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Graphene as Single Layer of Carbon Atoms: Perusal on Structure, Properties and Applications.

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ABSTRACT

Graphene, has been studied intensively in the last few years due to its unique characteristics. Graphene is a crystalline allotrope of carbon. In graphene, carbon atoms are densely packed in a regular SP^2-bonded atomic-scale chicken wire (hexagonal) pattern. Graphene a single layer of carbon atoms, combines several exceptional properties, which makes it uniquely suited as a coating material: transparency, excellent mechanical stability, low chemical reactivity, Optical, impermeability to most gases, flexibility, and very high thermal and electrical conductivity. Graphene is a material that can be utilized in numerous disciplines including, but not limited to: bioengineering, composite materials, energy technology and nanotechnology, biological engineering, optical electronics, ultrafiltration, photovoltaic cells.Graphene is undoubtedly emerging as one of the most promising materials because of its unique combination of superb properties, which opens a way for its exploitation in a wide spectrum of applications ranging from electronics to optics, sensors, and biodevices. Also Graphene-based nanomaterials have many promising applications in energy-related areas. This review aims to provide an overview of graghene structure, properties and some applications.

Keywords: Graphene, Carbon, Anti corrosion, Optical and Electrical properties, Sensors.

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INTRODUCTION

Graphene" is a combination of graphite and the suffix-ene, named by Hanns-Peter Boehm [1], and it could be mono layer and double layer. If 3-10 graphene layers put together they are few layer graphene [2], and 10-30 layer are called thick graphene or Thin nano-crystalline graphite (Figure. 1).

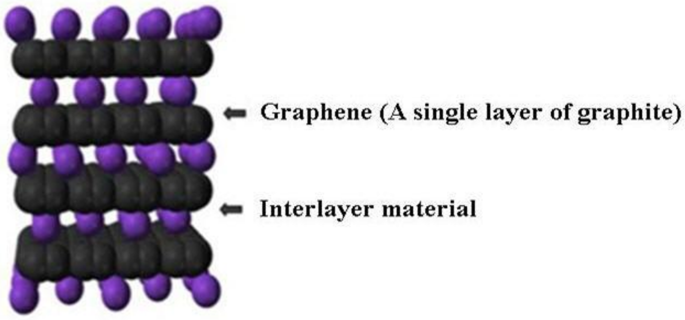

Figure 1: Graphite intercalation compounds [2].

Primarily graphene is the building block of graphite and combination far back to 1840,which it has been studied by many researchers. who described single-layer carbon foils in 1962 [2]. 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. Graphene introduced by Boehm in 1962. He was the first one who wanted to use this word for description of mono-layered carbon foil, but most of the researchers thought that carbon plate with this low thickness equal to one carbon's atom diameter, can not be stable [2,3].

The earliest TEM images of few-layer graphite were published by G. Ruess and F. Vogt in 1948 [3]. Later, single graphene layers were also observed directly by electron microscopy Before 2004 intercalated graphite compounds were studied under a transmission electron microscope (TEM) [3]. Researchers occasionally observed thin graphitic flakes (few-layer graphene) and possibly even individual layers.The term was also used in early descriptions of carbon nanotubes [4], as well as for epitaxial graphene [5] and polycyclic aromatic hydrocarbons.

Graphene can be considered an "infinite alternant" (only six-member carbon ring) polycyclic aromatic hydrocarbon (PAH). Graphene can be described as a one-atom thick layer of graphite (Figure 2) [5].

