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Universality of Graphene as 2-D Material

Solanki Bhaumikkumar Ketansinh*

Mechanical Engineering, Chhotubhai Gopalbhai Patel Institute of Technology, India

Abstract

World always asks for compact and effective equipment. For that we need suitable materials. Now think about the thinnest material which has extraordinary properties. Graphene is real two dimensional material. It has lots of useful properties like conductivity, high strength and good flexibility. This Material has lots of potential, but still there is no more researches occupied on Graphene. This research paper is about to introduce the Graphene to the present world and to shows the impotency of Graphene in future. But question arise that which type of equipment or machines need a Graphene, where we can use Graphene to increase the effectiveness of equipment. It has carbon as raw material so it is cheap, eco-friendly and sustainable. It is much stronger, transparent and good conductive material which can use in Conductors, Transistor, Heat spreader and Interconnect wires of Integrated circuits, super capacitors and also useful as micro sensor and actuator. In future with use of Graphene composite, we will able to make space elevator of 36000 km altitude. But still it has some challenges that we have to solve. Challenges like, High prize at this moment (1 cm^2 = 3700 rupees), Sensitive to environment with no effective passivation, High quality thin films still lacking of reproducibility, Large scale transfer of films still irreproducible, Sheet resistance still too high, No band gap which a transistor requires (turn off problems). This paper give you total overview of the all basic information require using Graphene in the future. This paper has all basic information regarding to every properties of the Graphene. Here all properties are equally justified on the bases of application too.

Keywords: 2-D Material; Graphene; Universal material; Super capacitors; Space elevator; Heat spreader; Interconnect wires of Integrated circuits; The thinnest material

Introduction

Graphene has carbon as core material. It is a one kind of atomic structure of carbon. Diamond and graphite both made of carbon but because of them atomic structure they are different. In diamonds 1 carbon atom connected with 4 other atoms and in Graphite 1 carbon is connected with other 3 atoms. In graphite it has layer structure, in each layer Carbons is connected with extremely strong bond. But between layers there are Vander Val Bond which easy to fracture. Graphene are discovered from graphite, one layer of graphite is known as Graphene which is harder than diamonds. Graphene can make by polishing process of Graphite but only 10micrometer thickness can be achieved. In 2004 Scotch tape is use to produce few layers of Graphene. This experiment was not for fabrication of Graphene it was just to verify its unique properties.

Graphene production with help of scotch tape

Figure 1 represents scotch tape experiment [1].

High Potential Application of Graphene

It has unique features; it integrates good electrical, optical, mechanical, thermal and chemical properties in one material. Like other Nano materials Graphene is more important.

This 2-D metal is use for,

- Transparent Conductor in Opt-electronics
- Biological applications
- Sensor and Actuators
- Integrated Circuits
- Composite materials
- Energy applications and many more.

Properties of Graphene

Electrical properties

Graphene is Semi-metal (conductor) so electron can easily accelerate in Graphene.

$$\mu = \frac{V}{E} \quad (1)$$

Where, μ= Mobility

V= Drift velocity of electrons

E= External electric field

Graphene has mobility at room temperature is $2*10^5$ unit which is higher than below material (Table 1). Conductivity is determined by Mobility and Density of material.

Materials	μ(Cm^2/[Vs])
Si	1000-2000
GaAs	9000
InP	5000-7000
InAs	33000
InSb	78000

Table 1: Mobility of different materials [22].

***Corresponding author:** Solanki Bhaumikkumar Ketansinh, Mechanical Engineering, Chhotubhai Gopalbhai Patel Institute of Technology, India, Tel: 02625292339; E-mail: bhaumiksolanki20495@gmail.com

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$$\sigma = ne\mu \quad (2)$$

Where; σ = Conductivity

n = Carrier Density

e = Elementary charge

μ = Mobility

Graphene is 65% more conductive than copper

Optical properties

Most of metal conductor are optically opaque because free electron in conductor have a screening effect, preventing the photons to pass through but Graphene is one of the transparent conductors known to us. It is just one atom thick and it absorbs only 2-3% of incident line so it is theoretically transparent (Figures 2-4).

