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A Study of Perovskite Solar Cells by High-Efficiency

Deepak Choudhary
D.J. College, Baraut, Uttar Pradesh, INDIA

Corresponding Author: choudharydeepak962@gmail.com

ABSTRACT

Faced with the world's growing energy and environmental crises, the development of renewable energy has piqued the interest of all governments. Solar one of the most promising renewable energy sources since it is abundant and inexpensive. While solar cells are high performance have advanced significantly in recent decades, the high module cost has hampered widespread adoption of photovoltaic systems. This urgent demand for cost-effective solar cells has tremendously helped solar cell research in the last ten years. This paper examines the recent progress of low-cost, high-efficiency solar cell technology. According to this article, perovskite solar cells are low-cost and high-efficiency. Perovskite solar cell technologies are also discussed, including their development and current state-of-the-art findings.

Keywords-- Perovskite, Solar Cells, High-Efficiency, Stability

I. INTRODUCTION

About 85 percent of the world's energy needs are currently met by nonrenewable fossil fuels, which have negative health and environmental repercussions. Furthermore, by 2050, global energy demand is expected to double. As a result, the development of renewable energy sources such as wind, water, and solar energy has become a pressing necessity. In 2014, electricity generation based on renewable energy capacity was predicted to be 128 GW, with wind power accounting for 37%, solar power for over a third, and hydropower accounting for more than a quarter (Fig. 1a). In 2014, this accounted for more than 45 percent of global power generation capacity increases, continuing a recent rising trend.

Solar energy is attracting increasing attention from around the world due to its abundance, low cost, and environmental friendliness, resulting in the rapid advancement of solar cell research in recent years. In general, the various PV technologies (both commercial and R & D stage) are divided into three generations: G1: wafer-based, primarily mono c-Si and mc-Si; G2: thin film; CdTe, a-Si, CuGaSe; CIGS, G3: multi-junction and organic photovoltaics (OPV), dye-sensitized solar cells (DSSCs).

Solar cells such as Si solar cells, III–V solar cells, perovskite solar cells (PSCs), thin film solar cells, dye-sensitized solar cells, and organic solar cells have all been developed as a result of the development of three-generation solar cells. The 3rd group solar cells that are practical, low-cost, and high-efficiency have yet to be proved. Solar cells made of silicon are well-developed and mature, with little possibility for improvement. The efficiency of III–V solar cells is quite high; nevertheless, the expensive cost limits its utilization. Because of their low cost and great efficiency, quantum dot solar cells have gotten a lot of interest, yet the most efficient devices have been made with poisonous heavy metals like Cd or Pb. Halide perovskites have lately emerged as a promising low-cost, high-efficiency solar cell material. The efficiency of perovskite-based solar cells has improved fast as perovskite solar cell technology matures, from 3.8 percent in 2009 to 22.1 percent in 2016.

However, more research into the stability difficulties is required. This study analyses the recent development of high-efficiency PSCs to provide an update on the topic.

Figure 1 shows the global additions of renewable-based electricity capacity by type and fraction of overall capacity additions. b From 2009 to 2016, rapid PCE growth of perovskite solar cells this paper briefly reviews the history of perovskite solar cells before focusing on recent advances in high-efficiency perovskite solar cells. It will also highlight recent efforts to improve the stability of perovskite solar cells. We also give a quick introduction to interface engineering at the end of the study.