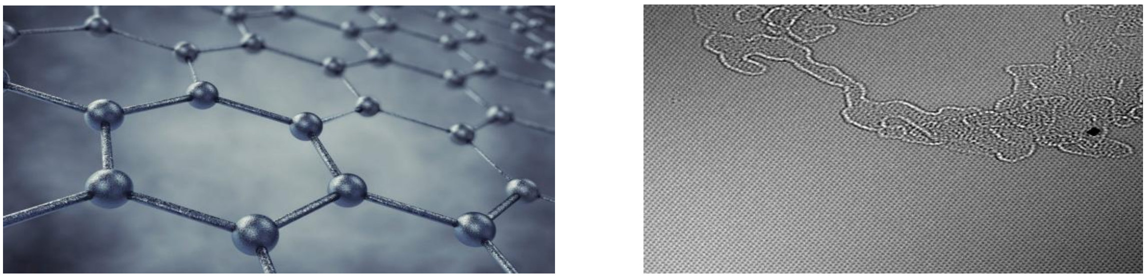

Figure 2: Graphene is an atomic-scale honeycomb lattice made of carbon atoms [5].

At the time of its isolation in 2004 [6], researchers studying carbon nanotubes were already familiar with graphene's composition, structure and properties, which had been calculated decades earlier. Andre Geim and Konstantin Novoselov at the University of Manchester [6] won the Nobel Prize in Physics in 2010 "for groundbreaking experiments regarding the two-dimensional material graphene.The reason nanotechnology researchers are so excited is that graphene and other two-dimensional crystals it's called 2D because it extends in only two dimensions : length and width [8-12]. The electrons moving around carbon atoms interact with the periodic potential of graphene's honeycomb lattice, which gives rise to new quasiparticles that have lost their mass, or 'rest mass' (so-called massless Dirac fermions) [9].

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Graphene improves both energy capacity and charge rate in rechargeable batteries; activated graphene makes superior supercapacitors for energy storage; graphene electrodes may lead to a promising approach for making solar cells that are inexpensive, lightweight and flexible; and multifunctional graphene mats are promising substrates for catalytic systems [10]. These examples highlight the four major energy-related areas where graphene will have an impact: solar cells, supercapacitors, lithium-ion batteries, and catalysis for fuel cells. Graphene has a unique combination of properties that is ideal for next-generation electronics, including mechanical flexibility [10], high electrical conductivity, and chemical stability. Combine this with inkjet printing and you get an inexpensive and scalable path for exploiting these properties in real-world technologies (Inkjet printing of graphene for flexible electronics) [11,12].

Currently, nanomaterials have an enormous range of applications owing to their structural features. However, material scientists are examining materials with improved physicochemical properties that are dimensionally more suitable in the field of nanoscience and technology. In this regard, the discovery of graphene and graphene-based polymer nanocomposites is an important addition in the area of nanoscience, playing a key role in modern science and technology [13].Graphene is considered a twodimensional carbon nanofiller with a one-atom-thick planar sheet of SP^2 bonded carbon atoms that are densely packed in a honeycomb crystal lattice. It is regarded as the“thinnest material in the universe”with tremendous application potential [13]. Graphene is predicted to have remarkable properties, such as high thermal conductivity, superior mechanical properties and excellent electronic transport properties [14]. These intrinsic properties of graphene have generated enormous interest for its possible implementation in a myriad of devices.These include future generations of high speed and radio frequency logic devices, thermally and electrically conducting reinforced nanocomposites, ultra-thin carbon films, electronic circuits, sensors, and transparent and flexible electrodes for displays and solar cells [14] .

Graphene, as a nanofiller, may be preferred over other conventional nanofillers (Na-MMT, LDH, CNT, CNF, EG, etc.) owing to high surface area, aspect ratio, tensile strength (TS), thermal conductivity and electrical conductivity, EMI shielding ability, flexibility, transparency, and low CTE [14,15].

