

Solar Cells Based on Perovskite Materials

Ourida Ourahmoun

Electronic Department, Faculty of Electrical Engineering and Computing, LATAGE laboratory,
University of Mouloud Mammeri of Tizi-Ouzou (UMMTO)

Tizi-Ouzou, Algeria
ourahmounourida@yahoo.fr

Abstract— Perovskite-based solar cells have attracted a great deal of attention due to their rapid increase in power conversion, which has reached to 24.2%. The performance of perovskite solar cells depends on several parameters such as the absorber layer, the electron transport layer and the electrodes, and the deposition technics. The environmental factors can influence the stability of the photovoltaic devices. Such as moisture, oxygen, temperature, and light intensity. The performance of the perovskite cells deteriorates under moisture and oxygen. In this work solution to improve performances and stability of perovskite solar cells are proposed.

Keywords—Perovskite solar cells; performances; structure; parameters; stability; improvement.

1 Introduction

Perovskite-based solar cells (PSCs) with the composition ABX_3 active layer [$A=CH_3NH_3^+$ (MA), $NH_3CH_2NH_3^+$ (FA) or Cs^+ ; $B=Sn$ or Pb ; $X=Cl$, Br or I] have attracted a great deal of attention due to their rapid increase in power conversion (PCE), which has reached to 24.2% [1]. PSCs are promising candidates for achieving high efficiencies due to their band gap around 1.55 eV, their high absorption coefficient, long charge carrier diffusion path, low recombination. The PSCs are made using different technics such as roll to roll, printing[2], spin-coating[3], and spray methods. The deposition of the layers at low temperature, and solution processing make it easy, low cost technology and possibility to realize large area cells using flexible substrates. In PSCs, organic and inorganic materials are used as hole transport layer[4].

Two typical architectures are constructed: mesoscopic structure and planar structure. In addition, the structure can be subdivided into n-i-p structure or p-i-n structure, depending on the deposition order. In general, the mesoscopic n-i-p structure is widely used to fabricate high-performance devices. This structure is composed of the fluorine doped tin oxide (FTO) electrodes, hole blocking layer (HBL), electron transport layer (ETL), hole transporting layer (HTL), perovskite absorber layer as photoactive layer.

Generally, high performance PSCs do not retain their efficiencies and degrade in a span of time ranging from few minutes to couple of days, whereas the cells which demonstrate better stability lacks high performance. To improve the stability of PSCs, systematic understanding of the degradation mechanisms and their effect on the device performance is essential.

The environmental factors can influence the stability of the PSC devices. Such as moisture, oxygen, temperature, and light intensity. The disadvantage of this cells is the sensitivity to humidity and oxygen. In the presence of water, the yield of this cells decreases. The toxicity of the lead used in the absorber layer is another disadvantage of this device.

This work presents the progress of perovskite solar cells. The performance of the cells depends on the structure, architecture of the device, hole transport materials, electron transport materials, and absorber layers. The use of free-lead absorber layer is discussed. Another point presented related to the stability of the materials used in PSCs and their effect on the device stability. Solution to improve performances and stability of perovskite are proposed.

2 Structure of the Perovskite solar Cells

The schematic structures of perovskite solar cells are shown in Fig.1. The structure of PSCs can be divided into three categories: perovskite sensitized mesoporous or n-i-

p structure, planar heterojunction structure and inverted or p-i-n structure. In all structures, after absorbing the incident photons by the perovskite materials, excitons with a low binding energy are generated and dissociated into the free charge carriers.

In planar structure, a perovskite absorber layer is sandwiched between the electron transport layer (ETL) and the hole transport layer (HTL). Two heterojunctions are provided which are the junction between the active layer and HTL, and the junction between absorber and ETL. Different types of materials are used as HTLs, and a compact layer such as TiO_2 layer is usually used as an ETL.

In the inverted devices, photogenerated electrons are collected in cathode and photogenerated holes are collected in anode. Organic materials such as PEDOT:PSS and fullerene derivatives are used as HTLs and ETLs, respectively.

deposition, soft-cover deposition, dip coating, and vapor based deposition. For industrial application, the second step is to fabricate solar modules, and the third step is to integrate multiple solar modules into solar panels. For large area devices and modules, transparent conductive electrodes (TCO) must be considered in terms of both sheet resistance and cost. Due to the sheet resistance of the TCO, the fill factor decreases significantly when the active area of a single solar cell device exceeds a certain threshold. FTO is the most expensive material in perovskite cells. It is necessary to develop low cost electrodes based on conducting organic materials, and fabricate flexible perovskite solar cells.

