Graphene Application as Solar Cell: A Review

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Abstract: Owing to its unique properties, Graphene, a one dimension honeycomb crystal, has emerge as futuristic material for electronics applications. Graphene has capability to replace silicon industry. In present scenario, Graphene has potential to replace other conductive transparent device and gained an exceptional opportunity to work in the energy industry.Graphene has been combined with photovoltaic material over the past years and has a very important role to play, in solar cell because of its electronic property. As a solar cell, Graphene has proved very energy efficient, cheap material. Graphene has found application in all type of solar cell e.g. organic, dye synthesized, Schottky, pervoskite solar cell and has enhanced parameters of these solar cells. This review article aim to present a brief review of Graphene and its applications in solar cell.

Index terms: Graphene, transparent conducting oxide, CVD, pervoskite solar cell, organic solar cell.

Introduction

Among the most renewable energy sources such as solar or photovoltaic cells, wind, biofuels, etc. solar cells are the best source of energy because they directly convert daylight into electricity without polluting the environment. In nature, carbon is the only material having allotropes in zero, one two and three dimensions Zero dimensional allotropes is fullerene, one dimensional is carbon nanotubes, two dimensional allotrope is Graphene and three dimensional allotrope is in form of graphite and diamond. Recently the two dimensional allotrope known as graphene has grown much interest among researchers. Graphene being a sp2 hybridized carbon atoms arranged in honeycomb structure have remarkable electronic, optical, mechanical and thermal properties. In 2004 a group of Andre Geim and Konstantin Novoselov british and Russian scientists. Managed separate graphene consisting of a single layer of carbon atoms forming the structure of the honey comb [1]. It consists of carbon atoms bouncing together in a network of hexagons repeating in a single plane only one atom[2-5]. The technique of cleavage led directly to the first observation of the irregular effect of the quantum hall in graphene[6],[7] which provided direct verification of the theoretical effect of graphene that was reported by the group of geim and by kim and zhang, whose papers appeared in 2005. Geim and novoselov, especially in 2010 noble prize in physics, received awards for their original research on graphene [8]. Single layer graphene has transmittance of 97.6 % and with free standing graphene showing charge carrier mobility up to 25,000 $cm^2V^{-1}s^{-1}$. These exceptional electronic and optical properties makes Graphene as a promising candidate for solar cell. Graphene mixed with other nanomaterial can enhance their properties used in solar cell. Now a days in the most of solar cell indium tin oxide (ITO) is used as transparent conducting oxide electrode. ITO has limitation due to lack of Indium in nature. Graphene is a good candidate to replace ITO due to its high transmittance and electrical conductivity. In recent, graphene has found application in different type of solar cell e.g., organic, pervoskite, dye synthesized and Schottky solar cell. There was a contrast between special designs of solar cells using graphene to examine which design of solar cells could be the best alternative to the current solar cell based on silicon in the future. For decades, highly efficient solar cells have also been the centerpiece of scientists worldwide in conventional semiconductor p-n junction based solar cells, structures based on noble metal nano-particles, automobiles. Based on graphene/silicon Schottky diode, the honeycomb connection of carbon atoms by covalent bond in a macroscopic two-dimensional extent has been widely considered . however, the solar cell graphene/GaAs was hardly explored. In photovoltaic devices such as organic solar cells(OSCs), dye-sensitized solar cells (DSSCs), perovskite solar cells(PSCs), and thin film solar cells(TFSCs), the advanes of graphene-based materials are constantly reviewed with their working principles, cell patterns, and current issues and possible instructions are provided in energy exchange applications for further research work on graphene-based materials. This article begins with a brief introduction of graphene and then review about its application in different type of solar cell.

