Application of Graphene in Solar Technology & Comparison of Graphene Solar Cell with Silicon based Solar Cell with respect to Efficiency.

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Abstract - *Graphene an atom thick 2-Dimension material derived from carbon which has excellent electron mobility; graphene absorbs 2.3% of light when it is a single layer, 97.7% of light passes through graphene's layer and it is 200 times stronger than steel. Due to its properties, it has a promising efficiency of 15-20%, be it in regions with high insolation or very low insolation compared to the popular silicon-based PV cells whose efficiency is 13-16% and needs proper insolation conditions. Clear graphene electrodes can also take the place of indium tin oxide in solar photovoltaic applications while making PV cells efficient and easily available. The ability of graphene to charge up its electrode when the salty rain water drops on cell makes it capable of circulating electron even during a rainy day. However, the maintenance of graphene-based panel would not be requiring because it is a self-healing material and there will be no gradual decrease in efficiency due to its chemical properties. The challenge now remains in production of cost-effective graphene. The current market value of 1X1 inch graphene sheet is $180 in other words; a highly efficient graphene sheet of size 10X10 mm is $380. This paper focuses on production of cost friendly graphene and on increasing panel efficiency using graphene in solar cell while comparing it with the silicon-based PV cells.*

Key Words: Carbon, Graphene, Silicon, Inexpensiveness, Thin film solar cell, Efficiency, PV Cell, Sustainable Energy.

1.INTRODUCTION

For a decade now harnessing clean and affordable energy has been the only lookout for the energy engineering firms and institutions. many recent devices have emerged resolute generate effective and efficient energy so on provide clean green energy. Sun is that the direct source of energy which is safe, clean, and abundantly available which does not pollute the environment or harm the living beings. Materials which are photo sensitive are ready to harness the daylight and convert it into required current which is believed as photoelectric effect. India contains a vision of going all clean with their energy production from 2022, energy is additionally one in every of the foremost important and reliable energy to supply clean and affordable energy.

Graphene, a 2D carbon material, where carbon atoms arranged in a hexagonal lattice like structure, exhibits rare electrical, mechanical, electronical, optical and thermal properties that are giving birth to new innovations [1]. Within last 2 decades, research on graphene for its optical and electronical properties is escalating [2]. Graphene or Graphene - based materials are researched widely in photovoltaic industry for its unique properties related to band gap, mechanical properties, optical properties, electronic mobility, etc. Popularly studied graphene derivatives are graphene oxide - GO and reduced graphene oxide rGO.

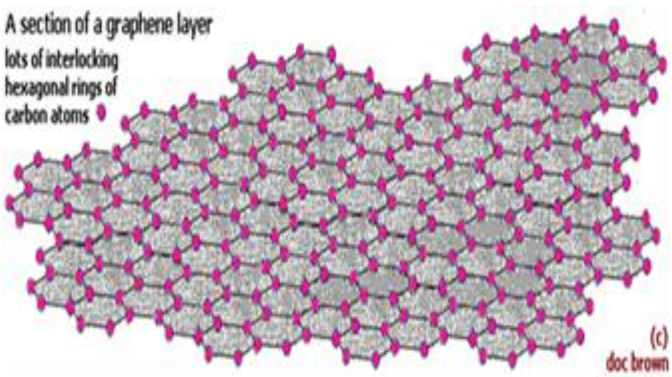

Fig -1: A Section of Graphene Layer

At present, variety of techniques are advanced for the extraction of graphene. The well iked method is chemical vapour deposition (CVD) few other methods are laser and supersonic sheet. Also, since graphene is just one atom thick material the exfoliation of graphene is much more exhausting process and the conventional methods doesn't work. Layers of graphene is critical to grow using a substrate. [3]

Currently, chemical vapour deposition method is widely used in research, academia and industry to extract graphene. [4] UV and IR regions are also included in graphene's spectrum band which is an advantage to the photovoltaic world. The need of graphene is increasing as the world energy consumption is escalating day by day due to expanding industrialisation and revolutionization of green energy consumption, graphene based solar panel can efficiently aid the energy creation process through its eco-friendly and low-cost fabrication which can gave a tough competition to present day silicon PV modules. [5]