In PSCs the metallic electrodes such as Au, Ag, and Cu are deposited using thermal evaporation under vacuum (10^{-6} mbar).

4 Performance of the Perovskite solar

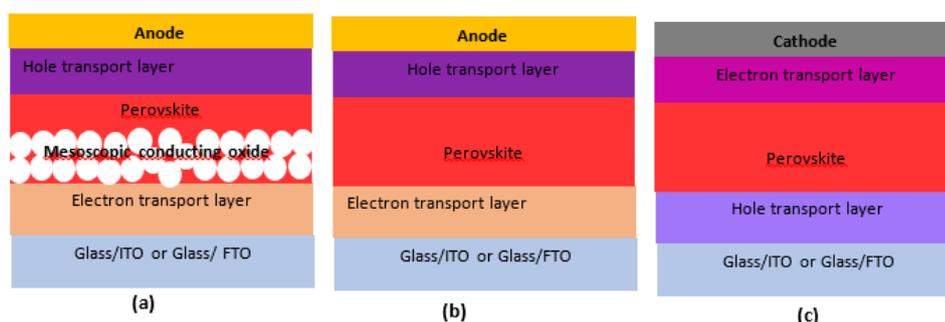


Fig. 1. Different structure of perovskite solar cell: (a) mesoscopic, (b) planar, (c) inverted planar

The advantages of this structure are: TiO_2 compact layer is replaced by organic ETMs which avoids the high temperature annealing process and device structure is simpler. The stability of the structure can be improving by removing TiO_2 layer which cause stability under UV light. The materials and process methods for this structure provide the fabrication of flexible perovskite solar cells. The high cost spiro-OMeTAD can be replaced by other organic materials. ITO or FTO are widely used as anodes. Au, Cu and Ag are used as cathodes. Recently, carbon based contact such as graphene are used as cathodes. And graphene oxide is used as HTL.

2 Fabrication methods

To fabricate large area perovskite films of high quality: good film uniformity, reduced surface roughness, and low density of structural defects, such as pinholes, various thin-film deposition technologies have been developed, including spin-coating, optimized for large areas, doctor blading, slot-die contact, printing, spray

Cells

A photovoltaic performance of a solar cell is determined by the open circuit voltage (V_{OC}), short circuit current (J_{SC}), fill factor (FF), and power conversion efficiency (PCE). The high crystalline structure of the perovskite material led to high carrier mobility and high conductivity of the charge carriers. Then good charge transport properties.

The origin of high V_{OC} in PSCs is due the enhancement of the internal charge density level.

The performance of PSCS depends on several parameters such as the architecture of the cell, the material used as active layer, the buffer layers for HTL and ETL and the type of substrates, electrodes, and the deposition technics.

Table 1, shows the performance of some of cells of the new generation based on perovskite materials. The addition of ITIC plays an important role in improving the quality of the perovskite film such as improving absorption and reducing roughness of perovskite films,

and improves thermal stability of the PSCs[7]. The preparation of TiO₂ using tetrabutyl-titanate (TT) as precursor is more suitable than TiO₂ prepared using titanium diisopropoxide bis (acetylacetonate) (TDB). PSCs with TT-TiO₂ used as ETL show a better PCE (17.4%) than PSCs with TDB-TiO₂. Because TT-TiO₂ has a superior interface quality, this is due to the reduced recombination carriers leading to an increase of photovoltaic performance[8]. The presence of guanidium molecule (Gua) at the interface between the perovskite absorber MAPbI₃ film and the spiro-OMeTAD hole transport layer improves the photovoltaic properties, in particular V_{OC} and the stability of the device. A PCE=18.54% and V_{OC} of 1.1 V are obtained. Gua eliminate the loss of non-radiative charge carriers in PSCs[9]. The addition of copper bromides to the absorber layers improve cell performance[12]. The use of

graphene oxide (GO) and reduced graphene oxide (rGO) as hole transport material are reported. Doping the HTL improve the yield of the PSCs[10]. A new architecture of electrodes is developed. This architecture consists of inserting a protective layer of doped graphene between the anode and the hole transport layer. A protective layer based on AuCl₃-Gr is used between ITO and PEDOT:PSS to improve hole transport[11]. Other multilayer electrode architecture TCO/metal/TCO can be realized to improve the efficiency of perovskite cells. The use of silver nanowires (AgNWs) as electrode is also showed a good performance in the case of organic solar cells.

