Optimization of Solar Cells Based on Perovskite Materials

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Abstract. With the rapid advancement of economy, human's demand for energy continues to grow, and energy shortage has become the primary problem hindering further economic development. Therefore, changing the existing energy structure and developing and utilizing sustainable clean energy are the research directions of all countries in the world. Perovskite solar cells have rapidly become a research hotspot in the field of solar cells worldwide in recent years due to their remarkable advantages such as low manufacturing cost and high efficiency. However, PSC (Perovskite solar cell) have many problems in the stability, reproducibility and performance evaluation of high-efficiency battery devices. By introducing the structure and performance of perovskite, this paper summarizes the research progress of solar cells based on this kind of materials, analyzes its working mechanism, summarizes the key issues affecting the performance of PSC, points out the direction of efforts to further improve the performance of PSC, and looks forward to the optimization development of PSC.

Keywords: Perovskite, Material, Solar cell, Optimization

1. Introduction

With the growth of the world's population, the development of industry and the acceleration of urbanization, energy consumption in the world is increasing, and environmental pollution is becoming increasingly serious [1]. It is urgent to replace traditional energy with clean renewable energy. However, how to use these energy sources efficiently and environmentally is still a challenge in theory and technology. Solar energy has attracted much attention because of its extensive distribution and inexhaustible use [2]. Over the years, various researchers have devoted themselves to the research and development of various types of solar cells, trying to develop solar cells with low cost, high efficiency, no pollution and easy industrialization [3]. PSC represent the third generation of solar cells. Because of their high photoelectric conversion efficiency and low production cost, PSC have been comprehensively studied as cheaper alternatives to silicon solar cells [4]. Moreover, it combines the advantages of high power factor, cost-effectiveness and processability of solutions, providing power for exploring large-scale applications [5]. Compared with traditional batteries, perovskite batteries have many advantages, such as high open circuit voltage, high efficiency, simple preparation process and low material cost [6]. However, the poor environmental stability of perovskite materials has become one of the main obstacles to the practical application of perovskite batteries [7]. When the battery is placed under high temperature, high humidity, oxygen and ultraviolet light for a long time, it will cause irreversible damage to the perovskite layer, resulting in serious performance degradation [8].

2. Development status

As a light absorption layer, perovskite layer is a main component of PSC, where photogenerated electrons and holes are generated, and plays a vital role in the photovoltaic performance of cells [9]. Perovskite light absorbing layers widely used at present contain lead, and sometimes toxic organic solvents are used in the preparation process [10]. The stability of PSC is greatly affected by ultraviolet light, water, heat and organic molecules. Perovskite materials with different structures and properties can be obtained by element replacement of perovskite materials [11]. The stability of the materials also changes when the optical properties change. Perovskite materials have many advantages, such as bipolar charge transfer, long electron / hole diffusion length and adjustable band gap, which show very good photoelectric performance after being applied in the field of solar photovoltaic. PSC have been developed rapidly. The power conversion efficiency of this battery has increased from 1.5% to 18.4% in the past 10 years, as shown in Figure 1, surpassing the dye-sensitized solar cells and organic solar cells that have been developed for many years.

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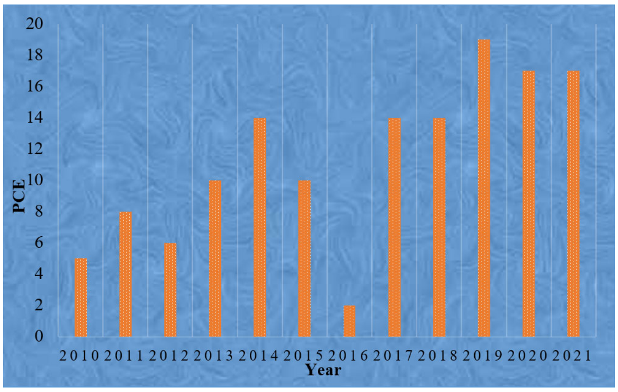

Fig. 1 Development history of conversion rate of PSC

With the advent of PSC, articles on improving the photoelectric conversion efficiency of PSC continue to appear, while the research on the stability of PSC is relatively lagging, and the stability of PSC has become a bottleneck restricting its further development. PSC still face many problems if they want to truly realize industrialization and market product production:

(1) Perovskite materials currently used have problems of decomposition in air and dissolution in water and organic solvents, resulting in short device life. Therefore, it is necessary to develop battery materials that are stable to air and water or solve this problem from packaging technology.

