Recent Advances in Photovoltaic Technology based on Perovskite Solar Cell- A Review

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Abstract - *Perovskite material used in fabricating solar cells as absorber have significantly improved the efficiency of solar cells for power conversion. They had proved to have a great impact on PV devices. They have PCE considerably higher than its other counter parts existing such as organic solar cell. They also have efficiency more than the dye sensitized devices. They are reported to have PCE of around 20%. There has been an impressive increase in the value of efficiency of Solar Cells using Perovskite material. This improvement has been reported in just last three years. The value of power conversion efficiency has increased from a value of 9.6% in 2012 to a value of 20.1% in 2015 for lead based halides. For halides employing tin the efficiency is still less at around 8%. So as to increase the performance of perovskite based solar cells, numerous processes of fabrication are being developed. There is development of various concepts for devices. For this various organic and inorganic hole transport mediums are being developed. For developing high-performing devices, there are lot of issues which need to be addressed in order to commercialize the perovskite solar cell device. Some issues are being addressed but the stability in particular in not that well documented in literature. In this paper the various advances in the field of perovskite solar cells have been reviewed and various challenges and properties of the perovskite solar cell have been reviewed.*

Key Words: Solar cell, Eficiency, Stability, Hole transport layer, Solar Energy

1. Introduction

The sunlight which we get from the Sun is directly available to us as a renewable source of energy and it is non-vanishing also in nature. The energy derived from sunlight is also free from the pollutants of environment and noise. It can be easily used to compensate the energy which we draw from other sources like non-renewable sources of energy viz. fossil fuels, petroleum products and deposits found under the earth [1]. To fabricate solar cells with high efficiency it has been put under large number of improvement stages from a long time. Earlier solar cells were developed by fabricating them on a single crystal of Si wafer. Those were regarded as the first generation solar cells. After that due to the development of thin films, organic materials as substitute to silicon, and dye sensitized solar cells the efficiency of conventional solar cells has been increased. The development and progress in the field of solar cell fabrication is generally hindered due to cost and efficiency factors [2].

The sun provides us daily with a tremendous and huge amount of energy which is in the form of heat and also the radiations known as solar energy. The energy received from the sun is available free of cost and is limitless in nature. It also has numerous advantages as solar energy can be easily harvested and used over other available conventional sources of power generator. The solar energy can be used by harvesting the sunlight in the form of solar energy by using the photovoltaic device called solar cell [3]. The sun is basically a huge mass of gases made up of helium and hydrogen atoms. The hydrogen nuclei combine by emission of huge amount of energy by process called nuclear fusion. During the process of fusion, four of the H atoms unite and release energy to form one He atom. This energy which is released from the fusion reaction is pollutant- free, free from gases or any by product from the reaction[4].

In the past years the stability of perovskite solar cells has been enhanced from several minutes to almost over 500 hours. This has been achieved by using spiro-MeOTAD as the material for the solid state hole transport material. Further the stability of the cell has been enhanced and improved by light soaking. It's a long term procedure and is done at a intensity of 100 mW/cm^2 at a temperature of about 45°C. The devices based on using tin oxide as the electron transport medium, have even attained a stable lifetime of over 500 hour. There are even materials like aluminium oxide which have further helped in stability over 1000 hours at a short circuit current of 15mA/cm^2. [5]

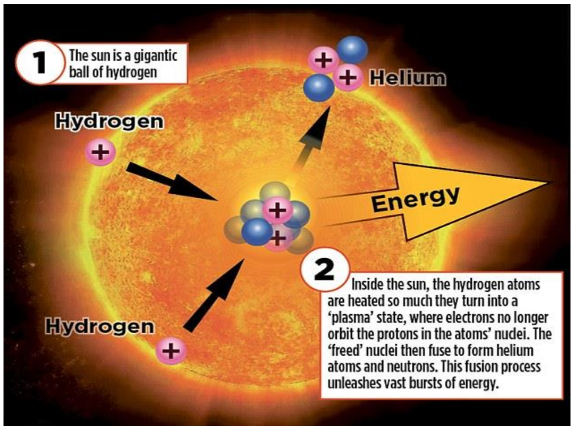

Figure 1- Nuclear fusion inside sun which serves as the source of solar energy [1]

In the last five years this area is under great research and there is possibility that there will be further improvement in the work. Various suggestions like using two or more layers of absorber of different halide compositions and diverse hole transport materials, are being proposed. Its playing a significant role in the commercializing the future generation PV devices[6].

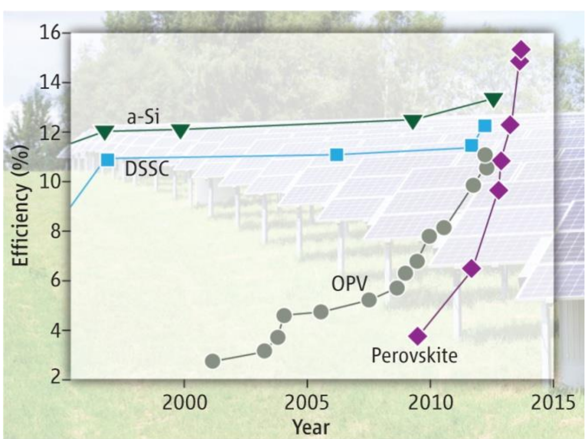

Figure 2- Efficiency comparison for different types of solar cells [NREL SURVEY]

2. Perovskite Based Solar Cells

Perovskite material has been named after L.A. Perovski who is a the Russian mineralogist. These type of solar devices made up of organic – inorganic halide have proved to have a great impact on the industry of photovoltaic devices. Also the power conversion efficiency is also considerably high in case of these type of cells when are compared with other types existing such as organic and dye sensitized photo voltaic devices[7]. In the past three years from year 2012 to year 2015 their efficiency has shown a tremendous increase from 9.8% to 20.2%. The efficiency of perovskite is greatly attributed to its various aspects like rate of charge recombination, optical absorption is strong and it is also easy to fabricate. One more important aspect is its synthetic feasibility. The hybrid perovskites are prepared by the simple synthetic methods which make them easy to capitalize when we compare them with the various existing PV technologies like excitonic Dye sensitized PV cells (DSSC) and the organic solar cell (OSC). One of the most important aspect for developing solar cell devices for high – performance applications is that the mobility of the charge carrier should be high[8].