Carbon atoms are covalently bonded in graphene. It is by 3 sigma bond and 1 pi bond. The out of plane pi-bond is in command of free electrons and also the electronic conduction of graphene. Among all the properties of graphene, its electronic property is most significant. In graphene, the pi-pi connection of carbon atom where valance and conduction band meet at 6 Dirac point is the reason for its best electrical property. Graphene is on among the rare semi-conductor which has zero band gap within which the charge carrier exhibits a linear electronic dispersion within the vicinity of the Fermi energy. [6] Top-down and bottom-up approaches are the methods used to extract graphene. Beginning material is graphite in top-down process and therefore the moto is to extract it in the form of sheet.

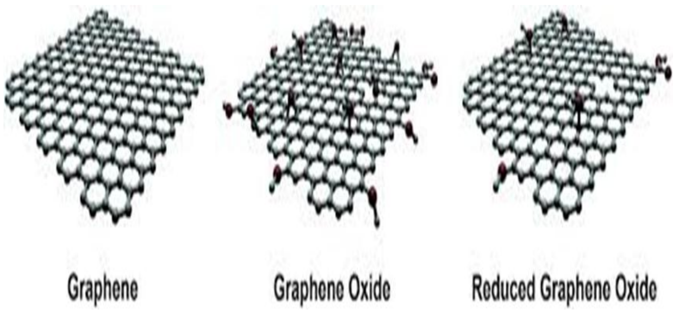

Fig - 2: Different Layer of Graphene

Graphene displays extravagant properties, every atom in Graphene is available for chemical reaction which makes it unique from all the other carbon elements. Graphene blazes at a lowest temperature of 340° C - 350° C. Graphene is an excellent conductor when compared to copper it is a million times better conductor. It is a zero-gap semiconductor to name few properties. Graphene displays assemblage of charge carriers at room temperature (up to 1013 cm-2) with electronic movement of 1*104 cm2 V-1s -1. But the electronic mobility increases to a range of 2*105 cm2 V-1s -1 at lower temperature. [7]

1.1 Preparation of Graphene

Graphene on industrial scale is produced by exfoliating graphite or Chemical Vapour Deposition (CVD). Top approach of preparation of graphene finishes up in defects, while corrosion of graphite to graphene oxide gives rise to exfoliation, the strategy requires raspy oxidation agent and it leaves the graphene with an imperfect hole structure after the reduction process. For chemical vapour deposition (CVD), bottom-up approach of good quality graphene is typically confined to ultra-small amounts, or it provides a defect-ridden structure if allotted in bulk solution.

Another method of production of graphene which is additionally eco-friendly was introduced by Rice University in January 2020 which is believed as Flash Graphene (FG). Flash joule of carbon rich materials like disposed food products, ash, bio char, plastic waste etc. can generate gram scale quality of graphene within a second. Flash Graphene method is eco-friendly, uses no gases or any chemicals during the strategy. the strategy shows turbostatic arrangement between the stacked graphene layers. The graphene production depends on carbon content present within the fabric used. When carbon rich material like sawdust, C and straw are used, purity of carbon is almost 100%. Purification process isn't required just in case of this method. [8]

Raman spectroscopy shows a less intensity for Flash Graphene or in fact absent D band for Flash Graphene, this suggests that Flash Graphene has rock bottom defect, it also confirms the turbostratic stacking of Flash Graphene, which means: carrier mobility is shown in multi-layer graphene. The unorganized orientation (arrangement) of Flash Graphene layers avails its fast exfoliation which is resulted by mixing during composite formation. The average voltage for Flash Graphene method is 7.2 kilojoules per gram (approximately), which makes it able for Flash Graphene is sustainable method of graphene extraction another advantage is that plastic can be used to extract graphene in flash graphene process. [9]