Techniques for Graphene Production

Graphene eluded scientists for years but was finally made in the laboratory in 2004 with the help of a common office supply clear adhesive tape.Today, graphene fabrication is much more sophisticated. The most commonly used method, however, which involves oxidizing graphite and reducing the oxide at a later stage in the process, results in a degradation of graphene's attractive conductive properties. These methods are divided into two general categories, based on the material which contain carbon molecules or graphite [16-20]:

1. Bottom-up approach :
   - Epitaxial Growth
   - Arc discharge
   - Opening carbon nanotubes (thermal fission)
   - Chemical vapor deposition (CVD)
   - Plasma
   - Thermal

2. top-down approach:
   - Exfoliation of Graphite Direct (new micromechanical layered graphite or adhesive tape)
   - Chemical synthesis (chemical or thermal reduction of graphite oxide)
   - With ultrasound (Sonication)
   - Creating colloidal suspensions
   - Electrochemical synthesis method

The Principal Base of Carbon Structure in Graphene

In the case of carbon, aside from soot and charcoal, the most commonly known forms are diamond, graphite, and the fullerenes. In diamonds, the atoms are arranged in a pyramid shaped lattice [21]. The atoms of graphite are sheets of hexagonal lattice, while fullerenes are similar lattices arranged into shapes such as balls (Buckminsterfullerine) or cylinders (carbon nanotubes). The different forms have different properties: diamond is electrically insulating and hard; graphite is an electrical conductor and is soft hence its use as pencil "lead" (Figure. 3) [22].

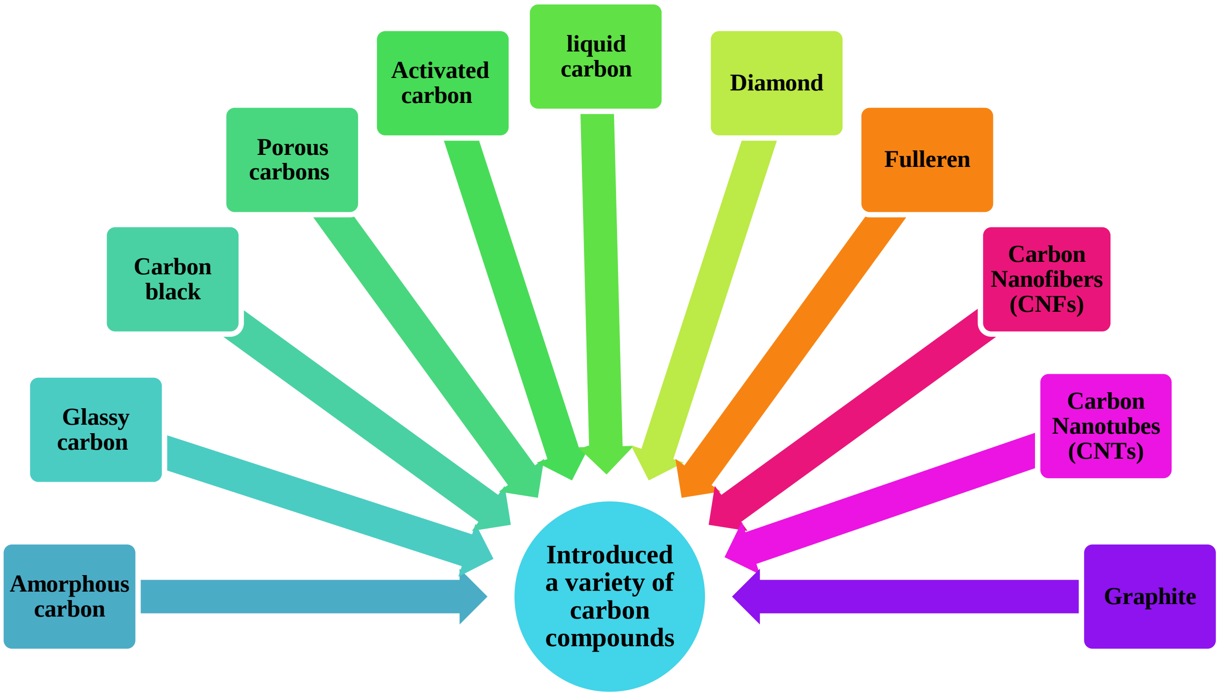

Figure 3: Introduced a variety of carbon compounds [21-23].

