REVIEW ARTICLE

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A brief review on third generation Solar Cell

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Abstract

Converting solar energy into a clean, practical alternative power source will require highly efficient and inexpensive devices that generate electrical power from solar irradiation. To meet the word wide energy demand solar power is highly acceptable. Photovoltaic industries are totally dominated by crystalline silicon solar cell and it grabs the 90% of photovoltaic market. Nowadays, different generations of solar cell using various type of fabrication technology have been emerged. Scientists have categorized solar cell into three different types. (i) first generation solar cell which include single crystalline and polycrystalline solar cell, (ii) second generation solar cell comprising of amorphous silicon solar cell and (iii) third generation solar cell fabricated with dye-sensitized solar cell, organic photovoltaic, quantum dot and perovskite solar cell. In this article, a brief review of different types of solar cell belonging in the 3rd generation and its evolution and progress has been discussed.

Keywords: Solar cell , Dye-sensitized solar cell, Perovskite solar cell.

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Introduction

The conversion of solar power in to pollution free green and clean energy requires high efficiency devices that can generate electricity for practical use. It also demands that the device and its fabrication technology must be cheap for industrialization. It attracts attention of researchers working on various photovoltaic materials and technologies. Besides mono-crystalline silicon solar cell, technology of different generations of solar cell have been developed. The thin film technology is mostly acceptable due to its low production cost under the 2nd generation solar cell. The low cost thin film amorphous hydrogenated silicon solar cell (a:Si:H) is very light, can be deposited on large area suitable for large scale application. Among the third generations solar cell, dye-sensitized (DSSC) solar cell, organic photovoltaic solar cell, hybrid metal halide perovskites are promising photo voltaic (PV) technologies. This type of new generation solar cell is in infant stage, far apart from commercialization. All this materials have poor stability. But the rapid increase of efficiency (16.4%) of organic photovoltaic solar cell (OPV) is also notable irrespective of the cell area which is again too small (.04 cm^2) for making outright record. Hybrid metal halide perovskite solar cell (PSC) has achieved high efficiency (certified 24%) for a small area 0.1 cm^2 and it is cheapable also, but there are some difficulties for large area production. The poor stability of such type material or device faces a great challenge which hinders the industrial applications. This article discusses about dye-sensitized solar cell and perovskite solar cell belonging to the third generation and provides a good idea about this.

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Materials and Methods

Dye sensitized solar Cell

Though the production cost is cheap in case of amorphous silicon solar cells but the main problem is the poor efficiency of this type of cells. For several years the efficiency of amorphous silicon solar cell is stuck around 10%. So people are searching for other types of materials which can overcome the challenges of future generation solar cells. To fulfill these requirements, it attracts attention of researchers working on various photovoltaic technologies, especially dye sensitized solar cells (DSSCs) and organic photovoltaic (OPV), perovskite solar cell (PSC) with emphasis on better efficiency.

Michael Gratzel first described low-cost photovoltaic cell using dye.[1] Optically transparent film of titanium dioxide of particle size few nanometers coated with a monolayer of a charge transfer dye. Dye sensitizes the film for light harvesting. It was also observed that organic dye produce electricity at oxide electrode in electrochemical cells. Due to high surface area of semiconductor film and the ideal spectral characteristics of the dye this device generates electricity for

the conversion of incident photon with high efficiency. One of the efficient DSSCs devices uses ruthenium-based molecular dye, e.g. [Ru (4,4'-dicarboxy-2,2'-bipyridine)$_2$(NCS)$_2$] (N3) which is bound to a photo-anode via carboxylate molecules.

The anode of a DSSC consists of a glass plate which is coated with a transparent conductive oxide (TCO) film (Figure 1). Generally Indium tin oxide (ITO) or fluorine doped tin oxide (FTO) are used as TCO. On TCO a thin layer of titanium dioxide (TiO_2) is applied which exhibits a high surface area because of its porosity. Thus, the dye molecules encapsulate the TiO_2 when the TiO_2 film is soaked with dye. The cathode is a Pt film coated on glass where the Pt film serves as a catalyst. An iodide/tri-iodide solution is used as the electrolyte.