The main issue which still remains associated with the lead organic – inorganic halides is the toxicity associated with the lead. Also perovskite gets easily degraded when it is exposed to environment where it comes in contact with humidity and the ultra violet radiations. The research now a days is basically focused to increase the use of these devices by focusing on their commercialization and also addressing the toxicity and degradation issues related to them [9].

2.1 Crystal Structure of Perovskite

The perovskite material generally has the formula of ABX_3 which is its common formula where A is for cation, B is also for cation, and X represents an anion . the cations A and B occupies the corner position whereas anion X is at the face center of pseudo cubic unit cell. The other alternative view point for its structure is that it can be assumed as a corner linked BX_6 in a octahedral geometry with cation A at interstitial position. Figure below depicts the crystal structure for perovskite material [10]. The basic crystallographic stability of the perovskite and the apparent structure for this can be formed by having a consideration of the Goldschmidt tolerance factor represented by t and also the octahedral factor μ.

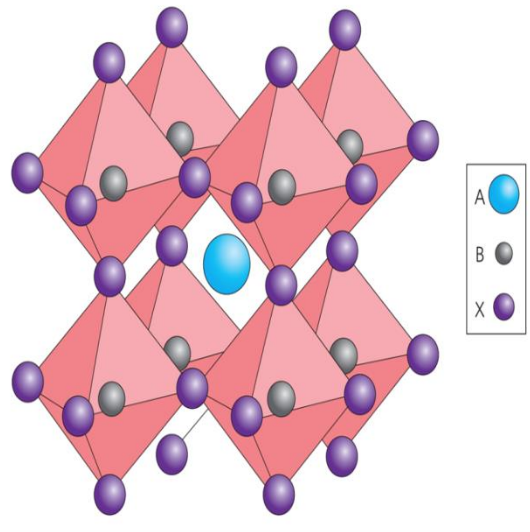

Figure 3 - Crystal structure of basic perovskite material ABX_3 [7]

In this , t is nothing but the ration between the distance between A and X to the distance between B and X where t is given as

$$t = \frac{R_A + R_X}{\left\{\sqrt{2(R_B + R_X)}\right\}} \quad (1)$$

Where R_A denotes the ionic radius of cation A, R_B denotes the ionic radius of cation B and R_X denotes the radius of anion X. In case of perovskites with halides X can be F, Cl, I, or Br. For halide based perovskites t and μ are having narrow range which lies between 0.88-1.1 and 0.45-0.89 respectively [11].

In the formula ABX_3 the larger one cation which is A here in generally considered to be organic and is generally taken to be methylammonium represented by $CH_3NH_3^+$. Here R_A = 0.18 nm. Also A can be ethylammonium with formula $CH_3CH_2NH_3^+$ with R_A = 0.23nm. Another important material in the list is formamidinium with formula $NH_2CHNH_2^+$ with radius R_A = 0.19 – 0.22nm. These materials are also providing excellent results. The X represents the anion which is usually taken as halogen [12]. The halogen normally taken is iodide having radius of 0.220nm. The other halogens such as bromine and chlorine are also used in perovskites as well as various mixed halides are also being used to increase the efficiency of the solar cells.

The cation B used is generally lead which is being universally used having band gap of 1.5eV. Although tin (Sn) also has the same band gap and is also in the same group to which lead(Pb) belongs but the oxidation of tin still remains a problem and poses a threat to the stability of solar cell. From the last few years perovskites based on methylammoniun lead triiodide are mostly used for solar cell fabrication and they are shown to possess good efficiency of upto 20%. Also the efficiency is being enhanced further with the use of mixed halides e.g. $CH_3NH_3PbI_{3-x}Cl_x$. Transitions in phase are usually observed while employing lead based perovskite materials when they are under the effect of temperature, electric field and pressure[13].

3. Properties of Perovskite Material

If we talk in more detail these organic – inorganic perovskite materials possess some enticing ability and potential to be used in numerous applications because of its some amazing properties which are

i) They possess very excellent characteristics of harvesting light and also serve as very capable hole transporting medium as it has the properties of transporting the hole generated [14].

ii) They have potentially low cost for processing.

iii) These kind of solar cells are a promising option when the processing is done at a low temperature by using the printing techniques. The printing technique also make its deposition possible when they are deposited on a flexible substrate [15].

iv) Due to its high absorption coefficient, the amount of light absorbed by the solar cell is also increased which ultimately increases the amount of charge carriers generated due to the light incident i.e. photogeneration rate is increased. Due to this the loss in energy is also reduced and also the collection of charge carriers is increased at the respective electrodes [16].

v) Because of low cost of processing and the high efficiency, these devices take less time to return back the equivalent amount of energy which it has used or which is expended on the manufacturing of such devices. It is called the energy payback time which is low for this kind of material owing to its less cost involved in production and also the higher performance [17].

