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RESEARCH ARTICLE

GRAPHENE AND ITS APPLICATIONS: A SURVEY

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ABSTRACT

It is not surprising because, at the time when the Silicon based technology is approaching its fundamental limits, any new candidate material to take over from Silicon is welcome, and graphene seems to offer an exceptional choice (Geim and Novoselov, 2007). Graphene's potential for electronics is generally justified by citing high mobility and conductance of its charge carriers. Graphene has attracted attention as a high-mobility channel replacement for Si in MOSFETs for very high frequency applications. The novel linear band structure and truly 2-D transport properties of graphene will likely lead to a plethora of beyond CMOS device possibilities (Sanjay and Banerjee, 2010). Currently, there is great interest in graphene as a base material for Nanoelectromechanical systems (NEMS) (Geim). Graphene is also a fascinating material for THz applications with its strengths in atomic thickness, easy tunability and high kinetic inductance. The high stability, large surface area and environmentally friendly nature of graphene makes it a potential candidate for environmental applications such as water purification, toxic gas sensors and acidic gas capture (Edward *et al.*, 2014).

INTRODUCTION

In 2004, Andre Geim, Kostya Novoselov and co- workers at the University of Manchester in the UK by delicately pelling a sample of graphite with sticky tape, they produced something that was long considered impossible: a sheet of crystalline carbon which is just one atom thick, known as graphene. Graphene's 2D nature and honeycomb atomic structure causes electrons moving in the material to act as if they have no mass. Electrons in graphene move at an effective speed 300 times less than the speed of light in a vacuum. Graphene Sheets interplanar spacing is of 0.335 nm and C-C Bond length is 0.142 nm.

Properties of Graphene (Novoselov, 2011)

- It is extremely electrically and thermally conductive.
- It is very elastic and impermeable to any molecules.
- Graphene is hydrophobic, it can be dispersed in other mostly, organic solvents.
- Carbon atoms in graphene are sp^2 hybridized, meaning that only three electrons form the strong bonds and the fourth has a communal use in forming the
- so-called ∏ bonds. So, graphene is a zero- overlap semimetal and conducts electricity very well (Novoselov, 2011).
- Room-temperature electron mobility of $2.5 \times 10^5 cm^2V^{-1}s^{-1}$
-
- A Young's modulus of 1 TPa and intrinsic
- strength of 130 Gpa.

Graphene Physics

The theoretical investigations on the band structure of graphene started in 1947 with the work of Wallace. At the time perfectly 2D crystals were considered unstable at any physical temperature, and graphene was just considered as a building block for graphite.

Energy Bandstructure of Graphene

Graphene has a honeycomb lattice structure of carbon atoms in the sp^2 hybridization state. Every unit cell of graphene lattice contains two carbon atoms and each atom contributes a free electron. The band-structure of graphene is uncommon with the valence and the conduction bands meeting at a point at the six corners of the Brillouin zone (shown in Figure 1(a)). Near these crossing points (named as Dirac points), the electron energy is linearly dependent on the wave vector.

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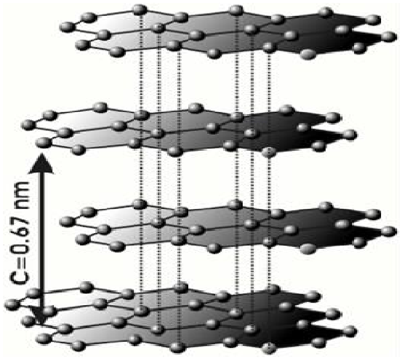

Fig. 1. Planar diagram of carbon atoms (Graphite)

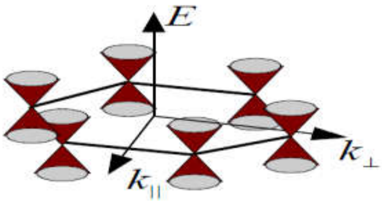

Fig. 1 (a). The valence and the conduction band of Graphene meet at a point at the six corners of the Brillouin zone (Yudong Wu, ?)

As a result of the linear energy-momentum dispersion relation, at the Dirac points an electron actually has an effective mass of zero and acts more like a photon rather than a conventional massive particle whose energy-momentum dispersion is parabolic. The calculation of the band structure of graphene is based on Schrödinger equation. At low energy levels, however, charge carrier transport can be described in a more natural way by using the Dirac equation (Yudong Wu, ?).

The most striking consequence of the lack of a bandgap is that a device made of graphene cannot stop the current flow. One of the most important achievements of Si CMOS technology, along with the ideal signal reconstruction, is the possibility to completely switch off the logic element to reduce the power consumption of the IC. A bandgap atleast comprised between 400 and 500 meV should be necessary for digital logic operation.

