A REVIEW OF SOLAR CELL FUNDAMENTALS AND TECHNOLOGIES

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Abstract— The paper is intended to through light on Solar cell fundamentals and various technologies developed from time to time. Solar cell and its parameters are introduced. Discovery of new materials lead to new solar cell technologies. Efforts are made to explain various solar cell technologies in brief. The materials used in different technologies are mentioned. The developments in various technologies are discussed. Some results from recent journal publications are also included. The paper is concluded with some suggestions to improve the performance of solar cells. It explains the the need of further research in this area.

Keywords— Solar cell, Solar cell technologies, Power conversion efficiency, Dye Sensitized Solar cell, Organic solar cell, Quantum dot solar cell, Perovskite solar cell.

1. INTRODUCTION

In order to perform work on or heat an object, energy must be transferred to it. Coal, Oil, Natural gas, Nuclear power, Wood, Straw, Cow Dung are the conventional sources of energy which are also called as non - renewable energy sources. Non-conventional energy sources which are also known as renewable energy sources are given by Wind Energy, Bio Energy, Tidal Energy, Geothermal Energy, Solar energy.

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The conventional energy sources (oil, gas and coal) are available in a fixed quantity and cause environmental pollution. According to an estimation coal, oil, natural gas can last only for 205, 40 and 53 years, respectively. Therefore there is a need of alternative energy sources which can provide us energy in a sustainable manner. Non-conventional energy sources are renewable, inexhaustible, generally pollution free, less expensive and easy to maintain. Among these sources, Solar Energy Systems require no maintenance and will last for decades. Once installed there are no recurring costs. They work without sound pollution and generate electricity (photovoltaic) or heat (solar thermal) at home. Solar Cells can be used at other planets and satellites .So it is necessary to understand the fundamentals of solar cells and technologies developed from time to time to fabricate solar cells.

2. WORKING PRINCIPLE

A solar cell is a solid-state electrical device (p-n junction) which converts light energy into electricity (DC) using the photovoltaic effect. Thus solar cell is a photovoltaic device, i.e., a device that generates voltage when exposed to light. The working of a Solar cell is given by the following three steps.

1. The generation of electron-hole pairs (or excitons) by absorbing light.

2. The separation of pairs into charge carriers with the help of internal field.

There is diffusion and drift of carriers (it is not possible to drift apart the photo generated EHPs without the internal field).

3.   The extraction of carriers into an external circuit.

The open-circuit voltage (Voc), is the maximum voltage available from a solar cell, when its terminals are left open. The short-circuit current (I_{SC}) is the maximum current produced when terminals of solar cell are shorted. There will be a photocurrent during illumination. If the load is short circuited, then the external current is simply equal to the photocurrent I_{ph} generated by the incident radiation.

$$I_{sc} = -I_{ph} = KI \tag{1}$$

where I is the intensity of incident light and K is a device specific constant.

The dark current is given by the usual forward biased *p-n* junction diode equation

$$I_{diode} = I_0[e^{eV/\eta kT} - 1] \tag{2}$$

where η is the diode ideality factor.

Hence total current through illuminated Solar Cell will be:-

$$I = -I_{ph} + I_{diode} = -Iph + I_0[e^{eV/\eta kT} - 1] \tag{3}$$

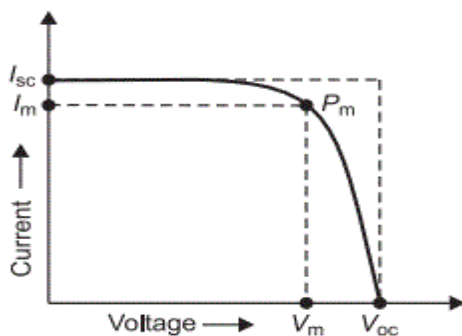The I-V characteristic curve in fourth quadrant is given by Fig.1.