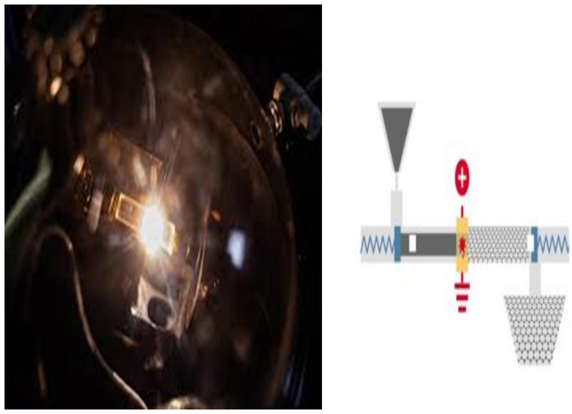

Fig - 3: Flash Graphene Method

Method: Flash graphene is formed by heating carbon rich material to 2,726°C for 10 milliseconds. the material could even be anything but with carbon content in it; material, plastic, coke, coal, wood clippings, sawdust, straw and bio char etc. With this price of 1X1 inch graphene sheet which is $180 in other words; a highly efficient graphene sheet of size 10X10 mm is $380, the prospects for this process look superb and cheap [10]. this will be often how the “flash graphene” technique can convert trash to useful material, to stay with Rice University [11].

Following are the Carbon-Nitrogen ratio of carbon-rich materials: Leaves, Legume Hay, Non-Legume Hay, Straw, Paper & Cardboard, Sawdust, Wood Ashes and Low Ground is 70:1, 15:1, 30:1, 80:1, 200:1, 400:1, 25:1, 20:1. Grass Cuttings, Kitchen Waste, Eggshells, Tea Bags etc are few other carbon-rich materials.

Fig - 4: Carbon-Rich Material

These materials are associated with dryness and rigidness. Every sort of mature plant-based material is considered carbon-rich because of the high level of carbon content. The other terminology for carbon-rich material is mature material. [12]

1.2 Graphene Based Solar Cell

Graphene in solar cells is specifically used to create transparent, flexible, conductive electrodes since graphene has high optical transparency; the amount of light intensity absorbed is as less as 2.3 % which is not dependent on the wavelength. The number is given by π and α, and α happens to be the fine structure constant. Therefore, there is no colour in suspended graphene, it is colourless. Graphene has an outstanding electron mobility at room temperature (i.e. more than 15000 cm2V−1s−1). Hole and electron mobility are almost equal (identical). The mobility is almost not dependent on temperature (i.e., in between 10 K and 100 K), which means that the dominant scattering mechanism is defect scattering. Since graphene is transparent, it decreases losses due to gridding electrodes. In momentum space there are six location which are known as Dirac points, the Brillouin zone is divided into 2 non-equivalent sets of 3 points, which are known as K and K'.

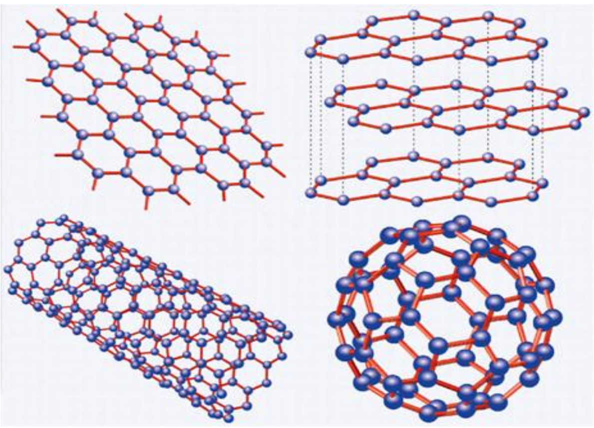

Fig - 5: Optical & Photonic property of Graphene

Generation of high photo-current on G/Si junction is limited due to transparency and excitons having short lifetime of graphene. In graphene and silicon, the junction is much thinner than that of the normal p-m junction solar cell. It is essential to dominate the thickness in graphene to monitor its function and for efficiency purposes. The thickness of graphene matters as the photoactive layer can increase its absorption with increase in thickness. Previously, M. Czerniak-Reczulska et al., in their research of thickness in graphene have implemented layer-by-layer shift of 1e4 sheets to scrutinise the efficiency on pure silicon, but their efficiency was limited to 1.48% [13]. Slacking up layers of graphene doesn't help with efficiency due to low transparency.