4. Major Challenges Faced by Perovskite Solar Cells

Although the perovskite materials have numerous advantages but despite having so many advantages these materials too face many challenges. The four main challenges which are hindering the commercialization of these type of perovskite solar cells listed below. Various researchers are working so as to address these problems and challenges to best of their capacities and their efforts have also proffered many solutions in overcoming those issues. Some of the problems are

i) The perovskites employed for manufacturing solar cells are very sensitive to air as air has presence of oxygen and water vapours. The presence of oxygen and water vapours degrade the PV cell as the salt – like crystal structure of perovskite gets dissolved. But this problem has been rectified by researchers as they have addressed that if perovskite films are prepared in an inert atmosphere using boxes filled with Nitrogen or Argon then this problem can be overcome. Further this step is followed by the immediately encapsulating the whole of device in an air tight sealant having the same inert gases . This method of protecting the perovskite from oxidation is not very cost effective when considered for large scale production but can be used to protect and reduction of degradation of tin based perovskite from getting oxidized from Sn^{2+} to Sn^{4+}. With the help of this the life span of a solar cell increases for a time period of four months [18].

ii) The preparation of large continuous films of perovskite in a glove box is also challenging which poses a restriction and limits its production for large scale . But the deposition of the constituent components in a sequential manner can be done to form a thin continuous film for a wider area without degrading the efficiency of the cell.

iii) One of the most commonly used material in perovskite based solar cells is lead, which is toxic in nature. Lead can leach out from the panel of solar cell panel into the surroundings into the environment and can cause various ecological and health related challenges. For this very problem an environmentally friendly and benign element like tin has been into the proposition as an alternate source to lead based perovskites [19].

iv) Perovskite based solar cells are reported to possess lower lifetime because of phase transition. Few studies on storage lifetime suggested their operation under sealed conditions at 45°C. Under those conditions the observers observed that the initial PCE was found to be 20% after 500h.

Much of the work in case of perovskite materials has been done using lead Halides combination. Relatively few work is reported in the field of tin based perovskite films. Owing to the low cost, better stability and also the easy fabrication process of perovskite, the solar cells based on perovskite will be able to contend with the traditional silicon based photo voltaic devices. Also with their invent solar cell industry has received a new direction to develop highly competent solar cells and panels [20].

5. Base Technology for Perovskite Solar Cell

The technology which serves as the base and foundation for the perovskite based solar cells is basically solid state sensitized PV cells. Those are basically dye – sensitized Gratzel devices of solar cells. In the year 1991 scientists O'Regan along with Gratzel formed a cost effective photo electrochemical cell which was based on sensitizing the high surface area nano crystalline film of tin oxide with molecular dye. Though the power conversion efficiency of dye sensitized solar device was reported to be above 12%, but there were issues which were of concern and they raised the concern regarding the leakage. The issues were related to usage of electrolyte. This problem was then brought into notice and further solved by replacing and substituting the liquid electrolyte with a solid hole transporter without making any subsequent changes in the basic concept which was behind the dye sensitized solar cell. Figure 4 (a) the structure for solid state sensitized solar cell comprising (1) conduvtive fluorine doped tin oxide coated glass surface (2) dense titanium oxide layer (3) heterojunction which is dye sensitized which is basically tin oxide absorbed in dye (4) the gold electrode and (b) electron transfer process occuring in a solid state device.

Also in the figure the process of transfer of electrons is being depicted. Here compact tin oxide layer is being provided so as to prevent the direct contact formation between the TCO i.e. transparent conductive oxide and hole transporting material i.e. HTM layer. Both the cells, one with a liquid electrolyte and other with hole transport material have same fundamental principles but the difference between the two solar cells lies in the phenomenon of electron hopping through the hole transport material layer [11].

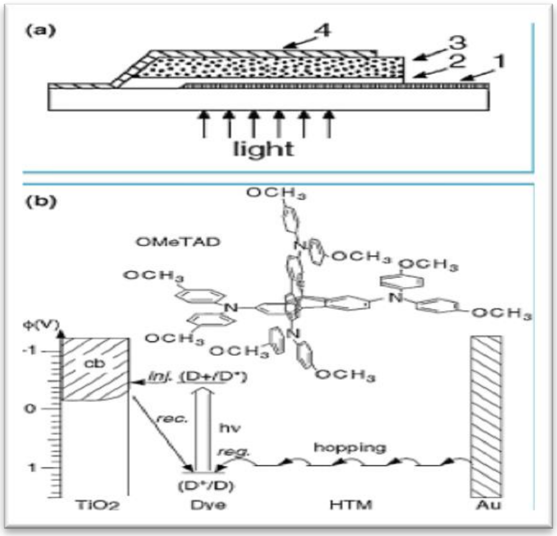

Figure 4 - (a) The structure for solid state sensitized solar cell (b) electron transfer process [11]

The pores of the dye sensitized mesoporous titanium oxide film must be filled with a HTM so as to induce the formation of a heterojunction. The molecular type of HTM such as spiro – MeOTAD is being preferred for filling the pores. The diffusion length of hole and the conductivity of HTM need to be considered at the same time as they both limit the thickness of the mesoporous titanium oxide film. The thickness of the TiO_2 film is inversely proportional to the absorption coefficient. So as the absorption coefficient is increased the thinner the titanium oxide layer becomes. This is so because while using spiro – MeOTAD the thickness of mesoporous titanium oxide film gets limited to around 2μm, and hence no improvement in solid state dye sensitized solar cell device is expected from molecular dyes with absorption coefficients of around $10^3 cm^{-1}$. It would hence require a minimum thickness of 10μm of titanium oxide film to harness the light sufficiently. Hence to achieve a high power conversion efficiency from solid state sensitized devices we need to have a new material for absorbing incoming light which would have an absorption coefficient which is greater than $(2\mu m)^{-1}$.