Graphene is known as a magic substance of 21st century. Graphene is made up of a flat monolayer of SP^2-hybridized carbon atoms [21]. Graphene is one of several forms of carbon known as its "allotropes". Allotropes are structurally different forms of the same element, in which the same atoms bond together in different ways. For example, molecules of oxygen can bind together as two atoms O_2, which makes up a fifth of Earth's atmosphere or as three atoms, ozone, which protects us from ultraviolet radiation [24]. As carbon is the only element present in graphene and graphite, Common graphite is the material in pencil lead and it's composed of sheets of graphene stacked together. There are other types of carbon materials with SP^2hybrid. For example, when plate dimensions of graphene sheets are small and the [25] distance between them is small, this carbon is categorized amourph.(like powders, glassy carbon) (Figure 4).

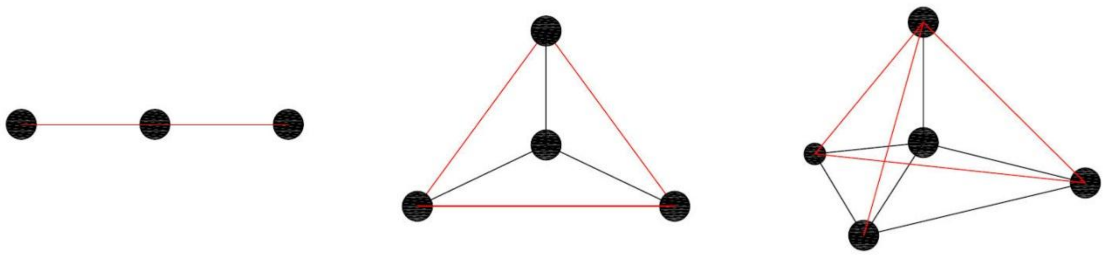

Figure 4: Hybrid molecular orbital of carbon atoms [23].

Graphene sheets are composed of carbon atoms linked in hexagonal shapes with each carbon atom covalently bonded to three other carbon atoms, Each sheet of graphene is only one atom thick [26]. Because of the strength of covalent bonds between carbon atoms, graphene has a very high tensile strength. (Basically, tensile relates to how much you can stretch something before it breaks.).

The sheets of graphene in graphite have a space between each sheet and the sheets are held together by the electrostatic force called van der Waals bonding (Figure. 5) [27]. Finally, in graphene, carbon atoms are bonded to only three other atoms, although they have the capability to bond to a fourth atom. This capability, combined with great tensile strength and the high surface area to volume ratio, make it very useful in composite materials.

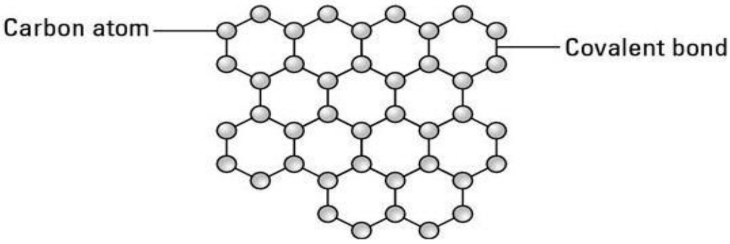

Figure 5: A graphene sheet [27].

Graphene has the same structure of carbon atoms linked in hexagonal shapes to form carbon nanotubes, but graphene is flat rather than cylindrical (Figure. 6) [28]. Graphene sheets in solid form usually show evidence in diffraction for graphite's (002) layering. This is true of some single-walled nanostructures [28]. However, unlayered graphene with only (hk0) rings has been found in the core of presolar graphite onions [29].