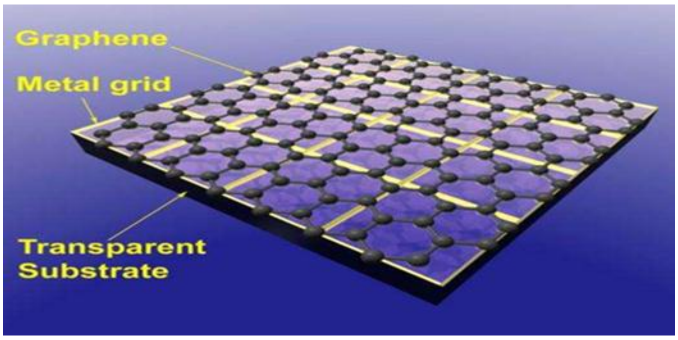

Fig - 6: Graphene Solar Cell

Dye-sensitized solar cells are most coherent when coated with a layer of graphene which is structured by The Ocean University of China in Qingdao and Yunnan Normal University in Kunming that gets triggered by both sunlight and raindrops. Rain isn't pure water, because it contains salts that dissociate into positive and negative ions. The positively charged ions, can bind to the graphene surface (Lewis acid-base interaction). [16]

When rain drops on graphene dye sensitised solar cell, the water becomes rich with positive ions and graphene becomes rich in delocalised electrons. This ends up in a dual-layer made of positively charged ions and electrons. Voltage and current is produced with the potential difference with this phenomenon. [17]

Fig – 7: Illustration of Graphene Solar Cell with Raindrops on It

Solar cell can produce an average efficiency of 6.53% under sunlight as well as a hundred of microvolts voltage by being charged up by raindrops. But with only a 6.53% light/water electricity conversion rate, the graphene dye sensitised solar panel are far from perfect. Now a day's classic solar panels have a 15% efficiency. The best panels, which are still in laboratories, have a 22% efficiency [18].

1.3 Parameters Characterising Solar Cell

There are various parameters that attributes to the functioning of solar photovoltaic cell. Few important ones are, Open - Circuit Voltage (Voc) [V], Short Circuit Current (Isc) [A], Maximum Power [W], Maximum Voltage (Vm) [V], Maximum Current (Im) [A], Fill Factor (FF), Power Conversion Efficiency η = PCE [%], Stability in Air.
Standard Test Conditions, Radiation = 1000 W/m2, Cell Temperature 25°C, no wind, Air Mass = 1.5
The basic characteristic defining the important parameters of a photovoltaic cell is current - voltage characteristic. Short Circuit Current and Open Circuit Voltage can be read with this characteristic. Further, determination of the current Im and the voltage Vm for maximum power cells can be done.
Fill factor (FF), the maximum power (Pmax) or cell efficiency (η) are all associated with above mentioned terms. The maximum power of the actual cell is always smaller than the cell's power ideal, equal to the product of open circuit voltage and short circuit current.

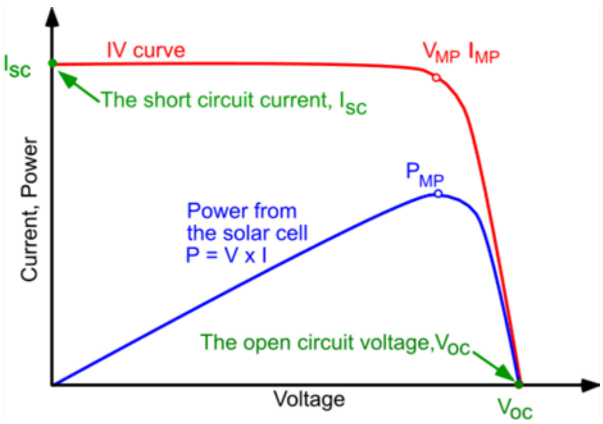

Fig - 8: Characteristics of voltage-current of solar cell

Fill Factor = (Vmax* Imax)/(Voc*Isc) (1)
POE = (Voc*Isc*FF)/Pin (2)
The POE can be defined as the fraction of incident solar light power (Pin) converted to electricity
Ƞ = (Im*Vm)/(J*S) (3)
Short-circuit current density (Isc) allows comparison between devices whose dimensions may vary.