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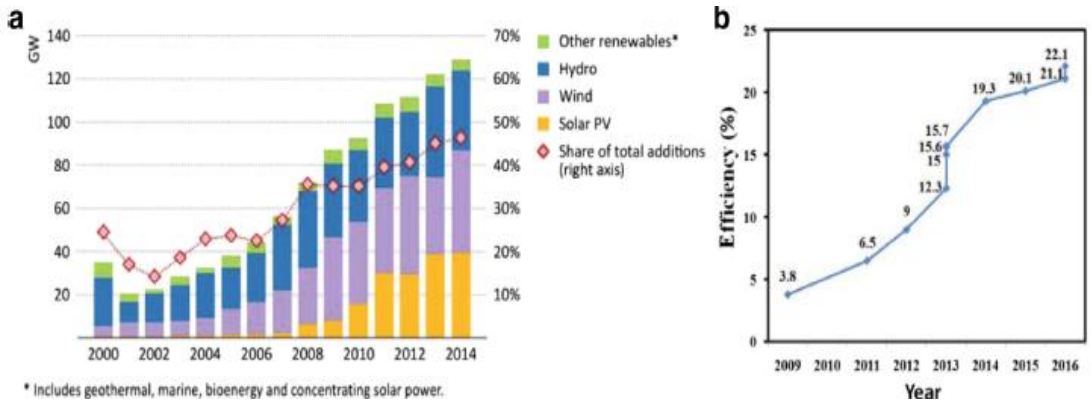

Figure 1

II. PRINCIPLES AND PEROVSKITE SOLAR CELLS

PSCs have lately been a hot topic in solar cell research due to their low preparation cost and excellent conversion efficiency. It's also seen as a high-potential material because of its superiority (when compared to other materials) that could help perovskite overthrow the reigning cell material.

Inspired by the idea of photosynthesis, Gratzel and O'Regan published a groundbreaking solar cell design in 1991 dubbed the dye-sensitized solar cell, which converts sunlight into electricity with a 7 percent efficiency. With numerous advantages over conventional solar cells, such as abundant raw materials, simple processing, and low cost, these novel solar cells became popular quickly after their invention. And it was as a result of this study that PSCs, a perovskite-based DSSC, were born.

Perovskite was first found in 1839 by German mineralogist Gustav Rose as a type of ceramic oxide having the generic molecular formula ABY3. Because it is a calcium titanate (CaTiO3) component found in calcium titanium ore, it was given the name "perovskite." Figure 2a depicts the crystal structure of a perovskite. Miyasaka and his colleagues were the first to use perovskite structured materials in solar cells in 2009. They used two organic-inorganic hybrid halide-based perovskites, $CH_3NH_3PbBr_3$ and $CH_3NH_3PbI_3$, to replace the dye pigment in DSSCs. And, in the end, they achieved relatively low power conversion efficiency (PCE) of 3.13 percent and 3.81 percent, respectively.

However, because to low efficiency and poor stability caused by a hole transport layer (HTL) with liquid electrolyte, the work did not receive much attention.

In 2012, Kim, Gratzel, and Park et al. Employed perovskite absorbers as the major photoactive layer to manufacture solid-state meso-superstructured PSCs, which marked an evolutionary leap. The whole transport and electron transport materials (HTM/ETM) in their work were Spiro-MeOTAD and mp- TiO2, respectively, and the first reported perovskite-based solid-statemesoscopic hetero junction solar cell had a comparatively high efficiency of 9.7%.

Following this accomplishment, PSC research grew increasingly popular in photovoltaic (PV) research over the next few years. PSC efficiency was eventually increased to 22.1 percent in early 2016. There is still room for advancement because the greatest possible PCE of PSCs using CH3NH3PbI3xClx is 31.4 percent.

The general configuration of PSCs is shown in Figure 2b, which typically includes a tin-doped indium oxide (ITO) or fluorine-doped tin oxide (FTO) substrate, metal electrode, perovskite photoactive layer, and necessary charge transport layers (i.e., a hole transport layer (HTL) [20] and an electron transport layer (ETL). Figure 2c and d depict two different device architectures: meso-superstructured perovskite solar cells (MPSCs) with a mesoporous layer and planar perovskite solar cells (PPSCs) with all layers planar.

The following are some quick methods to summarize the functioning principle of these PSCs: The incident light is absorbed by the perovskite layer, which produces electrons and holes, which are extracted and transported by ETMs and HTMs, respectively. Finally, electrodes gather these charge carriers, generating PSCs.