Thermal properties

Graphene is excellent thermal conductor. It has highest thermal conductivity in all material, even higher than diamonds. It has thermal conductivity >3000 W/m/K. It is also isotropic ballistic thermal conductance, means same effect in all direction [2].

Mechanical properties

It is the thinnest material ever (0.34 nm). It has breaking strength is 130 GPa, 100 time greater than steel (It is pressure so convert it into normal force per cross sectional area so we found that it is strongest material ever). Also this material is stretchable up to 20% of its initial length; $1m^2$ can sustain weight of 4 kg. It is completely flexible due to its atomic thickness.

Chemical and biological properties

Graphene are chemically stable, it can't attack by acids or basis although very strong acids or basis. It is strongest in nature. Graphene pump energy is 607 KJ/module where Diamonds has 347 KJ/module. At room temperature it is stable with oxygen but at high temperature near to 700°C Graphene convert into Carbon Dioxide. Surface of it can easily modify by oxygen or nitrogen containing fundamental groups. It use as a substance to be interface with various Biomolecules and Cells. It is largely Biocompatible (this property is under investigation) [3].

Applications of Graphene

Transparent conductor in optoelectronics

It has extraordinary conductivity, high mobility, high transitivity so one of the best conductor. It use as light emetic diode (LED). It will use as a key element in solid state lighting in future society and that LED will more efficient than traditional. It will also useful for touch screen so in future there are flexible touch screens and flexible mobile or laptop. It also uses as transparent light absorbers. Like, transparent solar cell. Recently Indium teen oxide use in solar cell but indium is rarely available, brittle and it is also not transparent for UV. Graphene are low cost, eco-friendly and large area of production. Technical threshold relatively low compare with transistor in integrated circuits [4].

Transistor of integrated circuits

IC are common for our modern information society, mobile phone laptop all base on IC. Transistor is key element in IC. Transistor is tunable resistor which can amplify and switch electronic signals and electric power. Most up transistors are made of silicon, from the definition of mobility we can see that given electric field can drift electron in higher velocity. So Graphene is use for Ultra-Fast transistor. So in future silicon will replace by Graphene, but Graphene is not a semi-conductor. Ideal transistors are made of semi conductive materials so that current can completely switch off. If current will not switch off completely than it carries lots of energy so it become over heated. Scientists are trying to open band gape of Graphene so ultra-fast Graphene transistor can turn off.

Heat spreader and interconnect wires of IC

Today's electronic and photonic systems are generating big amount of heat during process because more functionality. Like, Data servers of USA are 50% use to cool the system, 20% for computing and another percentage for the driving cable and Communication. Graphene is

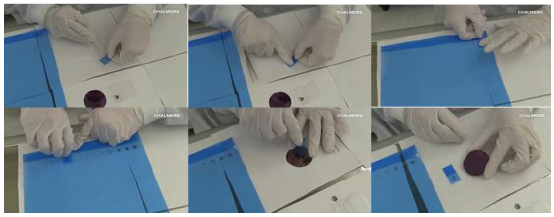

Figure 1: Skotch tape experiment.

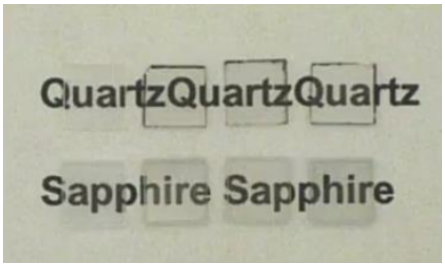

Figure 2: Transparency of graphene.

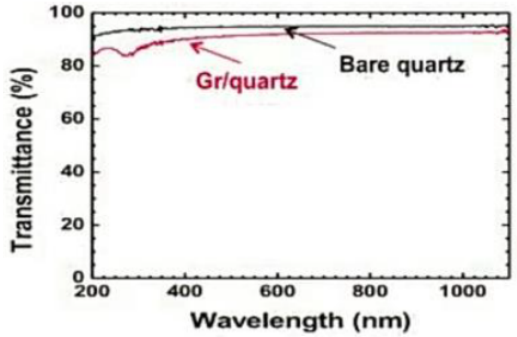

Figure 3: Graphene is transparent for UV and UR rays [22].

