Introduction of Solar Energy and Photovoltaic device

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Abstract

Solar is an electronic device which converts solar energy into electric energy by the photovoltaic effect. Photovoltaic effect is the physical and chemical phenomenon. Solar cell is the building block of the solar panel. The first generation of solar cell is silicon based and the next generation on thin film and nowadays used polymer based. Polymer based photovoltaic devices have attracted a lot of attention in the last decade due to their potential for application as flexible, renewable, non conservative energy sources. Since the discovery of photo induced charge transfer between organic donors and acceptors, a great effort has been devoted to explore these materials for photovoltaic applications. In this research chapter study the basic introduction and properties of solar cells.

I Introduction

The supply and stipulate of energy conclude the course of global enlargement in each sphere of human activity. Sufficient supplies of clean energy are intimately linked with global stability, economic affluence, and worth of life. Finding energy sources to convince the world's growing demand is one of society's foremost challenges for the next half century. The importance of this persistent difficulty and the perplexing technical problem of solving it, require a rigorous national effort marshalling our most advanced scientific and technological capabilities.

The world nowadays uses energy at a rate of about 4.1×10^{20} joules/year, equivalent to a continuous power consumption of 13 trillion watts or 13 terawatts (TW). Even with aggressive conservation and energy efficiency dealings, an enlarge of the earth's population to 9 billion people, accompanied by rapid technology development and economic growth worldwide, is projected to generate more than double the require for energy (to 30 TW) by 2050, and more than triple the demand (to 46 TW) by the end of the century [1]. The reserves of fossil fuels that currently power society will fall short of this stipulate over the long term and their constant use produces harmful side effects such as pollution that threatens human health and greenhouse gases associated with climate modify. The Alternative renewable fuels are at present far from aggressive with fossil fuels in cost and production capacity. Without viable options for supplying double or triple today's energy use, the world's economic, technological, and supporting horizons will be severely limited. Our primary source of clean, abundant energy is the sun. The sun deposits 120,000 TW of radiation on the surface of the earth, far beyond human needs even in the most aggressive energy demand scenarios. The sun is Earth's natural power source, driving the circulation of worldwide wind and ocean currents, the process of water evaporation and condensation which creates rivers and lakes, and biological cycles of the photosynthesis and life. On covering 0.61% of the land on the Earth with 10% capable solar conversion systems would supply 20 TW of power, nearly twice the world's consumption rate of fossil energy the equivalent 20,000 GW nuclear fission plants. These comparisons demonstrate the impressive magnitude of the solar resource, providing an energy steam far more potent than present day human technology can achieve.

All routes for utilizing solar energy use the functional steps of capture, conversion, and storage. The sun's energy reaches on the Earth as radiation distributed across the colour spectrum from infrared to ultraviolet. The energy of this solar radiation must be capture as excited electron- hole pairs (excitons) in a semiconductor, a dye, or chromospheres, or as heat in a thermal storage medium. Excited electrons and holes can be tapped off abrupt conversion to electrical power, or transferred to biological or chemical molecules for conversion to fuel. Natural photosynthesis produces fuel in the form of sugars and other carbohydrates taking from the reduction of CO_2 in the atmosphere and used to power the growth of plants [2]. The plants themselves become available as biomass for combustion as primary fuels or for conversion in reactors to secondary fuels like liquid ethanol or gaseous carbon monoxide, methane and hydrogen. We are now learning to imitate the natural photosynthetic process in the laboratory using synthetic molecular assemblies, where the excited electrons and holes can drive chemical reactions to produce fuels that link to our existing energy networks. Atmospheric CO_2 can be reduced to ethanol or methane or water can be split to create hydrogen. These natural fuels are the storage media for solar energy, bridging the day-night, winter-summer and cloudy-sunny cycles of solar radiation. In addition to electric and chemical conversion process, solar radiation can be converted to heat energy. Solar concentrators focus sunlight collected over a large area to a line or spot where heat is collected in an absorber. Temperature as high 3,000 ^{0}C can be generated to drive chemical reactions or heat can be collected at lower temperatures and transferred to a thermal storage medium like water for distributed space heating or steam to drive an engine. Effective storage of solar energy as heat requires developing thermal storage media that accumulate heat efficiently during sunny-day and release heat slowly during dark or cloudy- day. Heat is one of the most adaptable forms of energy, the common connection in nearly all our energy networks, Solar thermal conversion can replace much of the heat now supplied by fossil fuel.