6. Absorption Coefficient for Perovskite Material

The value of absorption coefficient for $CH_3NH_3PbI_3$ has been calculated by using a nanocrystalline tin oxide film whose surface is coated by the perovskite $CH_3NH_3PbI_3$. The Figure 5 below shows the absorption coefficient has been plotted as a function of the various values of the wavelength for the tin oxide film coated in a nano dot fashion with $CH_3NH_3PbI_3$. The absorption coefficient has been estimated to be around $1.5\times10^4 cm^{-1}$ at 550 nm which indicates that the depth of penetration is 0.66μm for light of about 550nm. At 700nm the value for the absorption coefficient was found out to be $0.5\times10^4 cm^{-1}$ which corresponds to a penetration depth of 2μm which makes it suitable to be used as sensitizer for the highly efficient solid state sensitized devices of solar cells [12].

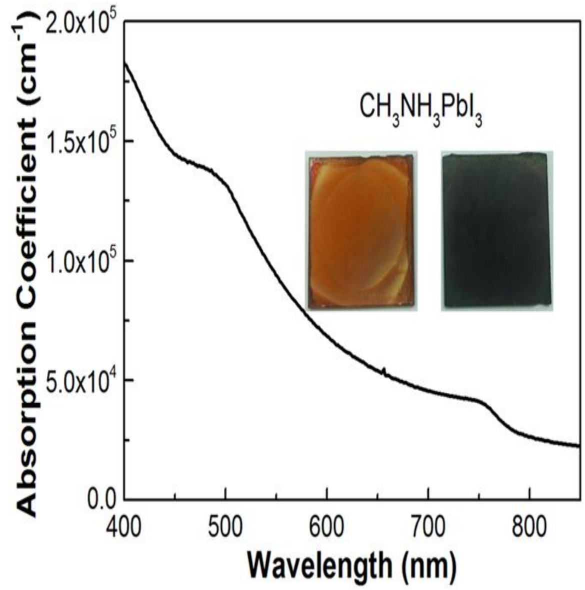

Figure 5 - Absorption coefficient v/s wavelength curve [12]

From the UPS i.e. UV photoelectron spectroscopy and also from the study of the Tauc plot which was obtained by using UV – vis spectral data, the values of valence band maximum, band gap, and the conduction band minimum for $CH_3NH_3PbI_3$ were calculated and they come out to be -5.44eV, -3.94eV and 1.55eV. The value of the absorption onset wavelength has also been calculated on the basis of the values of the energy of band gap and it is estimated at around 826nm [12].

6. The Carriers of Charge in Perovskite Material

In order to have the knowledge regarding the charge carriers in case of various solar cells employing perovskite material, one needs to face challenge. It is mainly because there is presence of organic as well as inorganic materials in its composition. The uncertain nature of the charge carriers which are transported has been reported by many scientists after doing experimental investigation. They have found that perovskite based solar cells employing the lead halide as its constituent material, generally operate in a similar fashion as p-i-n structure diode. In this type of configuration there is presence of an intrinsic semiconductor material which is sandwiched between two layers one is p-type semiconductor and the other one is the n-type semiconductor.

Figure 6 below depicts the band diagram for a perovskite material[13]. It can be noted from this diagram that the band diagram for perovskite based solar cell resembles closely to a typical p-i-n structure. Researchers have observed that the charge carrier which is dominant in case of lead halide based perovskite material is Wannier type of exciton which is also same as the one of the type of charge carriers which are observed in inorganic materials also.

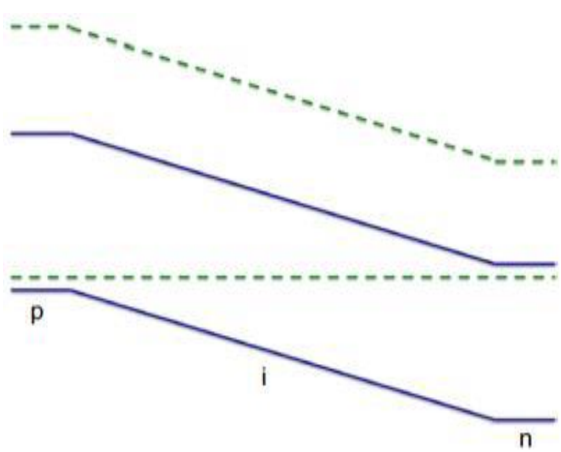

Figure 6 - Band diagram of perovskite material [13]

These types of excitons generally occur when the screening of the electric field tends to decrease the coulomb forces of interactions between the various holes and the electrons. This presence of screening also reduces the energy requisite for binding electron hole pair. Due to this the e-h pair generated can move independently which is different from the Frenkel excitons where the case is different and it occurs in case of organic materials [13].

7. Physics Based Model

The typical structure of perovskite solar cell usually has an absorber layer made up of perovskite material which has a thickness of around 300 to 500 nm. Also it comprises of a hole transporting medium which is p-type and a transporting medium for electrons which is n-type. Together with these layers there is presence of the front and the back contacts which are arranged in various different configurations. There have been numerous suggestions regarding the value of dielectric constant of perovskite, where it is suggested that its high value makes the dissociation of excitons which are photogenerated, into free charge carriers very swiftly.

