

Perovskite solar cells: A promising technology

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Abstract

Perovskite solar cells represent an emerging revolutionary photovoltaics technology. Rapid progress was driven in large part by improvements in solar cell and module efficiencies, reduction in manufacturing costs and the realization of leveled costs of electricity that are now generally less than other energy sources and approaching similar costs with storage included. This paper gives an approach to this research which has revolutionized the world of photovoltaics and addresses the various technological advances in order to increase the stability and efficiency of perovskite cells.

Keywords: Perovskite, stability, optical-electronic proprieties

1. Introduction

With climate change and the scarcity of certain energy sources, photovoltaics show promise for the generation of clean energy. With the first tests of solar cells carried out in the laboratory in the early 1980s, silicon has established itself for 40 years as the master technology of photovoltaics. Despite energy conversion yields that have grown slowly for several years, the fall in the price of silicon over the years has enabled it to retain its special place among manufacturers. Single-junction crystalline silicon solar cells have a theoretical efficiency limit of between 29.4 and 29.5% [1,2,3]. The silicon PV industry has enough options to drive the efficiency of single junction silicon solar cells to a practical technical limit of about 27.5% in laboratory and 26% in production [1].

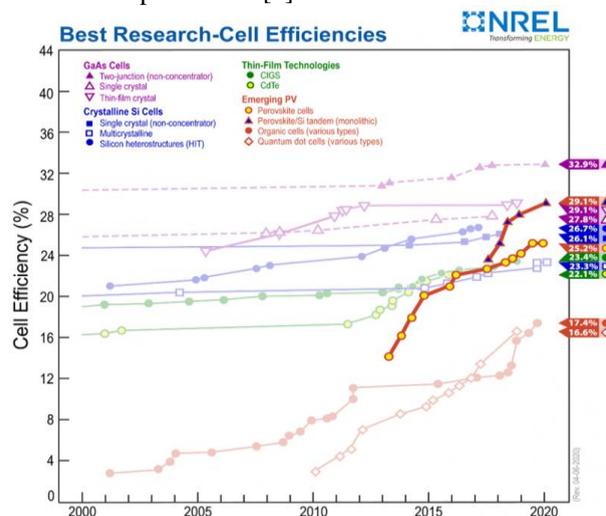


Fig. 1. Efficiency records chart with perovskite cells reaching 25.2% single junction; 29.1% tandem [5].

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Research is underway to find other types of materials that meet performance requirements at lower cost. It is in this context that fits the perovskite material which was discovered in 1839 in the form CaTiO_3 , and it was not until the 2000s that a first demonstration of a perovskite photovoltaic cell. Kojima et al. used $\text{CH}_3\text{NH}_3\text{PbBr}_3$ on nanoporous TiO_2 based on a Grätzel cell (or photosensitive pigment solar cell), and obtained a conversion efficiency of 2.2% [4]. Perovskite material has many advantages: excellent optoelectronic properties, low raw material costs, adjustable bandgap and wide range of deposition techniques [1,4]. Fig. 1 shows the evolution of cell efficiency Perovskite solar cells as a function of years. We find that only during the last 5 years, the efficiency of solar cells based on perovskite has greatly exceeded 20% inorganic cells based on monocrystalline silicon after 50 years of development.

2. The Perovskite Material

Perovskite is a mineral compound, consisting of calcium and titanium. Its chemical formula is CaTiO_3 , it was discovered by the Russian mineralogist Lev Alexeïvich Perovski (1792–1856). The simplest structure of perovskite and the simple cubic structure of formula ABX_3 (Fig. 2) with the A ion in the corners, the B ion in the center and the negative ion occupies the centered position of the face (Roth, 1957). Perovskite has impressive physical properties; it has a very high light absorption and a great length of distribution of charges. Indeed, the hybrid perovskite $\text{CH}_3\text{NH}_3\text{PbI}_3$ (MAPbI_3) has a large scattering of electrons and holes (more than $1 \mu\text{m}$ and potentially $100 \mu\text{m}$) and finally high mobility of load carriers [6,7]. This structure hybrid once doped with chlorine becomes $\text{CH}_3\text{NH}_3\text{PbI}_3\text{-xCl}_x$, it is a structure equivalent to MAPbI_3 and having almost the same mobility. However, its doping with chlorine allows it to have high crystallinity due to the smaller grain boundaries. In addition, the grain size represents a factor that limits the conduction of charge carriers, even in layers thinner bags of better quality [8]. On the other hand, the doping of chlorine makes the mobility of $\text{CH}_3\text{NH}_3\text{PbI}_3\text{-xCl}_x$ charges slightly lower compared to that of its neighbor MAPbI_3 [6,9]

