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GRAPHENE: THE EMERGING MATERIAL IN THE ELECTRONICS FIELD

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***Abstract* - Graphene is a rapidly rising star on the horizon of materials science and electronics field. The electronics industry has come way far in development of semiconductors, their operation. Where the horizon of Silicon semiconductors ends, Graphene comes into field. Graphene due to its vivid properties along with being cheap and easily accessible can be used in designing and manufacturing of several electronics devices. Primary intention of this paper is to provide a study of Graphene applications such as electronics, Wearable Technologies, Optoelectronics, communication and in medical fields.**

Keywords : Graphene , antenna , Optoelectronics, Graphene Supercapacitor

I . INTRODUCTION

Graphene is a wonder material with many superlatives to its name. It is the thinnest known material in the universe and the strongest ever measured. Its charge carrier exhibit giant intrinsic mobility, have zero effective mass, and can travel for micrometers without scattering at room temperature. Graphene can sustain current densities six orders of magnitude higher than that of copper, shows record thermal conductivity and stiffness, is impermeable to gases, and reconciles such conflicting qualities as brittleness and ductility. Electron transport in graphene is described by a Dirac-like equation, which allows the investigation of relativistic quantum phenomena in a benchtop experiment. This review analyzes recent trends in graphene research and applications, and attempts to identify future directions in which the field is likely to develop. Graphene possesses many properties like high electronmobility about 100,000 cm2/ Vs at room temperature which is significantly greater than Silicon. Although silicon has its own advantages, but graphene on the other hand has more mechanical strength, flexibility, stiffness that makes it ideal for wearable technologies and also flexible electronics. Graphene is mainly a sheet resistance with a very high transmittance of about 90%. This makes it suitable for the use in foldable touch panels, rollable e-paper and many such devices. Thus combining the properties, potential ability, and relative ease of availability graphene can be used in electronics .

Some of the mechanical properties of graphene are:

- High tensile strength
- High Young's Modulus (about 1TPa)
- High intrinsic strength (about 130GPa)
- High elasticity.

II. INVENTION OF GRAPHENE

Carbon is arguably the most fascinating element in the periodic table. It is the base for DNA and all life on Earth. Carbon can exist in several different forms. The most common form of carbon is graphite, which consists of stacked sheets of carbon with a hexagonal structure. Under high pressure diamond is formed, which is a metastable form of carbon.

A new form of molecular carbon are the so called fullerenes9. The most common, called C60, contains 60 carbon atoms and looks like a football (soccer ball) made up from 20 hexagons and 12 pentagons which allow the surface to form a sphere. The discovery of fullerenes was awarded the Nobel Prize in Chemistry in 1996.

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A related quasi-one-dimensional form of carbon, carbon nanotubes, have been known for several decades10 and the single walled nanotubes since 1993. These can be formed from graphene sheets which are rolled up to form tubes, and their ends are half spherical in the same way as the fullerenes. The electronic and mechanical properties of metallic single walled nanotubes have many similarities with graphene.

It was well known that graphite consists of hexagonal carbon sheets that are stacked on top of each other, but it was believed that a single sheet could not be produced in isolated form such that electrical measurements could be performed. It, therefore, came as a surprise to the physics community when in October 2004, Konstantin Novoselov, Andre Geim and their collaborators1 showed that such a single layer could be isolated and transferred to another substrate and that electrical characterization could be done on a few such layers. In July 2005 they published electrical measurements on a single layer. The single layer of carbon is what we call graphene.Graphene was first made by using scotch tapes and peeling them off from graphite (*Highly Oriented Pyrolytic Graphite - HOPG*). This led toproduction of flakes containing multilayers of graphene. It was required to isolate the graphene layers individually for more specific purposes. After this slowly and gradually there were advancements in production of graphene. Some of the methods used were *CVD (Chemical Vapor Decomposition)* of hydrocarbons on metal surface and Thermal Decomposition.

III. PROPERTIES OF GRAPHENE:

A. Density of graphene

The unit hexagonal cell of graphene contains two carbon atoms and has an area of 0.052 nm2. We can thus calculate its density as being 0.77 mg/m2. A hypothetical hammock measuring 1m2 made from graphene would thus weigh 0.77 mg.

B. Optical transparency of graphene

Graphene is almost transparent, it absorbs only 2.3% of the light intensity, independent of the wavelength in the optical domain. This number is given by π α, where α is the fine structure constant. Thus suspended graphene does not have any color.