Fig.1. Solar cell Characteristic

Solar cell equivalent circuit is given by Fig.2. Series Resistance (R_S) indicates ohmic resistance in solar cell, metallic contact and sc junction while parallel resistance R_p indicates crystallographic defect, grain boundary. R_S should 0 and R_P should be infinite for an ideal solar
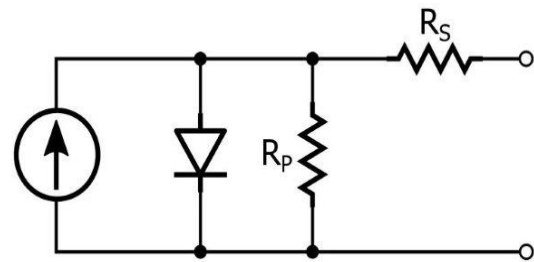

Fig.2 Equivalent of solar cell

Fill factor is the parameter that compares maximum power obtained and maximum theoretical power.

$$Fill\ Factor, FF = \frac{V_m I_m}{V_{oc} T_{sc}} \tag{4}$$

Power conversion efficiency is defined as the ratio of the output power to input power i.e.

$$\eta = \frac{V_m I_m}{P_{in}} = \frac{V_{oc} I_{sc}.FF}{P_{in}} \tag{5}$$

3.Solar cell technologies[1]:

In 1953 the first silicon solar cell was developed(First generation). These cells are used in space crafts. Development is to supply cells for communication with satellites and other space crafts. In 1973, solar cells are applied as renewable energy resources, with some change in standard technology. First generation solar cell is simply a single crystal silicon solar cell.

3.1 Single crystalline silicon solar cell Technology:-

The various stages involved in fabricating Single crystal silicon solar cell are given below[2],[3].

i) Reducing sand into metallurgical-grade silicon (which is 98% pure silicon).

ii) Purifying metallurgical grade-Si into semiconductor grade silicon using Siemens process to reach purity of 99.99%.

iii)Converting semiconductor grade silicon into single crystal silicon wafers using Czochralski method.

iv)Processing of single-crystal silicon wafer into solar cells.

v)Converting solar cell into solar module(series and parallel arrangement of solar cells).

These processes are performed at elevated temperatures. These solar cells have high efficiency(about 20%), high stability to withstand atmospheric changes but are costly.

3.2 Thin film technologies:-

These are referred to as second generation technologies[4]. The primary objective of thin film technologies is to decrease the cost of solar modules.Thin film technologies include amorphous Si, CdTe, CIGS and thin film crystalline Si solar cell technologies. Thin film solar cells are formed by using physical vapour deposition techniques such as evaporation, Sputtering, Molecular beam epitaxy etc., and chemical vapour deposition techniques such as Low pressure CVD (LPCVD) ,atmospheric pressure CVD, Plasma enhanced CVD, Hot wire CVD(HWCVD),Metal – Organic CVD (MOCVD),Liquid phase epitaxy (LPE).

There are four types of junctions that can be used in realizing thin film solar cells:-

i)Homo-junction solar cell(p and n regions are obtained using same type of material)

ii)P-i-N junction solar cell(intrinsic layer is used in between n and p regions)(Fig. 3)

iii)Hetero junction solar cell(p and n regions are obtained from different materials)

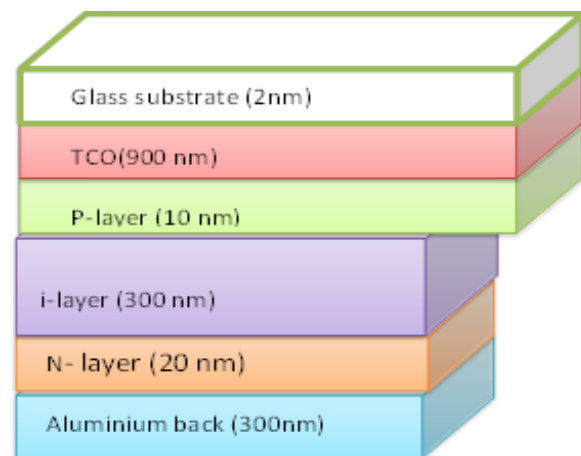iv) Multijunction solar cell(series of junctions are used).