(2) Commercial device development. Because large-area thin films are difficult to maintain uniformity, the working area of the reported high-efficiency PSC is only about 0.15 cm, which is still a long way from practicality. Therefore, it is necessary to develop perovskite solar cell device preparation technology with stable performance from the scale of laboratory square centimeter to the scale of application square meter.

3. Working principle and structure of perovskite solar cells

The research on PSC mainly focuses on two kinds of structures. The first is a mesoscopic solar cell based on porous structure, which is evolved from dye-sensitized solar cells. The second is a thin film solar cell based on a planar heterojunction structure, in which perovskite is both a light absorption layer and a transport layer of electrons and holes. Perovskite materials will undergo the following basic chemical reactions:

$$Pbl_2(s)+CH_3NH_2(aq)\leftrightarrow CH_3NH_2Pbl_3(s) \quad (1)$$

The forward reaction is the synthesis reaction of perovskite material, and the reverse reaction is the decomposition reaction of the solar material. Environmental factors also have certain influence on the stability of perovskite materials. The environmental conditions that affect the stability of PSC include: water and oxygen environment, temperature change, device processing conditions, illumination conditions, etc. At present, the research on the stability of PSC is still in the primary stage of development. In order to further expand the optical absorption spectrum of perovskite materials and increase the utilization of near infrared light to generate higher photocurrent, recently developed new titanium-type solar materials have smaller band gap, good thermal stability and photoelectric conversion performance.

The basic structure of PSC mainly includes a light absorption layer composed of perovskite materials, an electron transport layer / hole barrier layer, a hole transport layer / electron barrier layer, and a working electrode. The basic photoelectric conversion process is that under illumination, photons with energy greater than the band gap of the light absorption layer excite valence band electrons in the light absorption layer to the conduction band, and leave holes in the valence band. Holes are transported to the cathode and the external circuit. In addition to the above photoelectric energy conversion process, there are also some energy loss processes. There are charge recombination centers at the interfaces on both sides of the light absorption layer, resulting in unnecessary charge and energy loss. Improving these energy loss problems can effectively improve the efficiency of the device.

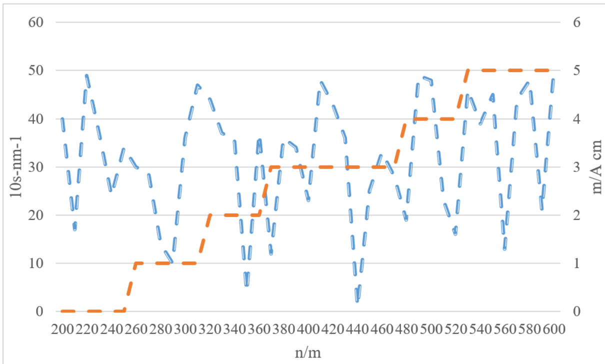

Fig. 2 The relationship between the theoretical photocurrent of the solar cell and the cut-off wavelength of the absorption spectrum of the light absorbing layer

The scheme used for the electron transport layer in the perovskite solar cell in the initial study is based on the research results of the dye-sensitized solar cell, that is, the porous layer composed of TiO2 nanocrystals, whose role is to accept the conduction band electrons in the photogenerated excited state in the perovskite light absorption layer and transport them to the transparent conductive electrode. The hole blocking layer uses a dense layer of TiO2, because its valence band energy level is far lower than the valence band top of the perovskite light absorption layer, which can effectively prevent hole injection (see Fig. 2). Changing the concentration of perovskite precursor additive and the preheating temperature of perovskite film during the preparation process will only cause changes in the surface morphology of the film, but will not change the perovskite phase structure. Changes in the surface morphology will affect the photoelectric performance of the perovskite film and improve the light absorption, charge transport and charge collection process of the light absorption layer.

4. Optimization development trend of solar cells

With the continuous deepening of the research on PSC, people are increasingly eager to find out the internal reasons behind the excellent photoelectric performance of PSC, so as to achieve further optimization and even industrial trials. The key to prepare excellent performance solar cells is to improve the effective light trapping ability of perovskite materials to obtain long-life excitons with small thermodynamic loss, which is the fundamental source of high voltage. In terms of improving the optical performance of perovskite, many research groups have established optical models of perovskite solar cell devices to calculate the EQE of different devices, so as to analyze the optical loss in the devices and optimize the devices. Among these models, the simulation of external quantum efficiency based on optical admittance can provide an important basis for the interpretation of many external quantum efficiency spectra, short-circuit current density JSC and the optimization of device performance. So far, new materials and technologies such as new structures, new perovskite materials, new hole transport layers, new electron transport layers, solution engineering and energy band engineering have achieved lead-free, flexible and large-area PSC. Obviously, this is not the end point. By further increasing the electron hole transport rate, matching the energy levels of each layer, reducing the resistance of the transport layer and other measures, perovskite cells will certainly achieve more efficient photoelectric conversion efficiency. Its development trend is as follows:

(1) In order to fundamentally improve the stability of perovskite materials and realize large-scale commercial production, it is necessary to find more stable new materials (perovskite absorption layer materials and hole transport layer materials), which are not only efficient and stable, but also low-cost and non-toxic.

(2) By changing the additive concentration of perovskite precursor and the preheating temperature of perovskite in the preparation process, combined with the volt ampere characteristic curve, ultraviolet visible absorption and steady-state fluorescence, it was found that the perovskite phase of Perovskite Thin Films did not change when the additive concentration and preheating temperature were changed, but the thin films with the additive concentration of 0.69 M and the preheating temperature of 100 ℃ were compact and flat without holes, and the perovskite had the most photogenerated electrons.

According to the current research results, PSC with high efficiency are promising photovoltaic converter devices. After comprehensive optimization, PSC are expected to achieve large-scale applications. At present, researchers have carried out research on all solid-state PSC from different perspectives such as the preparation method of materials, the development of new perovskite materials and hole transport materials, the selection of substrate materials, and the study of working mechanism, which is expected to achieve efficient and clean utilization of solar energy.

5. Conclusions

The rapid development of PSC has brought a ray of light to solve the future energy problem. However, PSC in the reproducibility, stability and performance evaluation of high-efficiency battery devices. The stability of solar cell materials and devices directly limits the application and development of PSC. Therefore, improving the stability of PSC is an urgent problem for the application and development of subsequent battery devices. At the same time, the battery packaging process needs to be further improved. So far, the main components of all high-performance PSC contain toxic lead, so toxicity problems will occur in the process of device manufacturing and disposal, which is a very unfavorable factor for the commercialization of PSC in the future. Therefore, the future research focus in the field of PSC also needs to explore the preparation of high-efficiency lead-free PSC. In short, in order to achieve large-scale solar power generation as soon as possible to solve the energy and environmental problems worldwide, it is a very urgent scientific and engineering problem to develop low-cost and high stability solar cells.

References

1. Liu Cheng, Shen Luying, Xu Zhengyu, et al. Research progress of perovskite solar cells [J]. Progress in Chemical Industry, 2017, 33(12):7.
2. Yao Xin, Ding Yanli, Zhang Xiaodan, et al. Review of perovskite solar cells [J]. Acta Physica Sinica, 2018(3):8.
3. Cui Xinghua, Xu Qiaojing, Shi Biao, Hou Fuhua, Zhao Ying, Zhang Xiaodan. Research progress of wide-bandgap perovskite materials and solar cells [J]. Acta Physica Sinica, 2020, 69(20):21.
4. Ke Xiaolong, Wang Xiaoping, Wang Lijun, et al. Key issues in the development of perovskite solar cells [J]. Functional Materials, 2017, 47(12):6.
5. Wang Yanxiang, Luo Jun, Guo Pingchun, et al. Application and development of hybrid perovskite materials in solar cells [J]. Journal of Inorganic Materials, 2019, 30(7):10.
6. Wei Jing, Zhao Qing, Li Heng, et al. Perovskite Solar Cells: New Hope in Photovoltaic Field [J]. Science in China: Technological Science, 2019, 44(8):801-821.
7. Zhang Bowen. Preparation and optimization of carbon-based perovskite solar cells with high stability [J]. Jilin University, 2019(7):039.
8. Wang Nan, Liang Zhurong, Wang Junxia, et al. Optimization of the fabrication process of perovskite sensitized solar cells [J]. Progress in New Energy, 2018, 3(6):6.
9. Dong Qiao. Structural design and optimization of perovskite solar cell materials [J]. North China Electric Power University (Beijing) North China Electric Power University, 2017(9):141.
10. Qian Liu, Ding Liming. The working mechanism of perovskite solar cells and the main factors affecting

the performance [J]. Journal of Chemistry in Universities, 2019, 36(4):13.

11. Li Xinli, Li Lihua, Huang Jinliang, et al. Research progress of novel perovskite solar cells [J]. Modern Chemical Industry, 2018(9):5.