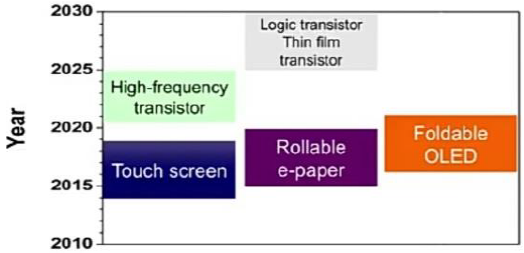

Figure 4: Future of Graphene in electronics and optoelectronics.

integrated between chip and thermal interface. Heat transfer from Heat sink to thermal interface material than dissipated in air. Graphene as interconnect wires of IC, Best conductor, lightweight & thinner also very stable and without electron migration. Electron migration means material transport caused by gradual moment of irons in the conductor due to momentum transport between conducting electron and diffusing metal atoms [5]. It has drawback when many metal inter connect such as copper but not for Graphene. It use as wires either in layer is not as could as emplaned conductivity. Other materials like CNTs (carbon Nano tube) is use to connect Graphene wires between laboring levels (Figures 5 and 6).

Energy applications

Graphene will use as super conductive plates of Capacitors, which are double layer capacitors. In super capacitor two conductive plates separated by dialectics layers. After the charging it will be more stable because of electrostatic charges. It also uses as electrode material for lithium ion batteries. It can store more energy for long time and charge discharge process is very quick. Graphene is electrically 10-100 times more conductive than activated carbon. Graphene base electrodes have 60% more density from recent capacitors. It also use for hydrogen storage, Mono layer Graphene can give hydrogen storage ratio up to 7.7% which useful for hydrogen vehicles (Figures 6 and 7).

Sensor and actuators

Graphene is mechanically strong so it is use full for Nano scale sensing and also useful as actuator in Nanoelecromechanical System (NEMS). It can able to sense 1 atomic change in element. It will use for Mass sensor, Gas sensor, DNA sensor, PH sensor (Figure 8).

Graphene composites

By adding other materials in Graphene atom we can able to make multi-tasking materials. Now Graphene and Epoxy composites are

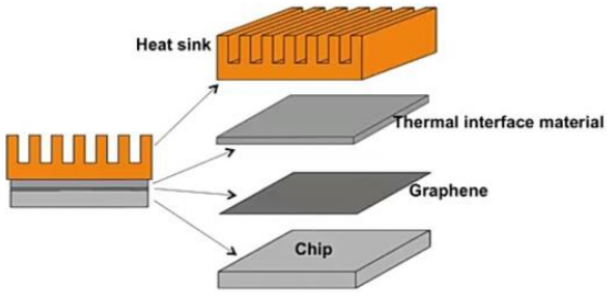

Figure 5: Graphene as heat spreader [6].

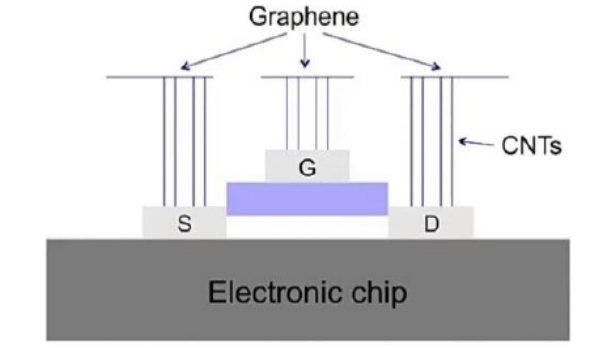

Figure 6: Graphene based interconnect wires [7].

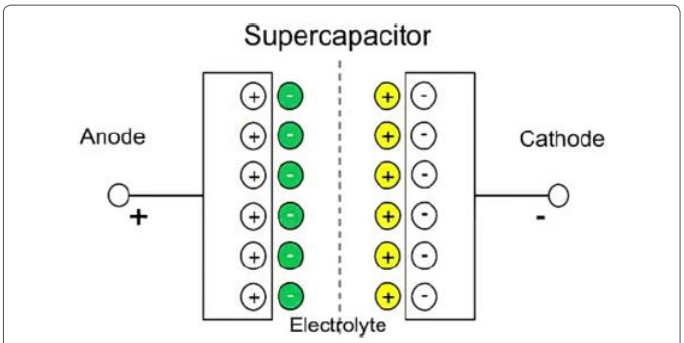

Figure 7: Super capacitors [13].