Graphene

Graphene is a two dimensional carbon allotrope consisting of a single carbon atom layer arranged in a hexagonal mesh. This is a combination of hans-peter boehm[9] graphite andene which saw a single layer of carbon fossil in 1962[10]. Every carbon atom has four ties :- a single σ bond with each of its three neighbors and a plane oriented π bond [11] it is zero gap semiconductors because at the Dirac-points it meets its conductive and valence bands. Graphene nanotubes may reproduce asbestosis effect[12][13] Graphene properties depends on its size, shape, purity, oxidative state, functional groups, methods of synthesis, direction. It is really a material that could change the world, with unlimited mixing potential in nearly and industry. Graphene is very exciting material, but it's not easy to produce. Several companies are producing graphene today and a lot of research is being carried out into rising new traditions in order to generate mass in a cheap way. Most of the graphene currently formed is used in universities and businesses for R&D. some products based on graphene enter the market, but graphene mass production has not yet been achieved.

Graphene Synthesis

The development of graphene synthesis includes exfoliation, chemical synthesis & thermal chemical vapor deposition (CVD).AFM cantilever was found capable of manufacturing monolayer to few layers of graphene in mechanical exfoliation, but this technique is becoming insignificant. In nanotechnology, this is a peak-down method by which a longitudinal or transverse anxiety is formed outside the covered arrangement equipment. It is a process that is secure and easy. The likelihood of dirt in the graphene thus obtained is lower, but its disadvantages is that the remains of tape do not affect the value of graphene flakes samples, it makes these samkples more complex to discover on the substrate. By inserting bulky alkali ions between the graphite layers, solution detached graphite is exfoliated in chemical exfoliation method. Chemical synthesis is the comparable procedure consisting of graphite oxide combination, dispersion in solution, followed by hydrazine reduction. It is a process of low temperature that makes the production of graphene synthesis method. In CVD method, the most important process for the manufacture of large-scale graphene is to replace Si with metal oxide semiconductor technology. It produces high value and clarity graphene films, but due to the unstable environment of the originator gases, the by-products created during the reaction may be poisonous. When a resistive heating system passes the thermal CVD method, it is known as thermal CVD and when the process consists of plasma- assisted growth, it is known as plasma-enhanced CVD or PECVD. The thermal CVD method is the best method to grow centimeter scale graphene that can be transferred over a wide variety of substrate.

PROPERTIES OF GRAPHENE

Electrical conductivity

It has a very high conductivity zero-overlap semimetal. There is a total of 6 electrons in carbon atoms; 2 in the inner shell and 4 in the outer shell. Graphene's electronic properties are dictated by the pi orbital's bonding and antibonding. Due to their lack of mass, graphene electron acts like photons in their mobility. These charging carriers can travel in ballistic way, upto sub-micrometer distances without deviating. The limiting factors, however, will depend on the quality of the graphene and substrate used. Being ambipolar single layer graphene has both hole and electron as carrier.

Mechanical strength

Graphene is the longest material ever found because of the strength of its 0.142 Nm long carbon bonds and ultimately 130 gigapascals of tensile strength compared to aramid. Strong and very light, it's unexpected. It's the most thin material. Improved production techniques, finally reducing costs and difficulty. The sheets of graphene are very elastic. Up to 20 percent of its original length can be stretched. It's more difficult than diamond. It has toughness of breakage. Zhang et.al [14] have developed an in situ micromechanical testing device and a nanoindenter to determine the fracture toughness of CVD synthesized Graphene within a scanning electron microscope.

Chemical properties

Graphene is carbon's most reactive form. Graphene is only a form of carbon in chemical reaction exposure. At very low temperature, it burns. It has the highest edgy carbon ratio. Graphene chemical properties can be modified with functional groups of oxygen and nitrogen.

Thermal properties

Graphene is a thermal conductor in its entirety. Its thermal conductivity, like carbon nanotubes, graphite and diamond, is higher than all other carbon structures. Graphene's ballistic thermal conductivity isotropic. Graphene was able to absorb unlimited heat. Thermal conductivity is effectively increasing. It is considered to be more tear-resistant than steel.