The mechanism is that, when sunlight enters the cell through the TCO and strikes the dye on the surface of the TiO_2 and absorbed in the dye. The absorbed photon took the dye to its excited state, from where an electron can be "injected" directly into the conduction band of the TiO_2 and diffuses (as a result of an electron concentration gradient) through the anode. In this way, the dye molecule will decompose due to loss of electron if another electron is not provided. The dye strips one from Iodide (I^-) in electrolyte below the TiO_2, oxidizing it into tri-iodide (I^-_3). The reaction is very fast, i.e, the time of reaction is lesser than compared to the time that it takes for the injected electron to recombine with the oxidized dye molecule. The oxidized dye molecule is again regenerated by electron donation from the iodide in the electrolyte. In return, iodide is regenerated by reduction of tri iodide on the cathode. This process prevents the recombination reaction that would effectively short-circuit the solar cell. The missing electron of the tri-iodide is recovered by mechanically diffusing to the bottom of the cell, where the counter electrode re-introduces the electrons after flowing through the external circuit. Recently building-integrated photovoltaics (BIPV) has pay attention in dye sensitized solar cell technology and think to incorporate DSSC in the BIPV by replacing Si-based PV technology as Si-based PV technology, operates under high intensity has restriction in their energy-intensive manufacturing methods and poor efficiency under low light intensities.

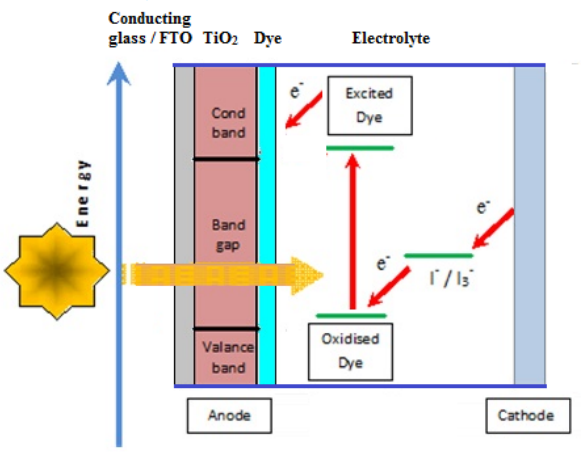

Figure 1: Schematic diagram of Dye-sensitized Solar Cell

DSSCs are currently the most efficient among third-generation solar cell. Efficiencies of other thin-film technologies are typically between 5% and 13%, and traditional low-cost commercial silicon panels operate between 14% and 17% of efficiency. In "low density" applications such as rooftop solar collectors it is to be think that DSSCs would be the best suitable replacement of existing technologies and more advantageous also where the mechanical robustness and light weight of the glass-less collector is prime importance. Though for large-scale deployments where higher-efficiency cells are more viable, dye sensitized solar cell is not applicable, but a thorough research will be required to raise the conversion efficiency in the DSSC might make them suitable for some of these roles.

The main disadvantage of dye sensitized solar cell is that dyes do not absorb entire incident light and it has major problem with temperature. At low temperature the electrolyte can freeze and stop power generation and also at higher temperature liquid electrolyte can disrupt the power production. Replacing liquid electrolyte with solid has been an ongoing research but still degradation takes place for constant using.

Perovskite Solar Cell

Organometal-trihalide perovskite semiconductors are one of the much anticipated and technologically promising materials among the third generations solar cell. The absorption of light by the perovskite layer of solar cell generates a greater no of electron and hole pairs in compared to that produced in the intrinsic layer (I-layer) in the PIN structure. On optimizing the device design and film-deposition parameters and techniques, it is expected that, perovskite thin film solar cells offer more advantages than other conventional thin film photovoltaic cells for high power requirement in future.