II PHOTOVOLTAIC CELL

A solar cell or photovoltaic cell [3] is an electrical device that converts the solar energy into electricity directly by the photovoltaic effect, which is a physical and chemical phenomenon. It is a photoelectric device, whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, known as solar panels. The working of a photovoltaic (PV) cell requires four basic properties:

- The absorption of light by active layer.
- Generation of electron-hole pairs or excitons when light is incident on active layer.
- The separation of charge carriers of opposite types due to electric field.
- The separate extraction of those carriers to an external circuit.

The photovoltaic effect was experimentally observed first by French physicist Edmond Becquerel in 1839 and he discovered the world's first photovoltaic cell in his father's laboratory. Willoughby Smith first described the "Effect of Light on Selenium. In 1883 Charles Fritts built the first solid state photovoltaic cell by coating the semiconductor selenium with a thin layer of gold to form the junctions and the efficiency of this device around 1%. In 1888 Russian physicist Aleksandr Stoletov built the first solar cell based on the outer photoelectric effect discovered by Heinrich Hertz in 1887.

In 1905 Albert Einstein discovered the quantum theory of light and successfully explained the photoelectric effect for which he received the Nobel Prize in Physics in 1921. Vadim Lashkaryov proposed *p-n*-junctions in Cu_2O and silver sulphide protocells in 1941 [4].Russell Ohl patented the modern junction semiconductor solar cell in 1948.While working on the series of advances that would lead to the transistor. The first practical photovoltaic cell was publicly made on 25 April 1954 at Bell Laboratories. The inventors were Daryl Chapin, Calvin Souther Fuller and Gerald Pearson. Solar cells gained importance with their incorporation onto the 1958 Vanguard I satellite.

Solar cells were first used in a prominent application when they were proposed and flown on the Vanguard satellite in 1958, as an alternative power source to the primary battery power source. By adding cells to the outside of the body, the mission time could be extended with no major changes to the spacecraft or its power systems. In 1959 the United States launched Explorer 6, featuring large wing-shaped solar arrays, which became a common feature in satellites. These arrays of the satellites consisted of 9600 Hoffman solar cells. In 1960s, solar cells were become the main power source for most Earth orbiting satellites and a number of probes into the solar system, since they existing the best power-to-weight ratio. However this success was possible because in the space application, power system costs could be high, because space users had some other power options, and were ready to pay for the best possible cells. The space power market for satellite drove the development of higher efficiencies in organic solar cells up until the National Science Foundation "Research Applied to National Needs" program began to push growth of solar cells for terrestrial applications. In the early 1990s the technology used for space solar cells diverged from the silicon technology used for terrestrial panels, with the spacecraft purpose shifting to gallium arsenide-based III-V semiconductor materials, which then evolved into the modern III-V multi-junction photovoltaic cell used in spacecraft.

III TYPES OF PHOTOVOLTAIC CELLS (SOLAR CELLS)

A. Crystalline silicon solar cell:

The most common bulk material for solar cells is crystalline silicon (c-Si), also known as solar grade silicon. Bulk silicon is classified into several categories according to crystalline and crystal size in the resulting ingot wafer. These solar cells are completely based about the concept of a p-n junction. Solar cells made of c-Si from wafers between 160 and 240 micrometers thick [5]. Solar cells made of crystalline silicon are often called conventional, traditional, solar cells, as they were developed in the 1950s and remained the most common type up to the present time. Because they are produced from 160-190 µm thick solar wafers slices from bulks of silicon, they are sometimes called wafer-based solar cells. Solar cells made from c-Si are single-junction cells and it is more efficient than their rival technologies, which are the second-generation thin film solar cells, the most important being CdTe, CIGS, and amorphous silicon (a-Si). Amorphous silicon is an allotropic alternate of silicon, and amorphous means without shape to describe its non-crystalline form.