Fig. 3. P-i-N junction solar cell

In case of mono or multi crystalline Si wafer based solar cells, the collection of charge carriers at front metal contact is done using finger bus bar contact arrangement. This is not the case with thin film materials. Here the function of continuous but transparent metal contact is fulfilled by transparent conductive oxide or TCO. The TCO is generally used at the front side of the solar cell where it becomes metal contact, but in many cases, it is also used at the back side of the cell mainly for improving the optical properties of the cell by refractive index matching. Conductivity of TCO layer should be as high as possible. Several types of TCO layers are used in solar cells. The TCO layers include indium tin oxide (ITO),

SnO$_2$(Tin Oxide), ZnO:B (boron doped zinc oxide), ZnO:Al (aluminium doped zinc oxide) etc. Among these, ITO fulfills almost all the requirements of a TCO layer and it is successfully used in front contact in substrate configuration of a cell. The ITO is normally deposited using APCVD technique at about 500°C temperature. The ZnO is also another famous abundant and non-toxic TCO material that can be easily deposited at low temperatures (300°C).

Amorphous silicon is generally known as "hydrogenated amorphous silicon", or a-Si:H. It absorbs about 2.5 times more energy than c-Si for a given layer thickness. Material required for a-Si:H films is much less and hence the solar cell will be lighter in weight and also less expensive. It can be deposited on substrates which are flexible, curved, and roll- away types. However the efficiency is around 10% which is lower than crystalline silicon. But it is improving. The main optical properties of a-Si:H are its absorption coefficient, band gap and refractive index. The band gap of the good quality a-Si:H layers lies in the range of 1.7eV to 1.8 eV. The optical band gap of the material can also be tailored by alloying it with Ge and C. The absorption coefficient of the a-Si:H is more than $10^4 cm^{-1}$ for the photons having energy more than the band gap energy. a- Si cells use P-i-N junctions rather than P-N junctions for having drift based carrier transport. The typical structure of a – Si:H solar cell with typical layer thickness is shown in figure 3. The doped P-type and N-type layers create electric field across the intrinsic of a-Si:H. The intrinsic layer in a-Si:H works as an absorber layer. The electron – hole pairs are generated in this layer. Even though the efficiency of thin film amorphous solar cell is smaller than single crystalline silicon solar cell , commercial solar panels are fabricated using thin film amorphous solar cell technology because of the less manufacturing cost.

3.3 Third generation solar cell technologies:-

The discovery of new materials made it possible to fabricate variety of solar cells using technologies viz., DSSC technology, organic solar cell technology, perovskite technology, quantum dot technology etc., which are known as third generation technologies.

3.3.1 Dye Sensitized Solar Cell(DSSC) Technology:-

The dye – sensitized solar cell(DSSC) concept is presented in 1991 by Regan and Gratzel. The DSSC solar cells can be made flexible. It has a good potential for being a low cost solar cell technology[5]. This is mainly possible because of the large availability and low cost of the ingredient material as well as due to low processing temperatures. The DSSC is a photo-electro-chemical device as its operation involves a photon, an electron and a chemical reaction. The operation of DSSC is considered similar to that of a photosynthesis process.
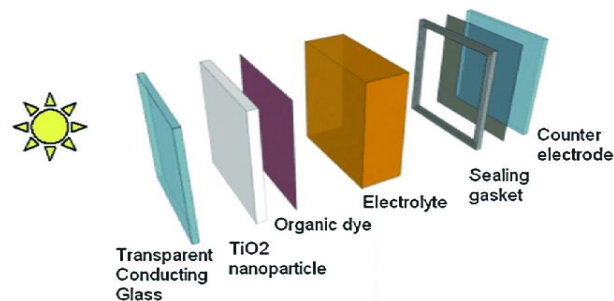

Fig. 4. DSSC components

The DSSC is made up of five components: a conductive mechanical support (TCO based), a semiconductor film(Titanium

dioxide), a sensitizer(dye), a redox couple (electrolyte), and a counter electrode(Platinum based conductive support)(Fig.4). Efficiencies of DSSCs can be increased by fine tuning two or three components. Photo sensitizer is an important component of a DSSC. It absorbs solar photons and the excited photo electrons are injected into conduction band of semiconductor. So in designing DSSC the optoelectronic properties, such as absorption coefficient and band alignment, morphology of dye and mode of assembly on the TiO2 photo-anode are considered.