2. Comparison of Graphene Solar Cell with Silicon Solar Cell

i. Silicon Based Solar Cell

The polycrystalline silicon based photovoltaic module is used in this experiment. The open circuit voltage and the short circuit current at different time intervals along with panel temperature and solar insolation are noted as on 21st & 22nd January 2020 at 15.3647°N location. The ambient temperature was 28°C on 21st January 2020 and 27°C on 22nd January 2020. The panel temperature and solar insolation on panel is determined using a pyrometer. A multimeter is used to determine the open circuit voltage and short circuit current.

Table -1: Panel Specification

Maximum Power	250
Tolerance	+/- 3%
Air mass	1.5 AM
Solar Cell Temperature	25°C
Solar Irradiance	1000 W/m^2
V_m	31.05 V
I_m	8.44 A
Dimension	1.9m x 1.0001m
Operating Temperature	-40°C to 85°C

Table – 2: Parameters of a panel measured at 15 minutes time interval as on 22nd January 2020.

Time	**Voc**	**Isc**	**W**	**°C**	**W/m2**
11:15	30.64	7.398	226.675	36.1	732
11:30	30.43	7.415	225.638	37.5	821
11:45	30	7.432	222.96	39.2	870
12:00	30.09	7.442	223.93	40	900
12:15	29.95	7.447	223.038	41.8	959
12:30	29.82	7.448	222.099	43.5	922
12:45	29.97	7.449	223.247	44.8	885
13:00	29.84	7.449	222.278	44.1	960
13:15	29.77	7.43	221.191	44.7	865
13:30	29.83	7.43	221.637	43.6	955
13:45	29.65	7.42	220.003	45.5	947
14:00	29.67	7.41	219.855	47.2	980
14:15	29.81	7.39	220.296	50.1	960
14:30	29.66	7.37	218.594	48.3	848
14:45	29.8	7.36	219.328	44.8	753
15:00	29.75	7.34	218.365	42.3	742
15:15	29.8	7.32	218.136	43.3	702
15:30	29.79	7.29	217.169	40.6	518
15:45	29.61	7.27	215.265	43.7	556
16:00	29.86	7.24	216.186	35	460
16:15	29.75	7.211	214.527	35.8	408
16:30	29.54	7.17	211.802	35.2	355
16:45	29.55	7.141	211.017	32.6	235
17:00	29.39	7.116	209.139	33.7	252
Average:	**29.8321**	**7.3495**	**219.266**		**732.708**

Therefore, the fill factor and efficiency of the panel can be calculated as,

Fill Factor = (Vmax* Imax)/(Voc*Isc) from Equation (1)

Fill factor = 0.73

Ƞ = (Im*Vm)/(J*S) from Equation (3)