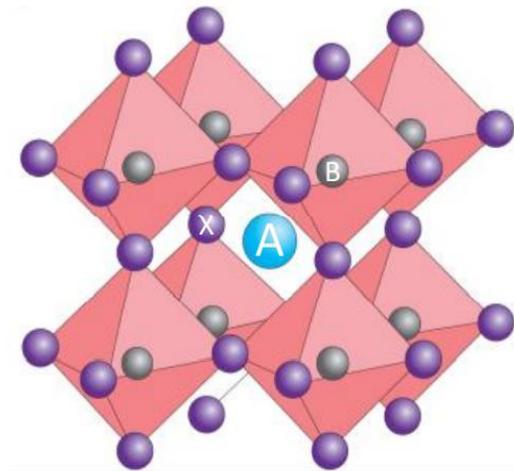


Fig. 2. The structure of perovskite.

The design of solar cells based on perovskite has undergone enormous development, new manufacturing methods have been used: techniques in solution: spin coating, dip coating, hot casting also gas phase techniques, and other techniques like microwave irradiation process MIP used by Cao et al. in 2016 [4,10] Spin coating remains the most widespread because the simplest.

2.1. Stability

Perovskite degrades in ambient air. It is a component that is extremely sensitive to moisture and

oxygen. The reaction: $\text{PbI}_2 (\text{s}) + \text{CH}_3\text{NH}_3\text{I} (\text{aq}) \rightleftharpoons \text{CH}_3\text{NH}_3\text{PbI}_3 (\text{s})$ which occurs between the precursors during crystallization is a reversible reaction. The reaction is reversed when perovskite undergoes one of the five main sources of degradation: moisture, oxygen, UV, solvents and temperature [4]. To increase stability, researchers are studying degradation in both the perovskite materials and the contact layers. Improved cell durability is important for the development of commercial perovskite solar products.

The stability of the perovskite cell is improved by doping it. For the previous example, the lifespan is improved when the FAPbI_3 is doped with MAPbBr_3 and MACl . These two molecules make it possible to obtain a layer of FAPbI_3 with a cubic and non-hexagonal phase, which increases the stability of the perovskite [2,11]. The stability of the perovskite is also improved by combining the 2D perovskite in a 3D perovskite. The cell is encapsulated in polymer to prevent contact of the perovskite with air, and to prevent leakage of volatile products from the perovskite. Recently, a novel research has reported a hybrid perovskites family. This family has been named deficient hybrid perovskite (abbreviated d-HP) and has been obtained as crystals, powders, and thin films. The incorporation inside the bulk of this large organic cations resulted in an improved air-stability compared to MAPI . Moreover, first deficient- MAPI (d- MAPI) solar cells showed an efficiency up to 6% that proved the great potential of this d-HP family [12].

2.2. Optical and electronic properties

Perovskites are promising for photovoltaics. They have a direct gap, and a virtual absence of defects in the gap. Perovskites have the advantage of having an adjustable gap depending on the cations or anions used (A) their absorption coefficient is very high (some 10^4 cm^{-1} at a wavelength of 550 nm [4,13]). This reduces the necessary layer thickness of perovskite to around 500 nm for almost complete absorption. The photogenerated charge carriers are then more easily collected because of the shorter distance to travel. It is possible to change the electrical properties of perovskite by changing its composition. These electrical properties are also modified depending on the method of synthesis of the perovskite and the mode of production of the layer. This is why we find several different mobility or diffusion length values in the literature. The Table 1 indicates some values of mobility and diffusion in most used compounds in photovoltaic field. H. Zhang and al [14] introduced the first kind of simple post-device ligand (PDL) treatment to significantly improve the PCE of completely fabricated PVSCs from 18.7% to 20.13%. The treatment is an off-the-shelf post-device approach that can be integrated into any existing perovskite-device fabrication, offering a general strategy to improve the stability and performance of perovskite optoelectronic devices. These methods are introduced during core-device fabrication processes which will increase the risk of introducing unexpected impurities during the fabrication Fig. 3.

Table 1. Physical properties of the most common materials for photovoltaics [4, 13].