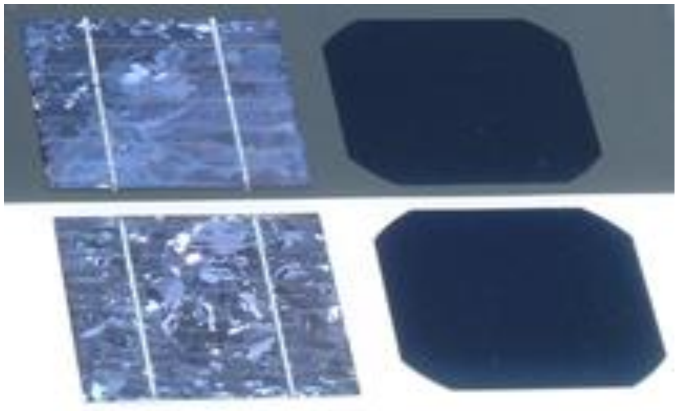

Fig. 1 crystalline silicon solar cell

B. Mono-crystalline silicon solar cell

Mono-crystalline silicon (or single-crystal silicon) is the base material for silicon chips used in virtually all electronic equipment today. Mono-Si also serves as photovoltaic, light-absorbing material in the manufacture of solar cells. It consists of silicon in which the crystal lattice of the entire solid is continuous, unbroken to its edges, and free of any grain boundaries. Mono-Si can be organized intrinsic, other elements added to change its semiconducting properties. Most silicon mono- crystals are grown by the Czochralski process into ingots of up to 2 meters in length and weighing several hundred kilograms. These cylinders are then sliced into thin wafers of a few hundred microns for further processing. Mono crystalline silicon is differs from other allotropic forms, such as the non-crystalline amorphous silicon which is used in thin-film solar cells and polycrystalline silicon, that consists of small crystals, also known as crystallites.

C. Thin-film solar cell:

A thin-film solar cell is a second generation solar cell that is made by depositing one or more thin layers or thin film of photovoltaic material on a substrate of different materials such as glass, plastic or metal. Thin-film solar cells are commercially used in several technologies, including cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and amorphous thin-film silicon (a-Si, TF-Si). Film thickness of the solar cell varies from a few nanometers (nm) to tens of micrometers (µm), much thinner than thin-film's rival technology, the conventional, first-generation crystalline silicon solar cell (c-Si), that uses wafers of up to 200 µm [6-7]. This allows thin film cells to be flexible, lower in weight, and have less drag or friction. It is used in building integrated photovoltaics and as semi-transparent, photovoltaic glazing material that can be laminated onto windows. Other commercial applications use rigid thin film solar panels in some of the world's largest photovoltaic power stations. Thin-film technology has always been cheaper but less efficient than conventional crystalline silicon (c-Si) technology. However, it has considerably superior over the years. The lab cell efficiency for CdTe and CIGS is now beyond 21 percent, outperforming multi-crystalline silicon, the dominant material currently used in solar cells. Accelerated life testing of thin film modules under laboratory conditions measured a somewhat faster degradation compared to conventional PV, while a lifetime of 20 years or more is generally expected. Despite these enhancements, market-share of thin-film never reached more than 20 percent in the last two decades and has been declining in recent years to about 9 percent of worldwide photovoltaic installations in 2013.

D. Cadmium telluride solar cell

Cadmium telluride (CdTe) photovoltaic describes a photovoltaic (PV) technology that is based on the use of cadmium telluride, a thin layer of semiconductor designed to absorb the light photon and convert sunlight into electricity directly. Cadmium telluride solar cell is the only thin film technology with lower costs than conventional solar cells made of crystalline silicon. On a lifecycle basis, CdTe solar cell has the smallest carbon footprint, lowest water use and shortest energy payback time of all solar technologies. CdTe's energy payback time of less than a year allows for faster carbon reductions without short-term energy deficits. The toxicity of cadmium is an environmental concern mitigated by the recycling of CdTe modules at the end of their life time. Though there are still uncertainties [8-9] and the public opinion is doubtful towards this technology. The usage of rare materials may also become a limiting factor to the industrial scalability of CdTe solar cell technology in the mid-term future. The abundance of tellurium of which telluride is the anionic form is comparable to that of platinum in the earth's crust and contributes significantly to the module's cost.