Perovskite was discovered in 1839, a kind of ceramic oxide with molecular formula ABX_3. Perovskites which do not contain the carbon-hydrogen bond, these are the natural Perovskites. The stoichiometry of the Perovskite is ABX_3 and is depicted in Figure 2. Here A is the corner position (it can be Ca, K, Na, Pb, Sr and other rare metals). B is the body

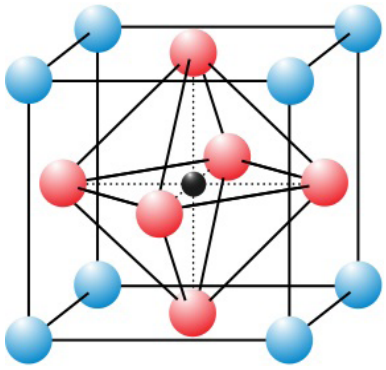

Figure 2: A schematic diagram of a perovskite crystal structure, blue spheres represent the 'A' cations, black spheres represent the 'B' cations and red spheres represent the 'X' anions

centered position (it can be the metal cation) and X_3 is face centered position (it can be oxide or halide anion such as Cl, Br, I). Perovskite is any type of material which has ABX_3 crystal structure, A and B are two cations of very different sizes and X is an anion that bonds to both.

Recently perovskite absorber layer which are used in solar cell contains organic –inorganic cations and anions maintaining the structure ABX_3.Where A is organic cation (i.e $CH_3NH_3^+$, $NH_2CH{=}NH_2^+$, $CH_3CH_2NH_3^+$), B is metal cation (Pb^{+2}, Sn^{+2}, Ge^{+2}) and X is halogen anion (F^-, Cl^-, Br^-, I^-) (Figure 3).

Both organic inorganic hybrid perovskite is used as an active layer to get good results. Organic structure provides good solubility whereas inorganic structure produces a precious crystalline structure on the deposited film by producing ionic/covalent interaction.

Mostly common architecture of PSC is depicted in Figure 3. Transparent conducting oxide (TCO) is deposited on the glass substrate. A blocking layer (Electron transport layer ETL)/perovskite absorber layer/Hole transport layer (HTL)/Gold (Au) are consequently deposited on transparent conducting oxide. Perovskite abosorber layer absorbs lights and generates electron hole pair. The electron-hole pair diffuses and separates by the electron –hole selective contacts. Once electron and holes are present at the cathode and anode respectively and deliver power when external load is connected in the circuit. For perovskite solar cell Tio_2, ZnO, SnO_2 are used as ETL materials. Spiro-OMeTAD is used as HTL materials. Common perovskite absorber is methyl ammonium lead halide ($CH_3NH_3PbX_3$). But the lead compounds are very toxic and harmful for the environment. So to fabricate lead free perovskite solar cell is of prime important

The benefit of perovskite material is it responds much quicker to light in quadrillionths of a second. This shows that the photo generated electrons flow freely due to very smooth deposition of the perovskite materials on the solar cell structure. By this process thick solar cells may be produced and eventually it would be able to absorb more light and generate more electron hole pair, producing more electricity. Also, some of beneficial mechanical properties of perovskite layer such as light weight, high flexibility, innovative architectural design owing to the ability of perovskite to generate multiple translucent colors, innovative and also ability to achieve solar cells efficiency nearly 25% now.

Perovskite solar cell mainly originates from dye sensitized solar cell. The key problem of dye sensitized solar cell was that dyes were unable to absorb entire incident light could

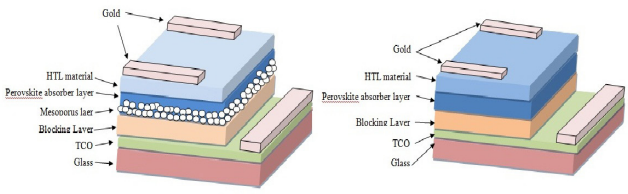

Figure 3: Schematic diagram of different Perovskite solar cells

be resolved in perovskite solar cell. In 2009, Miyasaka first replaced dye by perovskite materials and paved the way of new type solar cell. He[2] first developed organic-inorganic lead halide $CH_3NH_3PbBr_3$/TiO2-based and $CH_3NH_3PbI_3$/TiO2-based solar cells with a Power Conversion Efficiency of 3.13% and 3.81% respectively. The cell was constructed by combining $CH_3NH_3PbBr_3$/TiO2 as anode and pt-coated FTO glass as cathode electrode with a 50 micrometer thick separator film. The gap was filled with an organic electrolytic solution with lithium halide and halogen. Two organic-inorganic lead halide perovskite compounds sensitized TiO_2 and shows photovoltaic activities for visible-light conversion in photochemical cells.

