Journal of educational equipment: Applied research, Volume 2, Issue 301 (November 2023)
ISSN 1859 - 0810

Study of the Prospect of Perovskite Solar Cells

Thi Thuy Lieu Nguyen*

**Posts and Telecommunications Institute of Technology*
Received: 20/9/2023; Accepted: 25/9/2023; Published: 3/10/2023

Abstract: *Perovskite solar cells are known to belong to the third generation of solar cells. Owing to the ability to change the band gap energy when changing the material composition, it has a high absorption coefficient that reduces manufacturing costs and carrier mobility. and the diffusion length of large charged particles leads to higher efficiency, so compared to other types of solar cells of the same generation such as color sensitive batteries and quantum dot batteries, perovskite batteries have the most application prospects. According to publications in the last 14 years, the photoelectric conversion efficiency of perovskite solar cells has increased rapidly from 3.5% (in 2009) to 25.8% (in 2022).*

Keywords: *Perovskite solar cells, photovoltaic, energy storage.*

1. Introduction

As there is an increasing demand for renewable and sustainable energy sources, the conversion of sunlight into electricity is considered to be promising to satisfy the energy needs in the future without affecting global climate [1]. Over the years, solar cell energy has been a significant source of energy. When there is such a growing demand for clean energy in the field of solar photovoltaic (PV) with their success attributed to the practicality, low maintenance, and long lifetime; solar PV has led to a great effort in the research of improving the efficiency of solar cells. Sunlight, considered as the inexhaustible energy source, can be converted into electricity by the photovoltaic effect using semiconductor materials. The working principle is generally known to include the electromagnetic radiation from the sun, which generates an electron from the valence band to the conduction band, creating the electron-hole pairs and in the case when these excited electrons are fed through an external circuit back to the valence band, the electric current will then be created [2]. Nowadays, there is a plethora of research with the aim to maximize the power conversion efficiency (PCE) of photovoltaic materials.

The technology of PV has progressed through generations of the cells, which are named as the first, second, and third generation. The first generation is known as the basic wafer-based cells with the thickness ranging from a few hundreds of micrometers. However, this generation has a drawback of the production of ultra-pure semiconducting wafers as it is expensive. The second generation cells are based on amorphous and polycrystalline semiconductor materials deposited on a substrate. The second generation cells are widely known as thin-film cells. Although these second-generation cells are more economically viable in comparison to the first generation, they have some drawbacks on environmental, production process, material and scientific factors which hindered the acceptance of the cells in the market. The third generation of solar cells has been under study and development in the past few years; however, they have achieved potential results and rapid improvements. The materials for third generation cells have attracted much attention owing to their low-energy in manufacturing processes and their low cost. There are many materials tested for this third generation, known as organic photovoltaic solar cells, copper zinc tin sulfide solar cells, dye-sensitized solar cells, quantum dot solar cells, and perovskite solar cells (PSCs). Among all, PSCs are the most promising with the capability to attain high efficiency at a low cost, as well as their excellent optoelectronic properties, such as low excitation binding energy, long carrier diffusion length, high optical absorption coefficient, and low-cost fabrication [3]. In this article, we will mainly focus on perovskite solar cells.

Perovskite materials, has a specific crystal structure with the ABX_3 formula (in which X is an oxygen or halogen anion, and A and B are cations of different sizes, whereas A is larger than B). The figure 1 below illustrates the schematic representation of ABX_3 perovskite structure [4]. As shown in Figure 1, while the cuboctahedral site is occupied by the cation A, each cation B is surrounded by six anions X, which creates the $[BX_6]^{4-}$ octahedra [5].

ISSN 1859 - 0810

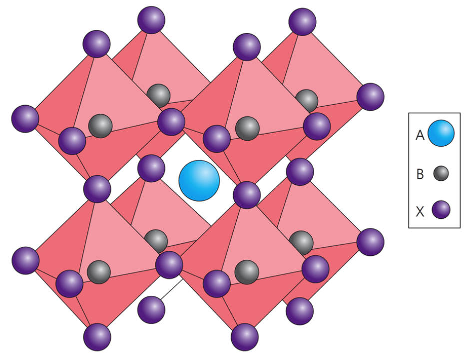

Figure 1. Schematic illustration of the ABX_3 perovskite structure [4].