E. Multi-junction solar cells

Multi-junction (MJ) solar cells are solar cells with multiple p–n junctions made of different semiconductor materials. Every semiconductor material's p-n junction will produce electric current in response to different light. The multiple semiconducting materials are the absorbed a broader range of wavelengths of light and improving solar cell conversion efficiency. Traditional single-junction solar cells have a maximum theoretical efficiency of 34%. Theoretically, a large number of junctions would have a limiting efficiency of 86.8% under highly concentrated sunlight. Currently, the best lab examples of traditional crystalline silicon solar cells have efficiencies between 20% and 25% [10-11] while lab examples of multi-junction cells have demonstrated performance over 46% under concentrated sunlight. Commercial tandem solar cells have available efficiency 30% under one-sun illumination , and improve to around 40% under concentrated sunlight. However, this efficiency is gained at the cost of increased complexity and manufacturing price. To date, their higher price and higher price-to-performance ratio have limited their use to special roles, notably in aerospace where their high power-to-weight ratio is desirable. In terrestrial applications, these solar cells are emerging in concentrator photovoltaic's (CPV), with a growing number of installations around the world.

IV ORGANIC SOLAR CELLS

An organic solar cell or plastic solar cell is a type of polymer solar cell that uses organic electronics, a branch of electronics that deals with conductive organic materials or small organic molecules, for light absorption and charge transport to produce electricity from sunlight by the photovoltaic effect. The plastic used in organic solar cells has low production costs in high volumes. Combined with the flexibility of organic molecules, organic solar cells are potentially cost-effective for photovoltaic applications. Molecular engineering can change the energy gap, which allows chemical change in these materials. The optical absorption coefficient of organic molecules is high, so a large amount of light can be absorbed with a small amount of materials. The main disadvantages of organic solar cells are low efficiency, low stability and low strength compared to inorganic photovoltaic cells. Organic solar cells and polymer solar cells are built from thin films (100 nm) of organic semiconductors including polymers, such as polyphenylene vinylene and small-molecule compounds like copperphthalocyanine (a blue or green organic pigment) and carbon fullerenes and fullerene derivatives such as PCBM. They can be processed from liquid solution, offering the possibility of a simple roll-to-roll printing process, potentially leading to reasonable, major production [12]. In addition, these cells could be beneficial for some applications where mechanical flexibility and disposability are important. Currently the efficiencies of solar cells are, very low, and these are not useful for practical purpose. The energy conversion efficiencies using conductive organic material are very low as compared to inorganic materials. However, Konarka Power Plastic reached efficiency of 8.3% and organic tandem cells in 2012 reached 11.1%. The active layer of an organic solar cell consists of two materials, one electron donor and one electron acceptor. When a photon is converted into an electron hole pair, typically in the donor material,[13] the charges tend to remain bound in the form of an excitons, separating when the excitons diffuses to the donor-acceptor interface, unlike most other solar cell types. The short excitons diffusion lengths of most polymer systems tend to limit the efficiency of such devices. Nanostructure interfaces, sometimes in the form of bulk heterojunction, can improve performance [14]. In 2011, MIT and Michigan State researchers developed solar cells with power conversing efficiency nearly 2% with a transparency to the human eye greater than 65%, achieved by selectively absorbing the ultraviolet and near-infrared parts of the spectrum with small-molecule compounds [15-16]. Researchers at UCLA more recently developed an analogous polymer solar cell, following the same approach that is 70% transparent and has 4% power conversion efficiency [17-18]. These lightweight, flexible cells can be produced in bulk at a low cost and could be used to create power generating windows. In 2013, researchers announced organic solar cells nearly 3% efficiency. They used block copolymers, self-assembling organic materials that arrange themselves into distinct layers. The research focused on P3HT-b-PFTBT that separates into bands some 16 nanometers wide.

V TYPES OF ORGANIC SOLAR CELLS

a. Single layer organic solar cell

Single layer organic photovoltaic cells are the simplest of the various forms of organic solar cell cells. These solar cells are made by sandwiching a layer of organic materials between two conductive electrodes one of transparent electrode ITO (Indium tin oxide) with high work function and other of low work function metal such as Al, Mg or Ca. The basic structure of such a cell is illustrated in Fig. 2.