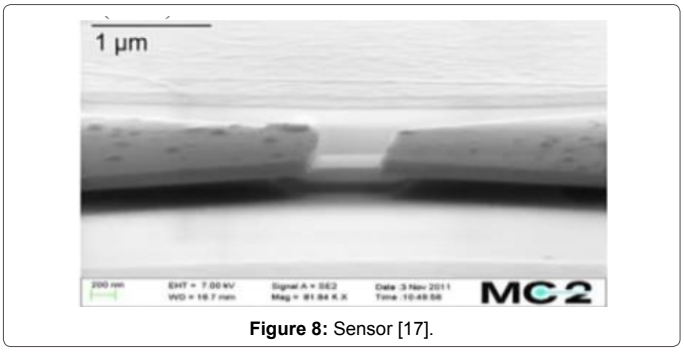

Figure 8: Sensor [17].

together extremely stronger, stiffer component. This material will use in future to make space elevator. The elevator which is connected to earth to space. It has 36000 km altitude. Means space travel without using rocket. In future it will be used to deliver a drug in body. It will use to impact drug directly inside the living cells. It will be a breakthrough for Medical filed (Figure 9).

Bio-applications

In future it will be used to deliver a drug in body [6-8]. It will use to impact drug directly inside the living cells. It will be a breakthrough for Medical filed (Figure 10).

Lattice of Monolayer Graphene

Different arrangement of atoms gives different play ground to electrons (Figure 11). Graphene's category is hexagon lattice which connect 1 atom with other 3 atoms (Figure 12). In Graphene there is no atom at center of hexagon. In Graphene atom A is connected with 2 B atoms at left side one is upper side and one at lower side and one atom at right side. B atom is connected with two A atoms at right side one at upper side and another at lower side and third atom at left side. This type of lattice is 'complex lattice' (Figure 13). If we observe only **A** atoms, it makes a hexagon lattice, Which can visible in above figure. One set of sub lattice has hexagon structure with one center. It called as Probe lattice. In above figure we can see that there are only two atoms. One is atom A and another is atom B (Figure 14).

Why only 2 A. carbon atoms are there?

The carbon has 6 electrons. Electron nearer to nucleus has low energy and high energy electron in outer orbits. Arrow shows the spine of electrons [9]. There is space for 4 electrons in second orbit. Electrons are connected with covalent bond. There is main two type of covalent bond, one is π bond and another is σ bond. π bond is intersecting for Graphene (Figure 15 and Table 2).

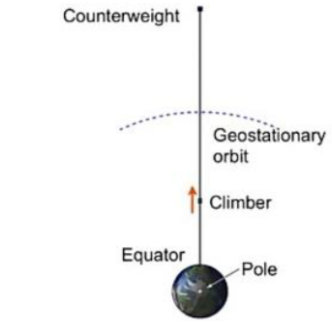

Figure 9: Space elevator [19].

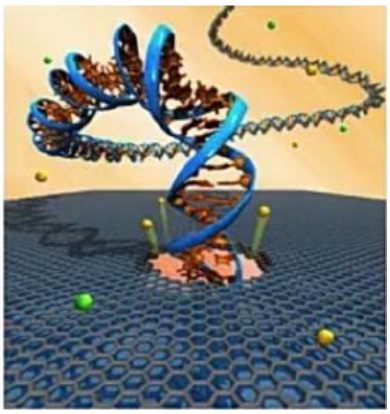

Figure 10: Graphene impact drug on live cells [18].

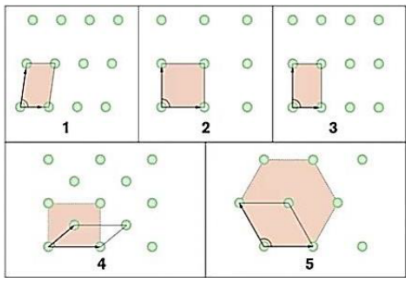

Figure 11: Lattices for 2-D material [20].

σ bond	[] bond
Heavily overlapped	Slightly overlapped
Stable, not very reactive	Unstable and reactive
Head to head connection	Shoulder to shoulder connection

Table 2: Covalent bonds.