C. Strength of graphene

Graphene has a breaking strength of 42N/m. Steel has a breaking strength in the range of 250-1200 MPa= 0.25-1.2x109 N/m2. For a hypothetical steel film of the same thickness as graphene (which can be taken to be 3.35Å=3.35x10-10 m, *i.e.* the layer thickness in graphite), this would give a 2D breaking strength of 0.084-0.40 N/m. Thus graphene is more than 100 times stronger than the strongest steel. In our 1 m2 hammock tied between two trees you could place a weight of approximately 4 kg before it would break. It should thus be possible to make an almost invisible hammock out of graphene that could hold a cat without breaking. The hammock would weigh less than one mg, corresponding to the weight of one of the cat's whiskers.

D. Electrical properties of graphene

The freely available electrons (pi-electrons) that do not get bonded are the reason for electrical conduction to take place. Graphene thus behaves as a semiconductor just like the Silicon, Germanium and GaAs. But since the cause of conduction in graphene is different from that of other semiconductor materials, it exhibits many unique properties. One such property is the electron mobility. The electron mobility of graphene in its pristine form is more than 200,000 cm2/Vs. The sheet resistance of graphene is about 30 ohms. Since graphene atoms are considered as massless, they behave much similar to photons.

E. Thermal conductivity

The thermal conductivity of graphene is dominated by phonons and has been measured to be approximately 5000 Wm−1K−1. Copper at room temperature has a thermal

IV. GRAPHENE FABRICATION TECHNOLOGY

Although graphene shares many of its outstanding properties with carbon nanotubes, graphene devices are strongly preferred from a commercial point of view because their fabrication is very similar to traditional planar wafer-size Si processing. Devices are patterned using standard

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photolithography tools or electron-beam lithography. Metal contacts are deposited through liftoff, and

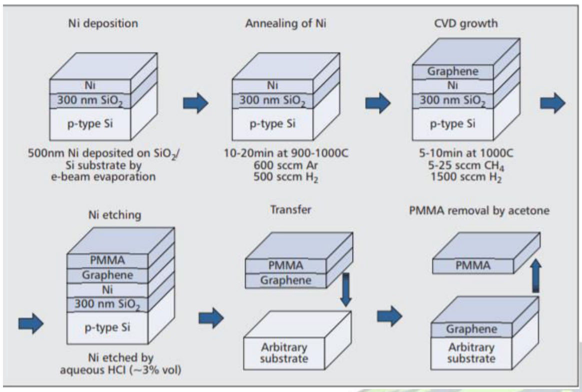

Fig: graphene fabrication technology

graphene is subsequently etched with oxygen plasma. Finally, a gate dielectric is deposited and the gate metal is patterned . Most of the fabrication technology mirrors all the work done on carbon nanotube field effect transistors (CNT-FETs) in terms of selection of ohmic metals, gate dielectrics, and so on. However, there are four main issues for graphene fabrication that still require optimization: substrate selection, contact resistance, gate dielectric deposition, and band gap engineering. Every atom in a graphene film is at the surface and strongly interacts with the surrounding environment, which opens numerous opportunities for new device concepts, but also new sources of performance degradation. So far the most dominant mechanism for mobility degradation in graphene is charged impurities. Therefore, much work has been dedicated to studying various high-k dielectric materials and substrates to screen the effects of any charged impurities and reduce surface phonon effects. By carefully controlling the graphene-substrate interface, mobilities as high as 20,000 cm2/Vs have been demonstrated. In spite of some partial success in identifying suitable substrates, more work is needed in this area as the reported mobilities are still far from the record mobility recorded in suspended graphene, where the substrate underneath the graphene film was etched away. The lack of substrate in these measurements prevents any degradation through surface vibrations (phonons) or nearby charged impurities, both of which greatly reduce graphene's intrinsic properties. However, most practical applications require that a substrate allows for proper heat dissipation; therefore, the choice of substrate and its interaction with graphene are of utmost importance. A second important processing issue in graphene devices is to optimize the metallization for reducing contact resistances. Most work has been done on matching work functions of graphite and the metal. The most common metal combinations are Cr/Au, Ti/Pt, and Ti/Pd/Au. Based on experiments done in our laboratory, Cr/Au contacts give contact resistances in the range 1 × 10–4 – 2 × 10–4 ohm.cm2. Ti/Pt gives similar contact resistance as Cr/Au contacts. Ti/Pd/Au contacts give contact resistances in the range 0.5 × 10–4 – 1 × 10–4 ohm.cm2. However, there is still no consensus as to which one provides the lowest contact resistance. Furthermore, since graphene is so easily doped by its environment, metal on graphene may end up doping the underlying graphene, creating a potential barrier into the undoped graphene channel. This increased resistance is detrimental towards high speed operation due to the increased RC time to charge and discharge all of the capacitances. One of the most difficult problems with graphene processing has been finding the appropriate gate dielectric material. Atomic layer deposition (ALD) is the most commonly used deposition method due to the accurate control of the layer thickness that it allows. Unfortunately, ALD relies upon alternating pulses of water and precursor materials. Graphene is hydrophobic and thus the deposition of high quality pinhole-free ALD is very difficult. Various approaches have been attempted utilizing chemical functionalization with NO2, aluminum oxidation, or seed layers to provide a template for ALD that does not reduce the mobility of the carriers in graphene. Recently, impressive results in mobility have been demonstrated through non-covalent bonding of polymers on graphene to serve as a thin buffered layer. Finally, there is growing interest in bandgap engineering of graphene. Unlike conventional semiconductors such as silicon, which contain a band gap, graphene is a zero-bandgap material and has ON/OFF ratios around 5–10, thus limiting its effectiveness for digital applications. Much work has been focused on generating a band gap of up to 500 meV through 1-D quantum confinement of