The electrons and holes which are then photo generated get drifted and diffused through their absorber layer and the transporting layer. After that they get collected at their respective contacts. Hence the analytical model has been developed after getting solution by solving the various steady state continuity equations for electrons and the holes within the absorber layer [15]

$$D\frac{\partial^2 n(x)}{\partial x^2} + \mu E(x)\frac{\partial n(x)}{\partial x} + G(x) - R(x) = 0 \quad (2)$$

$$D\frac{\partial^2 p(x)}{\partial x^2} - \mu E(x)\frac{\partial p(x)}{\partial x} + G(x) - R(x) = 0 \quad (3)$$

In the above cited equations n(x) is the electron and p(x) is the hole concentration respectively. The symbol D denotes the diffusion constant and μ denotes the mobility for the two charge carriers. Here G(x) denotes the rate of photo generation which is dependent on the position. The perovskite material has a long diffusion length, due to which the effect of charge recombination can be ignored within that layer. So we can assume R(x)=0. Lastly the representation of electric field inside the absorber layer is position resolved and is denoted as E(x) [15].

8. Parameters to Characterize Solar Cells

The various main parameters that are important and considered to characterize the performance of any solar cell device are the short-circuit current density denoted as J_{SC}, the peak power denoted as P_{max}, the open circuit voltage of device denoted as V_{OC} and the FF i.e. the fill factor. These parameters are calculated and determined by calculating from the curve of short circuit current density v/s voltage namely J-V curve. These parameters are calculated under the conditions of illumination. After calculating these parameters the power conversion efficiency denoted as η, is calculated from all these above values of the parameters. Below are explained briefly the respective parameters for p-n device [22].

i) Short circuit current density

It is defined as the current under the short circuit conditions. In broader terms it is the maximum photo generated current that can be delivered by the solar cell when its terminals are shorted i.e they have contact with one another. The equation for J_{SC} can be obtained from net value of current density i.e. J(V) as under

$$J(V) = J_{SC} - J_{dark}(V) \tag{4}$$

Where

$J_{dark}(V)$ is defined as the value of current density measured under dark conditions. It is denoted as

$$J_{dark}(V) = J_0\left(e^{\frac{qV}{mK_BT}} - 1\right) \tag{5}$$

Under the presence of illumination , the behavior of the solar cell is simply explained by the use of an ideal equation of diode and also one additional value of a current source i.e. J_{SC} because of illumination of the device. The values of various constants viz charge on an electron q and the Boltzman's constant K_B are given as 1.603×10^{-19}C and 1.38×10^{-23} JK^{-1} respectively. With these values the equation for solar cell under illumination conditions is given as

$$J(V) = J_{SC} - J_0\left(e^{\frac{qV}{mK_BT}} - 1\right) \tag{6}$$

The equation for short circuit current density is hence forth given as

$$J_{SC} = J(V) + J_0\left(e^{\frac{qV}{mK_BT}} - 1\right) \tag{7}$$

Here the parameter V is for the voltage applied across the junction and J_0 is called the current density after saturation under dark conditions. T here is absolute value temperature and m has the values ranging between 1 and 2 and is called the ideality factor.

ii) Open circuit Voltage

The open circuit voltage represented as V_{OC} is defined as the voltage when there is no load connected between the terminals i.e the open circuit condition. At this point no current flows in the circuit. It is hence the maximum value of voltage that can be delivered by any solar cell. The value of short circuit voltage depends on current density J_{ph}. J_{ph} is the photogenerated current density. For a simple p-n device, V_{OC} is given as

$$V_{OC} = \frac{mK_BT}{q}\ln\left(\frac{J_{ph}}{J_0} + 1\right) \tag{8}$$

This equation has been obtained from the equation of short circuit current density. If we set the net current and J(V) to zero, the above equation can be obtained. It hence forth leads to a effect of compensation between the two currents i.e. the dark current and the photo generated current, such that the values of J(V) = 0 and V = V_{OC} and J_{SC} = J_{ph} .

iii) Fill Factor

Fill factor denoted as FF is defined as the ratio of the maximum power that is generated at the output of a solar cell to the product of the short circuit current density J_{SC} and open circuit voltage V_{OC} . The fill factor value describes the squareness of any J-V graph.

$$P_{max} = J_{mp} \times V_{mp} \tag{9}$$

Where J_{mp} and V_{mp} are values of current density and voltage when the solar cell delivers the maximum power output i.e the maximum point values.

$$FF = \frac{P_{max}}{V_{OC}J_{SC}} = \frac{V_{mp}J_{mp}}{V_{OC}J_{SC}} \tag{10}$$

iv) Power Conversion Efficiency

The efficiency of a solar cell is defined in terms of its ability to generate maximum output power from the incident power. It is hence defined as the ratio of the generated maximum power to the power incident on the surface of solar cell. The equation for the same is given as:-

$$\eta = \frac{P_{max}}{P_{in}} = \frac{J_{SC}V_{OC}FF}{P_{in}} \tag{11}$$

The P_{in} is the irradiance power having a irradiance value of 1000 W/m^2 of AM1.5 solar spectrum. This value has also become a standard for measuring the power conversion efficiency of the solar cell [23].