Table 1. Photovoltaic Performance of Some PSCs

Solar Cell Structure	J _{sc} (mA/cm ²)	V _{oc} (V)	FF (%)	PCE (%)	Reference
FTO/TiO ₂ /CH ₃ NH ₃ PbI _{3-x} Cl _x /spiro-OMeTAD/Au	15.3	0.8	55	6.7	[5]
FTO/SnO ₂ /TiO ₂ /MAPbI _{3-x} (Ac) _x /Au	23.68	1.06	68	17.07	[6]
FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ /Po-Spiro OmeTAD/Au	22.3	0.98	68.2	15.4	[7]
FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ :ITIC/Po-Spiro-OmeTAD/Au	23.74	1	72.8	17.59	[7]
FTO/TBD-TiO ₂ /MAPbI ₃ /Spiro-OMeTAD/Au	20.5	1.05	63.1	13.9	[8]
FTO/TT-TiO ₂ /MAPbI ₃ /Spiro-OMeTAD/Au	23.2	1.1	68	17.4	[8]
ITO/SnO ₂ /MAPbI ₃ /spiro-OMeTAD/Au	22.01	1.05	69	15.98	[9]
ITO/SnO ₂ /MAPbI ₃ -(Gua _{1-x} MA _x)PbI ₃ /spiro-OMeTAD	22.46	1.1	75	18.54	[9]
FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ /rGO/FTO (rGO pur)	15.86	0.71	45	5.10	[10]
FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ /B-rGO/FTO (10% de bore)	15.91	0.71	56	7.09	[10]
FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ /B-rGO/FTO (20% de Bore)	16.74	0.88	60	8.96	[10]
ITO/PEDOT:PSS/ CH ₃ NH ₃ PbI ₃ (MAPbI ₃)/ PCBM/BCP/Al.	18.94	1.01	74.01	14.6	[11]
ITO/AuCl ₃ -GR/PEDOT:PSS/ CH ₃ NH ₃ PbI ₃ (MAPbI ₃)/ PCBM/BCP/Al.	20.13	1.01	77.53	15.77	[11]

3 Stability of the Perovskite solar Cells

Perovskite materials are sensitive to air; temperature, moisture, and UV light. For achieving long lifetime, a high level of encapsulation is required.

PCBM is the most common ETL used in p-i-n planar PSCs due to its excellent conductivity and electron extraction capability. However, limited by the low solubility and viscosity, it's difficult to form uniform and defect free PCBM films on the rough surface of perovskite. Moreover, the aggregation of PCBM results in the incomplete coverage on the perovskite

layer, which induces charge recombination and accumulation at perovskite/PCBM interface, as well as the degradation of perovskite. An ultra-thin layer of poly(9-vinylcarbazol) (PVK) was introduced as interfacial layer between perovskite and PCBM to reduce carrier recombination and accumulation. PVK improve the contact property and the crystallization of perovskite layer, which greatly reduce trap density and carrier recombination. This interface modification leads to better thermal and moisture stability[13]. Stability of perovskite solar cells was improved by employing Norland Optical Adhesive/ polyethylene Terephthalate (NAO/PET) as moisture barrier layer is reported [14]. The PSCs encapsulated by NOA/PET show stability under approximately

540 h exposure to moisture. However, the non-encapsulated solar cells are immediately deteriorated in PCE.

4 Conclusion

The performance of perovskite solar cells depends on photoactive layers, hole transport layers, electron transport layers and the electrodes. Various architectures and structures are studied. Improving the performance of photovoltaic devices requires the development of new materials, optimization of cell structure and associated manufacturing technology. Results show that the use of an inorganic materials as HTL and ETL improves the stability of the cells. doping the HTL improves the electrical properties of the layer then enhance the efficiency also the use of a protective layer between hole transport layer and the anode enhance the yield. The use of carbon contacts improves the stability of the cells. To protect cells against moisture and oxygen and avoid degradation, encapsulation of the device using plastic materials is required. NAO/PET is good material as moisture barrier in perovskite cells.

