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A Review on Solar Photovoltaic Technology and Its Future Trends

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ABSTRACT

A source of radiant energy is the Sun. Only a small part of the energy we receive from the Sun is actually used by us. Sunshine that reaches the surface of the Earth has the capacity to meet all of our rising energy needs. The process of converting incident sunlight energy into electrical energy is known as solar photovoltaic technology. The original generation of solar cells were made of silicon. Further advancements are required, according to research, for solar cells to operate more efficiently and to absorb large amounts of incident sunlight. To achieve these requirements, amorphous Silicon sola r cells and thin film technology were further developed. From first-generation solar cells to dye-sensitized solar cells, quantum dot solar cells, and some more current technologies, we have examined a gradual progression in solar cell technology in this review. The potential for these many generations of solar cell technologies to establish themselves is also discussed in this article.

Keywords: Solar Photovoltaic, Dye sensitized solar cells, Quantum dot solar cells, Tandem solar cells, Hybrid Perovskite solar cell.

1.INTRODUCTION

Since long time, mankind is using different types of conventional energy sources including fossil fuels, coal, natural gas, agriculture stalk and many more. Use of these fuels for so many years has caused lot many hazards to environment like water pollution, air pollution and hazard to animal species. Global warming, acid rain and soil eruption are adverse effects of using these conventional energy sources over so many years. Limited reservoirs of these conventional energy sources and their different environmental hazards has made us to opt for sustainable and clean energy sources which are called non-conventional energy sources. Different energy sources like tidal energy, wind energy, biomass energy, and solar energy are sustainable energy sources through which energy can be repeatedly obtained. Solar energy is available to the whole world, thus this make it highly desirable and suitable alternative to fossil fuels [1].

Sun is a big gaseous sphere, which is giving a large amount of energy due to fusion of hydrogen nuclei, in the form of solar radiations. Sun is emitting approximately $6.4*10^7$ W/m^2. Out of which ~ 1370 W/m^2 is incident on the Earth's atmosphere considering no absorption of sunlight in space and about 980 W/m^2 power density reaches Earth's surface [2]. Solar energy is available without any cost. Solar energy can be easily converted into electricity by using solar cells. There are few limitations to use of solar energy. First it's not available at night and second it's not uniform always. The sunlight incident on the Earth's surface go through different layers of atmosphere containg various particles and varies largely due to atmospheric effect including absorption of sunlight and scattering, local variations in the atmosphere like water vapors, dust particles, pollution and clouds, location of area on the Earth's surface and also season of the year and time of the day.

About half of the solar spectrum is in visible range. 70% of this visible incident solar energy is incident at sea level. Ozone layer absorbs a little of visible irradiance. Air mass (AM) is the path length which sunlight takes through atmosphere normalized to shortest possible path lengths (when Sun is overhead).

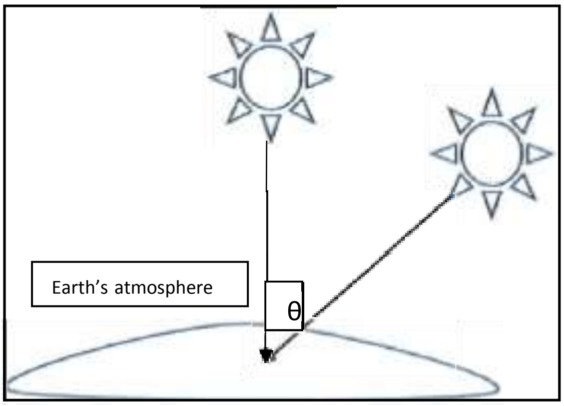


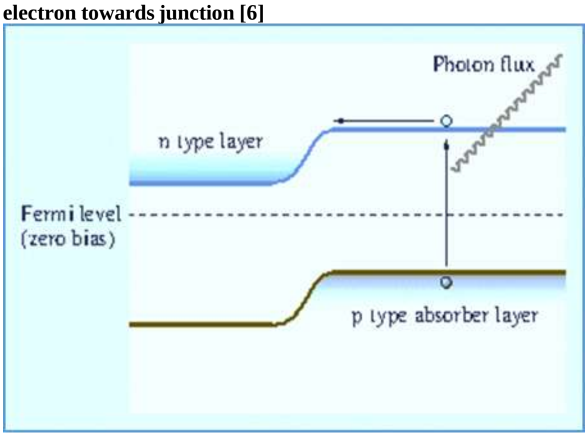
Figure 1. Air Mass coefficient depend on angle of inclination of Sun from vertical

1.1 Photovoltaic Effect

In 1839, a French Physicist, Alexandre-Edmund Becquerel, discovered creation of voltage when he was experimenting with an electrolytic cell made up of two metal electrodes placed in an electricity-conducting solution[3]. Electricity-generation increased when exposed to light. This effect is known as Photovoltaic effect. His discovery laid foundation of Solar cell Technology. Photovoltaic effect is the backbone of Solar cell technology. PV effect was first studied in solids like Selenium in 1870. It was costly and having less efficiency (1% to 2%) [4]. In 1940 and in early 1950, Czochralski method was developed for obtaining pure Silicon crystal. With use of this method crystalline Silicon solar cells were manufactured which were havingefficiency up to 11% [5].