IMPORTANT PRODUCTION METHODS FOR GRAPHENE

Chemical Vapour Deposition (CVD)

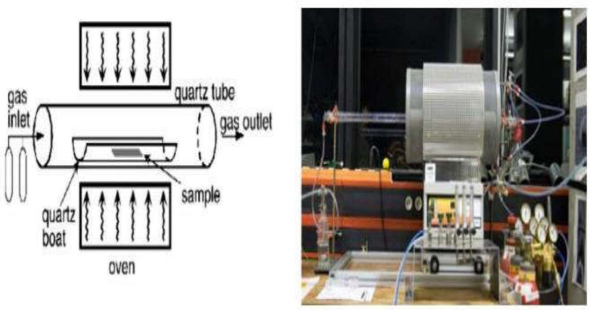

Fig. 2. Schematic diagram of CVD reactor (left) and photo of an oven for carbon nano-materials production (right)

Chemical vapour deposition (CVD) works on the principle of thermal decomposition of hydrocarbons on transition metals. Graphene growth occur due to the precipitation of graphite from carbon species within the Ni film and the carbon atoms form a solid solution resulting in an ultrathin graphene film (1 to ~ 10 layers) over the Ni surface. This method allows the transfer of the produced film to alternative substrates, in our case a polycarbonate (PC), by wet-etching the Ni film.

Exfoliation of Graphene

Graphite oxide (GO) is produced by the oxidative treatment of graphite via one of three principal methods developed by Brodie, Hummers, and Staudenmeier. GO consists of graphene sheets decorated mostly with epoxide and hydroxyl groups. Quick heating of GO results in its expansion and delamination caused by rapid evaporation of the intercalated water and evolution of gases from pyrolysis of the oxygen containing functional groups (http://www.inno-cnt.de). Such thermal treatment has recently been suggested to be capable of producing individual functionalized graphene sheets. For a schematic representation of the graphite oxidation, exfoliation and reduction see Figure

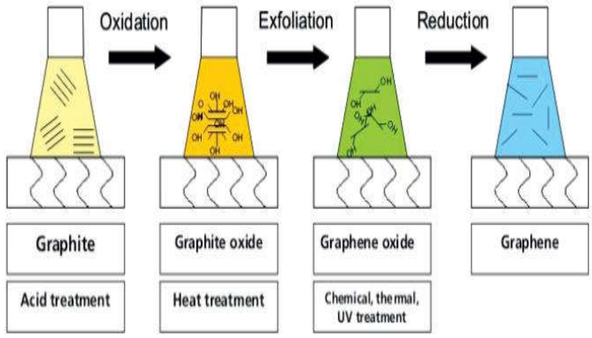

Fig. 3. Schematic representation of graphite exfoliation process resulting in graphene (reduced graphene oxide) (http://www.inno-cnt.de)

SOME APPLICATIONS OF GRAPHENE

High-speed electronics

- A high conductivity is ideal for high speed electronics. Scientists have worked tirelessly to create a graphene derivative with a band but the efforts have proved ineffective in terms of application.
- Graphene is a good material for THz applications with its strengths in atomic thickness, easy tunability and high kinetic inductance. The major hurdle for these resonant high frequency applications remains to overcome the dissipative losses.

Data storage

- Graphene oxide-based devices have data capacities of 0.2 Tbits cm^3.
- With the highly growing need for increased data storage, graphene could in theory replace current solid state technologies in the future if research is focussed towards improving storage capacity.

LCD smart windows and OLED displays

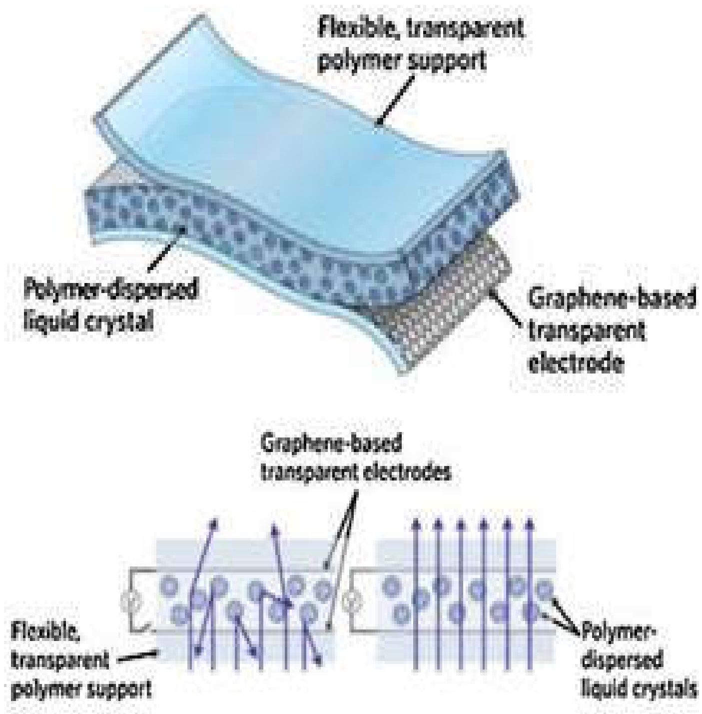

Fig. 4. Schematic representing the design of an LCD Smart Window (Edward and Randviir, 2014)