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graphene nano ribbons (GNR) or through strain induced substrate interactions. So far, GNR have demonstrated moderate band gaps that have translated to much higher ON/OFF ratios, however the fabrication of these GNR transistors is very challenging. Electron-beam lithography is limited to feature sizes around 10–20 nm. However, to generate an appropriate sized band gap requires dimensions on the order of

V. MAJOR APPLICATIONS OF GRAPHENE

A. Graphene in Transmitting Antenna

With decrease in size of metallic antenna generally the radiation efficiency is compromised. Scaling them to a size of m nanometers by using Graphene might be helpful. In terahertz band (THz) it was found that Graphene based Nano-antennas radiate electromagnetic waves at lower frequency and high efficiency .

B. Graphene in frequency multipliers

Frequency multiplication is very important part of radio communication and broadcasting. In early times FET and diode based multipliers were in rapid progress. Now commercially used only option, for generating signals at high frequencies are Schottky diode frequency multipliers that can generate signals with frequencies ranging from 1THz and above.

C. Graphene in Transistors

Transistors make up the base of any electronics system. Graphene also plays an important role here. As discussed earlier, the mobility of electrons and holes in graphene is very high of about 100,000 cm2/Vs. This property of graphene is used to design of FETs known as *GFET (Graphene- BasedField Effect Transistor)*. The zero band gap property of graphene possesses some threats to design of logic digital transistor. Electrostatic doping (a method used for increasing band gap) is done by inducing electric field between graphene and metal. This helps in designing of inverters.

C. Graphene based frequency multipliers

Frequency multiplication is very important part of radio communication and broadcasting. In early times FET and diode based multipliers were in rapid progress. Now commercially used only option, for generating signals at high frequencies are Schottky diode frequency multipliers that can generate signals with frequencies ranging from 1THz and above.

D. *Integrated Circuits with Graphene Transistors*

A working transistor means nothing unless it is integrated into a circuit, implying that a number of transistors are linked to perform a task. In this instance, IBM scientists constructed a broadband radio frequency mixer that is used in radio applications to process signals at a range of frequencies. It is a standard IC component and this achievement shows that graphene transistors can be used effectively in more complex systems.

E. *Transparent Memory with Graphene*

Researchers have succeeded in developing transparent flexible memory chips using silicon oxide as the active component. The transparent memory technology is based on the 2010 discovery that pushing a strong charge through standard silicon dioxide, which is an insulator used commonly in electronics, strips oxygen atoms off the material, resulting in pure silicon crystal channels less than 5 nm wide. In 2012, this phenomenon is used to create a two-terminal transparent memory device. After the initial large current creates the nano channels, smaller charges can then be used to break or make the circuit to encode binary information, and a still smaller current can be used to check the state of the memory without changing it.

F. *Graphene in Batteries*

There are a range of technologies available for energy storage, each having a number of tradeoffs in terms of capacity, weight and performance. Capacitors are quick to charge and lightweight, but do not have a large capacity. Batteries are capable of retaining more charge, but are heavy and take a long time to recharge. This variety is good as it offers a number of options to fine-tune a device to suit specific requirements.