In Photovoltaic effect, when light is incident on a PN junction (N type semiconductor region facing sunlight), incident photons those which have energy equivalent to that of energy gap of semiconductor material, are absorbed producing electrons and holes as charge carriers (figure 2). These electrons and holes are separated due to inbuilt potential. This developed voltage is measured (figure 3). This DC voltage is converted into AC voltage to run different household appliances or it is used for Industry

Figure 2. A PN junction showing absorption of incidence photon, generation of electron and hole anddiffusion of electron towards junction [6]



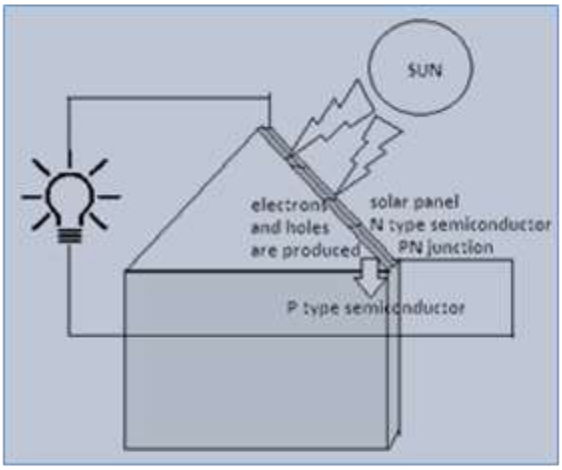


Figure 3. Photovoltaic effect

1.2 Solar cell

A solar cell more conventionally is a PN junction, which works on the principle of Photovoltaic effect. When sunlight is incident on a Solar cell, it produces DC voltage. The basic characteristics of a solar cell are short circuit current (ISC), open circuit voltage (VOC), Fill Factor (FF) and the solar energy conversion efficiency (η) [7]. (figure 4)

Fill Factor = ImVm/IscVoc

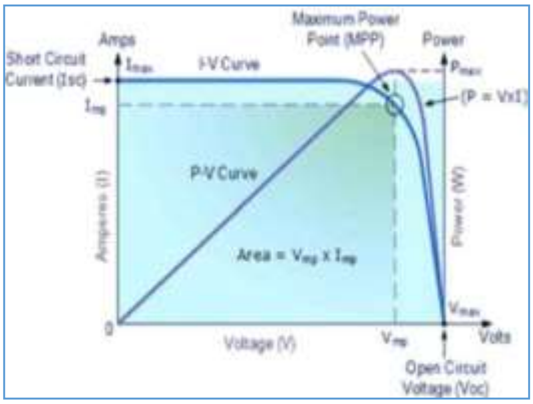


Figure 4. Solar cell I-V characteristics, showing operating point

In both, inorganic type and organic type solar cells, electron and hole separation or excitons preparation should take place before recombination. In inorganic solar cells, built in potential developed at the PN junction separates electrons and holes. Efficiency of these solar cells is determined by ability of these photo- generated minority charge carriers to reach PN junction before recombining with majority charge carriers near vicinity in bulk of the material. In organic solar cells, excitons produced are transferred to respective electrodes through specific electron or hole transfer mechanism.

Depending on different types of materials used for solar cells, these are classified in different categories. Silicon is used mainly for manufacturing of single crystalline solar cells. Silicon is essential component for polycrystalline Si solar cells and amorphous solar cells [8,35]. Thin film solar cell technology uses materials like amorphous Si [a-Si-, cadmium sulphide [CdS], Cadmium Telluride [CdTe], Copper Indium Gallium Di-Selenide [CIGS] etc. Third generation solar cell technology uses advanced concepts harvesting maximum amount of solar energy incident on solar cell and using solar photons conversion more efficiently. This category includes Quantum Dot Solar cell, Dye sensitized solar cell, Tandem solar cells etc. [9].

2. Different types of SOLAR CELL Technology

Figure 5 shows different solar cell generation technologies [10].

2.1 First generation solar cells

These are solar cells based on crystalline Si wafers. Manufactured from Crystalline Si, thus most costly technique of obtaining pure Silicon crystal is involved in this technology. These solar cells are used worldwide and these have highest commercial efficiency [11]. About 80% solar cell market is based on single crystalline solar cells. It was reported by Zhao et al (1998) that polycrystalline solar cells having honeycomb like structure have efficiency of about 19.8%. Polycrystalline solar cells are less efficient as compared to the crystalline solar cells.

