one can envision entire integrated circuits carved out of a single graphene sheet.

Transparent screens

Devices such as plasma TVs and phones are commonly coated with a material called indium tin oxide. Manufacturers are actively seeking alternatives that could cut costs and provide better conductivity, flexibility and transparency. Graphene is an emerging option. It is non-reflective and appears very transparent. Its conductivity also qualifies it as a coating to create touchscreen devices. Because graphene is both strong and thin, it can bend without breaking, making it a good match for the bendable electronics that will soon hit the market[10].

Integrated circuits

Graphene has the ideal properties to be an excellent component of integrated circuits. Graphene has a high carrier mobility, as well as low noise. Researchers are looking into methods of transferring single graphene sheets from their source of origin onto a target substrate of interest. In 2008, the smallest transistor so far, one atom thick, 10 atoms wide was made of graphene.

Transparent conducting electrodes

Graphene's high electrical conductivity and high optical transparency make it a candidate for transparent conducting electrodes, required for such applications as touchscreens, liquid crystal displays, organic photovoltaic cells, and OLEDs. In particular, graphene's mechanical strength and flexibility are advantageous compared to indium tin oxide, which is brittle, and graphene films may be deposited from solution over large area.[6]

The mysterious fundamental constant - and glimpse the foundations of the universe

The researchers have found that the world's thinnest material absorbs a well-defined fraction of visible light, which allows the direct determination of the fine structure constant. The universe and life on this planet are intimately controlled by several exact numbers; so-called fundamental or universal constants such as the speed of light and the electric charge of an electron. Among them, the fine structure constant is arguably most mysterious. It defines the interaction between very fast moving electrical charges and light - or electromagnetic waves - and its exact value is close to 1/137.The researchers have found the carbon monolayer is not crystal-clear but notably opaque, absorbing a rather large 2.3 percent of visible light. The experiments supported by theory show this number divided by π give you the exact value of the fine structures constant. The accuracy of the optical determination of the constant so far is relatively low, by metrological standards. With large membranes in hand, it will require barely anything more sophisticated than a camera to measure visual transparency of graphene.

Conclusion

The research shows that graphene is not just another 'smart material' it is full of surprises and shows far greater promise than one could reasonably hope for in a new experimental system. Indeed, studies of unique behaviors in graphene give us access to the rich and subtle Graphene could also have applications for camera sensors, DNA sequencing,gas sensing, material strengthening, water desalination and beyond, physics and chemistry in a bench-top condensed matter experiment. Larger graphene molecules or sheets (so that they can be considered as true isolated 2D crystals) cannot be grown even in principle and is still a challenge to physicists and chemists.

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