**Introduction of Solar Energy and Photovoltaic device**

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**Abstract**

Photovoltaic cell is an electronic device which Change solar energy into electric energy by the photovoltaic effect. The principal of solar cell depends on Photovoltaic effect which is the physical and chemical phenomenon. Solar cell is the building block of the solar plate or solar panel. The first generation of solar cell is made of silicon and the next generation of thin film and nowadays used organic solar cells. Organic solar cells have attracted a lot of attention in the last years due to their properties for application as flexible, renewable, non conservative energy sources. Since the generation of photo induced charge transfer between organic active layer materials, a great effort has been devoted to explore these organic materials for photonic device. In this research chapter study the basic introduction and properties of photovoltaic cells.

**I Introduction**

The world demand of clean energy includes the course of universal intensification in each sphere of anthropic activity. The supplies of clean energy are connected to global sustainability, gainful prosperity, and progressive of life. To discover sources of clean energy to assure the world’s progressing need is one of human being foremost challenges for the next half century. There is a need of correct national effort assemble our most advanced scientific and technological capacity to solve importance of this constant difficulty and the seriously technical problem. At the present time world required energy at a rate of about 4.1×1020 joules/year, which equivalent to the electric power consumption of 13 trillion watts or 13 terawatts (TW). Even with progressive conservation and energy efficiency trade, fast technology development and gainful growth worldwide, the Earth's population is projected to grow to 9 billion people, accompanied by fast technology development and economic progress 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 store of fossil fuels that give energy to society, they will finish short of this requirement over the long time duration and their sustain use and produces harmful side effects such as pollution that harmful human life and greenhouse gases related with climate change. The other renewable fuels are at present far from against with fossil fuels in high cost value and production holding ability. Without achievable options for supplying double or triple today’s energy use, the world’s economic, technological, and progress will be severely limited. Our natural source of clean, energy is the sun. The sun produce 120,000 TW of radiation on the surface of the earth, which is very large further human needs even in the most advancing energy requirement panorama. The sun is our Earth’s natural source of energy that driving the circulation of worldwide wind and ocean currents, the process of water evaporation and condensation. The sun produces rivers and lakes, and biological cycles of the photosynthesis and life which is the first requirement of human life. On covering 0.61% of the land of the Earth with 10% aplicapable solar conversion energy would supply 20 TW of electric power, which is nearly twice the world’s required rate of fossil energy the equivalent 20,000 GW nuclear fission plants.

The energy of sun reaches on the Earth as the form of radiation and scattered from infrared to ultraviolet. The energy of this solar radiation must be captured as excited excitons (electron- hole pairs) in a semiconductor as heat in a thermal storage medium. Excited electrons and holes pairs (excitons) can be captured sudden converted to electrical energy. Natural process of photosynthesis in the presence of sun light and colorful produces food in the form carbohydrates and reduces CO2 in the atmosphere and gain to power for the growth of plants [2]. The green plants themselves obtained biomass for combustion as primary fuels or for conversion in nuclear reactors to secondary fuels like liquid ethanol or gaseous methane and hydrogen. We are now learning to relate the natural photosynthetic process in the laboratory using synthetic molecular collecting, where the excited electrons and holes can drive chemical reactions to generate fuels that connect to our existing energy system. The atmospheric CO2 can be reduced to ethanol or methane or water can be split to produce hydrogen and oxygen. These natural fuels are the source of storage media for solar energy which circulate day-night, winter-summer and cloudy-sunny cycles of solar radiation. Electric and chemical conversion process, solar radiation can be converted in to heat energy. By Solar concentrators focus sunlight collected over a large area to a line or spot where heat is collected in an absorber. The high Temperature 3,000 0C can be produce to drive chemical reactions or heat can be stored at lower temperatures and transferred to a thermal storage medium like water for distributed space heating or steam to drive heat engine. Effective storage of solar energy as heat requires to generating thermal storage media that collect heat efficiently during sunny-day and allow to supply the heat gradually during night or cloudy- day. Heat is one of the most adjustable 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** PV cell [3] is an opto-electronic device that change the solar energy (Sun Light) into electrical energy directly by the application of photovoltaic effect, which is a physical and chemical Phenomenon, this idea borrows from the green plant. It is a photoelectric device, whose electrical properties, such as voltage, current, or resistance, vary with change in light intensity. A group of Solar cells are assembled together form the solar plate or solar panel. If we increase the number of solar cells than power of solar panel is also increases. These solar plates use in space body as alternative power source, no other source is possible except it. The working of a solar cell depends upon four main properties:

* The maximum light must be absorbed by the active layer materials.
* Generation of charge carriers ([electron](https://en.wikipedia.org/wiki/Electron)-[hole](https://en.wikipedia.org/wiki/Electron_hole) pairs) when light is incident on active layer.
* The charge carriers of opposite types are separated by the properties of internal electric field.
* The separate charge carriers move towards the opposite electrodes.

This effect was experimentally first observed by French physicist in 1839 and he discovered the world's first solar cell in his father's laboratory. The Light effect on Selenium first explains by the first physicist Willoughby Smith. In 1883 Charles Fritts built the first Solid State solar cell by coating the semiconductor selenium with a thin layer of gold to form the junctions and the efficiency of this device about 1%. In 1888 Russian physicist Alexander Stoletoy made the first solar cell based on the outer photoelectric effect discovered by H. Hertz in 1887. Albert Einstein explain the quantum theory of light and photoelectric effect successfully in 1905 for this great discovery he Received Novel price in physics in 1921. Vadim Lashkaryoy proposed P-N junction in Cu2O and silver sulphide photo cell in 1941 {\displaystyle \_{2}}2O2222[4]. Russel Ohl patented the modem junction semiconductor solar cell in 1948. The first solar cell developed by the Daryl Chapin, Calvin Souther Fuller and Gerald Pearson on 25 April 1954 at Bell Laboratories. Solar cells gained importance with their incorporation onto the 1958 Vanguard I satellite.

First time solar in 1958 used as a prominent application on Vanguard satellite, as an alternative power source to the primary battery. To increase the number of solar cells to the outside of the body, the mission time duration could be extended with no any more changes to the spacecraft or its power systems. The United States launched Explorer 6, which have large wing shaped solar panels like as aeroplane it becomes a common feature in satellites. This surface of the satellites consist a large number of solar cells to increase the working time as alternate power source. In 1960s, solar cells were become the main power heart for most Earth orbiting satellites and a number of investigation 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 program began to push growth of solar cells for satellites 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 modem III- V multifunction solar cell used in spacecraft.

**III TYPES OF PHOTOVOLTAIC CELLS**

**Crystalline Silicon Solar Cells:**

The material crystalline silicon (C-Si) is most important for solar cells which also known as solar grade silicon. The materials silicon is divided into different types according to crystalline structure. The concepts of solar cells are completely based on the P-N junction diode in reverse bias. The Photovoltaic cells are made of crystalline silicon wafers of size 160 and 240 µm thick [5] in 1950s. Silicon solar cells are produced from 160-190 [µm](https://en.wikipedia.org/wiki/Micrometers) thick [solar wafers](https://en.wikipedia.org/wiki/Solar_wafer), they are known as wafer-based solar cells. Solar cells made from crystalline silicon are single-junction solar cells it is more effective than their best technology, this types of solar cells are known as second-generation [thin film photovoltaic cells](https://en.wikipedia.org/wiki/Thin_film_solar_cell). Amorphous silicon is used at the place of crystalline silicon for manufacturing of solar cells.