1. Single crystalline solar cells
2. Polycrystalline solar cells

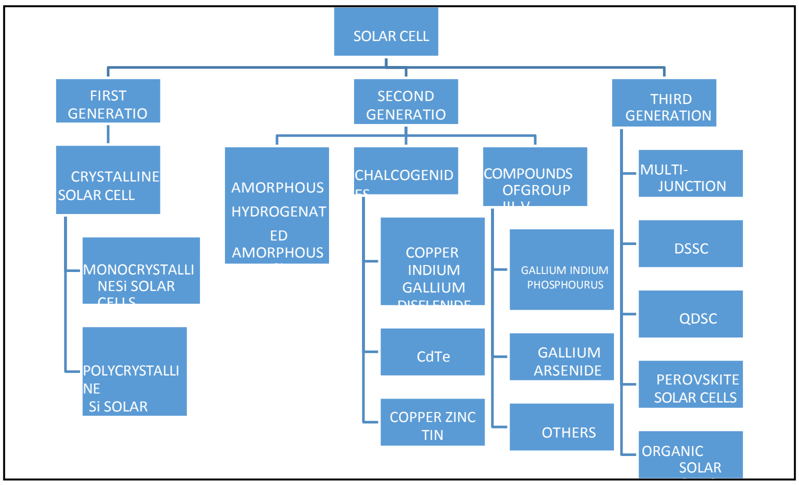


Figure 5. Various types of solar cells and current advancements [10].

*2.2 Second generation solar cell Technology (*Thin film solar cell technology)

Si crystal wafer technology is costly as it uses mostly pure crystalline Si. Obtaining pure Si is a complex and costly process. Cost of solar cells can be reduced if thin films of Si (1μm) can be deposited. Very little amount of Silicon is used by thin film technology as compared to wafer based technology. R. Chittick developed amorphous Si deposited thin films first [12]. Then his co-workers published a report on first systematic and explanatory study on plasma enhanced chemical vapour deposition technique.

2.2.1 Amorphous Silicon solar cells

Doping capability of a-Si:H is rather poor. In conventional PN junction solar cell, minority carriers produced due to photo-absorption are diffused in P and N regions, over the whole length of the junction where optical absorption take place, as diffusion lengths are very large (of the order of 200 μm). Diffusion lengths for minority charge carriers in amorphous Silicon solar cell, are extremely small around (0.1 μm) and thus it is impossible to collect minority charge carriers on the basis of diffusion alone [12].

Because of these reasons p-i-n diodes are always used for a-Si:H solar cells. Homo-junction, hetero-

junction solar cell and multi-junction solar cells are also manufactured using thin film technology. Some advantages of thin film solar cell technology are

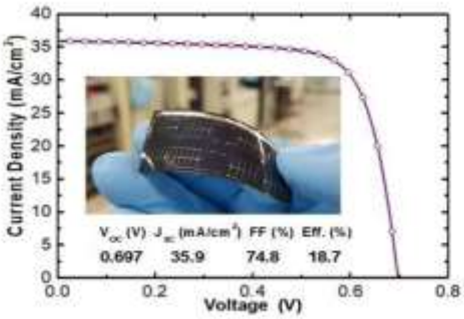
- Low material consumption
- Shorter energy payback period
- Monolithic integration
- Large area modules
- Tunable material properties
- Low temperature processes
- Transparent modules can be made

This solar cell technology is being used in pocket calculators and also to power homes, buildings and some remote facilities. It is well developed thin film technology being in market since 15 years.

2.2.2Copper Indium Gallium Di-Selenide [CIGS]

It is a thin film solar technology. This thin film solar cell is manufactured by depositing a thin layer of Copper, Indium, Gallium and Selenium on glass or plastic backing having front and back electrodes for collection of current. This semiconductor compound material has high absorption coefficient thus a very thin layer of material is required [13]. It was demonstrated that CIGS solar films with high efficiencies when deposited with heavy alkali elements like rubidium and cesium in place of sodium and potassium give high experimental resolution [14]. This thin film technology based on ternary chalcopyrite Cu(In, Ga)Se2 (CIGS) are found to have demonstrated efficiency of 20.8% [15] on flexible substrate (figure 6) and 22.3% on rigid substrates [14,15].

Figure 6. Lightweight and flexible CIGS thin film solar cell and its JV characteristics [15] [57]



2.2.3 Thin-Film Cadmium Telluride Solar Cell Technology

Thin film Cadmium Telluride solar cells are considered to be one of the most promising PV technologies. Band gap for this material is 1.45 eV, making it suitable for absorption of most of the incident sunlight. It is excellent match for absorption of solar spectrum. These are direct band gap materials having high absorption coefficient. Thus a very thin absorbing layer is needed for incident photon absorption. Theoretical efficiency of about 26% is stated for these solar cells, whereas 16.5% laboratory efficiency is being reported by NREL scientists [16]. Cadmium

Telluride solar cell technology is demonstrated to have efficiency of about 21% as published by First Solar [17].