References

- [1]. S. Feng, D. Ding, A. Runa, T. Liu, P. Su, W. Yang, H. Yang, H. Yang, “Enhanced photovoltaic property and stability of perovskite solar cells using the interfacial modified layer of anatase TiO₂ nanocuboids”. *Vacuum*, vol. 166, 255-263, 2019.
- [2]. C. Tian, A. Mei, S. Zhang, H. Tian, S. Liu, F. Qin, S. Xie, “Oxygen management in carbon electrode for high-performance printable perovskite solar cells”, *Nano Energy*, vol. 53, 160-167, 2018.
- [3]. P.P. Boix, K. Nonomura, N. Mathews, S.G. Mhaisalkar, “Current progress and future perspectives for organic/inorganic perovskite solar cells”, *Materials today*, vol. 17, 16-23, 2014.
- [4]. M.A. Mutalib, F. Aziz, A.F. Ismail, W.N.W. Salleh, N. Yusof, J. Jaafar, N.A. Ludin, “Towards high performance perovskite solar cells: A review of morphological control and HTM development”. *Applied Materials Today*, vol. 13, 69-82, 2018.
- [5]. G.E. Eperon, V.M. Burlakov, P. Docampo, A. Goriely, H.J. Snaith, “Morphological control for high performance, solution-processed planar heterojunction perovskite solar cells”. *Advanced Functional Materials*, vol. 24, 151-157, 2014.
- [6]. Y. Xiao, L. Yang, G. Han, Y. Li, M. Li, H. Li, “Effects of methylammonium acetate on the perovskite film quality for the perovskite solar cell”. *Organic Electronics*, vol. 65, 201-206, 2019.
- [7]. R. Singh, V.K. Shukla, “ITIC-based bulk heterojunction perovskite film boosting the power conversion efficiency and stability of the perovskite solar cell”. *Solar Energy*, vol. 178, 90-97, 2019.
- [8]. X. Li, J. Zhang, X. Zhu, J. Yu, K. Fan, K. “Effects of Ti precursors on the performance of planar perovskite solar cells”. *Applied Surface Science*, vol. 462, 598-605, 2018.
- [9]. S. Wang, Y. Zhu, W. Sun, X. Miao, Z. Ma, C. Yang, C. Wang, “Large guanidinium cation enhance photovoltage for perovskite solar cells via solution-processed secondary growth technique”, *Solar Energy*, vol. 176, 118-125, 2018.
- [10]. D. Selvakumar, G. Murugadoss, A. Alsalmeh, A.M. Alkathiri, R. Jayavel. “Heteroatom doped reduced graphene oxide paper for large area perovskite solar cells”, *Solar Energy*, vol. 163, 564-569, 2018.
- [11]. J.M. Kim, C.W. Jang, J.H. Kim, S. Kim, S.H. Choi, “Use of AuCl₃-doped graphene as a protecting layer for enhancing the stabilities of inverted perovskite solar cells”, *Applied Surface Science*, 2018.
- [12]. H. Tanaka, Y. Ohishi, T. Oku, “Fabrication and Characterization of the copper bromides-added CH₃NH₃PbI₃-xCl_x perovskite solar cells”, *Synthetic Metals*, vol. 244, 128-133, 2018.
- [13]. J. Zhang, W. Mao, J. Duan, S. Huang, Z. Zhang, W. Ou-Yang, X. Chen, “Enhanced efficiency and thermal stability of perovskite solar cells using poly (9-vinylcarbazole) modified perovskite/PCBM interface”, *Electrochimica Acta*, vol. 318, 384-391, 2019.
- [14]. B.J. Kim, J.H. Jang, J. Kim, K.S. Oh, E.Y. Choi, N. Park, N. “Efficiency and stability enhancement of organic-inorganic perovskite solar cells through micropatterned Norland Optical Adhesive and polyethylene terephthalate encapsulation”, *Materials Today Communications*, 100537, 2019.