The dye of DSSC absorbs light, generates carriers, transport carriers to the external load at higher voltage and brings back the carrier in the cell at lower voltage. The operation of a DSSC can be explained using the following steps:-

Step 1:- In this step, the absorption of a photon by a molecule of dye (S) takes place. After the photon absorption, the dye molecule goes into the excited state, S^*. Within a very short time, of the order of femto seconds, the electron is given off to the semiconductor wide band. And the excited dye molecule gets oxidized (loss of electrons) to S^+.This can be put in the form of the following equation:-

$$S + Photon \rightarrow S*(\text{excited state})$$

$$\rightarrow S^+ + e^- \qquad (6)$$
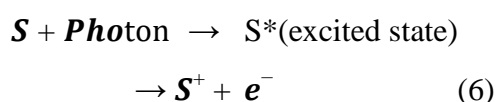
Step 2:- In this step, the excited electron is given off to the conduction band of semiconductor(TiO₂). A TCO layer is used to collect the electrons from the conduction band. Normally, fluorine-doped tin oxide (SnO2:F) is used for this purpose. The electrons then flow through the external load to the electrode counter.

Step 3:- In this step, the organic electrolyte solution gives away an electron to the oxidized dye molecule which in turn reduced to the original form S. The electrolyte solution contains the iodide redox system in which the iodide ions are being oxidized to tri- iodide molecules back to their iodide state. This step requires catalytic presence of Pt at the electrode. This makes the dye molecules again available for the excitation/reduction cycle.

$$S^+ + \frac{3}{2}I^- + e^- \rightarrow S + \frac{1}{2}I^- \qquad (7)$$
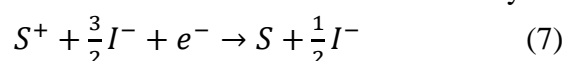
In the fig.4, anode (conductive) material can be TiO_2, ZnO, SnO_2 .

Dyes are Polypyridines, Porphyrins, Phthalocyanines, Organic dyes, inorganic semiconductors, 2nd generation dyes D-π-A, Quantum Dots.

Redox Mediator is I-/I3-, S2-/S22- (dithiolate), Co(LL)32+/Co(LL)33+, Spiro OMeTAD, and Additives (TBP, GuNCS).

Cathode will be Pt, C allotrophs, PEDOT:PSS, …

Remarkable properties of DSSC are Low cost, inexpensive to manufacture, non-toxic, earth-abundant materials (except Pt), good performance in diverse light conditions, high angle of incidence, low intensity, partial shadowing, lightweight, flexible, semi-transparent, bifacial and selected colors. Problems with DSSC are lab efficiencies <12% , stagnating low red and near-IR absorption, only I-/I3-redox couple has slow recombination kinetics, liquid electrolyte which is undesirable, during the course of the lifetime of a fuel cell the Pt cathode suffers from oxidation, loss of active surface area, and corrosion of the carbon support, impurities.

3.3.2 *Quantum dot solar cell technology:-*

History of QDs begins with their first discovery in glass crystals in 1980 by Russian physicist Ekimov. Systematic advancement in the science and technology of QDs was driven after 1984, when Luis Brus derived a relation between size and band gap for semiconductor nano particles by applying a particle in a sphere model approximation to the wave function for bulk semiconductors. It finally catches up the speed by successful synthesis of colloidal CdX (X = S, Se, Te). CdX is the most investigated QDs due to their excellent optical and electrochemical properties[6],[7]. QDs are tiny semiconductor particles with size a few nanometres. The optical and electronic properties of QDs are totally different from larger particles. By changing the dots' size, shape and material the optical, electrical properties are precisely tuned. QDs are excellent absorber materials and hence playing significant role in third generation PV cells such as QDSSCs. By utilizing hot photo generated carriers to produce higher photo voltages or higher photo currents, quantum dot solar cells have the potential of attaining maximum power conversion efficiency of about 66%.