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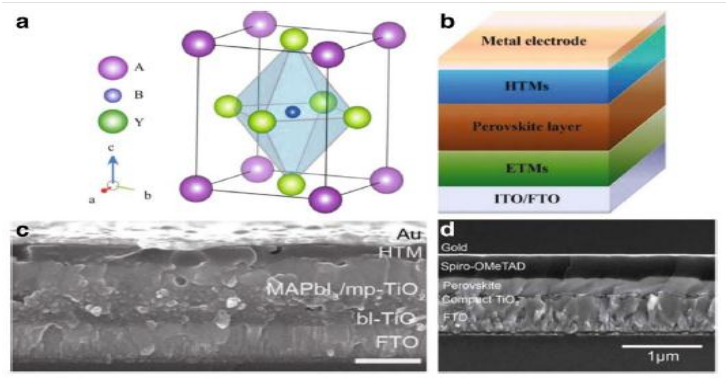

Figure 2

Figure 2 shows a perovskite crystal structure b) A schematic diagram of a general device is shown below. Images of a meso-superstructured perovskite solar cell taken in cross-section using scanning electron microscopy (SEM) (scale bar is 500 nm). The SEM cross-section photos show a normal planar perovskite solar cell with an HTL and an ETL.

III. PEROVSKITE SOLAR CELLS WITH HIGH EFFICIENCY

3.1 Intermolecular Exchange is a term that refers to the exchange of molecules within

Woon Seok Yang and colleagues published a paper in June 2015 describing a method for placing high-quality FAPbI3 films, claiming to have fabricated $FAPbI_3$ PSCs with a PCE of 20.1 percent under AM 1.5 G full-sun illuminations. Deposition of thick and uniform films is vital for optoelectronic properties of perovskite films and is a key research issue of highly efficient PSCs on the way to increasing solar cell efficiency. Woon Seok Yang and colleagues describe a method for forming high-quality $FAPbI_3$ films that involves direct intermolecular exchange of dimethyl sulfoxide (DMSO) molecules intercalated in (Figure-3). Films with (111)-preferred crystallographic orientation, large-grained dense microstructures, and flat surfaces without residual are produced using this method. They made PSCs with a maximum power conversion efficiency of additional 20% using films made with this technique.

3.2 Triple-Cation Perovskite Solar Cells with Cesium

Michael Saliba and his colleagues demonstrated a perovskite solar cell that not only has a higher PCE of 21.1 percent but is also more stable, contains fewer phase impurities, and is less sensitive to processing conditions by adding inorganic cesium to triple-cation perovskite compositions.

They looked into triple-cation perovskites with the generic form "Csx(MA0.17FA0.83)(100x) Pb(I0.83Br0.17)3, demonstrating that using all three cations, Cs, MA, and FA, gives them more flexibility when it comes to fine-tuning high-quality perovskite films. Figure-4. Under operational conditions, they produced stabilised PCEs of over 21 and 18 percent after 250 hours. Furthermore, triple-cation perovskite films are thermally more stable and are less impacted by changing environmental variables like solvent vapours, temperature, or heating protocols. It toughness is critical for reproducibility, which is one of the most crucial needs for cost-effective PSC manufacture on a big scale.

3.3 Perovskite Solar Cells with Different Band Gaps

On November 7, 2016, scientists from the University of California, Berkeley, and the Lawrence Berkeley National Laboratory announced a novel design that had already reached an average steady-state efficiency of 18.4%, with a peak efficiency of 27% [29–31]. They combined two materials into a tandem solar cell using a single-atom thick layer of hexagonal boron nitride and achieved high efficiency. The organic molecules methyl and ammonia are present in both perovskite materials, while one contains the metals tin and iodine and the other has lead and iodine doped with bromine. The former is tuned to absorb light with a 1 eV energy—infrared or heat energy—while the latter absorbs photons with a 2 eV energy, or an amber colour. The merger of two perovskite materials had previously failed due to the materials' electronic performance degrading each other. This new method for combining two perovskite solar cell materials into a single device has been developed.

