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Applications of Graphene for Communication, Electronics and Medical Fields: A Review

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***Abstract*—Primary intention of this paper is to provide a study of Graphene applications such as Optoelectronics, Wearable Technologies, Energy storing devices and Radio Transmission and broadcasting. For understanding the Graphene as a material, its mechanical, chemical, electrical and optical properties are discussed. Brief history about the discovery of Graphene is also included. The electronics industry has come way far in development of semiconductors, their operation. Where the horizon of Silicon semiconductors ends, Graphene comes into picture. Graphene due to its exclusive and extensive properties along with being cheap and easily accessible can be used in designing and manufacturing of several devices. There are immense opportunities to use Graphene technology in future communication, electronics, medical and other fields, as discussed in the article.**

Keywords—Graphene; Discovery; Properties; Slot antenna; Graphene Circuits; Graphene Transistor; Optoelectronics; Graphene Battery; Graphene Supercapacitor; Medical

I. INTRODUCTION

In this rapid and fast moving world, the technology has gone through a lot of major breakthroughs and remarkable new discoveries and inventions. One such invention or discovery that has potential of changing the way the future electronics would work about 15 -20 years from now is Graphene. It is the first 2D structure (monolayer) to be made. It is honeycomb in shape and sp^2 bonded carbon atoms. Graphene is an allotrope of carbon, a semiconductor that possesses many physical, electrical and chemical properties, so unique, that makes it an active area of interest. In this paper we have tried to review the future applications where graphene can be used, more specifically, in the electronics domain [7].

Graphene possesses many properties like high electron mobility about 100,000 cm^2/ 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 for many electronics and related applications[1-7].

Graphene has almost negligible band gap that increases its importance in electronics domain. Though synthesis of graphene is tedious job but producing it in large quantities for industrial purposes will reduce the cost and increase the ease of production of graphene. Some of the mechanical properties of graphene are:

- High tensile strength
- High Young's Modulus (about 1TPa)
- High intrinsic strength (about 130GPa)
- High elasticity [5].

All this properties make it adequate and appealing for designing of future gadgets and devices that requires being more flexible and at the same time must be strong enough for rugged usage. Before discussing the applications of graphene let us go through a brief history of graphene.

II. DISCOVERY OF MIRACLE MATERIAL "GRAPHENE"

The limit for any structure to be called as 2D crystal is less than 10 layers of atomic planes. Above than this limit crystal will be referred to as 3D. [1] [4] Graphene was first made by using scotch tapes and peeling them off from graphite (*Highly Oriented Pyrolytic Graphite - HOPG*) [2][16]. This led to production of flakes containing multilayers of graphene. It was required to isolate the graphene layers individually for more specific purposes. This was achieved at first by intercalating the graphite mass and separating the graphene layers using different types of atoms or molecules. Inspite of this what we got was a 3D layer [1]. 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 [7] and Thermal Decomposition of SiC [6-7].

For more than 60 years Graphene has been studied by various scientists. But since graphene was not available in Free State it was not considered as a practical material that can be used. More specifically it was being referred to Academic Material [1]. But this belief was very soon taken over as graphene in free state did exist and also when it was discovered that graphene had zero bandgap the potential of Graphene as a future fabrication material was understood [1] [9-10].

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III. PROPERTIES OF GRAPHENE:

Graphene has following key properties :

A. Mechanical Properties:

There are many forms of graphene available. Since single layer of graphite sufficiently isolated from its environment is considered to be as free-standing according to Geim [11], Pristine Graphene is very strong, with high tensile strength, elasticity, brittleness and intrinsic strength. With reference to the experiments of Lee and his coworkers, the Young modulus of 1.0 TPa, the third-order elastic stiffness of -2.0 TPa, ultimate tensile strength of 130,000,000,000 Pascals (or 130 gigapascals) [36]. This entire properties combined together makes Graphene superior to many other commonly used materials such as Silicon in electronics based applications.

B. Chemical Properties:

Graphene is a zero overlap semimetal. In graphene each carbon atom is connected to other three other carbon atoms. It has 6 carbon electrons, with four electrons in n shell (outer shell). These four electrons of each carbon atom when bonded with other three carbon atoms having same number of outer shell electrons leave 1 electron freely available. This freely available electron causes conduction to take place. These electrons are commonly known as π-electrons (pi-electrons). These are located in between two graphene ultra-thin layers. Thus these π-electrons cause overlapping of π-orbitals making the carbon-carbon bond in graphene much stronger[2][7][10].

C. Electrical Properties:

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 cm^2/Vs. The sheet resistance of graphene is about 30 ohms[1][7]. Since graphene atoms are considered as massless, they behave much similar to photons.