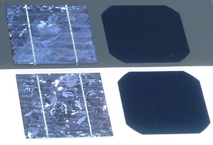


Fig. 1 Structure of Crystalline Silicon Solar Sell

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#### B. Mono-Crystalline Silicon Solar Cell:

Single-crystal silicon (Mono-crystalline silicon) is used as the main material for fabrication of chips or IC used in all electronic instruments today. Silicon becomes the heart of all electronics devices. Mono-crystalline (M-Si) is light-absorbing material (active layer material) for the manufacturing of solar cells. Mono-crystalline (M-Si) can be made by [intrinsic](https://en.wikipedia.org/wiki/Intrinsic_semiconductor), other elements (impurity) added to change its physical and chemical properties and increase the conductivity. All Most silicon [mono- crystals](https://en.wikipedia.org/wiki/Monocrystal) are manufactured by the Czocgralski method into slabs (sheet) of up to 2 or 3 meters in length and weight more than hundred kilograms. These slabs are then cut into thin wafers of order of hundred micro meters for the next step. Mono- crystalline silicon is differs from amorphous which is used in thin film technology.

**C.** **Thin Film Solar Cells:**

A thin-film technology for manufacturing of PV cells is a second generation that is made by depositing one or more layers of active materials on a substrate of different materials. Thin-film photovoltaic cells are traditionally used in different technologies. Film thickness of the solar cell changes from a few nanometers to micrometers. The first generation crystalline silicon solar cells, that uses slice of up to 200 µm [6-7]. This thin film provided to solar cells flexible substrate, light weight and has less friction. It is used to manufacture of solar plate (solar panel) on a large scale. Other trading applications of thin film photovoltaic cells to provided endless electric power to the satellites and alternative source of power to supply the world to short out the electricity problems and give the luxury life without any problem. This technology has always been cheaper but not more efficient than conventional crystalline silicon solar cells technology. However, it has considerably superior over the years. The solar cells efficiency for Cadmium telluride and CIGS is now more efficient, outperforming polycrystalline silicon, the presiding material currently used for solar cells. The working period of thin film solar cell in ideal condition is lower as compared to conventional PV solar cells. The expected working period PV cells of generally 20 years or more. Despite these enhancements, market-share of thin-film never reached more than 20% in the last 20 years and has been reducing in recent years to about 9% of world wide photovoltaic solar cells in 2013.

**D. Cadmium telluride photovoltaic cell:**

Cadmium telluride (CdTe) material has the great properties of the high absorption coefficient and it absorbed about 99% incident light. This is new technology which based on  CdT materials, a thin film of active materials (CdTe) made to absorb the sun light and converted into electricity directly. Cadmium telluride solar cells have good properties with low cost in comparing crystalline solar cells. On the stability basis, lowest water use and small working period of all solar cells technologies. CdTe solar cells have the drawback of toxicity due to this properties it is harmful for the environment. The toxic properties of cadmium are harmful for environmental concern reduced by the recycling of CdTe modules at the end of their life time. Though there are uncertain [8-9] and the public opinion is doubtful about this CdTe 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.

**E. Multi-junction** **photovoltaic cells:**

Multi-junction photovoltaic cells are made of multi p-n junctions of several semiconductor materials. Every semiconductor materials p-n junction solar cells will generate electric current with varying of light. The different semiconductors materials absorb maximum range of light and enhance the external efficiency. Commercially crystalline silicon solar cells have a maximum observed efficiency 34%. Theoretically, a multi junction would have a maximum efficiency of 86.8% under ideal condition. Currently, the silicon solar cells have efficiency from 20% to 25%. The conviction of the multi-junction solar cells has reveal performance over 46% under highly sunlight [10-11]. Commercial tandem solar cells have efficiency 30% under ideal condition, and enhance up to 40% under concentrated sunlight. To date, their higher cost and higher [cost to performance ratio](https://en.wikipedia.org/wiki/Price-to-performance_ratio) have limited their use to special roles.