An advantage of perovskite structure is the ability to integrate elements with different valances into the structure; for example, when X is O^{2-}, A and B would be divalent and trivalent, respectively. On the other hand [5]. Thus, there is a promising opportunity to modify their properties such as the bandgap of the material. Furthermore, based on the octahedral factor μ and the Goldsmith tolerance factor *t*, the crystallographic stability and probable structure can be deduced.

In general, the limits for the formation of perovskite structures are $0.4 \leq \mu \leq 0.9$ and $0.8 \leq t \leq 1$, with the upper limit of 1 describing the perfect fit. However, when *t* reaches the value of 0.8, the structure will be distorted due to the tilting of the BX_6 octahedra. In the case when *t* is above 1 indicates that the cation is too big to be fitted into the site, which will further stop the formation of perovskite [6].

2. Structure and working principle of PSCs

In general, the structure of PSCs contains an absorber layer, an electron transport layer (ETL), a hole transport layer (HTL), a transparent conductive oxide (known as anode), and a metal contact (known as cathode). Figure 2 shows the schematic description of the device structure of PSCs. Perovskite solar cells are divided into standard n-i-p and inverted p-i-n structures, based on the transport material on the external section of the perovskite solar cell that interacts with light first. The light will enter through the transparent conductive oxide (might be FTO or ITO) towards the perovskite absorber layer. The absorber layer will absorb the incident light, creating electron-hole pairs, which will then be transported via ETL and HTL, respectively, towards the external circuit with the aid of charge collecting contacts. In order to ensure that there will be proper carrier collection, the materials used in ETL and HTL must have the required band alignment [2]. According to a study conducted by Roy et al [6], the role of layer thickness and carrier concentration play an important role for all three layers. In detail, the thickness of the optimum transport layer (both ETL and HTL) must be as minimum as possible until it ensures proper film coverage across the perovskite layer.

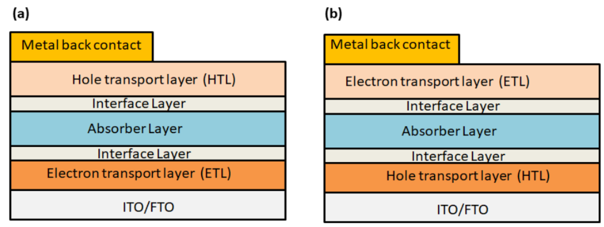

Figure 2. Schematic description of device structure of PSC with (a) n-i-p structure and (b) p-i-n structure [2].

Both organic and inorganic materials can be employed for the transport layer. The use of organic materials to fabricate the HTLs requires high cost, high purity, and it has poor stability. On the other hand, inorganic PSCs have been a potential alternative as the inorganic HTLs have lower cost and better stability. Nowadays, many materials that can be used for inorganic PSCs, such as Cuprous oxide (Cu_2O), Cupric oxide (CuO), Nickel oxide (NiO), Copper Zinc Tin Sulfide ($CuZnSnS_2$), graphene oxide (GO), carbon (C) [7]. Furthermore, the ETL layer is also a significant factor contributing to the stability. The most common ETL is the Titanium dioxide (TiO_2) with excellent stability; however, it requires high annealing temperature and assists the process of ion immigration leading degradation of the cell urges to find an alternative [2]. Among various materials, ZnO, CdS, PCBM, SnO_2, the most popular materials for ETL is SnO_2 owing to the wide bandgap 3.6 - 4.1 eV with deeper conduction band (CB) than TiO_2. Moreover, SnO_2 is considered to be the most potential ETL because of its higher mobility of 240 cm^2/V, enhanced charge carrier collection and transportation due to deeper CB, lower temperature in fabrication, and high optical transmittance and conductivity [2,5,6]. For the performance of a solar cell, a transparent conductive electrode (TCE) is also a crucial component as it passes the incident radiation towards the absorber layer and also extracts the photo-generated charge carriers towards the external circuits.

3. Properties of perovskite materials with advantages and disadvantages

Perovskite materials contain unique properties that make them become effective PV devices. With such a combination of the beneficial features, perovskite has become an effective material for photovoltaic applications. The bandgap for perovskite materials can vary in a wide range owing to their ability of being tuned easily. Perovskite materials also have high electron mobility (around 800 cm^2/Vs), long diffusion wavelength (more than 1 μm), and high absorption coefficient (10^5 cm^{-1}) caused by s-p antibonding coupling [8]. In addition, perovskite materials have a low excitation binding energy which is measured to be less than 10 meV, allowing the excited carriers to migrate as free carriers.