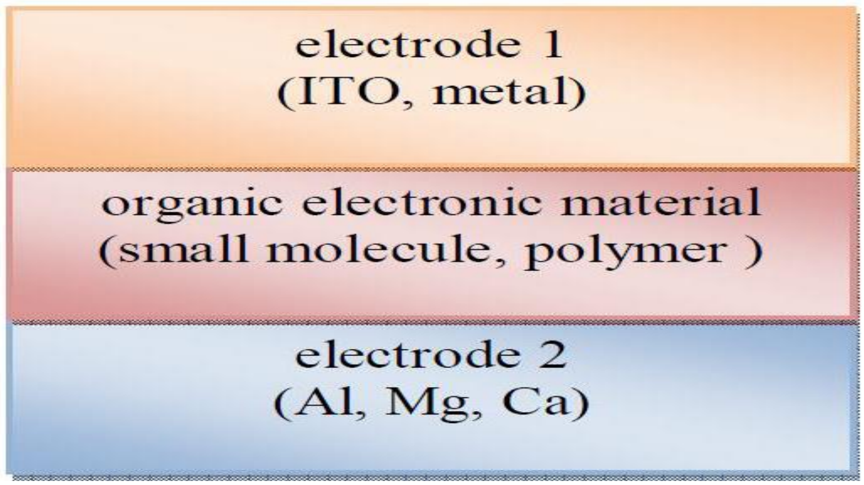

Fig. 2 SINGLE LAYER ORGANIC SOLAR CELL

In practice, single layer organic photovoltaic cells of this type do not work well. They have low quantum efficiencies less than 1% and low power conversion efficiencies less than 0.1%. A major problem with them is that the electric field resulting from the difference between the two conductive electrodes is seldom sufficient to break up the photo generated excitons. Often the electrons recombine with the holes rather than reach the electrode. To deal with this problem, the multilayer organic photovoltaic cells were developed.

b. Bilayer organic photovoltaic cells

This type of organic photovoltaic cell contains two different layers of organic material in between the conductive electrodes. These two layers of materials have different work function and different energy band gap and these layers also have the differences in electron affinity and ionization energy due which the electrostatic forces are generated at the interface between the two layers. The materials are chosen properly to make the differences large enough, so these generated electric fields are strong, which may break up the excitons much more efficiently than the single layer photovoltaic cells. The layer which has higher electron affinity and ionization potential is the electron acceptor, and the other layer is the electron donor. This structure is also called a planar donor-acceptor heterojunction.

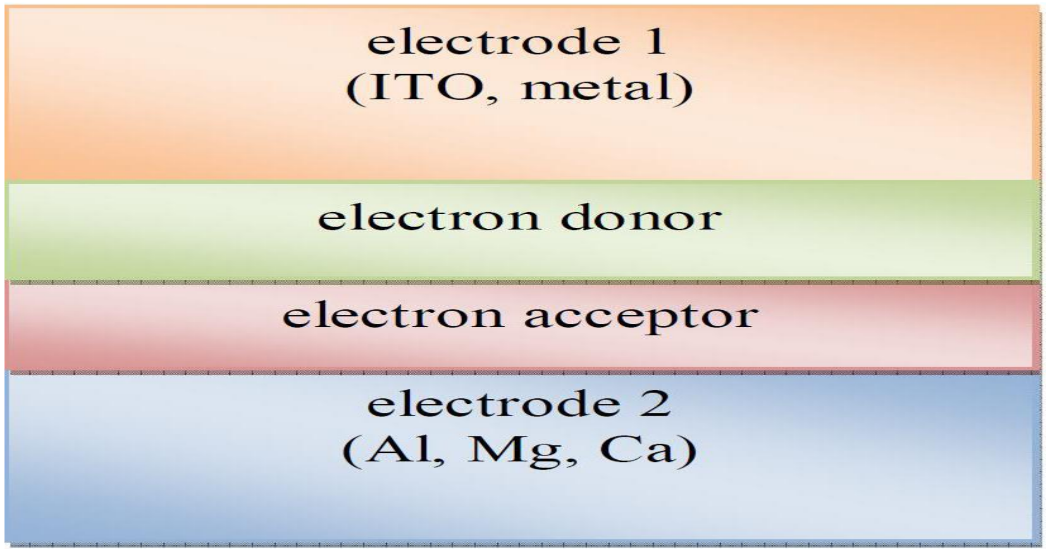

Fig. 3 BILAYER ORGANIC SOLAR CELL

In bilayer organic solar cell the diffusion length of excitons in organic materials is order of 10 nm. In order for most excitons to diffuse to the interface of layers and break up into electron and hole, the active layer thickness should also be in the same range as the diffusion length. However, an active layer of material typically needs a thickness of at least 100 nm to absorb maximum light. At such a large thickness, only a small fraction of the excitons can reach the heterojunction interface. To address this problem, [19] a new type of heterojunction solar cells are manufactures, which are the dispersed heterojunction photovoltaic cells.