9. Applications of Solar Cell

The shortest and the best possible way to combat the energy crisis and deficit is by enhancing the use of solar energy in various applications whether in industrial or in commercial sectors. There are huge number of barriers in the growth of solar cell devices such as upfront costs due to the imposition of taxes , quality standards and need the attention of the government. Below are some of the applications where solar cell technology is being used

i) Power Plants: The various conventional units of power plants which employ non renewable sources of energy are being in use for boiling water and hence form steam to get the rotation of turbine and leads to the production of electricity. In place of non renewable energy the solar light and energy can be used to get boiling water and steam so as to get turbine rotation. To achieve this and get solar light converted to electrical energy, solar panels and thermoelectric technologies etc are being in use [16].

ii) Homes: In homes also the solar energy's use is increasing. There are various residential appliances that are easily using the electric power generated from the solar power. Now a days solar water heaters are being used for the supply of hot water . It is basically achieved through the installed photovoltaic cell at the roof top. These roof top installed cells absorb the energy by capturing and storing it in batteries so that it can be used throughout the day for various purposes at homes. With this there is huge savings on the expenditures and they are cut down .

iii) Commercial Uses: The various buildings have now a day's installed huge glass photo voltaic modules or some other solar panel. These structures are used there to harvest the solar energy from the sun and convert it to electricity and then electric power is supplied to various offices and different parts of the buildings in a consistent manner. Due to this the different offices use their own electricity for number of purposes.

iv) Ventilation System: There are also devices which run on solar energy for the ventilation purposes. Some of those devices include bath fans, ceiling fans, and floor fans in buildings. Fans are must at every places whether it is house or office. Fans are used to control the moisture and also the smell. That's why exhaust fans are used in our kitchens also to take smell and heat out of place. Hence fan's usage adds a lot to our utility bills. With the usage of solar energy based devices for ventilation purposes there will be definitely a cut down in these utility bills [17].

v) Power pumps: the usage of solar power is not just limited to the improvement of ventilation system but also they help in improving the water circulation at any place. Six power pumps can be connected to a solar power supply unit. They need to run on DC current. It is required so as to make the water circulation possible, throughout the whole building.

vi) Swimming Pools: these places are a great joy for everyone whether they are kids or adults. Swimming in pools is a pleasure in summers but in winters it gets difficult to keep the water warm in these pools without much wastage of power. But by using the solar power this problem can be solved. Solar blanket can be added into the pool so as to keep the water warm by harvesting the solar energy and converting it to electric energy. Along with this solar panels for heating water in solar water heaters can be installed [20].

vii) Solar Lighting: There are some lights which store the energy of sun. These lights are also called as day lighting. They work well by using solar power. The energy is stored during the day time and at night this very light energy is converted to electric power. With the usage of these type of lighting systems the load of various local power plants has been reduced.

viii) Solar Cars: The solar panels are now being installed over the cars and they absorb the sun light during the day time and then this light gets converted to electrical energy. These type of vehicles are called solar cars. The electric energy generated is stored in the batteries embedded into the car. Due to this availability of storage the generated power can also be used by the car in the night. Hence solar vehicles can be driven during the night time as well.

ix) Remote Applications: Various buildings at remote places are making use of the electric power generated from the harvesting of solar energy. These buildings are using this energy at vast scale. Various remote schools, clinics and community halls take these solar panels and batteries along to produce and use the power generated. They can be taken anywhere.

x) Satellites: Communication satellites have a requirement of an electric power source that is light in weight, lasts for many years, and works well in the vacuum of space. Because solar energy is abundant above the earth's atmosphere, photovoltaic cells have proved to be an ideal solution for powering satellites [24].

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Figure 7 - Solar park for harvesting solar energy at large scale [16]

A study from Brianin's University the solar cells based on using perovskite material as absorber has potential of converting solar energy for various household activities. It converts solar energy to electrical energy much more cheaply than before. The perovskite mineral has a thickness of the order of nanometers which makes them 40 to 50% more efficient than the one commercially being produced now a days. Perovskite can absorb solar radiations of almost entire spectrum of sun which further makes it more efficient to be used in different conditions of atmosphere. They also work well in the diffused conditions far better than its other counterparts.[16]

11. Work done till date

Seelam Prasanthkumar, Lingamallu Giribabu et al demonstrated the most recent advancements in the field of perovskite solar cells. The various options for different layers in the cell structure have been suggested like Al_2O_3 for the electron transport layer.. Its suggested that the presence of HTM layer increases the charge collection at respective electrodes and ultimately the power conversion efficiency of the device is increased. CuSCN when used as hole transport medium is reported to have efficiency of 12.4%. Molecule based hole transport medium are also being in research. Polymeric HTM's have attained a efficiency of 12%.

Nam Gyu Park demonstrated how the idea of using solid state HTM basically evolved from the dye sensitized solar cells. Perovskite shows BX_6 octahedral structure. The absorption co-efficient values indicate that it can show absorption for almost entire solar spectrum and its band-gap is tunable. The structure of perovskite solar cells evolved firstly by introducing it as a sensitizer in DSCC where the molecular dye was replaced by perovskite.

Ao Zhang, Yunlin Chen, Jun Yan et al developed optimal design for high performance solar cell based on Perovskite material. The efficiency of solar cells without hole transport medium increases with the increase in thickness of absorber layer. With the thickness of 800 nm of the absorber layer, the value of efficiency for solar cell saturates. But due to the presence of HTM layer, the device structure cab be optimized and an increase in efficiency is possible only with an absorber thickness of just 150nm. CuSCN and ZnO are used as hole transport and electron transport layers and the donor density of ZnO is less than the acceptor density of CuSCN.

Chandu V.V.M. Gopi, Mallineni Venkata-Haritha, Kandasamy Prabakar, Hee-Je Kim et al prepared CNT's thin films for fabricating HTM free solar cells using Perovskite and using FTO/glass as substrates. It has been suggested that the efficiency of CNTs can be increased by doping the CNT. With doping the conductivity increases. Processing CNT electrodes on top of perovskite possesses vast possibilities to be chosen so as to optimize the device materials and structure.