2.2.4 Copper Zinc Tin Sulphide Thin film solar cells

CZTS is a quaternary semiconducting compound, which is used extensively for thin film solar cell technology. It has been reported that optical band gap energy and absorption coefficient of CZTS were about 1.5eV and 1.0×10^4 cm^{-1}, respectively [18] and efficiency was found to be 6.8%. It is always preferred to use low cost and abundant material for manufacturing of solar cells so that its PV technology cost can be reduced and it could be commercialized. As compared to c-Si PV technology which was having about 94% production, thin film PV technology production is only 6% [6, 19]. There are many Earth abundant materials which are tried and tested so that all conditions for efficient and commercial PV technology will be fulfilled.

These materials include both MY2 and Cu2XSnY4 (where M = Fe, Cu, Sn; X = Fe, Mn, Ni, Ba, Co, Cd; Y = S and/or Se) species [8][19].

2.2.5 Compounds of group III-V

One of major reasons behind less efficiency of a solar cell is energy loss in a solar cell because of the mismatch between incident photon energy and energy band gap of the used material. If energy content of incident photons is lesser than band gap energy of material, then photons are not absorbed. Also if incident photon have more energy that band gap energy of material, energy of photons is lost. Thus using multiple layers of photovoltaic materials having widespread of band gap energy value can be used for highly efficient type of III-V generation solar cells so that photon energy loss can be minimized and more photon energy can be absorbed from a wide solar spectrum incident on a solar cell. Multi-junction solar cell consisting of more than one junction is thus favourable to achieve more efficiency. According to Shockley Queisser theory, 33.7% is the maximum efficiency achieved theoretically for single junction solar cell technology when semiconductor material used of band gap energy 1.34 eV and the incident solar spectrum considered AM1.5 [20]. GaAS is a typical group III-V compound having band gap near about 1.42eV and it is a highly suitable material for a highly efficient thin film solar cells. High quality Gallium-Arsenide solar cells with useful back reflectance of photon energy and effective high photon conversion efficiency of 27.8 % were fabricated and demonstrated by Steiner et al. and an increased open-circuit voltage of 1.1 V was recoreded under the global solar spectrum [21]. InGaP is a semiconductor composed of Indium, Gallium and Phosphorous, having similar kind of lattice as that of GaAs [22]. It was demonstrated a single junction InGaP solar cell had band gap energy of 1.81eV and 20.8% solar conversion efficiency [23]. A single junction solar cell is not capable of absorbing all photons from incident sunlight spectrum, thus multi junction solar cells having two and three junctions in a solar cell are fabricated and demonstrated for higher efficiency.

2.3 Third generation solar cell technology

Third generation PV cell technology refers to single junction solar cell which can overcome Shockley– Queisser limit of 31–41% power efficiency. C-Si solar cells (First generation) and thin film solar cells are having some limitations for achieving higher efficiency and to be established as Photovoltaic technology to fulfil all conditions as per golden triangle. Third generation solar cell technology consists of the following types of solar cells

1. CZTS solar cells including materials CZTSe and CZTSSe
2. Dye sensitized solar cells
3. Quantum Dot solar cells
4. Perovskite solar cells
5. Organic solar cells

To increase efficiency of solar cell, it is needed to absorb all photons in incident sunlight. A single junction solar cell will not solve this purpose. Thus multi-junction solar cell is considered as a solution to this problem.

2.3.1 Double Junction solar cells

Double junction, InGaP/GaAs tandem cells were demonstrated with efficiency of 30%, under illumination of solar spectrum AM1.5g [24]. National Renewable Energy Lab (NREL) demonstrated world record of 32.6% efficiency of double junction solar cell under illumination of solar spectrum AM1.5g [25].

Double junction solar cell technology creates a base for multi-junction solar cell technology and three, four junction solar cells are designed to absorb most of light photons incident on a solar cell. With development of new materials and different sustainable designs of solar cells, an absolute efficiency increase of 1% per year is recorded [26].

Three Junction solar cells: Theoretical efficiency of multi-junction solar cells can reach up to 86% [27], stacking infinite number of junctions in a solar cell. Using compound semiconductors, multi-junction solar cells are successfully developed. The three cells in a three junction solar cell absorb different portion of incident solar spectrum (figure 7). The highest efficiency obtained so far is about 39% for triple junction GaInP/GaInAs/Ge [28]. Solar cell under high light concentration of 236 suns [29].

