



TANDEM PSC(PERVOSKITE SOLAR CELL) FOR ENERGY HARVESTING – REVIEW

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Abstract: Quest for high photo conversion efficiency have vastly increasing by the emergence of new novel solar cell materials that could support light capturing from sun. From the birth of solar cell in 19th century, research voyage of solar cells has proven to be an outstanding alternative source of energy. Among 4G (four generation) solar cells, this review put forth the PSC (Perovskite solar cell) which are next preferable choice as the top solar cell owing to its higher absorption edge (~ 2.23 eV) and efficiency of 22.7 %. The review and research findings presented provide valuable guidance in identifying new pathways in optimizing future PV designs towards sustainable energy harvesting.

Index Terms - Solar cell, Perovskite, Photo conversion efficiency.

I. INTRODUCTION

Solar deity, the sun is been worshiped in various mythologies as helios (Greek), Sol (Latin), Shamash (Arabia), Xihe(Chinese), Ra or Re(Egypt) Sunna(German) Sol Invictus (Roman), Saule(Baltic) Surya (Hindu)[1]. The biblical reference says that “The sun of righteousness will rise with healing in its rays...” - Malachi 4:2. Likewise the prevalence of sun’s energy acts as curative and is the most potential energy source for the future power generation, due to its characteristics of renewable and environmental friendly property [2,3,4,5]. However, the recent technology is yet unable to achieve high Watt/m² and cost effectiveness. Solar cell research is still ongoing to improve its efficiency and many researchers are involved in experimenting with novel technologies to enhance the light capture and conversion mechanism in the fabrication of cost-effective solar cell. Among 4G (four generation) solar cells, this review put forth the PSC (Perovskite solar cell) which are next preferable choice as the top solar cell owing to its higher absorption edge (~ 2.23 eV) and efficiency of 22.7 %. Perovskite materials have various attractive properties like optical properties, magnetoresistance, ferroelectricity, superconductivity, transport properties which can be utilized in designing effective devices for photovoltaic and photocatalysts for water splitting. The (PCE) photoelectric power conversion efficiency of the perovskite solar cells has increased from 3.8% in 2009 to 22.7% in 2017, making PSC the best potential candidate for the new generation of solar cells to replace traditional Si solar cells in the future.

II. 4G’S OF SOLAR CELL

As of now four generation (4G) solar cells are accessible depending on the choice of applications. 1G, first generation solar cell was pioneered by Bell Labs in 1954. Sliced C-Si from large ingots was used with dopants to make p-type and n-type for the junction. With advent of reducing the cost of 1G. This was extended to take in amorphous or polycrystalline Si, CIGS, and CdTe. Due to cost issues with thick films and poor performance of such 2G solar cells turned to the development of the third-generation (3G) solar cells, like nanocrystalline films, PVs based on active quantum dots, tandem or PSC, DSSC, CIGS. These cells are potentially able to overcome the Shockley–Queisser limit of 31–41% power efficiency for single bandgap solar cells. Shockley–Queisser limit, or SQ Limit, refers to the maximum theoretical efficiency of a solar cell using a single p-n junction to collect power from the cell.

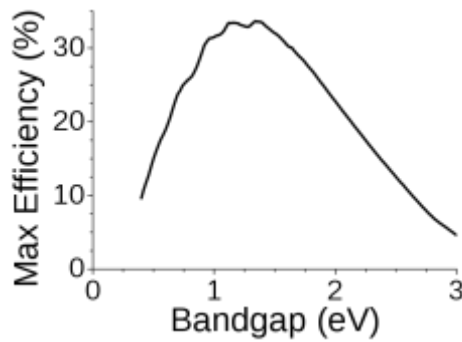


Figure 1: Shockley-Queisser limit for the efficiency of a solar cell, without concentration of solar radiation. The curve is wiggly because of IR absorption bands in the atmosphere. In the original paper, [william]

The 4G solar cells are a hybrid that combine the low cost and flexibility of conducting polymer films (organic materials) with the lifetime stability of novel nanostructures (inorganic materials).