Hybridization of Carbon

Hybridization is denoted as SP^1, SP^2, or SP^3 (Figure 16).

Why atoms perform hybridization process?

Because of hybridization process energy of electron reduces so atom become more stable. After hybridization Graphene become SP^2 $2P_z^1$ and Diamond become SP^3 (Figure 17). Graphene make 3 σ bonds (which are strongest bond) with angle of 120° other $2P_s^1$ are localized bond. It is to share electron with other atoms. It is the reason for more conductivity. If we make more layers than it make Vanderwall bond with each other and it became graphite [10-12].

Lattice staking graphene to graphite

1. A-B-A stacking = 1.42°A

2. A-B-C stacking = 1.42°A at right and 1.42°A at left too (Figure 18).

K-Space

To understand different properties of solid materials, it difficult with Spherical space (space of x, y, z dimensions). For that we have to take different space, we have to assume one space which known as K-space. In K-space $K = 2\pi/\lambda$, is the (circular) wavelength, K is the vector (Figure 19).

K = Unit 1 over length and K space = moment space.

Graphene's periodic lattice

K space is use to do study of different properties of Graphene. There is two lattice one is direct lattice another is Reciprocal lattice. When we rotate direct lattice at 90° angle it become reciprocal lattice. Atom, at the center is known as super lattice. The corners which we can see in the above figure are not part of the Reciprocal lattice (Figure 20).

Why Graphene is conducting the current?

Electron always tries to stay at low energy state. On the basic of this property of electron some materials become conductor or semi-conductor, some of them are insulator. It is also depends upon the band gap. Delivery of electrons depends on the rule, first come first served. Electrons with higher energy level are at the outer orbits. It is known as Fermi level (highest occupied electrons energy level) (Figure 21).

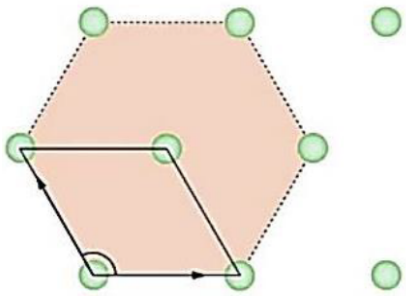

Figure 12: Graphene Structure [20].

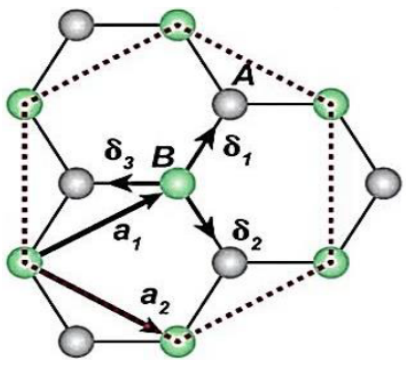

Figure 13: One set of sub lattice [20].

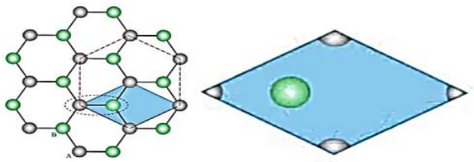

Figure 14: Primitive unit cell [20].

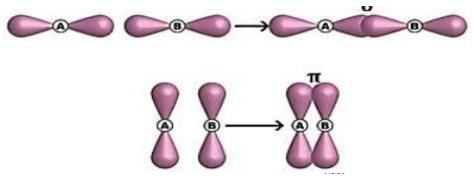

Figure 15: Covalent bonds [22].

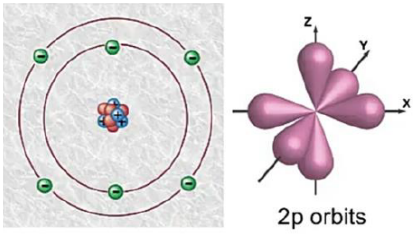

Figure 16: Carbon hybrid orbits [20].

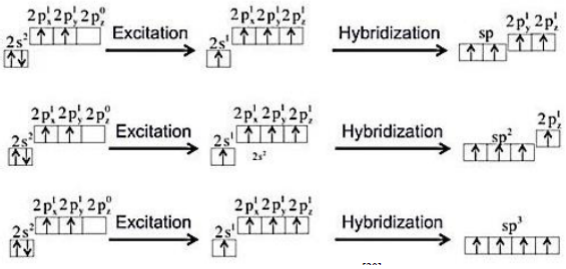

Figure 17: Hybridization [20].