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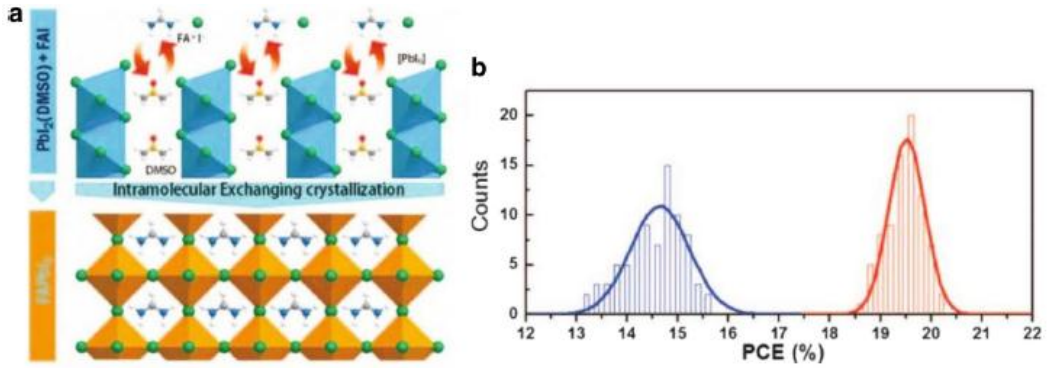

Figure 3

Figure 3 X-ray diffraction and the creation of the PbI2 complex a FAPbI3 perovskite crystallisation schematic utilising direct intramolecular exchange of DMSO molecules intercalated in PbI2 with formamidinium iodide (FAI). The DMSO molecules are intercalated between PbI_6 octahedral layers that share their edges. Solar cell efficiency histogram 66FAPbI3 based for each of the cells manufactured using the IEP and traditional processes.

The "graded bandgap" solar cell showed promising results. The solar cell absorbs nearly the entire visible light spectrum. This is extremely beneficial in terms of increasing efficiency. Figure 5 depicts the structure. They discovered that cells that have been illuminated for less than a few minutes have a higher PCE than cells that have been illuminated for longer. For example, in the first 2 minutes of illumination, the PCE of a given graded bandgap perovskite cell is between 25 and 26 percent, while after about 5 minutes, the cell reaches a "steady state" with a stable PCE of 20.8 percent. This finding suggests that the performance of perovskite-based solar cells varies over time. The average steady state PCE over all devices was 18.4%, while the best graded bandgap cell in the steady state had a PCE of 21.7 percent, according to measurements of 40 graded bandgap perovskite cells.