**IV ORGANIC PHOTOVOLTAIC SOLAR CELLS**

An organic Photovoltaic cell (OPV cell) or plastic solar cell is a type of photovoltaic solar cell that uses organic electronics, a branch of electronics that deals with conductive organic materials for light absorption and charge transport to produce electricity from sunlight by the photovoltaic effect. Organic photovoltaic solar cells aim to provide an earth-abundant and low energy-production. This technology provides electricity at lower cost than first and second generation solar cells technology. The low efficiencies of organic solar cells are related to their small exciton diffusion lengths and low charge carrier motilities. The current research goes on forward to increasing device efficiency and lifetime. Organic solar cells have cost-effective for photovoltaic applications. Organic solar cell offer numerous benefits, many people are unaware of this innovative technology. The absorption coefficient of organic molecules is high, so a large amount of light can be absorbed with a small amount of materials and generate electro-hole pairs. The main advantages of organic solar cells are low efficiency, low stability and low strength. Organic photovoltaic device made of organic semiconductor of thin films (100nm) such as small-molecule compounds like copperphthalocyanine and carbon fullerene derivatives such as P3HT- PCBM. They can be processed from liquid solution [12]. The efficiencies of these organic solar cells are, very low, and these are not useful for practical purpose. The energy conversion efficiencies of organic solar cells are very low as compared to inorganic materials solar cells. However, Konark Power polymer reached efficiency of 8.3% and organic tandem solar 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 photons are absorbed by active layers and converted into an electron hole pair (excitons), typically in the donor material,[13] the charges tend to remain bound in the form of an electron-hole pair , separating when the excitons diffuses to the donor-acceptor interface. 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]. Researchers at UCLA more recently developed an similar polymer solar cell, following the same approach that is 70% transparent and has 4% power conversion efficiency These lightweight, flexible cells can be produced in bulk at a low cost and could be used to create power generating windows [15-16]. In 2013, researchers announced [organic solar cells](https://en.wikipedia.org/wiki/Polymer_solar_cell) nearly 3% efficiency. They used [block copolymers](https://en.wikipedia.org/wiki/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 [17-18].

**V CLASSIFICATION OF ORGANIC SOLAR CELLS**

1. **Single layer organic solar cell:**

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



Fig. 2 Single Layer Organic Solar Cell

In practice, single layer photovoltaic cells do not work proper due to their low power conversion efficiency and have low quantum efficiencies less than one. The external power conversion efficiency is less than 0.1. A Large problem with them is that the electric field generating between the two conductive electrodes is not sufficient to break up the electron hole pair (photo generated excitons). Often the electrons recombine with the holes rather than reach the electrode. To short out this problem, the multilayer organic photovoltaic cells were developed.

1. **Double layer organic photovoltaic cells:**

Double layer photovoltaic organic solar cell is formed by two different layers of organic materials in between the two different conductive electrodes. These two electrodes and active layers of materials have different work function and different energy band gap. These layers also have the differences in electron ionization potential energy and electron affinity by the reason of electrostatic forces. This electrostatic force is developed at the interface between the two layers of active layer materials. This electric force is capable to split the electron hole pair and separates the electric charge. The materials are selected properly to make the differences large enough, so these generated electric fields are so strong, which may break up the electron- hole pairs (excitons) much more efficiently than the single layer Crystalline solar cells. The high electron affinity layer work as electron acceptor and the other layer as electron donor. This structure is also known as planar donor-acceptor heterojunction.

**Fig. 3 Structure of Double Layer Organic Solar Cell**

In double layer photovoltaic (PV) cell the diffusion length of excitons in active layer materials is order of 5- 20 nm. The most electron-hole pairs diffuse at the interface of layers material and split up into electrons and holes, the layer thickness of active material must be the same order as the diffusion length. However, a layer of active material required to need a thickness at least 100 nm to absorb maximum light. For large thickness, only a small fraction of the excitons can reach the heterojunction interface. To short out this problem, [19] a new type of heterojunction solar cells are developed, which are the disassemble heterojunction solar cells.

**c. Graded heterojunction solar cells:**

Graded heterojunction photovoltaic solar cells have with an active layer of active donor –blend acceptor structure. In this structure electron donor and electron acceptor materials are mixed together like as in bulk heterojunction, but according to this the declivity is shallowly. This structure includes the short distance traveled by electrons in the dispersed heterojunction with the gain of the charge gradient of the bi-layer technology.