There is to type of band. One is energy band and another is forbidden band. Energy band are allowed band and forbidden band are not allowed band [11-15]. Forbidden band is sandwiched between two energy bands. Highly full occupied allow band is valance band and first allowed band about the valance band is called as conduction band. On the basis of these bands we can differentiate conductor, semi-conductor and isolator in different category.

Metal: Valance band and conduction band partly occupied.

Semi-metal: Valance band and conduction band are touching or having overlaps.

Insulator: Band gap occupied at all Insulator.

Semi-conductor: It has small band gap, Electron may exit from valance bond to fill the gap of conduction bond.

For net current we need to fill band partially. When, m atoms come closer to form a solid, one energy level split into m levels (Figure 22) [16]. Upper side there are conduction band and lower side it is a valence band. SP^2 electrons are connected with σ bond 2 other bond for electric conductivity. Both bands are touches at Fermi level. Graphene is conductor with zero band gaps. If we add electrons than it go up to Fermi level, it create N type Graphene. If we remove electron than graph goes beloved the Fermi level, it create P type Graphene. Graphene has linear Dispersion (Figures 23 and 24).

Unique linear energy dispersion

- Liner dispersion with approximately ± 0.6 eV.
- Massless Dirac particle with (Effective) rest mass = 0.
- Special theory of relativity plays a role.
- Unusual properties of quantum electrodynamics can be observed at much smaller speed.

Photon has linear dispersion. Graphene atoms are act same like a photon atoms but at lower speed [17-19]. It is properties of quantum electrodynamics where relativity effect can be observe without need to accelerate the particle to close speed of light. Graphene is good for a study of relative effect. Graphene is a semi-metal with no overlapping.

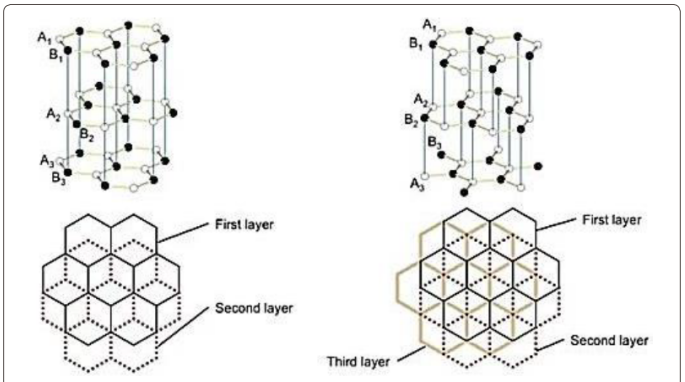

Figure 18: Lattice staking Graphene [20].

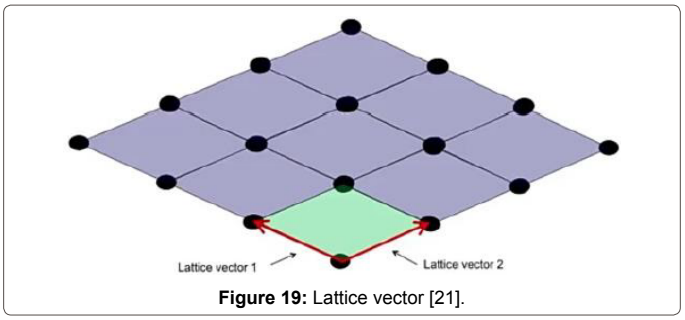

Figure 19: Lattice vector [21].