	Gap(eV)	absorption coefficient variation range between 200 and 700nm (cm-1)	carrier mobility ($\text{cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$)	diffusion length (μm)
MAPI	1,57	10^4 - $5 \cdot 10^4$	10	0,1
Perovskite	Ajustable	10^4 - 10^6	Up to 2000	Up to 100
Si	1,1	10^3 - $2 \cdot 10^6$	1430(electron)- 427(hole)	1to 20(hole)-30 to 300(electron)
CIGS	1,1	10^4 - $6 \cdot 10^5$	<10	1,5
GaAs	1,4	10^4 - $2 \cdot 10^6$	> 10^3	30 to 50(hole) – 10(electron)
CdTe	1,5	10^4 - 10^6	10	1,75
Organic	1,4 – 3,0	10^4 - 10^5	10^4 to 10	0,01

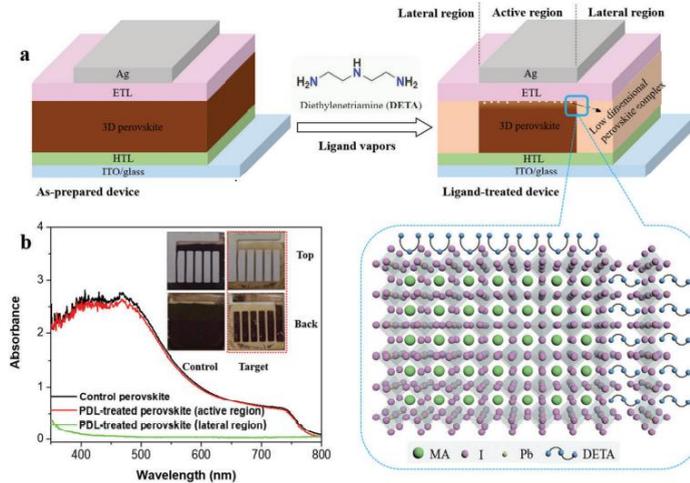


Fig. 3. Processing scheme and characterization of post-device ligand (PDL) treatment. (a) Schematic illustration of the PDL treatment process and the relevant device configuration, the molecular structure of DETA, and a possible model for DETA interaction with the MAPbI₃ cage. (b) UV-vis spectra [14].

3. How the Perovskite Works

Perovskite is based on a structure implementing selective contacts. The separation of the carriers takes place in the contacts and not in the absorber as with silicon. Two contacts are required, an n type to collect the electrons (Electron Transport Layer: ETL), and a p type to collect the holes (Hole Transport Layer: HTL). Rather, the whole cell resembles a p-i-n heterojunction (see Fig. 4) [4,15]. Once the electron-hole pairs are created, the charges move towards their respective collectors. They are then collected by the two conductive contacts, generally ITO (Indium Tin Oxide or indium tin oxide) on the - side, and Au or Ag on the + side, as can be seen in Fig. 4. The edge of the ETL conduction band should be less than the perovskite conduction band and the HTL valence band should be greater than the perovskite valence band. Thus, the ETL acts as barrier holes and the HTL acts as an electron (Fig. 5).

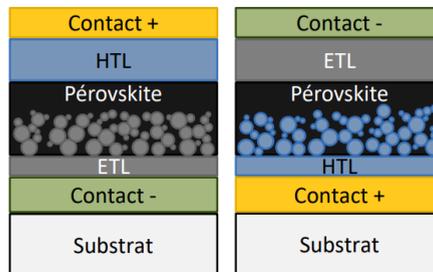


Fig. 4. Mesoporous type structure for perovskite cells n-i-p and p-i-n.

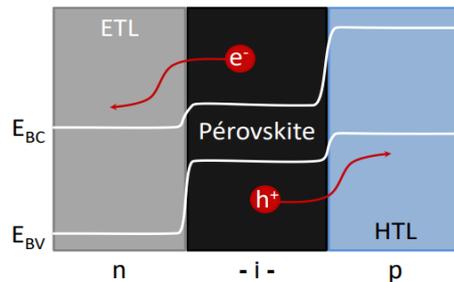


Fig. 5. Band of energy levels during separation of loads [4].

Research is underway to improve the interface between perovskite and ETL and the interface between perovskite and HTL. The charge carrier recombinations can take place. This has an impact on the open circuit voltage and the short circuit current. To reduce or eliminate these recombinations at interfaces, Zhou et al. modified conductor properties by doping TiO₂ with yttrium, and modifying ITO with ethoxylated polyethyleneimine [4,15]. It is also possible to passivate the surface of the ETL or the HTL. Indeed, when using TiO₂ as ETL, it has been shown that electrons can be generated in its conduction band under illumination, which leads to a generation of O₂ which can degrade the perovskite [4, 16]. To avoid this phenomenon, Wan et al. passivated the mesoporous TiO₂ with SnO₂ and were able to gain stability and performance while reducing the hysteresis of the cell [17]. To improve the extraction of photo-generated charges, the use of carbon nanotubes or graphene has been used and appears to be a promising strategy to improve the efficiency of charge transfer to electrodes for perovskite cells [18] (Fig. 6). A perovskite solar cell can be modelled by an equivalent diagram as shown in Fig. 7.