**d. Bulk heterojunction solar cell:**

Bulk heterojunction solar cell has the mixture of conjugate polymer of fullerene derivative of electron donor and electron acceptor. The P3HT material is electron donor and has a narrow energy band gap between LUMO and HUMO and P3HT material has longest absorption wavelength about 650 nm but PCBM material is a good electron acceptor material. The acceptor materials PCBM having high mobility of holes and it plays an important role of electron acceptor in many organic photovoltaic devices. Organic polymers have large energy band gap compared as inorganic semiconductors materials. They have high absorption coefficient in ultra violate region in comparison to other semiconductor material and high charge carrier mobility [20]. In many organic materials, bulk heterojunction structure has been acquire in the P3HT: PCBM mixture so that the donor/acceptor intersection layer is increase in size. This is shown in the fig.4

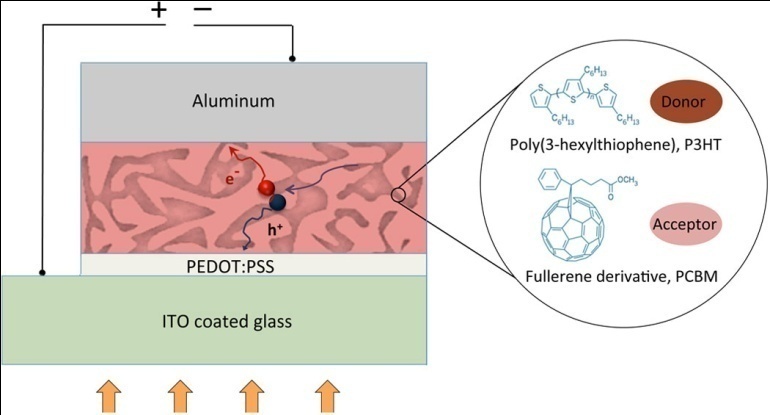


Fig. 4 Structure of Bulk Heterojunction Solar Cell

Bulk heterojunction solar cells have more advantage in comparison to inorganic solar cells is that they are chief, flexible in substrate. The PV Cell also be easily fabricate by [spray deposition](https://en.wikipedia.org/wiki/Spray_forming) technique or spin coating, and these are very cheap to fabricate [21]. The drawback is that they are amorphous but instead they are produced in a deliberately disordered mixture of electron-acceptor and donor materials. Their efficiency of charge transport is limited. The efficiencies of photovoltaic organic solar cells have enhance from 2.5% in 2001, to 5% in 2006 and achieved more than 10% in the year 2011. The research go forwarded to polymer-fullerene based photovoltaic cells that proceed toward enhance the efficiency. For bulk heterojunction organic photovoltaic cells, considering charge carrier transport is important in enhancing the external efficiencies of organic solar cells. Recently, bulk heterojunction solar cells have different mobility of charge-carriers. The mobility of holes is less in magnitude than the mobility of electrons, [22]. Due to low mobility of the charge carriers, efficient bulk heterojunction solar cell has to be formed at the interface of the materials to avoid recombination of the charge carriers, which is difficult to absorption and adjustability in processing. A theoretical study has being done in order to have a bulk heterojunction organic solar cell of fill factor nearly 1 and external quantum efficiency more than 90%. There is needed to be similar charge carrier mobility to overcome a space charge effect, as well as an increase in charge carrier mobility.

**VI Working of organic solar cell**

To form the organic photovoltaic cells, the active layer is sandwich between transparent glass electrode (ITO) and metal electrodes like as Ag, Al, Mg and Au. By absorbing the sun light the active layer generates the electron hole pair and these electron-hole pairs separated at interfaces due to the internal electric potential and move towards opposite electrodes. The active layer is made of the organic materials, electron donor P3HT and PCBM as the electron acceptor. The working principle of organic photovoltaic cells depends on the photo-voltaic effect and the operational mechanism of photovoltaic solar cells can be explained on the basis following diagram.

1. In the highest molecular orbital (HOMO), the active material to absorbs a photon and excited into the lowest molecular orbital (LUMO) and generating an excitons.