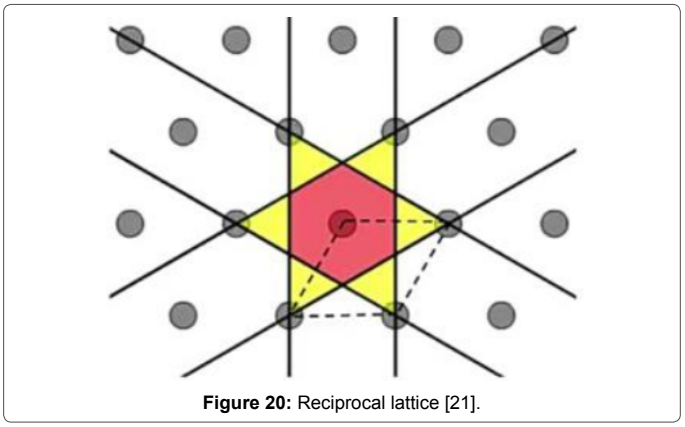

Figure 20: Reciprocal lattice [21].

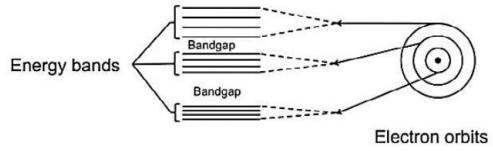

Figure 21: Energy band gap.

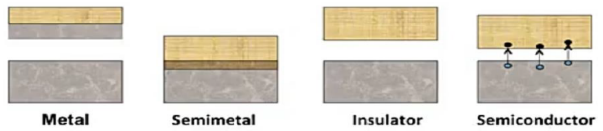

Figure 22: Metal, Semi-metal, Insulator and Semi-conductor [22].

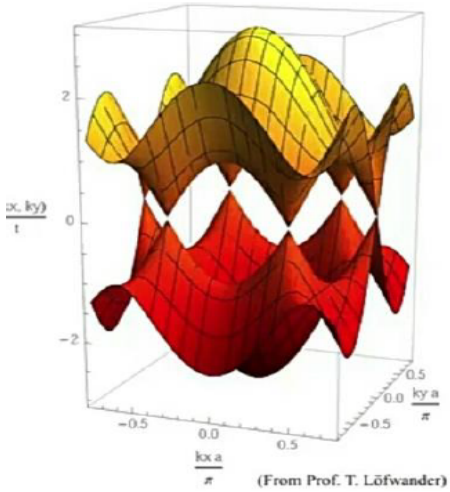

Figure 23: Energy band gap of Graphene in K-space [21].

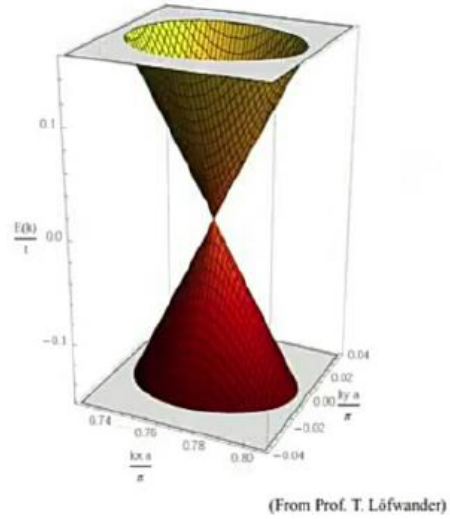

Figure 24: Linear dispersion of Graphene in K-space [21].

Advantages of Graphene

- Extraordinary properties in one material
- High potential in both, fundamental studies and application
- Abundant raw material carbon: Cheap, eco-friendly and sustainable.
- Planer structure that is compatible with traditional semi-conductor takes place of silicon.
- Much stronger material than steel [20,21].

Challenges of Graphene

- High prize at this moment (1 cm^2 = 3700 rupees).
- Sensitive to environment with no effective passivation but has only 10 year history.
- High quality thin films still lacking of reproducibility.
- Large scale transfer of films still irreproducible.
- Sheet resistance still too high.
- No band gap which a transistor requires, (so turn off problems) [22].

Conclusion

Nearest in future, Graphene will take over most up places of the other materials. It will be the most useful material in every filed. Above all examples are just begging of the list where Graphene will be used in future. After the solution of the challenges it will be an undefeatable material. So here I conclude that the most of problems which are accurse because of Size, Strength, Conductivity, Transitivity. That all problems can solved by the use of Graphene. Medical filed, Space elevator, Transistor of Integrated Circuits, Heat Spreader & Interconnect Wires of IC, Transparent Conductor in Optoelectronics, Energy Applications, Sensors, Actuators, Graphene composites all become more effective after the use of Graphene.

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