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G. Optical Electronics

Fig : Thin Graphene Sheet

It is believed that graphene will be used on a commercial scale in the field of optoelectronics especially LCDs, touch screens and organic light emitting diodes (OLEDs). Graphene is almost completely transparent material and can transmit up to 97.7% of incident light. It also has high conductivity, hence would be suitable for smartphones, tablet, desktop computers and televisions. Recent tests prove that graphene will match the properties of indium tin oxide (ITO) even in present states. Also it has been shown recently that the optical absorption of graphene can be changed by adjusting the Fermi level. Since high quality graphene has a very high tensile strength and is flexible it can be used for flexible displays. It is believed that we can eventually see devices such as graphene-based e-paper and flexible electronic devices.

H. Organic electronics

A semiconducting polymer placed on top of single-layer graphene vertically conducts electric charge better than on a thin layer of silicon. A 50 nm thick polymer film conducted charge about 50 times better than a 10 nm thick film, potentially because the former consists of a mosaic of variably-oriented crystallites forms a continuous pathway of interconnected crystals. In a thin film or on silicon, plate-like crystallites are oriented parallel to the graphene layer. Uses include solar cells.

I. Photodetector

A graphene/n-type silicon heterojunction has been demonstrated to exhibit strong rectifying behavior and high photoresponsivity. By introducing a thin interfacial oxide layer, the dark current of graphene/n-Si heterojunction has been reduced by two orders of magnitude at zero bias. At room temperature, the graphene/n-Si photodetector with interfacial oxide exhibits a specific detectivity up to 5.77 × 1013 cm Hz1/2 W² at the peak wavelength of 890 nm in vacuum. In addition, the improved graphene/n-Si heterojunction photodetectors possess high responsivity of 0.73 A W−1 and high photo-to-dark current ratio of ≈107. These results demonstrate that graphene/Si heterojunction with interfacial oxide is promising for the development of high detectivity photodetectors. Recently, a graphene/si Schottky photodetector with record-fast response speed (< 25 ns) from wavelength 350 nm to 1100 nm are presented. The photodetectors exhibit excellent long-term stability even stored in air for more than 2 years. These results not only advance the development of high-performance photodetectors based on the graphene/Si Schottky junction, but also have important implications for mass-production of graphene-based photodetector array devices for cost-effective environmental monitoring, medical images, free-space communications, photoelectric smart-tracking, and integration with CMOS circuits for emerging interest-of-things applications, etc.

J. Biosensors

Graphene does not oxidize in air or in biological fluids, making it an attractive material for use as a biosensor. A graphene circuit can be configured as a field effect biosensor by applying biological capture molecules and blocking layers to the graphene, then controlling the voltage difference between the graphene and the liquid that includes the biological test sample. Of the various types of graphene sensors that can be made, biosensors were the first to be available for sale.

K. Graphene-Based Ultracapacitors

The surface area of a single graphene sheet is 2630 m2 /g, substantially higher than values derived from BET surface area measurements of activated carbons used in current electrochemical double layer capacitors. Our group has pioneered a new carbon material that we call chemically modified graphene (CMG). CMG materials are made from 1-atom thick sheets of carbon, functionalized as

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needed, and here we demonstrate in an ultracapacitor cell their performance. Specific capacitances of 135 and 99 F/g in aqueous and organic electrolytes, respectively, have been measured. In addition, high electrical conductivity gives these materials consistently good performance over a wide range of voltage scan rates. These encouraging results illustrate the exciting potential for high performance, electrical energy storage devices based on this new class of carbon material.

VI. CONCLUSION

Once the growth and fabrication technology these new devices matures, their integration with conventional Si electronics, and/or flexible and transparent substrates has the potential to transform communications. Advanced graphene devices could enable the introduction of advanced communication systems in a broad array of new applications. Graphene, the ultimate nano-material, is therefore in an excellent position to help communication systems become even more ubiquitous and versatile than they are today.

In summary, graphene is both quantitatively and qualitatively different from any other material conventionally used in electronic applications. Not only does it have room temperature electron and hole mobilities more than 100 times higher than those of Si, as well as excellent mechanical properties, but also, its ambipolar transport properties, ultra thin and flexible structure, and electrostatic doping offer a new degree of freedom for the development of advanced electronic devices with many potential applications in electronics and communication fields.

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