2. The excitons dissociated at the interface of the materials which are shown in figure.

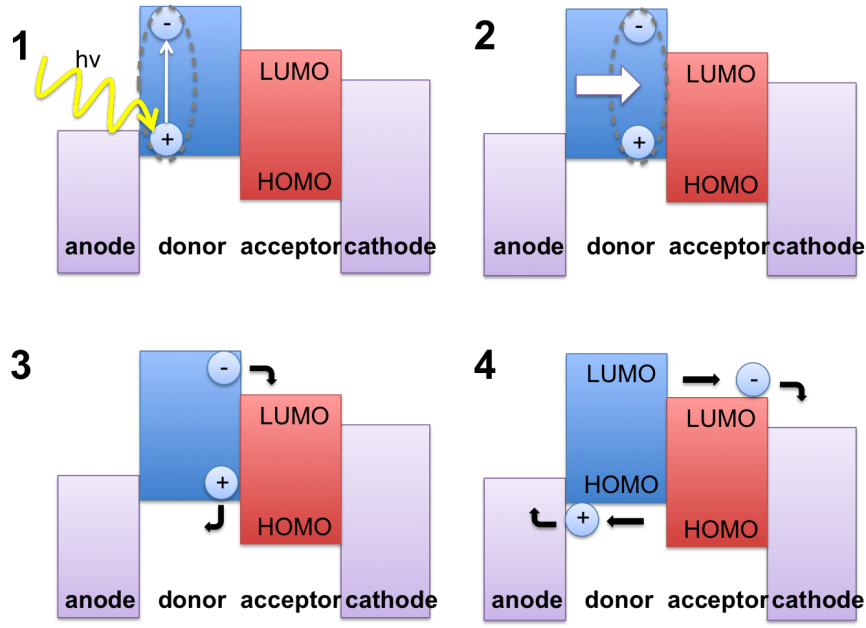


Fig. 5 Operation of Organic Solar Cell

3. The excitons are separated at the interface of the active material and move towards opposite electrodes.

4. When the opposite charge carrier move towards the opposite electrodes than current will start flow in the circuit.

**VII PROPERTIES OF PHOTOVOLTAIC CELLS**

Organic conjugated polymers based photovoltaic cells are a promising alternate option to the silicon based 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 automatic door.

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

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

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

6. They are used to give the power supply and home and other offices.

## IX Current Challenges and Future Scope

The Organic photovoltaic cells has low external quantum efficiency as compared to inorganic silicon solar cells.. The internal quantum efficiency and fill facture of organic solar cells is maximum due to the maximum absorption with active layers on the order of 100 to 200 nanometers, evaporation in opposition to oxidation and reduction, re-crystallization. Due to the temperature variations of the photovoltaic device the solar cell degradation and decreased their efficiency over a long time. The working field of solar cell is increase by the active research in different fields. On the hand the important factor is which effect the motion of the charge carries and dissociation of excitons, the excitons diffusion length, charge separation and charge collection, which are affected by the presence of impurities. In this research chapter study the basic introduction and properties of solar cells and future planning to increase the efficiency and stability remain constant in all weather. The solar cells can be used in long time without any degradation.

**X Conclusion**

In this research work study the basic introduction of photovoltaic solar cells and its types. In an organic solar cell, Bulk heterojunction is formed by blends of electron donor and electron acceptor conjugated molecules that allows light absorption, generation of excitons (electron hole pair) and 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 substitute of electricity and it is using in a large scale in the world to generates the electric power by the solar energy.

**REFERENCEES**

[1]. Solar cell efficiency tables. Process in photovoltaics research and application 19(37) 84-92. [http://onlinelibrary.wiley.com/doi/10.1002/pip.1088](http://onlinelibrary.wiley.com/doi/10.1002/)/pdf, 2011.

[2]. IEA. World energy outlook 2010.http://www.iea.org/weo, 2010.

