

The Principle and Research Progress of Perovskite Solar Cells

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Abstract. Perovskite materials have unique optoelectronic properties, such as high light absorption coefficient, long carrier diffusion length, adjustable band gap, etc., which make it have huge application potential in the field of solar cells. As a new generation of high efficiency photovoltaic technology, perovskite solar cells have attracted extensive attention from researchers around the world in recent years due to their unique photoelectric conversion characteristics and low manufacturing cost. This paper briefly summarizes the working principle of perovskite solar cells, firstly reviews its development process from the 1990s to the global market from the laboratory, and then focuses on the research progress of improving the efficiency of perovskite solar cells. Not only can the efficiency of the cell be greatly improved by enhancing light absorption, optimizing carrier transport and innovating the structure design of the cell, but also can be greatly improved by optimizing the interface structure between the perovskite layer and the electron transport layer and the hole transport layer, as well as optimizing the material properties, improving the preparation process and device structure. Finally, in the context of globalization, its market potential is deeply analyzed, and its commercial use and future development direction are further prospected.

Keywords: Development course; research progress; development direction.

1. Introduction

With the continuous growth of global energy demand and the increasingly urgent environmental protection, the development and utilization of renewable energy has become a hot topic in global scientific and technological research. Among many renewable energy sources, solar energy has attracted widespread attention due to its advantages of clean, pollution-free, and infinite renewability. Therefore, as a device that converts solar energy into electrical energy, the research and development of solar cells are particularly important. Perovskite solar cells are a new type of solar cell technology. Since it was first reported in 2009, perovskite solar cells have attracted widespread attention and research due to its high photoelectric conversion efficiency, low cost, and easy preparation. Perovskite materials have unique optoelectronic properties, such as high light absorption coefficient, long carrier diffusion length, and adjustable band gap, which make it have huge application potential in the field of solar cells.

The basic principle of perovskite solar cells is based on the photovoltaic effect. When the sun shines on perovskite materials, photons are absorbed and excited electron-hole pairs. These electron-hole pairs are separated by a built-in electric field, and the electrons are transferred to the cathode and collected, while the holes are transferred to the anode and collected, thus forming a photocurrent. Perovskite materials have high photoelectric conversion efficiency due to their unique photoelectric properties, such as high light absorption coefficient, long carrier diffusion length and adjustable band gap [1].

As a new type of solar cell technology, perovskite solar cells have huge research value and application prospects. First of all, the high photoelectric conversion efficiency of perovskite solar cells makes it a strong candidate for future solar cells. Through continuous research and optimization, the photoelectric conversion efficiency of perovskite solar cells is expected to be further improved, thus reducing costs and improving the competitiveness of solar cells. Secondly, the preparation process of perovskite solar cells is relatively simple and low cost, which is expected to achieve large-scale production and application. Compared with traditional silicon-based solar cells, the preparation process of perovskite solar cells is simpler and the raw materials are more abundant, so it has lower

cost. This makes perovskite solar cells have broad application prospects in developing countries and regions. In addition, the research of perovskite solar cells also helps to promote the development of new energy materials. As a new type of optoelectronic material, perovskite materials have wide application potential in solar cells, optoelectronic devices, photoelectric detection and other fields. Through in-depth study of the optoelectronic properties and application principles of perovskite materials, it is expected to promote the development and innovation of new energy materials.

The research of perovskite solar cells not only has far-reaching scientific significance, but also carries the important mission of promoting the development of clean energy. In the context of global climate change and energy transformation, perovskite solar cells are expected to become an important force for future solar energy utilization with their high efficiency, stability and low cost advantages. Through unremitting efforts and continuous research, we have reason to believe that perovskite solar cells will shine in the field of photovoltaic and make important contributions to the sustainable development of mankind.

Few publications have thoroughly examined the present development and research process of perovskite solar cells; instead, the majority of pertinent research in this subject concentrates on the materials and technologies of perovskite solar cells. Thus, the development and research process of perovskite solar cells will be the starting point for this study, which will then examine the material and technological innovation of perovskite solar cells and how it affects other solar cells. Finally, the study will provide an overview of the commercial prospects and potential future trends of perovskite solar cells. To serve as a resource for the pertinent academics working in this area.

2. Material Innovation and Technology Application

2.1. Development Process and Principle

2.1.1. Development process

Since the 1990s, the research field of perovskite solar cells has gradually entered the line of sight of scientists. At that time, many researchers began to dig deeper into the potential of perovskite materials in photovoltaic applications, and carried out a series of material synthesis and property research. These studies have not only pointed out the direction for the development of perovskite solar cells in theory, but also laid a solid foundation for subsequent practical applications [1].

Into the 21st century, the rapid development of science and technology has also ushered in an unprecedented breakthrough in the field of perovskite solar cells. Especially in terms of photoelectric conversion efficiency, with the continuous deepening of scientific research, its efficiency value has risen rapidly. All this is inseparable from the hard work of researchers in the optimization of material composition and device structure. It is because of their efforts that perovskite solar cells have gradually moved from the laboratory to the market, and have even begun to rival traditional commercial photovoltaic products in some properties [2].