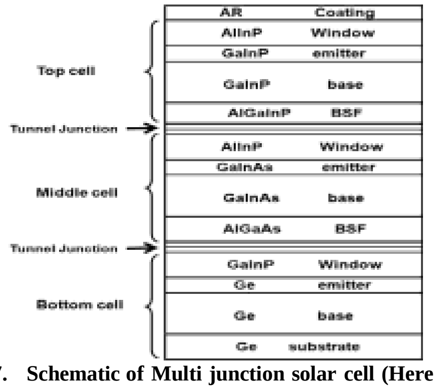


Figure 7. Schematic of Multi junction solar cell (Here Eg1>Eg2>Eg3)

2.3.2 Dye Sensitized Solar Cells (DSSC)

Dye sensitized solar cells work in less intense light like at dawn, dusk or in cloudy weather also. This technology uses less costly materials or even natural dyes and fabrication process of DSSC is simpler (figure 8), in comparison with high cost Si solar cells. Because of these advantages of DSSCs, a large amount of experimentation is continuously being carried out in this area. DSSC provide a strong alternate option for costly crystalline Si technology. DSSC devices can be fabricated using low cost techniques like inkjet/screen printing, roll-to-roll technique [30]. Using these techniques, large area devices are made on flexible substrates. Light from solar spectrum is efficiently absorbed by dye molecules in these DSSCs. There are five different components of a DSSC: a conductive fixed mechanical support, a suitable film of semiconductor material, a suitable sensitizer, an electrolyte which will act as a redox couple and a counter electrode. If optoelectronic properties of any of these components are used selectively then efficiency of a DSSC can be increased significantly. The molecular design of Dye Sensitized Solar Cell need selective optoelectronic properties that include absorption coefficient of used sensitizer material and energy band alignment of sensitizer matching to that of incident soalr spectrum so that large incident photons are absorbed as well as solid-state properties of sensitizer such as aggregation of dye, optimization of morphology and mode of assembly on the TiO2 photo-anode.

Natural dyes like leaves, seeds, flowers, fruits etc. containing natural sensitizers obtained from plants contain pigments such as anthocyanin, carotenoid, flavonoid, and chlorophyll that invokes absorption of light and chemical reactions giving injection of charge carriers to conduction band of TiO2 by sensitizer. Use of synthetic dyes in DSSCs increases efficiency and durability. But it may lead to high cost and use of toxic materials.

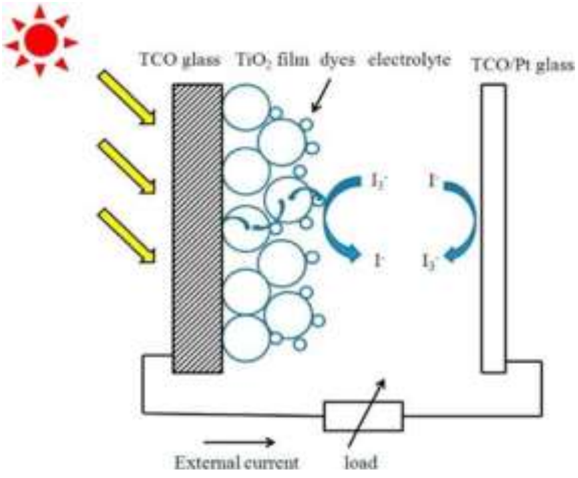


Figure 8. Schematic diagram of a dye-sensitized solar cell [30] [58]

Another way to increase efficiency of DSSC is to use Co-sensitization technique. Two or more sensitizing dye agents having different absorption ranging over wide solar spectrum are mixed together so that large amount of incident spectrum can be utilized [31]. Metal complexes derived from heavy metals like ruthenium (Ru), Osmium (Os), and Iridium (Ir) are widely used in inorganic dyes [32].

In 1993, Nazeeruddin et al. reported DSSC based on Ru-complex dye known as N3 dye, N3/N719/N712, {cis-di (thiocyanato)bis(2,2-bipyridine-4,4-dicarboxylate)ruthenium}, obtained 10.3% efficiency for N3 dye system and dye covered film was treated with TBP. At NREL a black dye (N749)-sensitized DSSC showed efficiency of 10.4% with JSC = 20.53 mA/cm^2, VOC = 0.721 V and FF = 0.704, where active area of the used cell was 0.186 cm^2 [33]. For achieving lesser cost PV cells, organic dyes are used. Low cost, easy preparation methods and environment friendliness are some advantages of organic dyes. D149 Indole derivative die when used as photosensitizer in DSSC, efficiency of 8% was observed [34]. LD4 Zinc porphyrins derivative dye when used as photosensitizer in DSSC, efficiency of 10.6% was observed [35]. Natural dyes are also used in DSSCs and lot much research is still going on in this field of DSSC. Laser ablation technology is considered very important when good module quality dye-sensitized solar cell is needed. Simple pulsed Nd:YAG laser system with TEM00 mode is used to ablate the FTO thin film layers. More efficient Si doped YAG with some structural impurities studied for its structural changes [36] if used in Nd:YAG laser, it can be used for ablation of FTO thin film in DSSC.

2.3.3 Quantum Dot Solar cells (QDSC)

A Quantum Dot Solar cell is designed in such a way that it is using tiny particles called as quantum dots (few nanometers in size) for absorption of incident sunlight photons for Photovoltaic effect. Quantum dots (QDs) are semiconductor particles having size of about few nanometers, having optical and electronic properties that differ drastically from bulk material (figure 9).