Qing-Dong Ou, Chi Li, Qian-Kun Wang, Yan-Qing Li, Jian-Xin Tanget et al discussed the energetic of the various Perovskites employing metal halides. Mixed-halide Perovskites are reported to exhibit excellent light absorbing capabilities. The substitution of the halide with the another is possible because of the lattice compatibility between different pure halides based compounds. The annealing effect also affects the opto electric properties. The band structure of the perovskite and the adjacent charge transport materials should have matching compatibility so as to enable efficient transportation of charge across the layers.

Steve Albrecht, Michael Saliba, Juan Pablo Correa Baena, Felix Lang, Bernd Rech, Michael Gratzel in et al demonstrated that silicon single junction solar devices when used in conjunction with perovskite absorbers in a tandem fashion increases the efficiency of the device. Efficiency of about 18% has been achieved enabling V_{OC} of 1.78V. Silicon is used as a bottom cell with perovskite as the top cell. Its efficiency is basically reduced due to the silicon bottom cell, in which photo generated current is limited by the reflectance losses. FTO electrodes reduces the hysteresis effect, which is pronounced while using ITO electrodes. Doping Spiro-OMeTAD enables it to have broader absorption peaks at 500 nm and 380 nm.

Rahul Pandey, Rishu Chaujar et al simulated Perovskite and silicon solar cells with SiC passivated rear contact and an efficiency of 27.6% has been achieved. The configuration is an example of a tandem solar cell. Use of SiC as rear contact diminished the interface recombinations which were more pronounced in the earlier reported silicon bottom subcell. Tin oxide is N-type and has doping density of 5×10^9 / cm^3. While Perovskite and spiro-OMeTAD has doping densities of 2.14×10^{17} / cm^3 and 3×10^{18} / cm^3.

Aaesha Alnuaimi, Ibraheem Almansouri, Ammar Nayfeh et al proposed if there is high band offset between the VB of perovskite layer and the VB of the hole transport medium, there is large energy loss which ultimately decreases the V_{OC}. Increasing mobility of HTM layer also increases the efficiency. Decreasing mobility increases the resistance in the hole transport layer and there will be drop in the values of FF and J_{SC} . This is because of the increase in the series resistance.

Shubhra Bansal, Puruswottam Aryal et al evaluated various materials for the hole and the electron transport layers. Various alternatives were explored for lead halide based perovskite solar cells. The alternatives were simulated using SCAPS-1D. ZnOS and NiO are shown as good potential alternatives to spiro-OMeTAD. $CuSnI_3$ can be used for the hole transport layer. Issues like lattice mismatch and material stability can be investigated in future for further investigation.

Kurt Taretto, Marcos Soldera, Alejandro Koffman Frischknecht et al elucidated the loss mechanisms which are predicted from the appropriate models. So for it drift diffusion model is adapted for obtaining the current-voltage characteristics of the hysteresis free perovskite solar cells. The carrier recombination have values of above 1μs and also its suggested that there is less recombination velocities at the interface between the layer of perovskite material and the other transport layers of around 1000 cm/s. The value of built-in voltages is slightly less than the open-circuit voltages of around 1.05V. The carrier mobility obtained is around $0.1cm^2/Vs$.

Pankaj Yadav, Kavita Pandey, Parth Bhatt, Dhyey Raval, Brijesh Tripathi, Chandra Kanth P, Manoj Kumar Pandey, Manoj Kumar et al demonstrated the improvement in V_{OC} , FF and efficiency respectively with the incorporation of HTM in the structure of the device. The structural properties are studied by XRD. The morphological properties are studied using FESEM while the optical properties are studied by U-V Vis spectrophotometry. The interface between tin oxide and the perovskite layer resembles the Schottky diode and is found to act as a heterojunction for the dissociation and the excitation of the charge carriers. SCAPS simulation is used to explore the effect of band offsets and the interface defects.

Xin Yan, Chen Zhang, Jiamin Wang, Xia Zhang, Xiaomin Ren et al proposed and simulated a hybrid cell comprising Si nanowire array and perovskite. In this solar cell is comprised of a silicon p-i-n structure of nanowire array which is filled with $CH_3NH_3PbI_3$. Here both the nanowires and the $CH_3NH_3PbI_3$ act as absorber and absorbs the incident light. The nanowires also act as the channel for transportation of photo generated charge carriers. This hybrid structure shows highest efficiency of absorption in broader wavelength region of 300 – 800 nm. The power conversion efficiency achieved with this structure is around 13.3%.

Amu, Tochukwu Loreta et al used device simulator SCAPS to solve the poisson and the electron and hole continuity equations so as to obtain the complete information about the properties of the device constructed using tin-based perovskite solar cells. Firstly experimentation was done in the lab to produce results then the performance of the tin-based solar cell was improved further by reducing the acceptor doping concentration in the absorbing or the active layer. Due to this the efficiency increased and reached up to a value greater than 18%. Tin based halide perovskite was used because lead used is a toxic material and it possesses serious health hazards. So there is a drive to replace the toxic materials by the non toxic tin based perovskite.

Hui-Jing Du, Wei-Chao Wang, Jian-Zhuo Zhu et al simulated perovskite based solar cell based on lead free $CH_3NH_3SnI_3$. They have used tin based perovskite because of the much interest of the research in tin based halides owing to the toxicity of the lead. It seems to be a viable substitute to lead based halide because it has narrower band gap of 1.3eV whereas the absorption spectrum is quite wide than the lead halide. They adjusted the doping concentration of the absorber layer and the electron affinity of etl and htm layer. The efficiency was further increased by further optimizing the defect density of the absorber layer. They achieved an efficiency of 23.36%. Reducing the defect density can further enhance the efficiency of the solar cell which can be solved with further improvement in the fabrication and the encapsulation of the device.