III. PEROVSKITE SOLAR CELL (PSC)

Perovskite solar cells are fabricated by grouping materials in the form ABX_3 : with A = An organic cation - methylammonium ($CH_3NH_3^+$), B = A big inorganic cation - usually lead(II) (Pb^{2+}), X_3 = A slightly smaller halogen anion – usually chloride (Cl^-) or iodide (I^-).

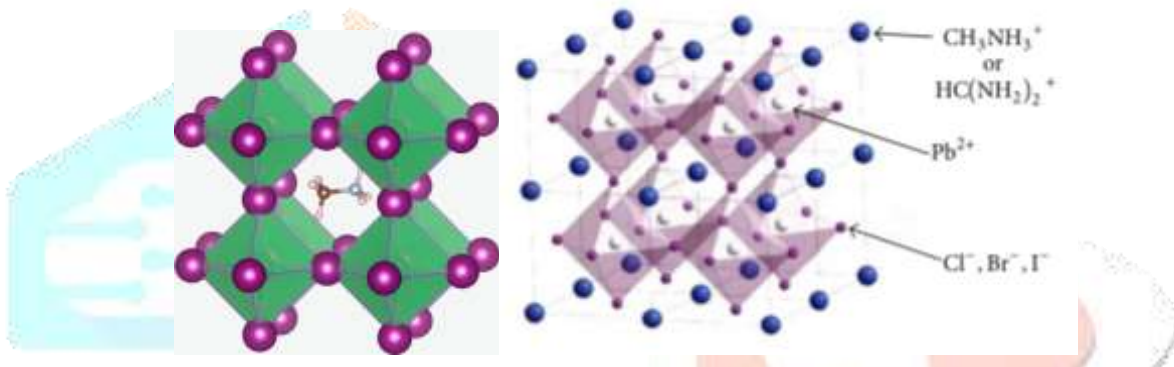


Figure 2: Typical Crystal structure of $CH_3NH_3PbX_3$ perovskites ($X=I, Br$ and/or Cl). The methylammonium cation ($CH_3NH_3^+$) is surrounded by PbX_6 octahedra. [Eames] [chen]

Although these perovskite structures offer high PCEs, reaching >20% PCE with band gaps of around 1.55 eV [14], fundamental issues have been discovered while tuning their band gaps to the optimum 1.7 - 1.8 eV. But, the four important characteristics that makes to thrust Perovskite structure are (i) photoelectric properties, lower exciton binding energy, and high optical coefficients of absorption $\sim 10^4 \text{ cm}^{-1}$ [S. Sun], (ii) efficacy of light-absorbing layer to absorb solar energy [C. C. Stoumpos], (iii) large dielectric constant transmission and collection of charge carriers (electrons and holes) [T. Baikie], (v) Both the charge carriers (electrons and holes) can be transmitted concurrently leading to a transmission distance more than 100 nm to 1 μm [M. A. Green, S. P. Singh, M. Luan]. $CsPbBr_3$ [Stoumpos, C], $CsPbI_3$ [Eperon 2015], $MAPb[I_{(1-x)}Br_x]$ $MAPb[I_{(1-x)}Br_x]_3$ is some of the organo-inorganic metal halide PSCs that has been attempted.

IV. PREPARATION METHODS

Various methods are being adopted for the preparation of PSC such as dip coating [Rsingh], spin coating [Yuji, Jeong], electrospray [Pei-Ying], sequential deposition method [Julian], Vapour assisted solution process (VASP) [Qi Chen], (VAOS) Vacuum assisted one step solution [Hao], room temperature solution [Xiong Li] processing technique [Liu], vacuum-flash solution processing method [Xiong], vapour deposition [Mingzen liu].

Table 1. PSC fabrication methods and the corresponding Short circuit current density J_{sc} , Open circuit voltage V_{oc} , Fill factor FF, efficiency η .