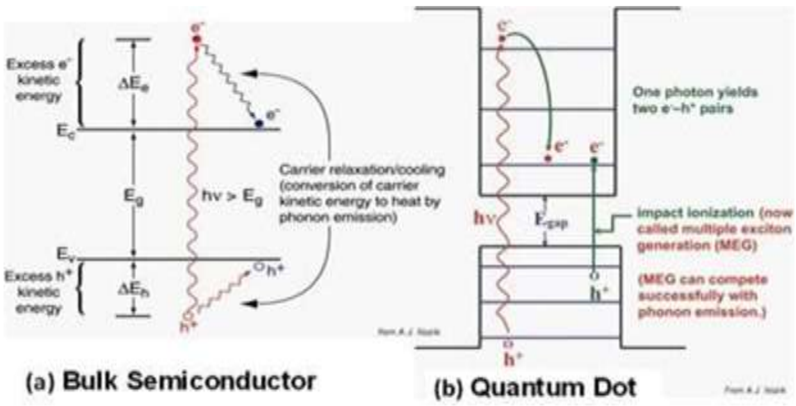


Figure 9. Difference between physics of Bulk material and Quantum dot (Google images)

By changing Quantum dot's size, shape and material, frequency of light emitted by quantum dot can be precisely tuned. Quantum dots of different sizes and types emit light of different frequencies and this frequency can be changed precisely as per requirement. Quantum dots can also be termed as artificial atoms having characteristics like their singularity, having bound structure, discrete electronic states, same as that of naturally occurring atoms or molecules. Many methods like Chemical Ablation, Electrochemical Carbonization, Laser Ablation, Microwave Irradiation, and Hydrothermal/Solvothermal Treatment are used for synthesis of Quantum dots. Quantum dot Solar cells are considered to be derived from Dye sensitized solar cells. QDs, like CdS [37], CdSe [38] , PbS [39], and InAs [40], are used as photosensitizer in place of organic dyes because they have versatile optical and electrical properties [41], and these include: 1) a tunable band gap which is dependent on size of QD, 2) a larger extinction coefficient, 3) higher stability toward water and oxygen, and 4) multiple exciton generation (MEG) with single-photon absorption[42]. Recent research carried on Zinc Oxide quantum dots and nano-rods and also TiO_2-coated ZnO nanowire arrays have different applications. DSSC of such type had come out with solar conversion efficiency of 6– 9%. [43][44]. Quantum dot-sensitized solar cells (QDSCs) with much larger photon absorption possible because of tunable energy band gap have theoretical efficiency of 44%. Kim et al. have reported a high performance Zinc oxide/Lead Sulphide hetero-junction Quantum Dot Solar cells with a certified PCE of 10.7% by depositing robust self-assembled monolayers on ZnO surface so that energy alignment of the interface can be adjusted.

2.3.4 Perovskite Solar cell

Perovskite is the name given to mineral $CaTiO_3$, after a Russian mineralogist, L.A. Perovski and type of all compounds which crystallize in same structure of ABX_3, where A and B are cations and X is the anion species [45]. For hybrid organo-lead perovskites, A is a monovalent organic cation, B is Pb(II) or Sn(II) and X is an halogen anion such as I^-, Br^-, Cl^-[46] $CH_3NH_3PbI_3$, $CH_3NH_3PbBr_3$ and the mixed halide structure, $CH_3NH_3PbI_{3-x}Cl_x$ or $CH_3NH_3PbI_{3-x}Br_x$ are the most common semiconductor perovskite material used for solar cell applications. Advantages of using these materials in solar cell are 1) low recombination losses 2) lower material costs, 3) longer charge carrier diffusion lengths and the possibility of substitution of cation and anion for tuning of bandgap energy (Energy Initiative Massachusetts Institute of Technology, 2015). Perovskite Solar Cell efficiency has been increased significantly in very few years as compared to any other PV technology. With use of methylammonium lead halide perovskite material films more stable and efficient solar cells can be manufactured. Thus use of high quality Perovskite films have created a significant impact on advanced solar cell technologies. The two most common architectures of a perovskite solar cell are the so called mesoscopic and planar. (As shown in Fig. 10)

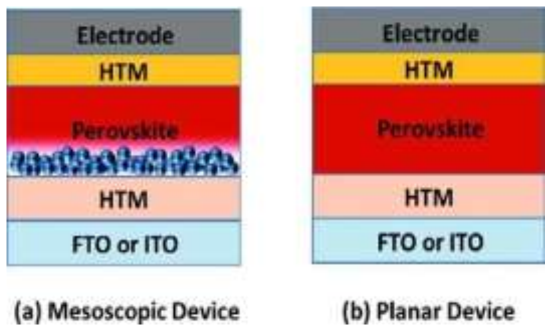


Figure 10. Mesoscopic and Planar device architecture for Perovskite solar cell [48] [59]

In the former type of solar cell, a compact thin layer (10–30 nm) of TiO_2 is deposited on to a conductive transparent oxide such as FTO material or ITO material supported on the glass.