3.3.3 *Organic solar cell technology:-*

In this case the active layer(Dye in case of DSSC) will be organic semiconductor material which can be obtained from conjugate polymer and small molecule organic polymer material known as donor material and acceptor material(equivalent to n and p regions of inorganic semiconductor)[..Organicpolymer junction can be bilayer junction or bulk hetero junction[8]. When a photon gets absorbed in an organic semiconductor, it results in the excitation of one electron to the lowest molecular orbital unoccupied (LUMO). The excited carrier leaves behind a hole in the highest molecular orbital (HOMO). These holes and electrons are not free charge carriers.

They remain bound because of columbic forces. The bound pair is called exciton. It was discovered that efficient charge separation of exciton and free carrier formation can occur if the junction is made of two different organic materials, a donor type and an acceptor type. The bulk hetero-junction increases the donor-acceptor interface area and allows each of them to be thinner around the junction (Fig.5). It is required because the exciton generated, close to the junction (within the exciton diffusion length, a few tens of nanometers) results in charge separation else the exciton gets recombined. The bicontinuous phase separated network at donor-acceptor interface separates the excitons generated in donor material because of the photons absorption. To make the carriers free, hole transporting layer (PDOT:PSS) and electron transporting layer(Ca)are used on either side of the active layer(Fig.6). In commercial organic solar cell the combination of P3HT (Donor) and PCBM (acceptor) is used to get efficiency of about 5%. For the transparent front electrode Indium Tin Oxide (ITO) on a glass substrate was used. ITO is one of the most commonly used materials for this purpose. For the back electrode a layer of PEDOT:PSS was included to help the charge extraction process, again a common practice. For this purpose metals such as Al (aluminium), Ag (Silver) and Au(gold) are also used(Fig.6). Advantages of organic solar cells are enormous

availability, easy processing, flexible, transparent and semitransparent, low cost and eco-friendly. Disadvantages are less efficiency, stability issues, degradation problems, poor generation and extraction of electrical charge carriers.
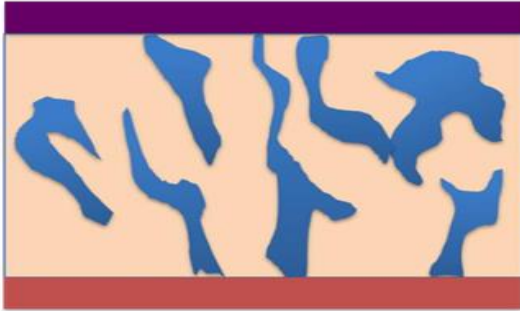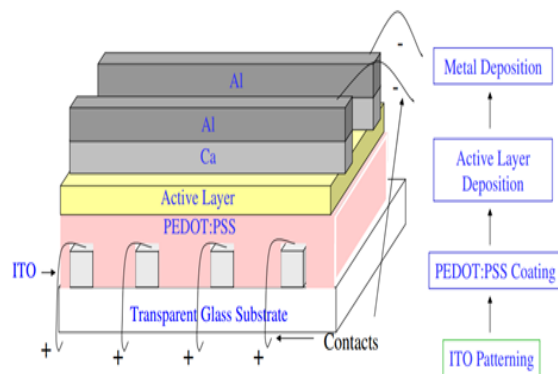

Fig.5. Donor-Acceptor interface in active layer

Fig. 6. Organic solar cell

3.3.4 Perovskite solar cell technology:-
The chemical composition of perovskite crystal is given by the formula AMX_3 where X is halide anion such as O, Cl, Br and I while M refers to a metal cation with a coordination number of 6 and A is usually a large cation that fills the cuboctahedral holes with coordination number of 12. A can be Ca, K, Na, Pb, Sr, other rare metals. Here A cations can be organic or inorganic like Methyl Ammonium (MA), Cs. To absorb photons of longer wave length the band gap tuning is must without sacrificing the absorption