Perovskite	Method	J_{sc} mA cm^{-2}	V_{oc} V	FF	η %	Ref
$\text{CH}_3\text{NH}_3\text{Pb}_{3-x}\text{Cl}_x$	Dip coating	11	0.87	0.55	> 5	R singh
$\text{FA}_x\text{MA}_{1-x}\text{PbI}_3$	Spin coating	13.0	0.653	0.371	3.15	Yuji
$\text{CH}_3\text{NH}_3\text{PbI}_3$	Electrospray	19.71	0.87	0.55	9.3	Pei-Ying Lin,
$\text{CH}_3\text{NH}_3\text{PbI}_3$	Sequential vapour deposition	17.1	0.992	0.73	12.9	Julian
$\text{CH}_3\text{NH}_3\text{PbI}_3$	VASP	19.8	0.924	0.663	12.1	Qi Chen
$\text{CH}_3\text{NH}_3\text{PbI}_3$	VAOS (Vacuum assisted one step solution)	17.7	0.874	0.71	11.5	Hao
$\text{FA}_x\text{Cs}_{(1-x)}\text{PbI}_y\text{Br}_{(3-y)}$	vacuum-flash solution processing method	22.60	1.143	0.76	19.6	Xiong Li
ITO/ZnO/ $\text{CH}_3\text{NH}_3\text{PbI}_3$ /spiro-OMeTAD/Ag	Room-temperature solution processing techniques	20.5	1.01	0.696	14.4	Dianyi Liu
FTO/ TiO_2 / $\text{CH}_3\text{NH}_3\text{PbCl}_3$ /spiro-OMeTAD/Ag	vapour deposition	21.5	1.07	0.67	15.4	Mingzen liu
ITO/PEDOT: PSS/ $\text{CH}_3\text{NH}_3\text{PbI}_3$ /PC61BM/Al	low-temperature solution-processable	10.829	0.905	0.756	7.4	S.Sun

V. DEVICE STRUCTURE OF PSC

The simple PSC consists of an electron transport layer/perovskite/hole transport layer on the FTO/glass substrate.

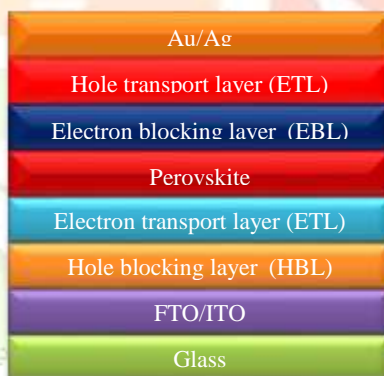


Figure 3: Device architecture of the PSC [Khalid Mahmood].

A schematic diagram of device architecture of the PSC is presented in Figure 3. The simple PSC consists of an electron transport layer/perovskite/hole transport layer on the FTO/glass substrate. Low and high work function electrodes can be used at the electron transport layer (ETL) and hole transport layer (HTL) sides, respectively. The balanced diffusion length of electron and hole is more than 500 nm in a perovskite absorber, which inhibits charge recombination in the perovskite absorber. Recently, electron – hole diffusion length of about $175\mu\text{m}$ was reported by Dong et al in $\text{CH}_3\text{NH}_3\text{PbI}_3$ PSC. Therefore, a smooth electron injection requires a charge separation for further process. Sometimes a compact hole blocking layer is used before the ETL, and an electron blocking layer is used before the HTL to block the excess hole and electron at either side, respectively. Some earlier studies focused on compact hole blocking layer (HBL) being beneficial for PCE by blocking the hole from the ETL side. The electron and hole clouding in the device architecture lead to a high recombination rate.

VI. SURFACE STUDIES

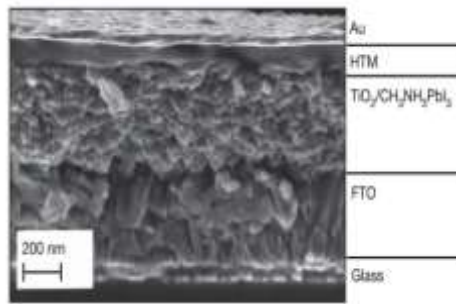


Figure 4: cross-sectional view of a completed PSC device [Julian]