A thicker porous layer of TiO_2 nanoparticles is then deposited subsequently, sintered and then infiltrated by perovskite solution. In planar configuration there is no such mesoporous layer. On top of perovskite absorber layer, hole transport material layer (HTM) and a 60–80 nm thick layer of Au as top contact are one by one deposited using spin coating method and evaporation, respectively. In this kind of configuration, light rays travel through glass and thus the HTM and top contact layer can be completely made opaque.

Various types of additives at anion and cation site have been used to dope into the perovskite layers so that the surface morphology can be enhanced efficiently in Hybrid Perovskite Solar Cells, such as inorganic salts, organic halide salts, inorganic acids, fullerene, polymers and even water. In general, hybrid perovskites can become more crystalline if additives are doped into perovskite layers, so that highly purified and smooth layers of perovskite material can be formed, leading to increased efficiency and stability of HPSCs. Since 2015 many researchers are using methylammonium cation on A site of the perovskite structure with formamidinium (FA) and/or Cs [47] and partially replacing I- with Br-, to tackle drawbacks of MAPbI3: water sensitivity and thermal stability.

Effect of environmental factors like moisture and oxygen can become less damaging due to encapsulation of PSC. While using PSC, the most important issues are instability of intrinsic bulk perovskite material and interface between the perovskite material and the charge transport layers. Three main intrinsic factors are responsible for instability of Perovskite solar cell: hygroscopicity, thermal instability, and ion migration. Hygroscopicity is related to the environmental factors and can also be solved by encapsulation. By spraying water onto the MAPbI3 layer some researchers have found that a reversible healing effect occurred due to suppression of non-radiative recombination sites [48]. Another obstacle for mass production of Perovskite Solar Cell is large cost of organic Hole Transport Material SPIRO-MeOTAD for a glass-based substrate architecture and cost of manufacturing even increases if fullerene-based polymers are used such as PEDOT:

PSS. Thus optimizing morphology of a Perovskite solar cell photon conversion efficiency that could be achieved so far is 20%.

2.3.5 Organic Solar Cell

Photovoltaic technology that uses organic semiconductor electronics is organic solar cell technology which deals with conductive organic polymers or small organic molecules [49] such that light is absorbed and charge carriers are produced by Photovoltaic effect. Most organic photovoltaic cells are polymer solar cells composed of conjugated polymers or small organic semiconductor molecules. Some characteristics of Organic solar cells are (a) It combines the virtues of plastics with those of semiconductors (b) High optical absorption coefficients (c) Properties tuned with flexible synthesis (d) Low cost fabrication. Either Bilayer or Bulk hetero-junction architecture can be used for organic solar cell fabrication. Bulk hetero-junction is always preferred since organic materials have very less diffusion path lengths. These solar cells are fabricated using very less expensive deposition techniques like thermal evaporation and inkjet printing [50]. Different transparent organic materials are synthesized and used for building design integration. For organic solar cells, lab efficiencies of 11.1% have been reported [51] [56] but module efficiency is lower.

A hetero-junction made of donor and acceptor semiconductors basis for operation of an organic solar cell [51]. Organic semiconductor materials are very much different from crystalline classic semiconductor materials. Incident light photon is absorbed and an exciton is produced in organic solar cell. Exciton is couloumbically attached pair of electron and hole. These excitons are then distributed along the interface of donor to acceptor material. It is needed that organic semiconductor layer thickness to be tiny because it has short exciton diffusion length thus restricting efficient absorption of incident solar energy. In order toachieve more absorption of incident photons at the interface of D/A, nanorods and nanotubes of donor and acceptor materials are being investigated. In organic solar cells, Single Walled carbon Nano Tubes (SWNTs) are employed as acceptor and the poly (3-octylthiophene) (P3OT) is used as donor [52]. Low photocurrent was observed when this type of solar cell was fabricated. Also Nanotubes do not help in photo generation process. The same research group used an organic dye having high absorption coefficient at the polymer/nanotube junction and an improvement was observed in photo generation process, especially in UV region [3, 52]. Discotic-based solar cells made by the columnar array of the donor, perpendicularly oriented to substrate and embedded in an acceptor material has been proposed wherein external efficiency of about 5% with an external quantum efficiency (EQE, photon to current) of 34% at incident monochromatic wavelength of 490 nm has been claimed [53].

Major setbacks for achieving high efficiency in organic solar cells consists very lesser and not so effective transport of excitons and charge carriers. Stability of organic solar cells is poor if it exposed to sunlight for a long time and it also have less efficiency. Thus getting bulk-ordered separated structure for both donor and acceptor organic semiconductors and improving transportation of free charge carriers to respective electrodes is needed to increase efficiency. Most promising research direction is to investigate the possibility to use semiconductor crystal liquid molecules in organic solar cells [54].