D. Optical Properties:

Graphene has very good absorption capacity. Even though graphene in pristine form is just 1 atom thick, it has ability to absorb 2.3% of white light. This property is much appreciable considering the size of graphene. In other words the opacity $\pi\alpha$ of graphene is 2.3% which is almost equal to the universal dynamic conductivity (eq. 1) over the visible frequency range[41].

$$G = e^2 / 4\hbar \ (\pm 2\text{-}3\%) \tag{1}$$

IV. AVAILABILITY AND MANUFACTURING OF GRAPHENE

Graphene is generally easily available as it is to be obtained from graphite. Although for a long time it was considered that graphene was not available in isolated form, instead, it consisted of multiple layers of graphite, but later in 2009 it was defined that free standing graphene was available or in other words single layer of graphite sufficiently isolated from its environment to be considered as free-standing according to Geim [11]. Graphene can be manufactured using:

CVD (Chemical Vapor Decomposition): This method is generally used for large scale production of graphene for industrial applications by using Ni and Cu catalysts. For producing large area and high quality graphene Catalytic CVD is used7. The graphene is transferred on insulating substrates for making transistors, logic gates, and other industrial purpose devices. Graphene is grown by carbon diffusion through grain boundaries of copper [12].

By using SiC: Epitaxy of Silicon Carbide is another method of producing graphene. Heating SiC at very high temperature and at very low pressure leads to the formation of Graphene [ref 14]. On heating the SiC the bonds between Si and C starts to break and at last only weak Van Der Waal's are left to maintain crystalline structure [15].

Graphene can also be manufactured using *carbon nanotube slicing technique* [17], *Carbon dioxide reduction* [18], *Intercalation* [19], *LASER* [20] and *Supersonic spray* [21].

V. APPLICATIONS OF GRAPHENE

Now let us see in what ways the graphene has started revolutionizing the whole Silicon Electronics Era [13]:

A. Graphene in Slot Antenna

Graphene is just a one atom thick layer of carbon atoms. Thus being ultrathin, graphene can be used for designing of antennas, more specifically, micro patch antennas or slot antennas. Due to ultra-small size the losses are very less compared to metallic antenna but at the same time the radiation efficiency is being compromised. The radiation efficiency of graphene based patch antenna is just 6%[32]. Referring to [33], it is necessary to have a gain of at least 0dBi and radiation efficiency of 40% at low power. It was shown in [33] that if IDC (inter-digitated capacitor) was used with thin graphene films matched with slot antenna, the IDC matches antenna at around center frequency of 3.5 GHz with a bandwidth of (100:1). With decrease in size of metallic antenna generally the radiation efficiency is compromised. Scaling them to a size of 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 [34].

B. Full-wave rectifiers and frequency doublers based on ambipolar conduction in graphene:

After being discovered in 2004 graphene has been a wide topic of interest in technology field [28]. Having high mobility of e- and holes i.e. about >100000 cm^2/V at room temperature and with a combination of critical electric field and thermal stability this material now become an important part of every high frequency applications. G-FETs are ambipolar devices [28-31]. Below the minimum conduction point voltage (Vg_{min}) the drain current is based on hole conduction for gate-to-source voltages, while at higher voltages, electron conduction dominates. Graphene devices with the structure can also be used as frequency multipliers where the output signal has a fundamental frequency double that of the input signal.

C. 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. [24] [27]

D. 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 cm^2/Vs. This property of graphene is used to design of FETs known as *GFET (Graphene- Based Field Effect Transistor)*. The zero band gap property of graphene possesses some threats to design of logic digital transistor. Electrostatic doping [8](a method used for increasing band gap [28]) is done by inducing electric field between graphene and metal. This helps in designing of inverters [35].

E. Graphene in Optoelectronics:

In optoelectronics, graphene is used for designing of devices such as photo-detectors, optical modulators, graphene waveguide and photonic limiter [37]. Let us have a brief look on these applications. After creation of band gap in graphene as discussed earlier, the graphene semiconductor junction can be formed. This device works on the same principle as that of photodiode. When photons (small energy packets) are bombarded on this junction a very large current flows due to high electrons and holes mobility. All the devices discussed above works on the nearly the same principle with a little or no modifications.[38]