c. Graded heterojunction photovoltaic cells

In this type of photovoltaic cell, the electron donor and acceptor are mixed together, like in the bulk heterojunction, but in such a way that the gradient is gradual. This construction combines the short electron travel distance in the dispersed heterojunction with the advantage of the charge gradient of the bi-layer technology.

d. Bulk heterojunction solar cell:

Bulk heterojunction is the mixture of conjugate polymer of fullerene derivative of electron donor and acceptor. The poly (3-hexylthiophene) P3HT is electron donor and have a narrow band gap between LUMO and HUMO and has longest absorption wavelength around 650 nm but PCBM (6-6 phenyl C61-butric acid methyl ester) is a good electron acceptor material and having high hole mobility it plays the role of electron acceptor in many organic devices. Organic polymers have wider energy band gap than semiconductors. They give an efficient absorption in UV region in comparison to other material and high carrier mobility [20]. In many organic photovoltaic materials, bulk heterojunction structure has been adopted in the P3HT: PCBM blends so that the donor/acceptor interface is enlarged. This is shown in the fig.

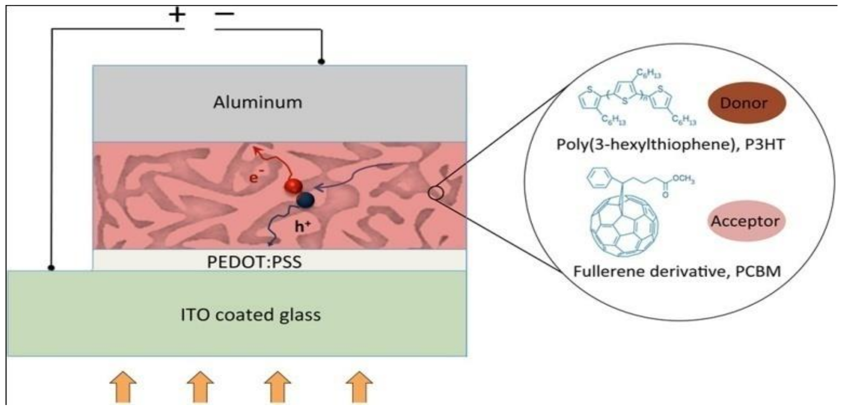

Fig. 4 bulk heterojunction solar cell

Some of the improvements that bulk heterojunction solar cells have over inorganic solar cells are that they are flexible, low cost fabrication and therefore can be applied to a larger range of surfaces. They can also be produced much more easily via inkjet printing or spray deposition, and therefore are vastly cheaper to manufacture [21]. A downside is that, because they are not crystalline (like silicon), but instead are produced in a deliberately disordered blend of electron-acceptor and donor materials (hence the name bulk heterojunction), they have a limited efficiency of charge transport. However, the efficiencies of these new types of photovoltaic cells have risen from 2.5% in 2001, to 5% in 2006, to greater than 10% in 2011. This is because improved methods for solution processing of acceptor and donor materials (P3HT) led to more efficient blending of the two materials. Further research can lead to polymer-fullerene based photovoltaic cells that approach the efficiency of current inorganic photovoltaic cells. Especially for bulk heterojunction solar cells, understanding charge carrier transport is vital in improving the efficiencies of organic solar cells. Currently, bulk heterojunction solar cells have imbalanced charge-carrier mobility, with the hole mobility being at least an order of magnitude lower than that of the electron mobility, [22] this results in space charge build-up and a decrease in the fill factor and power conversation efficiency of a device. Due to having low mobility of the charge carriers, efficient bulk heterojunction photovoltaic has to be designed with thin active layers of materials to avoid recombination of the charge carriers, which is harmful to absorption and scalability in processing. Simulations have demonstrated that in order to have a bulk heterojunction organic solar cell of fill factor above 0.8 and external quantum efficiency of organic solar cell more than 90%, there needs to be balanced charge carrier mobility to reduce a space charge effect, as well as an increase in charge carrier mobility.