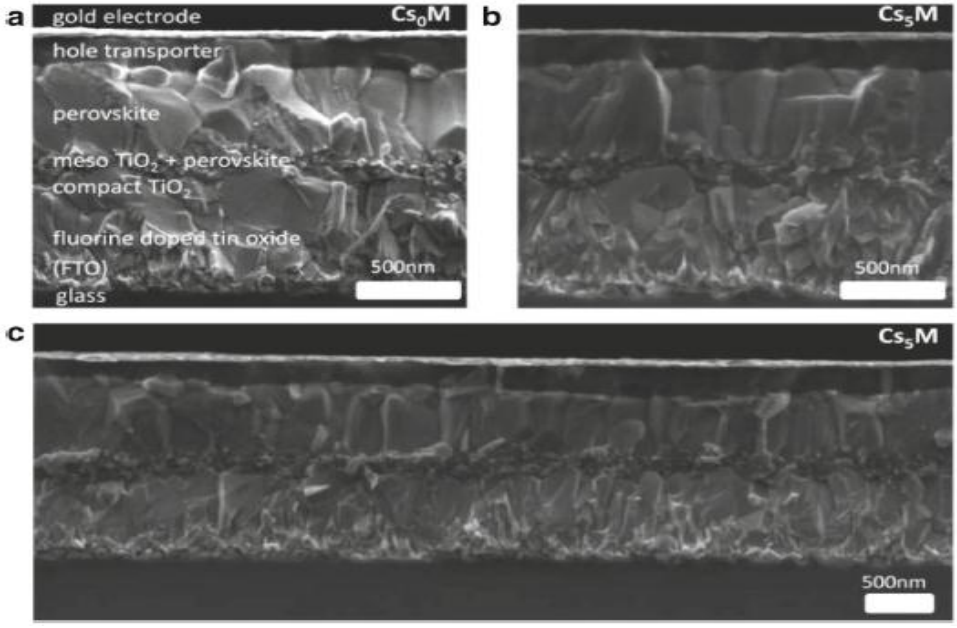

Figure 4: SEM pictures of a Cs0M, a Cs5M, and a low-magnification Cs5M device in cross-section

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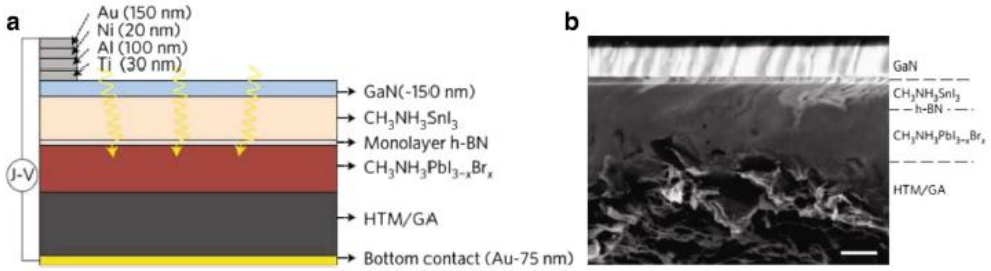

Figure 5

Figure 5 Perovskite cell cross-sectional schematic and SEM images with integrated monolayer h-BN and graphene aerogel. A schematic of a perovskite solar cell with a graded band gap the high-efficiency cell architecture includes gallium nitride (GaN), monolayer hexagonal boron nitride (h-BN), and graphene aerogel (GA). A SEM image of a representative perovskite device in cross-section in this SEM view, the separation between perovskite layers and the monolayer h-BN is not evident. The dashed lines serve as a visual indication of the approximate placement of the perovskite layers and the monolayer h-BN. The EDAX analysis is used to extract the positions of perovskite layers and monolayer h-BN. The $CH_3NH_3SnI_3$ layer is 150 nm thick, while the $CH_3NH_3PbI_3$xBrx layer is 300 nm thick. Scale bar of 200 nm.

IV. PEROVSKITE SOLAR CELL STABILITY

The record efficiency of PSCs has been upgraded from 9.7% to 22.1 percent in recent years. However, PSCs' poor long-term device stability remains a significant challenge for PSCs, which determine whether exciting laboratory successes can be applied to industry and outdoor applications. As a result, long-term stability is an issue that PSCs must address immediately. A large number of people have expressed interest in the topic of stability and offered advice on how to improve it.

Moisture and oxygen, UV light, solution processing, and temperature stress are four significant parameters affecting the stability of PSCs, according to multiple research. When devices are subjected to various environmental variables, there is observed (and sometimes quick) degradation.

Many factors, according to Guangda Niu and his colleagues, should be considered when modulating the stability of PSCs, including the perovskite's composition and crystal structure design; the preparation of the HTM layer and electrode materials; the thin film fabrication method, interfacial engineering, and encapsulation methods (multilayer encapsulation or helmet encapsulation); and module technology. Their findings showed that oxygen, in combination with moisture, can cause irreversible degradation of $CH_3NH_3PbI_3$, which is commonly used as a sensitizer in PSCs. They exposed a $TiO2/CH_3NH_3PbI_3$ film to air at 35 °C for 18 hours with a humidity of 60%, and the absorption between 530 and 800 nm significantly decreased (Figure-6d).