F. Graphene in OLEDs:

In some recent years we all have observed a drastic change in display technologies. Good display means high contrast ratio, appreciable color quality, high luminance, adequate brightness, large in size and pure black back. To this demands the OLEDs had proven to be a very good alternative. But still there remains a further scope of advancements in OLEDs by making them flexible using graphene. Till date the touch panels mainly use ITO (Indium Tin Oxide) for designing. It also requires sophisticated nanowires and nanoribbons for connections. But when we use Graphene instead of ITO this problem is eliminated. Graphene here should be considered as a low sheet resistance (125 ohm/sqm) layer that has very high transmittance (97.4% at 550 nm wavelength)[23] . Due to high mechanical strength and chemical versatility the use of graphene for transparent conducting electrode can be seen as the future of display devices. While comparing graphene to other transparent conducting electrodes, the best part is the transparency of graphene along with it being ultrathin to avoid light being trapped[22]. Smart phones that we are using today uses touch screen having transparent electrodes made of indium tin oxide. But as ITO has some major limitations they are 1) Indium is a material that is hardly available and already costly, and as demand will increase its price will also rise. 2) A rigid substrate such as glass is required for ITO because ITO is brittle and hence it can't be used as an organic LED or as in flexible displays[21-22].

And now a single layer of graphene have the ability to transmit more than 97% of incident light which is well above the 90% of ITO, and hence due to graphene's strength and flexibility it is attractive for flexible screens. It is a fact that a

Table 1 :Different applications related to graphene, their general lead and requirements

Applications	General Lead	Requirements
Organic Light Emitting Diode (OLEDs) Graphene	Can be used in wearable technologies. Can be folded to a radius of < 5mm	A better control over sheet resistance required
Touch Screens	Easy to implement compared to ITOs and nanoribbons	A better control over contact resistance required.
E-paper	High transmittance of monolayer graphene could provide visibility	Requires better control of contact resistance
High-frequency transistor	No manufacturable solution for InP high-electron-mobility transistor (low noise) after 2021	Need to achieve current saturation, and fT5850GHz, fmax51,200GHz should be achieved
Tunable fiber mode-locked laser	Graphene's wide spectral range	Requires a cost-effective graphene-transferring technology
Optical modulator	Graphene could increase operating speed (Si operation bandwidth is currently limited to about 50GHz)	High-quality graphene with low sheet resistance is needed to increase bandwidth to over 100GHz
Frequency Multiplier	output signal has a fundamental frequency double that of the input signal	Difficult in designing
Batteries	Graphene electrodes are used due to their ultra-thin size and flexibility	It is susceptible to oxidation environment and may not give desired results

single-layer graphene is having less conductivity than ITO, but by adding layers to it can increases its conductivity. However, grapheme is having a biggest advantage that it does not require costly raw materials; because availability of carbon is abundant, so efficient and effective manufacturing can be achieved to make graphene cheap.[14][22]

G. Graphene in Batteries:

Graphene due to its excellent flexibility, high thermal conductivity and mobility has become 1st choice for using it as electrode in batteries. By adding Boron, lithium ions can stick to graphene anode nicely. This research of using graphene along with Boron was done by car company- Honda. Also many car companies such as Hyundai and Kia motors have shown interest in using graphene in their batteries.

H. Graphene in Supercapacitors:

Super-capacitors are devices that can hold up a large amount of charge for a very long time. Also their charging time is very less. Graphene has come as a key player in this domain due to high electron mobility. It is basically a hierarchical nanostructure comprised of graphene and carbon sphere[37]. Graphene based super-capacitors can store almost same energy as that of Ni:MH batteries.

I. Graphene in Medical:

Graphene has extensive applications in medical field. One such field is drug delivery. According to the research at Monash University, sheet of graphene can be converted into small graphene crystal droplets. This is done by simply keeping the graphene oxide layer in a solution of appropriate pH and then applying electric field [3]. These droplets reach the active affected site and then open up. This method is more accurate and precise. Since graphene exhibits a very good physical, chemical, electrical and optical properties it is now a days used to manufacture biosensors[39]. Now these biosensors can be intuitively used for research in biotechnology field and improve the quality of medical sciences and thus providing better and accurate healthcare. Also an NGO-PEG-SN38 complex has been developed that has high cancer cell killing potential and is also water soluble[40]. This in turn has led to revolution in drug delivery and precise targeting of cancer cells. Thus graphene is going to be an important area of research in medical field as well.

VI. Issues Related to Graphene:

Although graphene has a lot of unique and remarkable properties it has some major shortcomings too. One such disadvantage of graphene is that it has zero band-gap. Another flaw is that graphene as a catalyst gets prone to oxidative environments. Also it has been found that graphene inhibits some toxicity too. So a very careful use of it is required [1-7].

VII. Conclusion:

In this paper, we have tried to explain, how graphene out of its excellent properties is going to revolutionize the electronics industry in near future. In next 20-30 years the key component of electronics industry will be graphene. Some of the applications, their general leads and requirements has been discussed in Table 1.1. Graphene has come out to be exhibiting very unique and fascinating properties in all, mechanical, chemical, optical and electrical domains which shows us a foresight of how it is going to replace all its contenders in future.[25-26]

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