[3]. Martin A. Green, Third Generation Photovoltaics: Advanced Solar Energy Conversion. Springer.  65(2003)

[4]. J.J.M. Halls, R.H Friend, M.D Archer, R.D Hill, Clean electricity from photovoltaics, London Imperial college press 377-445(2001).

[5]. R. Holmes, R. Pandey , Organic photovoltaic cells based on continuously graded donor acceptor heterojunction ,IEEE Journal 16(6) 7(2010).

[6]. A. K. J. Ghosh et al .Photovoltaic and rectification properties of Al/ Mg Phthalocyanin/ Ag Schottky – barrier cells. J. app. Phy.45, 230-236 (1974).

[7]. S. Glenis et al Influence of the doping on the photovoltaic properties of thin film of Poly-3 Methylthiophene, Thin solid films 139 (3) 221-231 (1986).

[8]. J.Alan Heeger “25 Anniversary” Article Bulk heterojunction solar cells understanding the mechanism of operation, Ad.Mat. 26(1) 10-28 (2014).

[9]. M.C Scharber, N.S. Sariciftci, Efficiency of bul heterojunction organic solar cells,Prog. In polymer science. 38(12) 1929-1940 (2013).

[10]. F. Yang et al. Controlled growth of a molecular bulk heterojunction photovoltaic cells, Nature Materials 4,37-41 (2005).

[11]. B. Li et al.Review of recent progress in solid state dye- sensitized solar cells, Solar energy material and solar cell 90(5) 549-573 (2006).

[12]. P. Peumans et al.Efficient bulk heterojunction photovoltaic cells using small molecular – weight organic thin films. Nature 425 (6954) 158-162 (2003).

[13]. [New South Innovations News - UNSW breaks solar cell record"](https://web.archive.org/web/20120425080341/http:/www.nsinnovations.com.au/news/solar_cell_record.html). NewSouth Innovations. 2008-11-18. Archived from[*the original*](http://www.nsinnovations.com.au/news/solar_cell_record.html)on April 25,2012*.* Retrieved 2012-06-23

[14]. Dimroth, Frank. "Four-Junction Wafer Bonded Concentrator Solar Cells".IEEE Journal ofPhotovoltaic’s.6. [2501729](https://dx.doi.org/10.1109%2Fjphotov.2015.2501729)(2015)

[15]. J.F.Klem, S.Park, J.C.Zolper, Semiconductor tunnel junction with enhancement layer, [U.S. Patent 5,679,963](https://www.google.com/patents/US5679963)(1997)

[16]. H.Albuflasa, R. Gottschalg, T. Betts, "Modeling the effect of varying spectra on multi junction A-SI solar cells". Desalination. **209** (1–3): 78–85. (2007).

[17]. J.Aiken Daniel ["Antireflection coating design for multi-junction, series interconnected solar cells"](http://photovoltaics.sandia.gov/docs/PDF/aikencell.pdf) (PDF). Progress in Photovoltaics: Research and Applications. **8** (6): 563–570. (2000).

[18]. M.Yamaguchi, T. Takamoto,K. Araki, "Super high-efficiency multi-junction and concentrator solar cells". Solar Energy Materials and Solar Cells. **90** (18–19): 3068–3077(2006).

[19]. J.F.Klem, S.Park, J.C.Zolper, Semiconductor tunnel junction with enhancement layer, [U.S. Patent 5,679,963](https://www.google.com/patents/US5679963)(1997)

[20]. Tang, C. W. “2-layer organic photovoltaic cell”, Appl. Phys. Lett. 1986, 48, 183–185.

[21]. Koster, L. J. A.; Mihailetchi, V. D.; Blom, P. W. M. “Ultimate efficiency of polymer/fullerene bulk heterojunction solar cells”, Appl. Phys. Lett. 88, 093511( 2006).

[22]. Y. Liang, et al. For the bright future bulk heterojunction polymer solar cells with power conversion efficiency of 7.4%. Adv. Mater. 22, 135–138 (2010).

[23]. D.G. Mc. Gehee, M.A.Topinka, Solar cells pictures from the blended zone, Nature Materials 5(9) 675-676 (2006).

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