Ƞ = 13.7 %

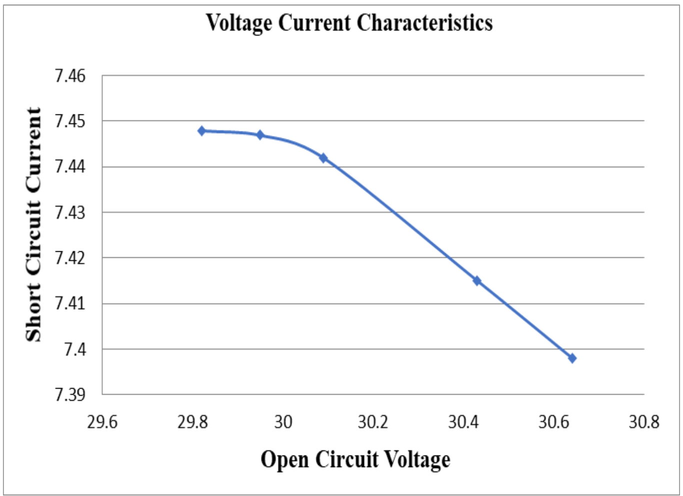

Chart -1: Voltage Current Characteristics of Silicon Based Cell

ii. Graphene Based Solar Cell

In recent times, the number of research articles containing graphene based solar has increased. However, it is tedious to translate the research work into practice. Even though graphene solar cells are under inspection and experimental stage, the conversion efficiency of graphene solar cell is higher than that of silicon solar cell i.e., 17%-20%. The principle of these graphene solar cell is not very different form the regular popular PV cells produced these days. The only contrast is that some of the materials which are currently used are replaced with graphene material. Similar to that of few other devices, there are numerous parameters that can refine the characteristics and increase conversion efficiency. Graphene material has exceptional agreeable adaptability. Two parameters can change the efficiency of the solar panel, i.e., the character of graphene solar cells changes with respect to the number of layers of graphene in the device and the doping effect of a graphene material. Malik Abdul Rehman et.al, conducted an experiment using graphene based photovoltaic module by varying its thickness to check the material's transmittance. The end result hints that 2 nm thin graphene has very high sheet resistance 4.17 kΩ/sq. In the case of 4 nm, there is almost three times decrease in conversation efficiency. Therefore, consistent with Malik Abdul Rehman et.al, the transmittance is more when the thickness of the material is less. And when the transmittance is high the efficiency is less [14]. With 8nm of thickness, the transmittance is 58.6 and the efficiency is 19.78%. [15] scientists form Spain and the United Kingdom have developed a solar cell with graphene in it which is a nanocomposites graphene – perovskite titanium dioxide. The cell consists of layers of graphene flakes and pre synthesised TiO_2 nanoparticles, whose conversion efficiency is 15.6% for temperature lesser than 150°C. [3] This turned out to be an achievement as it is the highest reported conversion efficiency of perovskite solar cell.

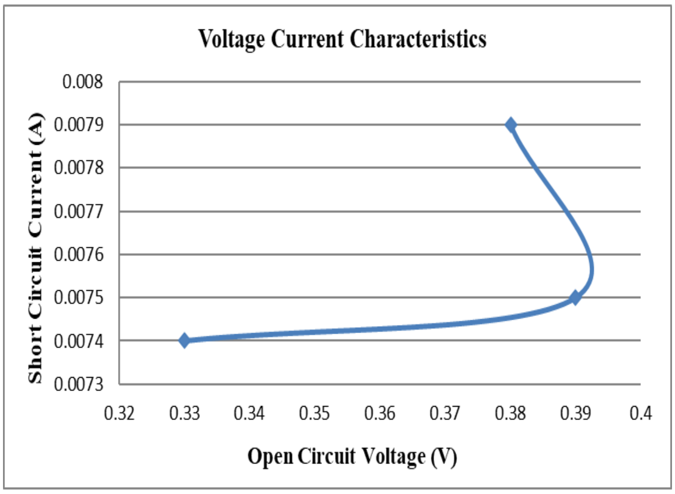

Chart -2: Current Characteristics of Graphene Based solar Cell with respect to material thickness [2].

3. CONCLUSIONS

Graphene being a unique material with extraordinary optical, electrical & thermal properties is a boon for the millennial generation. Graphene based research in various research fields is at the top notch. In this work, the preparation of inexpensive graphene is illustrated where any carbon rich trash can be converted into graphene in 10 milliseconds using the Flash Graphene method by heating it at 3000K. Silicon based solar panel efficiency and Graphene based solar panel is been compared and following is the result, the silicon panel has an efficiency of 15 % and the graphene based solar panel promises +3% efficiency with 2nm thickness. The transmittance of the panel depends on the thickness of the material and the transmittance is accountable to panel's efficiency. Finally, the raindrop property of graphene dye sensitized cell is reviewed. The future of renewable energy can be revolutionised by inculcating graphene in energy engineering as graphene is one promising material to explore on.

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