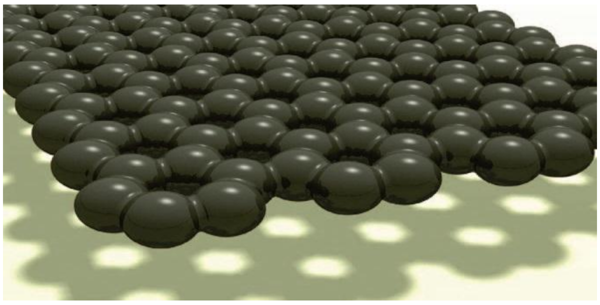

Figure 6: A single plate of graphene that made up of a flat monolayer of SP^2-hybridized carbon atoms. [28].

Due to the high density of graphene plates, it is resistant to impedes or penetration of small molecules such as Helum [30]. graphene's plates are 200 times stronger than steel and it must be a weight equal to the weight of an elephant on it, also due to the low thickness of the graphene (0.142 nm), it is known as the most strongest and thinnest material in the world [30]. Graphene is the basic structural unit of some carbon allotropes, including graphite, carbon nanotubes and fullerenes (Figure. 7) [30].

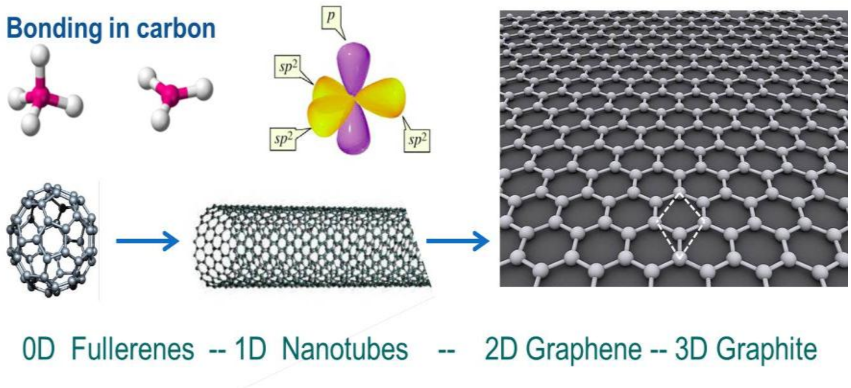

Figure 7: Graphene is a honeycomb lattice of carbon atoms. Graphite can be viewed as a stack of graphene layers. Carbon nanotubes are rolled-up cylinders of graphene. Fullerenes (C60) are molecules consisting of wrapped graphene through the introduction of pentagons on the hexagonal lattice [30].

Today graphene is proposed as an important substance in nanotechnology, and due to its different functional groups which can easily combined with various polymers, the high productivity,low cost raw material, is considered as a replacement for organic and other inorganic fillers [31].

Coordinate of Graphene plate

To study graphene structure similar to the new coordinate system, Cartesian coordinate system is defined [31]. The difference is the angle between the unit vectors i and j is 60 and for moving on this system vector C= mi + nj can be defined. This vector, is called vector chira (asymmetric) (Figure 8).

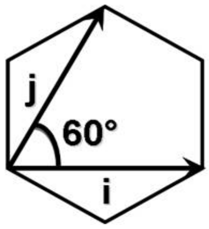

Figure 8: Unit vector i, j in Coordinate of Graphene plate [31].

It is also possible to assume the angle between the chiral vector and a corresponding unit vector i as the chiral angle which is the characteristics of the chiral vector. This angle is shown in the picture that is one of the characteristics of carbon nanotubes (Figure. 9) [32].

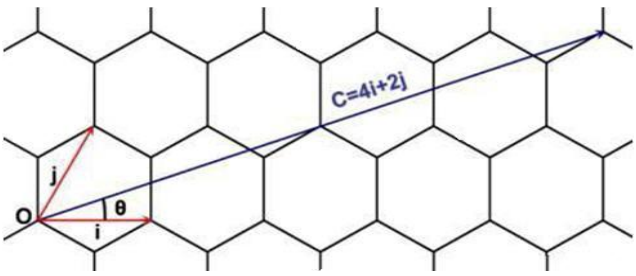

Figure 9. The chiral angle between unit vector c=4i+2j and the axis of vector i [32].