Solar Cell

Solar cell or photovoltaic cell converts light from a chemical and physical incident directly into electricity by a photovoltaic effect. photo means 'light' and voltaic means 'electricity'. Solar cells are also called photovoltaic cells or PV cells in an edge is called a solar panel, which can than be grouped into larger module groups to form a solar array. Solar cells provide cost-effective power supplies to people away form the main power grid. Current solar cell technology contains platinum based electrodes with at least two problems: - first are cost and the other one is less abundance of material for solar cell. There is a potential for graphene electrode design with graphene being an excellent conductor that would reduce graphene cost and weight and maintaining graphene efficiency as described by H. Wang et.al [15] dye-sensitized solar cells show efficiency of 7.8 percent which is 0.2 percent lower than a platinum based counter electrode, but make the efficiency of platinum baed electrodes develop at a small cost. Solar cell research has been generally slow for many years, however, graphene has just given the field the 'shot in the arm' it needed[16-20]. Some estimates of the common solar cells being sold currently comprise multiple silicon types, 90% of all solar cells being silicon. However, silica takes various forms. Due to the silicone molecules, the more efficient is the sunlight to become electricity. The most common type of solar cell consists of 95% crystalline silicon. But the most common type of solar cell is silicone. But two types, monocystalline and polycrystalline, are in existence. Their taint identifies monocrystalline also known as single crystalline cells . It's believed that it's made from a very clean silicon type. They are the most efficient in space. Solar panels made of monocrystalline cells are the most expensive of all solar cells, so polycrystalline and thin film cells are customers first choice from a deal perspective. The first solar cells ever introduces into production were polycrystalline solar cells, also known as polysilicon and multisilicon cells. In 1981, polycrystalline cells are not used for monocrystalline cells throughout the harsh procedure. Usually, the polycrystalline solar photovoltaic system operated at an efficiency of 13-16 percent, due to the fact that the material is less pure. Because of this reality, polycrystalline is less space-efficient, another drawback of polycrystalline is that it is less acceptable than monocrystalline; at high temperatures they do not perform as efficiently. The thin film solar cell without growth rates of around 60 percent between 2002 and 2007 is another future type of solar cell. The thin film solar cell industry accounted for roughly by 2011. Five percent of all market cells. For these reasons the constant growth of the thin film market. A big drawback is that thin film technology requires a lot of space and costs, and has a shorter life span than its glassy counterparts as evidenced by shorter warranties from the manufacurer. Thin film technologies that use different photovoltaic substances, including amorphous silicon, telluride cadmium, indium copper and selenide gallium. For different types of solar applications, each type of substance is suitable. Usually used for smaller-level applications, amorphous silicone thin film solar cells are equipment such as compact calculators, travel lights and camping equipment for remote use. A new stacking process involving several layers of amorphous silicon cells, but is still very costly, has brought about higher efficiency rates of up to 8 percent. Cadmium telluride is the only material of thin film that was viable with crystalline models of silicon. In fact, in recent years, they have been surpassed by some cadmium models in terms of cost-effectiveness. Levels of efficiency range from 9-11 percent. Copper indium gallium selenide cells have verified their most promising levels of efficiency varying from 10-12 percent, rather similar to crystalline technologies. These cells, however, are still in the growing stages of research and have been deployed viable on any broad scale.

Why Graphene is used as a solar cell

Graphene is known as a zero-gap semiconductor and has different physical and chemical properties. Therefore, Si has two times less electron mobility than graphene, making it super-conductive. Therefore, graphene also has exceptional optical properties and can be used in solar cells as translucent electrodes and interconnections between two sub cells. Graphene layers may be able to generate power form solar cells when it rains. With maximum strength, it is the slimmest material. It's extremely behavioral. It provides a potential increase in efficiency of up to 20%. In essence, the basic principle of a graphene based solar cell is not that different from the current silicon solar cells being produced today, except that some of the currently used materials are replaced by graphene deraviatives. The number of graphene layers in the device and the effects of doping a graphene based materials are the two clear parameters that can potentially change the nature of the device. The number of graphene layers in the device and the effects of doping a graphene-based materials are the two clear parameters that can potentially change the nature of the device. The basic principle of graphene-based solar cell is mainly not that special of today's silicon solar cells being developed, except that some of the currently used materials are replaced by graphene derivatives. There are parameters that can be improved to increase operational efficiency, as with any material or device. Graphene stands out in terms of flexibility and durability. The number of graphene layers in the device and the effects of graphene-based material doping are the two important parameters that can potentially change the nature of the graphene-based solar cell appliance.