- Figure depicts a Liquid Crystal Display (LCD) Smart Window, a flexible device which is opaque until subjected to an electric field when it becomes transparent.
- The technology utilized in this device consists of a layer of liquid crystals sandwiched between two flexible electrodes consisting of a flexible polymer and graphene; the electric field aligns the light-scattering liquid crystals to reveal a transparent background with a decal embedded in the middle.

Supercapacitors

- Energy storage devices are utilized in almost every electronic device as they are responsible for delivering high electric currents over a short space of time.
- Supercapacitors are energy storage devices which deliver very high currents as compared to a normal capacitor. Most supercapacitor technologies utilize high internal surface area materials to store charge, and given that graphene exhibits a large internal surface area it seems to be an obvious choice (Edward and Randviir, 2014).
- One example of the need for a supercapacitor is to power electric cars which require high currents for acceleration.

Solar Cells

- Photovoltaic cells, or solar cells, are potential application of graphene. Current solar cell technologies contain platinum based electrodes.
- Graphene being an excellent conductor there is potential for graphene electrode design which would reduce cost and weight whilst maintaining efficiency. Their graphene electrode in a dye- sensitized solar cell actually exhibited an efficiency of 7.8% which is 0.2% less than a platinum-based counter electrode, but produced at a fraction of the cost (9)

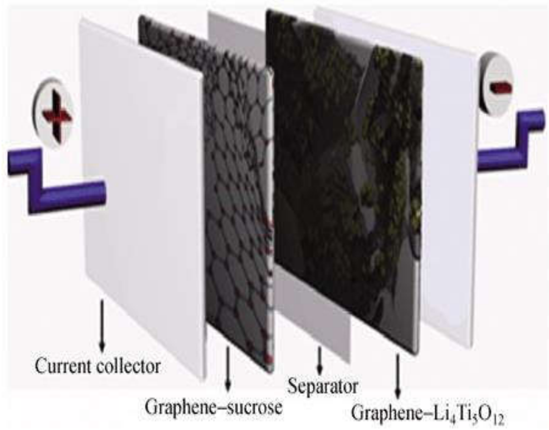

Fig. 5. A Supercapacitor

Adsorption of organic pollutants

- Graphene-based materials have been successfully applied in the adsorption of organic pollutants in the form of dyes, polycyclic aromatic hydrocarbons and gasoline. Graphene can be successfully applied in the adsorption of various dyes from polluted water.
- In these graphene materials, the adsorption is determined by physisorption between the pollutants and the graphene surface, as such the larger the surface area the greater will be the adsorption capacity.
- The high stability, large surface area and environmentally friendly nature of graphene makes it a potential candidate for environmental applications such as water purification, toxic gas sensors and acidic gas capture (Edward *et al*., 2014)

The advantages of graphene for radio-frequency (RF) applications derive in part from its high electron and hole mobility, which can exceed 100,000 $cm^2/V.s$ at T=240 K. In addition, the main limitations of traditional RF electronics in terms of maximum frequency, linearity and power dissipation may be overcome by the combination of the unique properties of this material, with new device concepts and nanotechnology. For radio frequency transistors, the cut-off frequency is the most widely used figure-of-merit for characterizing the fundamental speed limit. The cut-off frequency is defined as the frequency at which point the magnitude of the small-signal current gain of the transistor is reduced to unity. It is the highest possible frequency at which an FET is useful in radio frequency applications.

Graphene Based Electronics Devices

By connecting graphene nanoribbons of different widths, graphene PN junctions or quantum dots can be formed. Figure 5 shows a graphene FET based on two armchair graphene nanoribbon junctions, the widths of the nanoribbons are carefully chosen so that the device has a semiconducting channel and conductive source and drain. The semiconducting channel is double gated so as to control the electric potential.

Conclusion

Since the invention of the transistor in 1947 the rapid and continuous growth of the semiconductor industry has been based on one material, silicon. Other materials such as gallium arsenide have uses in specialised applications but the market for semiconductor devices has been dominated by those based on silicon. Although this dominance is expected to continue into the foreseeable future the formation of freeform graphene in the mid-1980s has revolutionised semiconductor device research. Prior to the fabrication of graphene devices carbon nanotubes were being considered as the basis for electronic devices in a post-silicon era. However, carbon nanotubes are not compatible with silicon technology whereas graphene is as it is planar. One of the main attractions of graphene is the very high electron mobility is observed within the material. However, graphene has demonstrated other surprising properties too.

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