coefficient. It can be achieved by changing in any of A, M and X in AMX_3 . $CH_3NH_3PbI_3$ is the most commonly used material for making high efficiency perovskite solar cells. The first organic-inorganic metal halide perovskite solar cell $CH_3NH_3PbI_3$ is a semiconducting pigment with a direct band gap of 1.55 eV with absorption coefficient as high as 10^4 – 10^5 cm^{-1}. After only few years of work, perovskite solar cells of efficiency 15.9% with facile low temperature solution-based fabrication method, high absorption coefficient, higher stability in air, very high values of open circuit voltages, high diffusion length, high charge-carrier mobility's are discovered. More than 90% of the present market share is taken by silicon PV solar cells because it delivers a package of decent module efficiency of 21% with lifetime of more than 25 years and cost of 0.3 \$ W−1. In comparison, perovskite single cells hold promise because of their efficiency reaching 23% and above and low manufacturing cost, which has been estimated to be able to reach the half of that of crystalline Si. [9],[10] The rapid growth of efficiency of perovskite solar cells up to 2015 is shown in Fig.7.
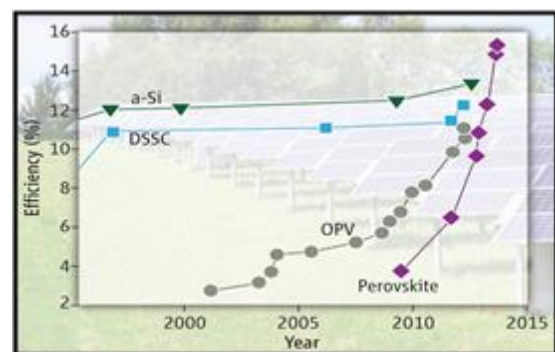

Fig.7.Growth of PVC

The best lifetime obtained for perovskite solar cells is 10,000 h (around 1 year), but the PCE is only 12% which is much shorter than 25 years as expected from commercialized PV technologies. By setting an efficiency threshold of 20%, the stability is found to be only 1000 h. That means the device efficiency and stability are not simultaneously optimized currently. However both high efficiency and high stability in PSCs can be achieved sooner. Research interest on the stability studies is growing rapidly to resolve stability problem for perovskite solar cells. The interface plays a crucial role in photovoltaic devices. The high performance of solar cells can be pursued by controlling the carrier behavior across relevant interfaces. Interface modification of hybrid perovskite solar cells can be realized by the inter layer (or so-called buffer layer),electron buffer layer (EBL) and hole buffer layer (HBL), which are deposited either above or below the perovskite layer in order to modify the energy level alignment and/or improve the surface morphology.Various kinds of interfacial modification layers are applied to enable better contact between hybrid perovskites and ETL or HTL, and to increase the efficiency of electron and hole transport[11,[12]. Such a hybrid perovskite solar cell will be as shown in Fig.8.

Fig. 8. Perovskite solar cell

Studies of optoelectronic properties indicated that a single-crystalline perovskite solar cell is much better than its thin-film counterpart because of less defects present in it.

3.3.5 *Organic nano particle solar cell technology:-*

Organic optoelectronics devices like organic solar cells and organic LED has attracted significant research interest due to high figure of merit, scalability as well as flexibility. Organic photo voltaics are advantageous for their reduced cost and high flexibility. Photo physics and morphology in nano scale in these devices play a significant role to control their performance and can be optimized. The stable hetero structure is achieved in a single step through self-assembly of nano particles. Tunable packing geometry of semiconductor assemblies and hence better characteristics is achieved by varying the radii of nano particles and keeping radius ratio constant. Nano particles are fabricated from water and hence it is greener route of fabrication. Thus organic nano particle solar cell technology is advantageos over organic solar cell technology. Organic nano particles can be carbon nano materials, fluorescent organic nano particles (FONs),water soluble organic nano particles, Starch nano particles(SNPs), Metal Organic Frame works(MOPs). The fabrication of nano size particles from bulk materials is understood from nano chemistry. The properties of nano particles can be changed simply by changing the size of particles (with same composition) which can not be done with bulk materials. Nano particles can be synthesized by two methods viz., Bottom-up method i.e., getting bigger