APPLICATION OF GRAPHENE AS A SOLAR CELL

Dye Sensitized Solar Cell

It is special type of low-cost solar cell that converts visible light into electrical energy efficiently. It was invented by professor Michael Graetzel and Dr. Brian O'Regan in 1991, it is given the name because by absorbing natural light it limitates the photosynthesis process. The generation and separation of carrier in DSSC is processed in separate material, any type of dye is used to generate photo-carrier, at the same time semiconductor material is used to seperate these charge carriers. Due to low cost material and simple arrangements, DSSCs have a capable result for future energy concerns. They have potential to substitute traditional silicon based solar cells. With advances in semiconductors of nanostructure, sensitizers of high efficiency. The outlet of modern DSSCs is increasingly suitable. Even under low-light conditions like non-direct sunlight and cloudy sky, DSSCs can work. Thay are cheap, flexible, durable, lightweight, easy to produce and built from rich and smooth resource materials. Even under low sunlight flux, they have good efficiency. They produced plastic substrates on a thin film, flexible, robust. It is a major task to use graphene materials in DSSCs to achieve ecological consistency, non-toxicity and overall cost. They have plenty of opportunities, but they grows slowly. Zhang et.al have grown graphene based counter electrode with DSSCs and examined that annealing temperature of graphene nanosheet materials played a significant role in the value of graphene nanotube counter electrode and photovoltaic presentation of DSSCs and achieved a total conversion efficiency of 6.81% in full sunlight [21]. A color sensitized solar cell based on a photo anode of graphene TiO_2 arranged by a novel in situ [22], it was verified that the immediate reduction-hydrolysis procedure showed better photovoltaic performance with generally light conversion efficiency of 7.12 percent. Simone et. al. have verified a large spray-coated graphene ink counter electrode. Through liquid phase exfoliation of graphite in dimethyl formamide (DMA) and formed a graphene based ink, the efficiency of cm of the active area of dye-sencitized solar cell module was 3.5% [23]. Yang et.al have grown NiO/graphene composite and used for the production of the photo cathode for p-dye sensitized solar cell. The NiO/graphene combined with an appropriate amount of graphene over faster hole transport and better surface area than that of the plain NiO film, resulting in an increase in both photocurrent short-circuit and open-circuit photo voltages [24]. Graphene can enhance both light harvesting and charge collection efficiency of material. Tang et. al., [25] have used two type of graphene based material to improve overall efficiency of DSSC, graphene -titanate nanotube as efficient light harvesting material and graphene-TiO_2 composite as more efficient charge collector. As Graphene has high transmittance, it was found that transmittance of other material is not effected and power conversion efficiency have improved upto 6.46 and 7.53 %.