With the development of The Times, the technology of perovskite solar cells has also continued to make breakthroughs. Researchers in the pursuit of high efficiency on the road to explore, brave to climb the peak, and finally achieved one after another remarkable results. These achievements not only prove the feasibility and advanced nature of perovskite solar cell technology, but also set off a new round of photovoltaic technology innovation wave in the world.

Of course, the development of any new technology is not always smooth. Facing the future, perovskite solar cells still need to deal with many challenges, such as material stability, production costs and environmental impacts. But it also brings boundless opportunities. Especially in the context of the transformation of the global energy structure and the increasingly popular concept of environmental protection, perovskite solar cells as a clean and efficient new energy technology, its application prospects in the field of photovoltaic is very broad.

With the passage of time and the accumulation of technology, we have reason to believe that perovskite solar cells will be more widely used in the near future, and make greater contributions to

the sustainable development of mankind. All this is inseparable from the efforts and dedication of every scientific researcher who works hard in this field. Their stories and spirit will also become an inexhaustible source of power to promote scientific and technological progress and social development [3].

2.1.2. Principle

The novel thin-film photovoltaic device known as a perovskite solar cell is seen in Figure 1 with its common structure consisting of a transparent conductive electrode, an electron transport layer, a perovskite absorption layer, a hole transport layer, and a metal electrode layer. Figure 2 depicts the perovskite solar cells' operating mechanism: Photons with energy greater than the band gap width of the perovskite materials can be effectively absorbed by the battery when sunlight strikes it. This results in the formation of holes in the valence band and the migration of excited electrons from the valence band to the conduction band. The electrons and holes then inject themselves into the transport layer at the interface where the perovskite layer and the transport layer meet. In order to supply energy to the external circuit, the carrier is transmitted to the electrode, realize photovoltaic power generation [4, 5].

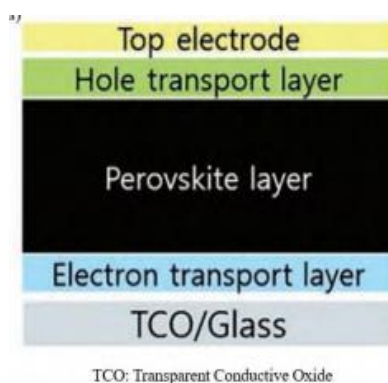


Fig 1. Perovskite solar cell structure [4].

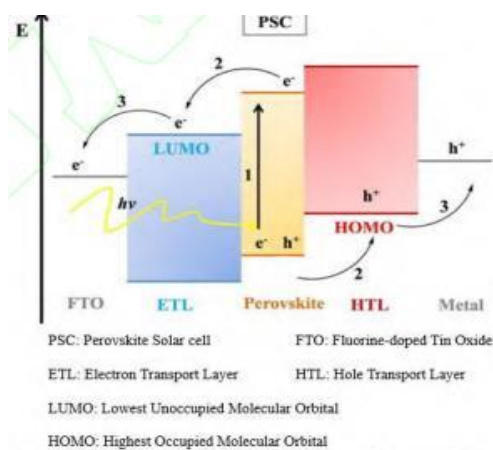


Fig 2. Working mechanism of perovskite solar cell [5].

2.2. Research Progress and Technology Optimization

2.2.1. Research progress

As a bright new star in the field of photovoltaic, perovskite solar cells have attracted wide attention in scientific research and industry in recent years. Its unique crystal structure and photoelectric properties give it great potential, especially in terms of battery efficiency improvement, but also show remarkable prospects.

In the process of in-depth study of perovskite solar cells, researchers found that by enhancing light absorption, optimizing carrier transport and innovative cell structure design, the photoelectric conversion efficiency of the battery can be significantly improved. The exploration and

implementation of these methods requires not only a deep understanding of materials science, but also a broad range of interdisciplinary fields such as nanotechnology and optical design.

Light absorption enhancement is one of the key ways to improve the efficiency of perovskite solar cells. By carefully designing nanostructures, such as nanowires and nanoparticles, researchers have effectively increased the specific surface area of the perovskite layer, thereby improving the light absorption efficiency. Other research teams have explored the use of photonic crystals and other structures to regulate the propagation path of light, so that it is reflected and refracted several times in the perovskite layer, thereby increasing the absorption of light. The design and application of these nanostructures provide strong support for the enhancement of light absorption of perovskite solar cells.

Carrier transport optimization is also an important part of improving the efficiency of perovskite solar cells. The efficient transfer of carriers is essential to reduce energy loss and improve battery performance. Researchers have significantly improved carrier mobility and lifetime by synthesizing new high-performance transport materials, such as organic-inorganic hybrid materials and low-dimensional materials. They also fine-tuned the interface between the perovskite layer and the transport layer to reduce interface recombination and energy loss. These transmission optimization measures have laid a solid foundation for the efficiency improvement of perovskite solar cells.