The advantages of PSCs are derived from some of their unique properties. First and foremost, PSCs are famous for having the ability of tuning the bandgap. With the ability to modify their band gap by making small changes in composition or adjusting the doping level help them to become appealing for the photovoltaic use. Secondly, with the high absorption coefficient, the fabrication cost is reduced. The absorption coefficient is the amount of light that a material with a specific thickness can absorb. For example, the visible area of $MAPbI_3$ has an absorption coefficient larger than 3×10^4 cm^{-1} [9], which is 10 times higher than that of silicon. Moreover, perovskite materials can be tailored to absorb various colors in the spectrum range; thus, this material possesses a higher high light-absorption coefficient and it has cheaper production cost. Another advantage is the high carrier mobility, which leads to higher efficiency. The carrier mobility and diffusion length have both surpassed hundreds of $cm^2/V.s$ and hundreds of μm, respectively. Furthermore, with the longer length of charge carrier diffusion, the efficiency of PSCs is higher. When the absorber layer is thicker, the produced carriers will recombine before they reach the ETL. Hence, the mesoporous TiO_2 layer is positioned over the hole-blocking layer for recombination prevention. Finally, another advantage of PSCs is the crystalline structure.

Nevertheless, there are still some drawbacks of PSCs. The instability of PSCs is one of the most concerning drawbacks. The short lifetime of PSCs might be attributed to the deterioration of the light-harvesting interface and the instability of the perovskite material itself. Some factors attributed to the instability are the moisture, temperature, UV, or the defects and vacancies in perovskite structure itself. Regarding the environmental problems, PSCs have another disadvantage with the use of lead (PbI_2). Although lead is the most common material for high efficiency, lead is poisonous and it could be released from PSCs through natural phenomena like heavy rain, wildfires, and strong winds. The development and reproduction of plants and animals might be reduced as there is an increased amount of lead in the environment [10].

4. Conclusion and perspectives

In conclusion, the urge of renewable and sustainable energy sources has led to the importance of using the abundant solar resources incident on Earth. Third-generation solar cells are currently under development and they have great potential to dominate the solar PV market in the future; among those, PSCs are the most promising candidate with PCE of 25.8% in under 10 years [3]. Although the perovskite material has the key structural and fundamental features that make them become effective solar cells, there are still some drawbacks that need to be addressed in the near future.

References

[1]. X. Liang, C. Ge, Q. Fang, W. Deng, S. Dey, H. Lin, Y. Zhang, X. Zhang, Q. Zhu and H. Hu, *Front. Mater*., Vol 8, 2021, pp. 634-363.

[2]. P. Roy, A. Ghosh, F. Barclay, A. Khare, and E. Cuce, *Coatings* Vol. 12, 2022, pp. 1089 (24).

[3]. H. Wang, Z. Qin, Y. Miao, and Y. Zhao, *Transactions of Tianjin University* Vol. 28, 2022, pp. 323-340.

[4]. M. Green, A. Ho-Baillie, and H. Snaith, *Nat. Photon* Vol. 8, 2014, pp. 506-514.

[5]. A. Roy, A. Ghosh, S. Bhandari, S. Sundaram, and T.K. Mallick, *Buildings* Vol. 10, 2020, pp. 129 (33).

[6]. W. Travis, E.N.K. Glover, H. Bronstein, D.O. Scanlon, and R.G. Palgrave, *Chem. Sci.* Vol. 7, 2016, pp. 4548-4556.

[7]. A.M. Elseman, S. Sajid, A.E. Shalan, S.A. Mohamed, and M.M. Rashad, *Appl. Phys. A* Vol. 125, 2019, pp. 1-12.

[8]. P. Roy, N.K. Sinha, S. Tiwari, and A. Khare, *Solar Energy* Vol. 198, 2020, pp. 665-688.

[9]. J. Huang, Y. Yuan, Y. Shao, and Y. Yan, *Nat. Rev. Mater.* Vol. 2, 2017, pp. 17042 (19).

[10]. J.C. Yu, B. Li, C.J. Dunn, J. Yan, B.T. Diroll, A.S. Chesman, and J.J. Jasieniak, *Adv. Sci.* Vol. 9, 2022, pp. 2201487 (12).