structure of nano dimension starting from small structure and Top-down method i.e., getting nano structure starting from bulk material. Top-down methods include physical methods such as mechanical grinding, laser ablation. Bottom-up methods include chemical methods such as Solvent Replacement, Anti solvents for Precipitation, Chemical Reduction in Solution, Ion Association, Synthesis of Nano particles in Water–Oil Emulsion, Photochemical Method, The use of Supercritical Fluids, Cryochemical Synthesis and Modification of Nano particles. Properties such as size of particles is studied by Dynamic Light Scattering(DLS), Scanning Electron Microscopy(SEM), Transmission Electron Microscopy(TEM) etc., methods. The property of chemical bonding can be studied by FTIR, X-ray microscopy and surface charge can be understood measuring electrophoretic mobility by DLS method. Experimental studies indicate that the absorbance, morphology optimization and performance of nano particle device mimic the that of thin film device. But the efficiency of organic thin film solar cell is limited to 8 to 10% and that of organic nano particle solar cell is found to be 15%.

3.3.6 Multi junction tandem solar cell technology:-

Even with a very good morphology, the efficiency of a single crystal silicon solar cell is limited to be 32% only. So efforts are made to improve efficiency by joining solar cells of same type or different type together. A unique way is joining two or more sub-cells .The sub-cells are connected on top of one another and can be constructed from different solar cell materials or from the same family of solar cell material. Such arrangement is called as a Tandem solar cell. Tandem cells are effectively a stack of different solar cells on top of each other. By arranging them like this, we can capture more energy from the sun.
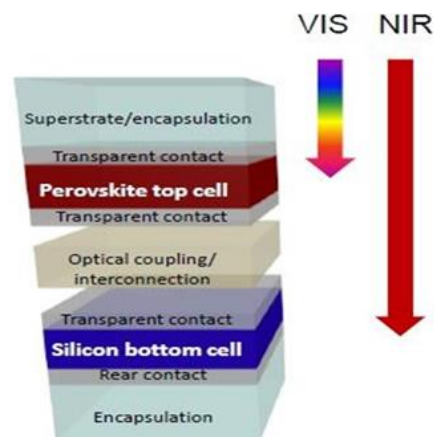
Fig.9. Perovskite/Silicon tandem solar cell

Tandem cells are an attractive option for achieving high efficiency. A perovskite/silicon tandem solar cell is shown inFig.9. Band gap of $CH_3NH_3PbI_3$ perovskite is1.56eV and Band gap of c-Si is 1.1 eV. Tandem cell illuminated through perovskite cell. Perovskite absorbs visible light, c-Si cell near-infrared light. In a two-terminal (2T) tandem configuration the top and bottom cells are electrically connected in series. In a four terminal (4T) tandem solar cells the top and bottom cells are independently electrically connected, with bottom cells of crystalline silicon and CIGSSe (CIGS).The 4T perovskite tandem had efficiency of 25.2% in 2016. The current record for a two-terminal perovskite tandem cell is with a perovskite– silicon tandem is 23.6%,.

Tandem solar cells have higher efficiencies than single junction solar cells because a high-band gap top cell material can generate photocurrent with higher voltage than the bottom solar cell with

lower band gap but broader absorption coefficient,. The theoretical efficiency limit for a tandem solar cell under unconcentrated sunlight (AM1.5G spectrum) is 47%, markedly higher than the Shockley- Quiesser limit of 31% for single-junction cells under unconcentrated sunlight.

Perovskite–perovskite 4T tandem efficiencies are expected to surpass record perovskite single-junction efficiencies by the end of 2020, with 2T efficiencies greater than 26% expected before 2030. Just as organic metal–halide perovskite solar cells have risen from below 4% in 2009 to above 22% in 2016, so too have tandems; debuting below 14% in 2014 to reach above 25% in 2016.The efficiencies for tandem solar cells are not constrained by the single junction limit, and we expect this trend in increasing efficiency to continue in the decade to come, predicting a perovskite–silicon 4T tandem beyond the 'break-even' efficiency of 26% by end of the year 2020, and 2T tandems breaking even by 2030.