The SEM depicts the cross-sectional view of a completed PSC device is shown in figure 4 with layers of glass/FTO/TiO₂-CH₃NH₃PbI₃/HTM/Au. The optimized thickness of mesoporous TiO₂ film is around 350nm and was infiltrated with the perovskite nanocrystals using the above-mentioned two-step procedure. The HTM was subsequently deposited by spin coating forms a 100-nm-thick layer on top of the composite structure. A thin gold layer was thermally evaporated under vacuum onto the HTM, forming the back contact of the device. The J-V characteristics shows that (J_{sc}), (V_{oc}) and the fill factor are 17.1mAcm², 992mV and 0.73, yielding 12.9% PCE.

VII. HYSTERESIS

The effect of migration of ions in perovskite along with trapping of charge at the perovskite interfaces leads to hysteresis effects in PSC's that causes large densities of electrons and holes at the interface. Even solar cells exhibiting >20% efficiency exhibit some hysteresis, and the efficiency has been determined by taking the average of the forward and reverse scans or by holding the cell close to the maximum power until stabilized steady-state power output is achieved. The physical origin of this hysteresis has been concurrent to a large variety of processes like (i) trapping of electronic carriers at the perovskite interface(s);^{11,12} (ii) ionic displacement;¹³ or (iii) ferroelectric effects.^{14,15} Experimental work supports these theories because, for instance, surface passivation of perovskites has led to a reduction in trap density and simultaneous reduced hysteresis.^{11,16}

VIII. EFFICIENCY

According to the reports of 2017 NREL Best Research-Cell Efficiencies, 1st generation solar cells Crystalline-Si was 27.6 %, Cadmium Telluride (CdTe) had 22.1 %, The second generation Copper Indium Gallium diSelenide with a maximum next to c-Si as 23.3 %, the upcoming Copper Zinc Tellurium Selenide (CZTSe), Dye sensitized solar cells(DSSC), Organic cells with 12.6, 11.9, organic 11.5 % respectively. Another arising efficiency of 22.7 % was from PSCs [NREL] showing a remarkable efficiency enhancement and has put forth the rest at the back.

Table 2. Efficiency table adopted from NREL chart 2017

Type of cells	Efficiency % [NREL]
c-Si	27.6
CdTe	22.1
CIGS	23.3
CZTSe	12.6
DSSC	11.9
PSC	22.7
Organic	11.5

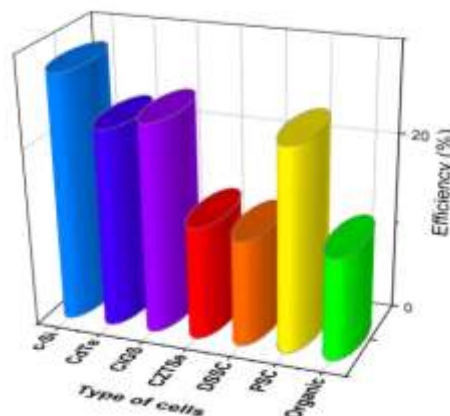


Figure 5: Efficiency of different types of cells

IX. CONCLUSION

Perovskite solar cells have developed rapidly, but some critical factors may restrict the development of perovskite solar cells. Firstly, the stability of the organic lead halide perovskite is greatly affected by external environmental factors (such as humidity, temperature, and ultraviolet radiation), which lead to the low stability of the devices and the great difficulties in encapsulating cells in the later stage. Organolead halide perovskites are capable of a high light harvesting, possess excellent electro transport properties and have a low defect density and low intergrain potential barriers. The high-efficiency and cost-effective materials and processes for perovskite solar cells make them economically viable for commercialization. However, commercialization is still challenging because of (1) the toxicity of Pb atoms, (2) long-term stability, and (3) cost-effectiveness. So far, the champion cells have been based on Pb-based perovskite materials. However, the utilization of Pb-based materials has been restricted due to their intrinsic toxicity. Pb-free absorber layer would be the future research directions with a protection technology, in order to arrest Pb within the Pb-based perovskite solar cell device, will be an important concern. [Hyun Suk Jung]

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