These two organic inorganic lead halide perovskite nano crystalline particles assembled on mesoporus TiO_2 act as n-type semiconductors and gives power conversion efficiency. But there was a big challenge that liquid electrolyte dissolved away the perovskite within a minute. The instability issue was resolved by M. Gretzel and N. G. Park et al[3] in the year 2012.They used solid state mesoscopic heterojunction solar cell where perovskite nanoparticles of methylammonium lead iodide (CH_3NH_3) PbI_2 act as light absorber. By replacing liquid electrolyte with solid hole transporting layer (HTL) Spiro-OMeTAD, 9.7% efficiency was achieved with long term durability. Spiro-OMeTAD is the mostly accepted hole transporting layer, 2,2′,7,7′-tetrakis(N, N-di(4-methoxyphenyl) amino)-9,9-spirobifluorene (Spiro-OMeTAD) provides flawless transport of hole and contribute to the increasing cell performance. Perovskite nanoparticles (NPS) produced by the reaction of methylammonium iodide with PbI_2 deposited onto a thick mesoscopic TiO_2 film invaded to the hole-conductor spiro-MeOTAD generated large amount of photocurrent illuminated under standard AM-1.5 sunlight . In 2013, M. Z. Liu, M. B. Johnston and H. J. Snaith[4] fabricated planar hetero junction Perovskite solar cells (PSCs) via vapor deposition, and the efficiency of the PSCs device is up to 15.4%. The next few years research and development of organic–inorganic halide perovskite solar cells have been introducing a great attention for the researcher. Hui-Seon Kim et al. (2013)[5] have analyzed that by the gathering of photo generated charge and charge separation photovoltaic conversion was possible. They analyzed the mechanism of carrier gathering in the lead-halide Perovskite. First time they observed the gathering of charge in the light absorbing material, which is $CH_3NH_3PbI_3$ Perovskite in the NS solar cell, so that it creates a new kind of photovoltaic device, which different from the sensitized solar cells. Jeffrey A. Christians et al. (2013)[6] have studied about the organo lead halide Perovskite solar cells. These are expensive and having low hole mobility. For the thin film photovoltaics copper iodide is identified as hole conducting material in the Perovskite solar cell. By using this copper iodide in the Perovskite, they can achieve the 6% power conversion efficiency with good photocurrent stability. Because of higher electrical conductivity, copper iodide gives the better fill factor than the spiro-OMeTAD. Copper iodide used as a low

Table 1: Year wise performance of different types of solar cells

Effiency	*2009 (%)*	*2012 (%)*	*2013 (%)*	*2017 (%)*	*2019 (%)*
Amorphous silicon	10.0	10.0	10.0	10.0	10
Perovskite cell	3.8	9.7	15.4	22.1	25
Crystailine silicon cell	24.0	24.0	24.0	24.0	24