Pervoskite Solar Cell

Perovskite solar cell is a type of thin film solar cell. It is very efficiently solar cell as it converts ultraviolet and visible light to electricity. This type of solar cell uses composite prepared pervoskite, which is materials based on hybrid organic-inorganic lead or tin halide. Pervoskite solar cell have exhibited more than 22% of the efficiency. They have an exceptional crystallographic structure which makes them extremely efficient due to their low cost potential and capacity to generate energy. Pervoskite solar cell can be fabricated from general metals and chemicals from industry. Materials based on pervoskite could also be used to produce phtotvoltaic solar cell directly on glass or other materials, which would be cheaper than thin film solar cell production methods. In nature, the material is poisonous and will rapidly break down due to heat, moisture, snow,etc. contact. Solar cell efficiency of devices using these materials has increased form 3.8% in 2009 [26] to 23.3% in single junction architecture at the end of 2018 and 27.3% in silicon-based tandem cells [27] exceeding the maximum efficiency achieved in single junction silicon solar cell. Since then, pervoskite solar cells have the fastest growing solar technology [28]. Zhu et.al have reported on a significant increase in the power conversion efficiency of perovskite solar cells from 8.81 percent to 10.15 percent due to the insertion of the ultra-thin graphene quantum dot layer between perovskite and TiO_2[29]. In the last few years, pervoskite solar cells have been of great importance, moving from 9.7 percent power conversion efficiency [30] to 20.1 percent [31]. Wei et.al. [32] have used Graphene oxide as a hole conductor in inverted planar heterojunction pervoskite solar cells, and methyl ammonium lead halide devices as an absorber achieve more than 12 percent efficiency.

Quantum Dot Solar Cell

A quantum dot solar cell use quantum dots as the photovoltaic materials. The bandgap in the quantum dot can be tuned and used to create intermediate band gaps. With this method, the solar cell's maximum theoretical efficiency is as high as 63.2 percent. Graphene quantum dot works as a light harvesting material and becomes very important in the current energy crisis scenario, especially when solid sensitized solar cell devices become more reliable and continuous with regard to dye-based solar cells for an extended period of time. As Yan et.al have demonstrated, the graphene quantum dot has a great potential to be used as a sensitize for the solar cells. Because they are harmless, bio-compatible and low-cost, these quantity dots in solar cells may be the right choice as an alternative to compassionate sensitizing materials for ZnO [33]. Chen et.al. have displayed a novel solar cell architecture by incorporating thin graphene film into a solar cell that is sensitized to quantum dots. Quantum dot sensitized nanorods with a graphene layer have shown a 54.7 percent enhancement compared to ZnO nanorods without a graphene layer sensitized by a quantum dot. The filling factor was obtained as high as approx.62 percent[34]. Guo et.al. have explained a simple approach to create an original layered electron transfer system based on graphene/ quantum dot. The significantly better photo responses, especially photocurrent ones, have been achieved to confirm that graphene is a good aspirant for the collection and transport of photo charges generated, and the layered nano-film can provide a new and promising direction for the development of high-performance of light harvesting devices for solar cells of the next generations[35].

Organic Solar Cell

Conducting organic polymer or small organic molecule are used in organic solar cell with photovoltaic effect and charges transfer to generated in these organic molecule. They have low efficiency, cheaper, breakable, low stability, low weight strength, environmentally friendly, east to integrate. Compared with silicon based cells, organic solar cells can be produced simply, but organic solar cell have a problem of low stability. Researchers are currently working to improve the efficiency without sacrificing transparency using graphene in organic solar cells. The duration of solar cells is less than inorganic. In mobile charger, clothes with embedded cells are used organic solar cells. Park et.al have used as transparent electrodes in organic photovoltaic devices with a graphene sheets grown by chemical vapor deposition with controlled number of layers. It was found that the power conversion efficiency is comparable to their counterparts with indium tin oxide electrodes for devices with pristine graphene electrodes [36]. Wang et.al have worked on the concept of using TGFs as window electrodes in solar cells. The potential application of the solar cells is in an the field of flat-panel displays, diodes emitting organic light and other modern optoelectronic devices [37].