Askari Mohammad Bagher, Mirzaei Mahmoud Abadi Vahid, Mirhabibi Mohsen et al highlighted the phenomenon of conversion of sunlight into electricity. The conversion process requires a material which would absorb the light falling on its surface and then raises an electron to a state of higher energy and after that this electron moves out from the cell to an external circuit. With regard to the development of sustainable energy like solar energy, the types and applications of solar cells are being studied.

Usha Mandadapu, S. Victor Vedanayakam, K. Thyagarajan et al analyzed the solar cell architecture using SCAPS which runs and does simulation based on Poisson's and continuity equation of holes and electrons. The analysis is done by optimizing the various parameters such as the defect density, the thickness of absorber layer. Doping concentrations of the electron transport layer and the hole transport layer. The best results are achieved when the thickness of perovskite layer is 0.3μm.

Takashi Minemoto, Masashi Murata et al studied the effect of band offsets in perovskite based solar cells having planar junction configurations. The band offset between buffer and absorber layers is a decisive factor for the carrier recombination at the interface which determines the open circuit voltage. Two kinds of offsets i.e. the conduction band offset and the valence band offset were studied. The optimum position of VBO of the HTM was calculated to be 0.0-0.2 eV lower than the absorber and the conduction band of the buffer was 0.0-0.3 eV higher than the absorber.

Takashi Minemoto, Masashi Murata et al analyzed the impact of work function of a metal back contact on lead iodide based perovskite solar cells. The analysis was carried out by removing the hole transport material from the device structure. With the removal of HTM layer, a back junction is formed between perovskite absorber and the metal back contact. Hence the built in voltage was high if the work function was equal to or deeper than $E_{v\text{-absorber}}$. Its important to match the value of work function of back contact to design HTM-free perovskite based solar cells.

Mohammad I. Hossain, Fahhad H. Andrabi, Nouar Tabet et al suggested the use of inorganic layers as hole transport materials to enhance the resistance to degradation of lead halide perovskite based solar cells. The computations were carried out by considering defect free perovskite and HTM layers. The results show that when copper oxide was used as HTM layer, the results were best. Hence the expensive and moisture sensitive spiro-OMETAD can be replaced by copper oxide to achieve high efficiency of around 23%.

Aaesha Alnuaimi, Ibraheem Almansouri, Ammar Nayfeh et al revealed that the low mobility of HTM material limits the improvement in power conversion efficiency of perovskite based solar cells under concentration. Also large band offsets at the interfaces of HTM and perovskite contributes to the high series resistance which ultimately results in losses and significantly deteriorates the performance of perovskite solar cells under concentration.

K. Masuko, M. Shigematsu, T. Hashiguchi, D. Fujishima, M. Kai, N. Yoshimura, T. Yamaguchi, Y. Ichihashi, T. Yamanishi, T. Takahama, M. Taguchi, E. Maruyama, S. Okamoto, T. Mishima, N. Matsubara, T. Yamanishi, T. Takahama, M. Taguchi, E. Maruyama, and S. Okamoto et al developed that the crystalline silicon heterojunction structure adopted in photovoltaic modules commercialized as panasonic's hit has significantly reduced recombination loss, resulting in greater conversion efficiency. the structure of an interdigitated back contact was adopted with our crystalline silicon heterojunction solar cells to reduce optical loss from a front grid electrode, a transparent conducting oxide (tco) layer, and a-si:h layers as an approach for exceeding the conversion efficiency of 25%.

C. Wehrenfennig, G.E. Eperon, M.B. Johnston, H.J. Snaith, L.M. Herz et al established that methylammonium lead trihalide perovskites are particularly well-suited as light absorbers and charge transporters in photovoltaic cells because they allow for an unexpected combination of both low charge recombination rates and high charge-carrier mobilities. They revealed that planar heterojunction photovoltaic cells may only be achieved because the ratio of bi-molecular charge recombination rate to charge mobility is over four orders of magnitude lower than that predicted from Langevin theory. Such effects are likely to arise from spatial separation of opposite charge carriers within the metal-halide structure or across a crystalline domain. Modelling and tuning recombination channels, e.g. through halide and metal substitutions, or crystallite size, will hold the clue to raising material performance.

Kai Tan, Peng Lin, Gang Wang, Yan Liu, Zongchang Xu, Yixin Lin et al developed that PCE of solid-state perovskite solar cells has achieved 20.1% recently. There is reason to believe that ssPSCs is a strong competitor with silicon and CIGS solar cells in photovoltaic field. The configuration and excition type are similar to inorganic semiconductor solar cells. Therefore, Solar Cell Capacitance Simulator (SCAPS), a device simulator widely used in inorganic solar cells, was employed to controllably design ssPSCs. The validity of device simulation was verified by comparing with real devices from reported literatures. The influence of absorber thickness on device property was discussed, which indicate that it exists an optimal thickness range.

12. Conclusion

Organic – inorganic halide perovskites are significant for research and commercialization of solar cells in the next few years due to high efficiency and durability. PSC can show better performance if integrated with other cell technologies. However, few problems need to be resolved with respect to commercialization such as toxicity of lead atoms, long term durability and cost-effectiveness. Until now highest efficiency has been obtained only from lead – based perovskites. But their utilization is restricted due to their toxic nature. In order to overcome this issue, most of the research is on lead-free based materials together with commercialization. Fortunately, tin based materials have been developed and reached efficiency of approximately 7% which is undoubtedly lower as compared to lead based perovskite devices. But it has shown the way for commercialization of perovskite solar cells and provides better durability and eco-friendly paths.

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