Multi-junction (MJ) solar cells/Tandem solar cells – In this solar cell technology multiple junctions are used. Each material's p-n junction will absorb specific amount of incident solar spectrum and produce electric current. This type of solar cell design technology allows larger absorbance of solar spectrum thus increasing photon conversion efficiency. A solar cell having an infinite number of junctions would have a limiting efficiency of 86.8% under highly concentrated sunlight [55]. One of the important conditions to increase efficiency of a solar cell is to make it absorb all photons incident on it. By using Tandem cell configuration, efficiency of solar cell can be greatly increased. Metal–halide perovskites in organic and inorganic form are the first thin-film solar cell material having high energy bandgap thus making absorption of large incident photons possible. Different easily available earth-abundant material is used in these solar cells. Using a Tandem solar cell configuration, it is possible to increase efficiency of a solar cell beyond average efficiency value of 26% and using thin film Tandem solar cell configuration, efficiency greater than 30% can be achieved. For commercialization of PV technology it is needed to have more efficiency, larger lifetime and lesser cost (in $kWh-1) of the system. These are three main characteristics of solar cell performance in solar cell PV research. Four-terminal tandem devices using perovskite cells having high efficiency are fabricated on ITO/glass substrates (figure 11), with multilayered electron-transport/charge-selective layer, perovskite absorber layer consisting methylammonium (MA) or formamidinium (FA) lead iodide, Spiro-OMeTAD hole conductor, MoO3 buffer layer, and ITO top contact with metalized grid. Efficiency records for four terminal tandem solar cells: with perovskite- CIGS combination is 22.1%. For perovskite-perovskite based combination efficiency is recorded at 20.3% on FA0.75Cs0.25Sn0.5Pb0.5I3 (FACSPI).

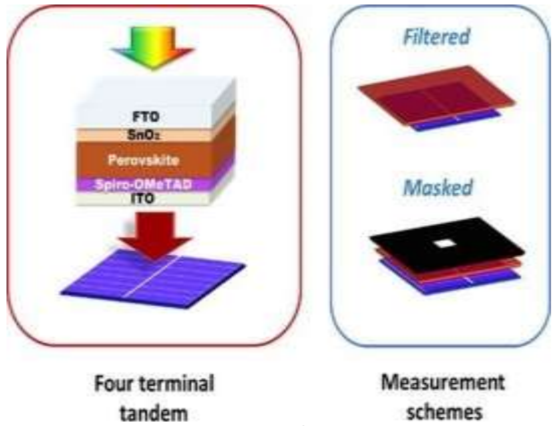


Figure 11. Schematic diagram of Four Terminal Perovskite Tandem Cells

By selecting different suitable material layers for top and bottom of tandem solar cell and using optimized materials; efficiencies less than 60% of maximum theoretical efficiency limit is recorded.

With an advancement of previous progress of the perovskite solar cells and its efficiency in last ten years, it is expected that a 4T perovskite–silicon tandem solar cell can achieve efficiency of 26% or even beyond 26% in the laboratory followed by a 2T perovskite–silicon cells by the year 2025. Considering different Solar cell technologies discussed here, it can be stated that a hybrid multi-junction, multifunction solar cell technology can give more efficient and durable PV cells.

3. Future of Solar cell Technology

Solar cell technology is vast field in which, we can harness a large amount of solar energy incident on Earth's surface. Large solar panels are required to capture incident sunlight. This transformed energy can be stored and used in different applications. Erecting large solar panels and maintaining these solar panels could become cumbersome and hectic. Moreover large landscape is wasted for erecting these solar panels. In Asian countries land available per square feet for an individual is very less and erection of large Solar panels would cause crisis of land. More advanced and smart solar panels can be designed to overcome this problem.

Bifacial Solar cells: Passivated Emitter Rear Cell (PERC) is an advanced kind of solar cell technology that could give more efficiency. Bifacial solar cells are capable of generating electricity not only from the sunlight incident on the front surface of a solar cell but also from reflected sunlight at the rear part [60].

Floating PV technology: In order to obtain solution for wastage of large landscape, large water bodies can be used to erect PV cells. In India, Floating PV technology project would be developed and its further development would be pursued.

Integrated PV panels: PV panels integrated in building architecture would be providing solution to bulky solar panel arrays, installation and maintenance difficulties.

Solar Trees: Like natural trees, solar trees could be erected, which would be capable of converting almost whole amount of incident sunlight and producing electricity.

Agro-photovoltaic: Same agriculture land can be used for growing crops as well as for solar panel installation.

4. CONCLUSION

Changing climate has become a major concerned issue in this century. Environmental hazards caused by conventional fuels, crisis of energy sources, volatile oil prices, security and safety of energy sources had laid the way of transforming energy sector of the globe. De-carbonization of world's conventional energy system can be done by using clean energy i. e. solar energy. Hybrid energy systems like solar energy and wind energy could be used together for transformation of energy into electricity. Remarkable solar cell technologies like thin film solar cells, Dye sensitized solar cells, Multi-junction solar cells, Perovskite solar cells have caused an evolution in solar cell industry. Ever increasing energy demand of world's growing population could be satisfied by using one or more energy technology along with solar energy.

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