Graphene Properties

Graphene is suitable substitution for Silicon and its properties change the world od science and technology. 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) [33]. In addition, various types of defects within the sheet, which are very common, increase the chemical reactivity [34]. 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 oxygen [35] and nitrogen [36] containing functional groups is a difficult task unless the structures are well controlled.

Graphene is the strongest, thinnest material known to exist. And get ready for this: It is not only the hardest material in the world, but also one of the most pliable. Only a single atom thick, it has been called the wonder material [37].Thickness graphene sheets is about 0.142 nanometers [38]. Among its any extraordinary properties is its conductivity, which at about 100 times that of copper triggered much excitement about what the material might do for electronics. The American Chemical Society said in 2012 that graphene was discovered to be 200 times stronger than steel and so thin that a single ounce of it could cover 28 football fields. Graphene is one of the few materials in the world that is transparent, conductive and flexible all at the same time [39]. Common properties of grapheme shows in fiqure 10.

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Figure 10: Common properties of grapheme

Determin Methods for Graphene Characteristics

Different techniques can be used to characterize graphene and its derivatives are used as follows (Figure 11) [40].

- Transmission electronic microscopy - TFM
- Electron diffraction - ED
- High-resolution transmission electron microscopy - HRTEM
- Scanning tunneling microscopy - STM
- Atomic force microscopy - AFM
- Scanning electronic microscopy - SEM
- X-ray diffraction - XRD
- X-ray photoelectron spectroscopy - XPS
- Fourier transform infrared spectroscopy - FT-IR

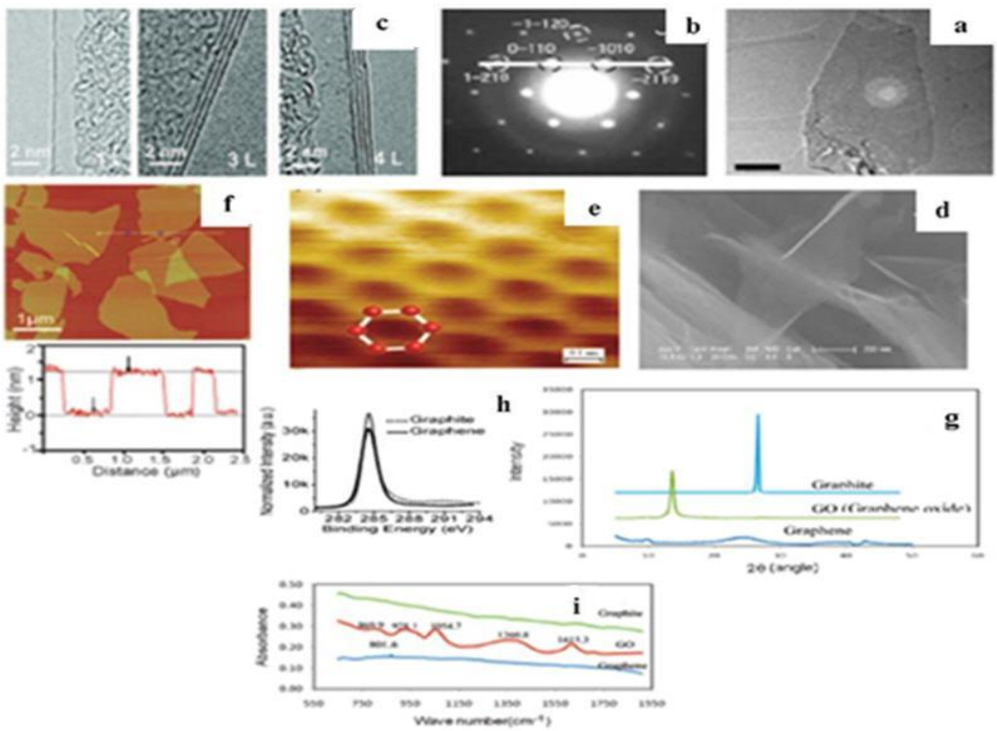

Figure 11: a) TEM, b) ED, c) HRTEM, d) STM, e) AFM, f) SEM, g) XRD, h) XPS, i) FTIR [40].