cost hole conductor for the organo lead halide Perovskite and also achieve the good power conversion efficiency. The simple planer device structure at room temperature deposition process was employed by Olga Malinkiewicz et al. (2013).[7] Before this all high efficiency perovskite solar cell deposited on metal oxide required high temperature sintering process. Here methylammonium lead iodide is used as an absorber layers. This layer is sandwiched between the two organic charge transporting layers acted as an electron and hole blockers. This comes in contact with the indium tin oxide ITO/PEDOT: PSS which is used as the hole extraction and Au as electron extraction contact so that the electrons and holes are extracted yielding the power efficiency of 12%. By using the sublimation process in the high vacuum chamber they got high purity Perovskite layers. Hairong Li et al. (2014)[8] have studied about 3,4-ethylenedioxythiophene, which is the electron rich molecule. The power conversion efficiency was increased to 13.8%, when they used the 3,4-ethylenedioxythiophene as the hole transporting in the Perovskite solar cell under the AM 1.5G solar simulations. This is the first material which contains the heterocycle and helps to achieve the efficiency more than 10%. Also this material is the alternative replacement of the costly spiro-OMETAD and so they achieved the cheaper synthesis process. The rapid increase of efficiency of perovskite solar cell was mainly depends on the development of various solution synthesis and film deposition techniques for controlling the morphology and composition of hybrid perovskites. Yixin Zhao and Kai Zhu et al. (2014)[9] have studied the one step solution process for the formation of $CH_3NH_3PbI_3$ Perovskite films. In this solution they added CH_3NH_3Cl with the standard $CH_3NH_3PbI_3$ precursor solution. By using the methylammonium chloride (MACl), they obtained the pure $CH_3NH_3PbI_3$ and efficiency was increased. Mohammad Khaja Nazeeruddin and Henry Snaith (2015)[10] analyzed that by applying the methylammonium lead tri iodide based Perovskite solar cells, the power conversion efficiency was increased to 20% and got the good photovoltaic properties of Perovskite devices . S. I. Seok et al. in 2017[11] showed that by incorporating additional iodide ions into the organic cationic solution used to form the perovskite layers through an intra-molecular exchanging process decreases the concentration of deep-level defects and raises the (power conversion efficiency) PCE of PSCs at 22.1% in small cell and 19.7% in 1-squre-centimeter cells. Recently single crystal $MAPbI_3$ perovskite solar cells exceed 21% power conversion efficiency.[12] Seo et al 2019 obtained a perovskite solar cell with certified cell efficiency 25.2%.[13] Long carrier lifetimes

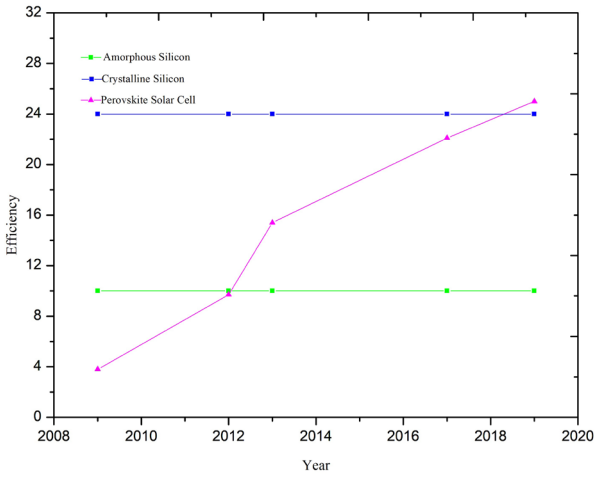

Figure 4: Year wise performance of different types of solar cells (including 1st, 2nd and third generation) with respect to their efficiency

combination, electronic defects and charge carrier mobility are responsible for the high power conversion efficiencies. The methyl ammonium lead tri-iodide based perovskites are used as a solar cell, photo detector, light emitting diodes etc. But their disadvantages are that the sensitivity toward the humidity and under the heat and light conditions they are not stable.

Results and Discussions

There is an exciting promise for research and development of organic–inorganic halide perovskite solar cells in next few years. It is to be expected that rapidly growing efficiency of organic inorganic halide perovskite is very much interesting and attractive for photovoltaic researcher. Deeply understanding of their material properties and optimization of cell designs makes to think that perovskite solar cell would be a correct alternative among the third generation. Some data shows Table 1 efficiency of different types of solar cell and Figure 4 shows the year wise performance of different types of solar cell.

Conclusion

In case of Dye-sensitized solar cell using liquid electrolyte is a major issue for industrialization. Replacing electrolyte by solid is very much developing field of research. Though there is advantage of greater Power Conversion Efficiency but for production of large-area PSCs device are still has some issues needed to be solved for industrialization In the

case of large-area PSCs device, surface, bulk defects and interfaces introduce recombination centers producing fast non-radiative losses and interface losses, which decreases the Voc, Jsc and fill factor (FF). Also, the perovskite material is easily thermal decomposed and hydro decomposed which leads to the lack of stability for PSCs device in practical use. This challenge hinders the Perovskite solar cell device to be used in industry and outdoor applications. A thorough research would resolve the problem and perovskite solar cell might be the future endeavour of photovoltaics.

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