Schottky Junction Solar Cell

Solar cells based on silicon are on a stable uptrend. Due to traditional semiconductor equipment such as diffusion, the cell efficiency was generally better in the pre-time phase. Due to its large availability, non-toxicity and constant cell efficiency, the development of manufacturing infrastructure and the bottomless and general level of capacity available with regard to silicon devices, silicon is always the first choice. Significant improvements have been made in the mas making of high-quality wafers in recent years, the ability to switch slim wafers, maintaining high alternative carrier lifetimes, surface passivation, minimizing optical losses, classification of appliances and in additional area. They have a percentage of efficiency of about 20 percent on averages. Schottky junction is hetero-junction between metal and semiconductor. A built in field is developed nearby junction due to difference of band gap. Photo carrier are generated in semiconductor and are separated by this built in field. Graphene, a zero band gap semiconductor with high conductivity and transmittance can be equate to metal and a Schottky junction is fabricated on graphene-semiconductor interface. Early transparent conducting oxide such as ITO was used, yet graphene is a promising replacement of ITO as low availability of indium. S. K. Behura has investigated the hetreojunction silicon cell with chemically consequent graphene in an experimental and hypothetical manner, the stability study of graphene oxide and reduced graphene oxide in aqueous medium was conducted through graphical examination and surface load capacity, achieving an efficiency of 0.02%, open circuit voltage of 0.27 V [38]. A Schottky junctiona has formed on reduced graphene oxide and Si interface, the photo carrier generated in Si are seperated by this built in field. Lin el. al. have fabricated solar cells based on custom graphene and Si pillar arrays and found 7.7 percent improved cell performance [39]. Xie et. al have demonstrated the production of high-efficiency, air-stable graphene/Si hole array (SiHA) schottky junction solar cells. By increasing the depth of the hole, the SiHA's light harvesting capacity was significantly better, resulting in the most useful efficiency of 10.40% [40]. By doping of $AuCl_3$ the solar cell performance has been significantly enhanced with open circuit voltage of 0.60 V due to increase in work function of graphene. Jiao et. al. have showed that the most useful efficiency improved by >100 percent by introducing a GO interfacial layer between graphene and Si. Efficiency of solar cell has been enhanced upto 12.3 % by further treatment such as anti reflection coating etc. This simple method presents a new option for high-efficiency solar G/Si solar cells that could potentially open up new generations of high efficiency and low-cost solar cells [41].

Table 1: Different Solar cell characteristics with Graphene

Material	Type of solar cell	Efficiency (%)	V_{oc} (V)	FF (%)	Jsc ($mAcm^{-2}$)	References
NiO-graphene	Dye sensitized	1.31	0.90	33	0.19	Yang et.al[24]
TiO_2 - graphene	Dye sensitized	7.1	0.70	73.4	13.93	Chen et. al [22]
Pt- graphene	Dye sensitized	6.3	0.72	68	13.05	Hong et. al [42]
GSCT-P25-GTNT	Dye sensitized	8.6	0.74	54.9	21.3	Tang et. al [26]
ITO (indium-tin oxide)-graphene	Organic	1.17	0.41	0.48	1.0	Wang et. al [43]
TGF (transparent graphene constructed film)	Organic	0.29	0.38	0.25	0.36	Wang et. al [43]
Graphene oxide	Perovskite	11.11	0.99	0.72	15.59	Wu et. al [32]
GO-Li	Perovskite	11.8	0.859	70.3	-19.61	Agresti et. al [44]
Graphene- CdSe	Quantum	0.016	0.423	64.34	0.06	Sun et. al [45]
G/Si	Schottky	7.5	0.51	0.6	24.28	Xui et. al [46]
CVD- G/Si + HNO3	Schottky	7.72	0.515	66.0	22.70	Lin et. al [47]
rGO-Si	Schottky	0.02	0.27	0.11	12	Behura et. al.[38]

Conclusion

Solar power is becoming increasingly attractive as other methods of generation such as fossil fuels are increasingly under scrutiny. It increases the efficiency of solar energy conservation by using Graphene in different types of solar cells and also reduces the manufacturing costs that help preserve the environment and also helps rural people. For future large-scale solar energy converters, nano-crystal photovoltaic devices are becoming a viable contender. Large scale and size growth of Graphene solved by researchers and roll to roll production with successful transfer process of Graphene has been started.

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