Graphene Applications

Researchers have developed a new fabrication process that allows for the precise creation of a graphene hybrid with potential uses in the electronic industry. However, graphene has no band gap. So unlike silicon, its electrons are always on the move not so useful for making transistors, which need to be able to switch on and off.

Tata has already established the ability of graphene, the super-strong, flexible form of carbon made from a single layer of atoms, to protect steel from corrosion but its researchers still don't yet fully understand how it works. When steel is coated with a metal such as zinc (a process known as galvanising), the electric potential between the two metals changes alters the corrosion reaction and the zinc is effectively sacrificed, corroding faster than the steel. Carbon's properties mean it typically causes the steel to be sacrificed to corrosion, but in its graphene form it doesn't. Corrosion is a progressive, electro-chemical reaction and, for whatever reason, by using graphene we totally stabilise the reaction, said Collingham[41-43].

Samsung has announced a new breakthrough in the manufacture of graphene that could bring lighter, faster and more flexible devices in the near future. In graphene, carbon atoms are densely packed in a hexagonal lattice, quite resembling a honeycomb. It remains one of the strongest, most durable materials on the planet. In the past, researchers have found that multi-crystal synthesis – the process of synthesizing small graphene particles to produce large-area graphene – deteriorated the electric and mechanical properties of the material, limiting its application range and making it difficult to commercialize, Samsung's Tomorrow blog said or If you want to read the company's complete findings, you can check out today's issue of science journals Science Magazine and Science Express [44].

Graphene could change the electronics industry, ushering in flexible devices, supercharged quantum computers, electronic clothing and computers that can interface with the cells in your body. The company has partnered with the Engineering and Physical Sciences Research Council (EPSRC) to study whether graphene-based steel coatings could become an alternative to chrome and other potentially toxic chemicals that are increasingly restricted under EU law.

Graphene is one of the strongest materials known. It conducts heat better than diamond, and may conduct electricity better than silver. As it's two-dimensional, it could be used to detect single molecules of a gas – if a gas molecule were to stick to a sheet of graphene there would be a local change in the electrical resistance. This could also be useful for detecting microbes [43-45].

A key electrical property of graphene is its electron mobility (the speed at which electrons move within it when a voltage is applied). Graphene's electron mobility is faster than any known material and researchers are developing methods to build transistors on graphene that would be much faster than the transistors currently built on silicon wafers. Another interesting application being developed for graphene takes advantage of the fact that the sheet is only as thick as a carbon atom. Researchers have found that they can use nanopores to quickly analyze the structure of DNA [45].

CONCLUSIONS

Graphene is two-dimensional carbon nanofiller with a one-atom-thick planar sheet of SP^2 bonded carbon atoms densely packed in a honeycomb crystal lattice. Graphene has quickly become an exceedingly hot topic in a number of fields including electronics, energy and nanotechnology Specifically, owing to its structure, graphene is characterized by exceptional biological (e.g. biocompatibility), electrical (e.g. high carrier mobility and capacity), electrochemical (e.g. high electron transfer rate), mechanical (e.g. robust and flexible), optical (e.g. high opacity, able to quench fluorescence), and structural properties (e.g. high surface-to-volume ratio).

Graphene has very high mechanical, thermal and electrical properties suitable for thermally and electrically conducting reinforced nanocomposites, electronic circuits, sensors, and transparent and flexible electrodes for displays and solar cells etc.

Graphene is extraordinarily strong (the strongest material ever known or tested), supernaturally light, and electrically super-conductive. Its flexibility and structure also make it the leading candidate as the primary component of next-generation, ultra-high speed circuitry in everything from computers, to smartphones, to televisions. It is therefore of interest to a range of industries.

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