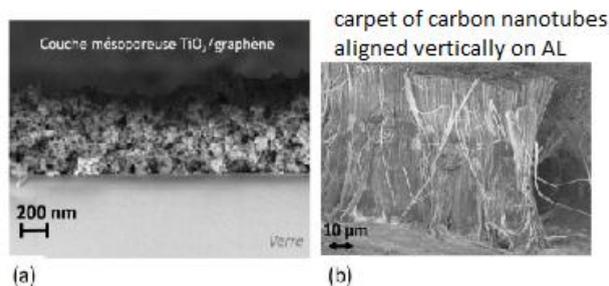


Fig. 6. Use of carbon nanotubes in perovskite cell [18].

The Series resistance R_s represents the interfaces between electrodes and perovskite layer. Parallel resistance R_{sh} represents the phenomena of recombination of perovskite materials. The table shows different procedure to enhance performance of perovskite the presence of guanidinium (Gua) molecule at the interface between the perovskite MAPbI₃ film and the spiro-OMeTAD hole transport layer improves photovoltaic properties, in particular the open circuit voltage V_{oc} , as well as the stability of photovoltaic devices. A conversion efficiency of 18.54% and a V_{oc} of 1.1 V are obtained. The Gua molecules help eliminate the loss of non-radiative charge carriers in hybrid perovskite cells [19, 20].

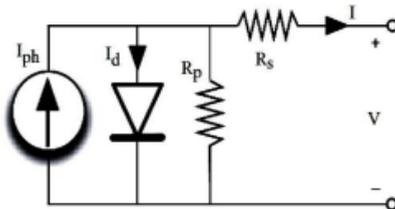


Fig. 7. Equivalent diagram of a perovskite cell.

4. Conclusion

Research and development focus on improving operational lifetime and intrinsic and extrinsic stability and degradation. Efforts include improved surface passivation of absorber layers; alternative materials and formulations for absorber layers, charge transport layers, and electrodes; and advanced encapsulation materials and approaches that mitigate degradation sources during fabrication and operation [5]. To more rapidly progress to market Accelerated lifetime testing ALT protocols must be developed to more rapidly assess stability along with sophisticated computational tools and advanced data analytics [1]. Degradation and stability studies must be carried out to ensure good reproducibility and long life with high conversion yields. The use of graphene oxide, rGO allows the possibility of producing perovskite cells with a large

surface area with high efficiency (Table.2). The insertion of a protective layer between the ITO anode and the PEDOT: PSS hole transport layer improves the performance of perovskite cells. One of the solutions to increase the lifespan of perovskite cells and improve their stability is the encapsulation of the slides, in order to stop the diffusion of oxygen, water and impurities in the cell [19].

Table 2. Comparison of the performance of cells based on perovskite materials [19].

Structure de la cellule	J _{cc}	V _{co}	FF	η	R éference
FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ -xxClx/spiro-OMeTAD/Au	15.3	0.8	55	6.7	G.E Eperon and al 2014
FTO/SnO ₂ /TiO ₂ /MAPbI ₃ -x(Ac)x/Au	23.68	1.06	68	17.07	Y. Xiao and al 2019
FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ /Po-Spiro OmeTAD/Au	22.3	0.98	68.2	15.4	R. Singh, and al 2019
FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ : ITIC/Po-SpiroOmeTAD/Au	23.74	1	72.8 9	17.59	R. Singh, and al 2019
FTO/TBD-TiO ₂ /MAPbI ₃ /Spiro-OMeTAD/Au	20.5	1.05	63.1	13.9	X. Li,and al 2018
FTO/TT-TiO ₂ /MAPbI ₃ /Spiro-OMeTAD/Au	23.2	1.1	68	17.4	X. Li,and al 2018
ITO/SnO ₂ /MAPbI ₃ /spiro-OMeTAD/Au	22.01	1.05	69	15.98	S. Wang and al 2018
ITO/SnO ₂ /MAPbI ₃ -(Gua1-xMAx)PbI ₃ /spiroOMeTAD	22.46	1.1	75	18.54	S. Wang and al 2018
FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ /rGO/FTO (rGO pur)	15.86	0.71	45.5	5.10	D. Selvakumar and al 2018
FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ /B-rGO/FTO (10% de bore	15.91	0.71	56	7.09	D. Selvakumar and al 2018
FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ /B-rGO/FTO (20% de Bore	16.74	0.88	60	8.96	D. Selvakumar and al 2018
ITO/PEDOT:PSS/ CH ₃ NH ₃ PbI ₃ (MAPbI ₃)/ PCBM/BCP/Al	18.94	1.01	74.01	14.6	J.I. Kim and al 2018

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All authors contributed to the design and the writing of the article.

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