Humidity is very important when conducting an experimental inquiry into the topic of stability. The hygroscopic quality of amine salts is due to the origin of moisture instability, according to research led by Kwon et al. Frost et al. demonstrated the expected pathway of $CH_3NH_3PbI_3$ breakdown in Figure 6a. The procedure shows that HI and MA are water soluble, resulting in irreversible breakdown of the perovskite layer.

In situ absorbance and grazing incidence X-ray diffraction (GIXRD) measurements were used by Yang et al. to explore this degradation process. They carefully controlled the relative humidity (RH) in which the films were measured to produce a valid contrast in degradation.

Figure 6b depicts their findings on the effect of RH on film degradation. For the 98 percent RH scenario, the absorption was decreased to half of its original value in only 4 hours, however for a low RH of 20%, extrapolation of the degradation curve would take 10,000 hours. The results show that greater RH levels promote a faster drop in film absorption than low RH values. Furthermore, different carrier gases, such as N2 or air, had no significant effect on the degradation of the absorbance, indicating that moisture is the primary source of degradation in the perovskite layer under normal conditions.

DeWolf et al. employed photothermal deflection spectroscopy (PDS) to evaluate moisture-induced breakdown of $CH_3NH_3PbI_3$ in 2014. They measured the PDS spectra of $CH_3NH_3PbI_3$ layers after 1 and 20 hours of exposure to ambient air with 30–40% relative humidity. Figure 6c demonstrates that after 20 hours of exposure to humidity, the absorptance between photon energies of 1.5 and 2.5 eV reduces by two orders of magnitude. Furthermore, the absorption edge shifts from 1.57 eV in its initial condition to 2.3 eV, which corresponds to the bandgap of PbI2.

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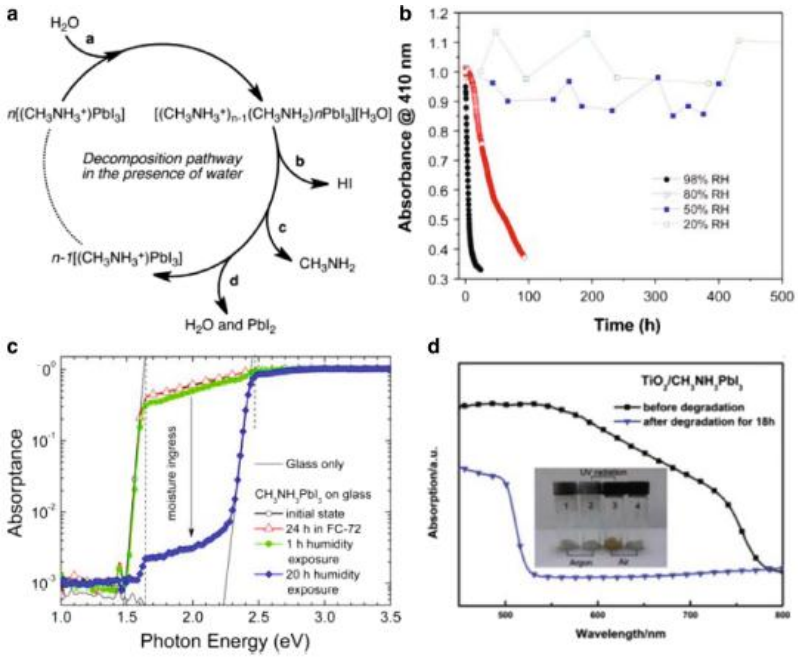