VI Working of organic solar cell

In organic solar cells, the active layer is sandwich between transparent electrode (ITO) and metal electrodes like as Ag, Al, Mg . The active material is responsible for light absorption, charge carrier production, and carrier separation. Since excitons dissociation occurs at interfaces, the active material is composed of the electron donor poly (3-hexylthiophene) (P3HT) and the fullerene [6, 6]-phenyl-C_{61} butyric acid Methyl ester (PCBM) as the electron acceptor. The working principle of organic photovoltaic devices depends on the photo-electric effect. In organic solar cell the organic materials (P3HT: PCBM) are responsible for generating free charge carriers (excitons) from sunlight in organic solar cells. The operational mechanism of OPVs is illustrated in given figure and can be summarized as follows.

1. An electron in the highest occupied molecular orbital (HOMO) of an organic material absorbs a photon and is excited into the lowest unoccupied molecular orbital (LUMO), creating an excitons (bound electron- hole pair).

2. The excitons diffuse to the interface of two materials which is shown in figure.

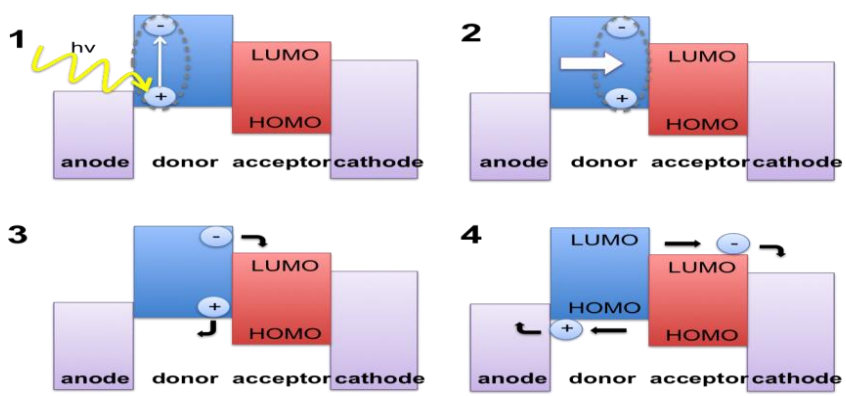

Fig. 5 operation of organic solar cell

3. The excitons is dissociated or separated at the interface of the active layer.

4. The newly separated free charge carriers diffuse to the electrodes at opposite ends of the cell, flow through an external load, and do work.

VII PROPERTIES OF ORGANIC SOLAR CELLS

Organic conjugated polymers based on photovoltaic cells are a promising alternate to the convention inorganic solar cell due to following properties [23].

1. Organic devices have high absorption coefficient.
2. Low cost device manufacturing and ease of device fabrication.
3. Ease of processing using conventional polymer processing technologies.

4. Large area device fabrication possible at room temperatures.
5. These devices are light weight and flexible.
6. Organic solar cells are environment friendly, biodegradable and utilize non toxic processing.

VIII Applications of Solar Cell

1. They mostly use in the field of satellites.

2. They also use in the field of water treatment and pumping.

3. Its may be use in the field of emergency power.

4. Its mostly use in the field of toys, watches.

5. They mostly use in the field of portable power supplies.

IX Current challenges and recent progress:

Organic photovoltaic cells have low external quantum efficiency compared to inorganic photovoltaic devices. The organic solar having good internal quantum efficiency; this is due to deficient absorption with active layers on the order of 100 nanometers, volatiles against oxidation and reduction, re-crystallization. Due to the temperature variations of the device the solar cell degradation and decreased performance over time. This occurs to different extents for devices with different compositions, and is an area in which active research is taking place. Other important factors include the excitons diffusion length, charge separation and charge collection, which are affected by the presence of impurities. In this work, we study the different characteristics of organic solar cell; at different active layer thickness, at different temperatures and different series resistances as well as observed the effect of thickness of active layer on absorption of the photons.

X Conclusion

In this research chapter study the basic introduction of photovoltaic solar cells and its types. In an organic solar cell, Bulk heterojunction is a mixture of interpenetrating of electron donor (P3HT) and electron acceptor conjugated molecules (PCBM) that allows light absorption, generation of excitons, excitons splitting at donor-acceptor interface and efficiently transportation of positive and negative charges to opposite electrodes. Solar cells become the one of the most important alternate electricity and it is using in a large scale in the world to generates the electric power by the solar energy.

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