The innovation of cell structure design has also brought new breakthroughs for the efficiency improvement of perovskite solar cells. Traditional perovskite solar cell structures have been difficult to meet the increasing performance requirements. Researchers have actively explored new battery designs such as multi-layer structures and gradient structures. These innovative designs can not only improve the light absorption and carrier transport performance of the battery, but also effectively inhibit the defects and recombination centers in the battery, thereby further improving the battery efficiency [6].

2.2.2. Technology optimization

The properties and applications of perovskite materials heavily depend on the synthesis process used. The solution method, gas phase method, and solid phase method are currently the most widely used synthesis techniques. The solution method is one of the most popular among them due to its inexpensive and easy to use nature. Perovskite films with superior qualities can be created by carefully regulating the solution's concentration, composition, and reaction conditions. The perovskite materials thesis approach is crucial to its support [7].

The photoelectric conversion efficiency of solar cells can be increased by reducing charge recombination and energy loss at the interface by improving the structure connecting the perovskite layer, electron transport layer, and hole transport layer. One of the obstacles preventing perovskite solar cells from being commercially viable has been their stability. Researchers have created a number of technologies, including additive engineering, interface passivation, and packaging, to increase stability. With the use of these methods, perovskite material deterioration may be efficiently slowed down and solar cell service life can be prolonged. Designing the device structure is a crucial step in maximizing perovskite solar cells' performance. Solar cells' transmission performance, charge separation efficiency, and light absorption capacity can all be further enhanced [8].

The main objective of the study is to increase perovskite solar cells' conversion efficiency. Perovskite solar cell conversion efficiency continues to rise as a result of material property optimization, enhanced preparation techniques, and improved device architectures. Simultaneously, novel approaches to boost spectral response, control carrier dynamics, and other tactics have the potential to enhance conversion efficiency even more. The fields of use for perovskite solar cells are gradually growing as their performance continues to improve. Perovskite solar cells can also be used in wearable technology, the Internet of things, building integrated photovoltaics, and conventional photovoltaic power plants and residential photovoltaic systems. Higher standards for the flexible, translucent, and lightweight are required in these industries. Also for the development of perovskite solar cell provides a new opportunity [9].

2.3. Commercialization prospects and future trends

In the evolution of the global energy market, perovskite solar cells are gradually emerging with their unique advantages and huge market potential. This battery is not only efficient, but also excellent in environmental protection, becoming a shining star in the field of renewable energy today. As the global demand for renewable energy continues to grow, perovskite solar cells are ushering in unprecedented development opportunities.

The reason why perovskite solar cells can receive such widespread attention, in addition to its efficient environmental protection characteristics, but also benefit from global policy support. Governments have introduced relevant policies to encourage and promote the development of renewable energy, providing a strong guarantee for the commercialization of perovskite solar cells. The implementation of these policies has not only created favorable conditions for the popularization and application of perovskite solar cells in the energy market, but also injected strong impetus into their development on the road to commercialization [10].

With the deepening of scientific research and the continuous progress of technology, the performance of perovskite solar cells is expected to be further improved. For example, by optimizing the material structure, improving the preparation process, and improving the photoelectric conversion efficiency, the performance of perovskite solar cells may be significantly improved. And the material cost of perovskite solar cells is relatively low, which has potential cost advantages. With the expansion of production scale and technological progress, the cost of perovskite solar cells is expected to further reduce, improve its market competitiveness. With the growing global demand for renewable energy, the market demand for perovskite solar cells is expected to continue to grow. Especially in some areas with rich light resources and large power demand, perovskite solar cells may be more widely used.

In terms of commercialization, perovskite solar cells have made remarkable progress. More and more enterprises have begun to devote themselves to this field, to seize the market opportunity by developing and producing perovskite solar cells. Some countries have begun to incorporate perovskite solar cells into their energy strategic planning in order to gain an advantageous position in the future energy competition. These measures undoubtedly provide strong support for the commercialization process of perovskite solar cells [11].

The development of perovskite solar cells will also lead to the prosperity of related industries. From raw material production to equipment manufacturing, to installation and maintenance, the perovskite solar cell industry chain involves many fields. With the continuous expansion of the market and the continuous progress of technology, these areas will usher in a broader space for development and inject new vitality into global economic growth. In the context of the global energy market, perovskite solar cells, with their unique advantages and huge market potential, are becoming a new driving force leading the development of renewable energy. With the increase of policy support, the advancement of technological innovation and the growth of market demand, perovskite solar cells are expected to achieve more brilliant achievements on the road of commercialization and make important contributions to the prosperity and sustainable development of the global energy market [12].

3. Conclusion

In summary, perovskite solar cells, as an efficient and low-cost photovoltaic technology, have broad application prospects in the field of renewable energy. The future development direction of perovskite solar cells will be toward higher photoelectric conversion efficiency, longer service life, better stability, and lower manufacturing costs. Perovskite solar cells will become an important weapon for human beings to cope with the energy crisis, protect the environment and achieve sustainable development. It will be widely used in various fields such as home, industry and transportation, bringing more convenient and green energy solutions to human life.

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