Figure 6

Figure 6: A breakdown mechanism for $CH_3NH_3PbI_3$ in the presence of a water molecule has been proposed. PbI2 is the primary result of this route. B Absorbance data (at 410 nm) for $CH_3NH_3PbI_3$ films exposed to various relative humidity levels. c PDS spectra of $CH_3NH_3PbI_3$ films before (initial condition) and after 30–40% relative humidity exposure for different times. This plainly shows that there is a after exposure to humidity, there was a considerable reduction in absorption in the 1.5–2.5 eV range. (D) Degradation of CH3NH3PbI3 in moisture and air atmosphere. Before and after degradation of the TiO2/$CH_3NH_3PbI_3$ film's UV-vis absorption spectra An image of CH_3NH_3I exposed to light is shown in the inset. Several conditions exist: (1) CH_3NH_3I exposed to argon but not UV radiation; (2) CH_3NH_3I exposed to argon but not UV radiation; and (3) CH_3NH_3I exposed to argon but not UV radiation.(4) CH_3NH_3I in the presence of air and UV radiation; and (5) CH_3NH_3I in the presence of air and UV radiation.

Due to the breakdown of disordered CH_3NH_3I, $CH_3NH_3PbI_3$ can disintegrate into PbI2 in a humid environment. In recent years, many strategies for improving the stability of PSCs have been investigated. At low temperatures, Xin Wang et al. established a simple solution-processed CeOx (x = 1.87) ETL. CeOx-based devices, according to their findings, are more stable under light soaking than TiO2-based PSCs [53]. The first long-term stability study of the new mixed-halide mixed-cation perovskite composition FA0.83Cs0.17Pb(I0.6Br0.4)3(FA = ($HC(NH_2)_2$) was presented by Zhiping Wang et al., who discovered that the cells are remarkably stable when exposed to full-spectrum simulated sun light in ambient conditions without encapsulation. Han et al. used thick carbon as the electrode and created their own whole 1000 over the transport layer; was stable for the cell hours in ambient air under full sunlight and had a PCE of 12.8%.

4.1 Engineering of Interactions

The interface is crucial to the device's performance because it not only affects exciton production, dissociation, and recombination but also influences device deterioration. As a result, to obtain high-performance and high-stability PSCs, engineering interface for minimized recombination is critical.

Tan et al. reported a contact-passivation approach in low-temperature planar solar cells that uses a chlorine-capped TiO_2 colloidal nanocrystal coating to reduce interfacial recombination and increase interface binding. For active areas of 0.049 and 1.1 cm2, the PSCs attained certified efficiencies of 20.1 and 19.5 percent, respectively. Furthermore, next 500 hours of continuous room-temperature operation at their maximum power point under 1-sun illumination, PSCs with efficiency greater than 20% retained 90% of their initial performance. Between the perovskite and the electron transport layer, Wang and colleagues added an insulating tunneling layer. The thin insulating layer allowed photo-generated electrons to tunnel from perovskite to C60 cathode while blocking photo-generated holes from returning to perovskite. Under 1-sun light, devices with these insulating materials showed a 20.3 percent increase in PCE. Correa-Baena et al. gave

some theoretical assistance by delving into the recombination at the many interfaces in a PSC, including charge-selective contacts and grain boundaries.

V. CONCLUSION

PSCs have advanced in recent years, making them an attractive candidate for next-generation, low-cost, high-efficiency solar cell technology. PSCs have been extensively researched in recent years, driven by the urgent demand for cost-effective, high-efficiency solar cells. To boost performance, a variety of strategies are employed. We review the most recent advancements in high-efficiency PSCs. In the last several years, the documented efficacy of single junction PSCs has grown by a few folds to around 22%, reaching the best single crystalline silicon solar cells. Traditional silicon solar cells have unquestionably emerged as a viable alternative to traditional perovskite materials. However, the issue of stability must be addressed immediately. Recent advancements in device architectures and new materials have opened up new possibilities for very stable PSCs.

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