4. Some results from recent studies:

i) Performance and stability improvement of single junction a-Si:H p-i-n solar cell is reported by interface engineering[13]. It is reported that a-Si:H solar cell without buffer layer has higher degradation on soaking with sun light for 1000 hours when compared with solar cell having buffer layer.

ii)It is reported that cost effective solar cell fabrication by synthesizing small size ZnO nano particles from Azadira Indica (Neem) leaves extract using domestic microwave oven shown better PCE of 2.1% with increasing stability and it is advantageous over organic materials[14].

iii)All solution processed small molecule solar cells by stripping-transfer method has advantages of simple synthesis process at low temperature. The efficiency of ZnPc/C60 based solar cell could reach PCE of 1.37%[15]. It can accelerate commercialization of small molecule solar cells.

iv)The antireflection coating material of nano structured $ZnAl_2O_4$ (Gahnite) improved PCE of polycrystalline Silicon solar cell and is increased to 21.27% at open atmosphere condition and to 23.83% [16] controlled atmosphere condition.

v)Cobalt doped PbS thin film with different Co concentrations improved PCE from 35% to 60% [17]]with Co concentrations ranging from 0% to 5% as it impress the particle size, energy band gap of PbS.

vi)The double perovskite structure material $Pb_{1.5}$ $Ca_{0.5}$ Nb O_6 is in polycrystalline form has high dielecric constant(500) at room temperature and can be used as energy storage device such as Solar cell material[18].

Conclusion:

Solar power in India is a fast developing industry. The country's solar installed capacity reached 26 GW as of 30 September 2018.

Research is required into the fabrication of long-lasting OPVs that can resist morphological degradation under diverse environmental conditions. By optimizing their morphologies, high performing OPVs with PCEs above 15% can be

obtained in the near future for their commercialization to advance the OPV market.

Despite the rapid progress in the performance of hybrid perovskite solar cells, there are still many more opportunities for further improvement. The interaction mechanism between the hybrid perovskite and other interface layers still remains unclear and needs to be further explored to facilitate the application of morphology engineering. With regard to the next direction in morphology engineering, film quality could be improved by either integrating these existing techniques with different functions or by exploring new technologies to reach distinctive and goal oriented morphology control. In addition to experimental approaches, theoretical calculations can definitely make a significant contribution to further advances in the design of morphological techniques. Knowing the basic properties of a semiconductor material, such as carrier concentration, trap position and density, carrier mobility, carrier lifetime, diffusion length, is a primary step before designing a suitable application for it. This also holds true for perovskite crystals.

Since single-crystal perovskite thin films have shown significant superiority in terms of their crystal quality and optical and electrical properties compared to those of their polycrystalline counterparts, the photovoltaic performance is reasonably expected to outcompete the records set by polycrystalline perovskite films. To achieve higher efficiencies, more effort is suggested, including perovskite composition adjustments (e.g., $(FAPbI_3)_{0.85}(MAPbBr_3)_{0.15}$), crystal thickness optimization and reducing the amount of surface defects. Hence, it is an optimistic expectation that the PCE of single-crystal perovskite solar cells would increase to 25–30% soon. Direct growth of single-crystal perovskite thin films onto functional target substrates (e.g., transparent conducting substrates, patterned electrodes) is regarded as an efficient route for developing highly integrated systems, which greatly reduce device fabrication complexity.

Perovskite/silicon tandems will have to meet the performance guarantee of silicon panels of 80% performance after 25 years. These lifetime constraints could perhaps be reduced for niche markets (such as flexible devices), for which a device shelf time of 5 to 10 years might suffice, but large scale deployment of GW-scale perovskite photo voltaics will not occur before robust demonstration of stability in environmental testing.

Scope of future work:

Current experimental studies indicating that air exposure causing variation of series and shunt resistances of solar cell material and hence life time is get effected. Further, alloying with material of suitable refractive index and using antireflection coatings over the material improves power conversion efficiency Using thin film technologies rather than single crystalline silicon solar cell technology reduces the cost. Hence more research is needed to find the suitable material with suitable technology to fabricate solar cells with high efficiency, long life time and at low cost.

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