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Development status and future prospects of photovoltaic cells

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Abstract. With the rapid development of social economy, the consumption of conventional energy is growing at an amazing rate. The energy shortage crisis and the environmental problems brought by conventional energy will seriously restrict social development and affect the daily lives of residents. Therefore, paying attention to the creation and use of new energy, protecting the environment, improving efficiency, controlling the emission of pollutants and realizing sustainable development have become the main research topics in the new era of the energy sector. Photovoltaic energy has the advantages of economic energy saving, green environmental protection, wide application and sustainability, and is an ideal new energy, that has been developed to the third generation. This paper mainly combs the development process of photovoltaic technology, summarizes the characteristics, advantages and disadvantages of the third generation of photovoltaic technology, analyzes the current situation and prospects of photovoltaic technology development, and analyzes the problems and challenges faced. This research finds that as the economy and technology continue to advance, photovoltaic cell technology is developing rapidly, and the application cost is constantly reduced. The photovoltaic cell industry will get more attention and better development, and its application prospect is very broad. The research of this topic is helpful in enhancing the comprehensive and objective understanding of the development of photovoltaic cell technology, and will provide a valuable reference in order to advance the photovoltaic sector in the future, which has important practical significance.

Keywords: Photovoltaic cells; Development status; Three Generations.

1. Introduction

In recent years, the frequent occurrence of conventional energy crises has seriously affected the national economic development and the daily life of the residents, therefore the energy issue has elevated to the level of a barrier to global social and economic progress. In order to get rid of the problem of energy shortage, the development of photovoltaic resources and seeking new driving force for economic growth has become the main topic of energy development in various countries [1]. The development and utilization of new environmentally friendly and clean energy can provide great help for the global energy shortage. Photovoltaic is the most abundant energy reserve in the world, which is inexhaustible [2]. It is an ideal renewable energy source. Making good use of photovoltaic and developing efficient and stable photovoltaic cells can greatly alleviate the global energy crisis. In the future development of science and technology and production and life, photovoltaic cells will play an increasingly important role [3]. Photovoltaic technology is one of the main ways to develop and utilize

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photovoltaic technology. Photovoltaic cells have been developed to the third generation, and considering the ongoing development of photovoltaic energy production efficiency and the decline of solar energy panels in recent years, the application prospect of photovoltaic power generation is unprecedented [4].

This paper uses the method of literature survey to discuss the advantages and disadvantages of each generation of photovoltaic technology, the international development status of photovoltaic cells, the development status and prospects of domestic photovoltaic cells. This study summarizes past experience and provides references for how the photovoltaic business will grow in the future.

2. Three Generations of Photovoltaic cells

2.1. The three generations of photovoltaic cells

The first generation of photovoltaic cells was invented in 1954 by researchers in the Bell Laboratory. This battery is made of silicon materials, represented by crystalline silicon photovoltaic cells, including single crystal, polycrystalline, and amorphous silicon photovoltaic cells; this battery is mature, reasonably affordable, and has been widely used in commercial and civil fields, accounting for 90% of the global photovoltaic market. However, the efficiency is very low, only about 6%, and it is struggling to overcome the energy conversion efficiency (PCE) improvement bottleneck.

The second generation of photovoltaic cells are made of polysilicon, called polysilicon photovoltaic cells. The cells are cheaper than monocrystalline silicon photovoltaic cells and are more efficient, to about 10%.

In the mid-1970s, researchers began studying using compound semiconductor materials to make photovoltaic cells. Such cells are called efficient photovoltaic cells because they greatly improve efficiency from the first generation; they have high theoretical conversion efficiency, but are expensive to produce and difficult to use, usually only in aerospace, military and other fields. One of the compound semiconductor photovoltaic cells is gallium arsenide photovoltaic cells, which can achieve an efficiency of more than 20%.

Midway through the 1990s, research on the third generation of solar cells began. These cells are also referred to as "new photovoltaic cells", and they primarily consist of inorganic and organic thin-film photovoltaic cells, dye-sensitized photovoltaic cells, quantum dot-sensitized photovoltaic cells, and perovskite solar cells. These cells are inexpensive, light, and well suited for application in wide spaces. The main goal of this kind of battery is to lower the price based on the second generation. Although it took little time to build, it has a high theoretical conversion efficiency, is relatively inexpensive, and has a lot of room for growth [1]. The efficiency and price of the third generation photovoltaic cells are as shown in Figure 1.

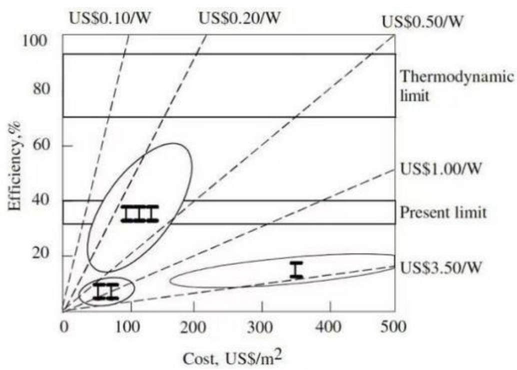

Figure 1. Efficiency of third-generation photovoltaic cells-Price diagram [5].

2.2. Representative third-generation photovoltaic cells

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2.2.1. Inorganic thin-film photovoltaic cells. Generally speaking, inorganic thin film photovoltaic cells have a long service life and have excellent development prospects because they have low production costs, little pollution, stable performance, low light performance, and strong applicability. The PCE is high and is comparable to that of crystalline silicon photovoltaic cells, but the cost is relatively low. In addition, inorganic compounds have good stability and are not easily affected by their environment. The two primary examples of inorganic thin film photovoltaic cells are copper indium gallium selenium (CIGS) and copper zinc tin sulfur (CZTS) thin film photovoltaic cells. The maximum PCE of the present CIGS thin film photovoltaic cells is 22.3%, relatively mature, and CZTS thin film photovoltaic cell PCE is 12.6%, and CZTS non-toxic pollution-free, more in line with the needs of the current environmentally friendly photovoltaic cells, very suitable for large-scale commercial production.

The main structure of the inorganic thin-film photovoltaic cell includes the opposite electrode, window layer, buffer layer, light-sensitive layer, bottom electrode and transparent substrate. The CIGS or CZTS in the light-sensitive layer can be used as a P-type semiconductor to form a PN junction with the N-type material (generally cadmium sulfide CdS) in the buffer layer, forming the core part of the whole battery.

CIGS solar cells currently have a PCE that is comparable to crystalline silicon photovoltaic cells, which has largely satisfied the conditions for commercialization. However, the Ga and Se found in CIGS have some toxicity and have the issue of environmental pollution. However, there is still a significant difference between CZTS thin-film photovoltaic cells and conventional crystalline silicon solar cells. PCE needs to be enhanced since it is still in the laboratory research stage. The preparation process of CZTS materials is relatively complicated, so it is necessary to optimize the process or explore new preparation methods to reduce production costs, so as to meet the needs of commercial development [1].

2.2.2. Organic thin-film photovoltaic cells. Organic material source, low price, and can also be obtained by artificial synthesis, which makes the organic photovoltaic cell production cost lower than the traditional crystalline silicon photovoltaic cells, and organic material flexibility is better, can be prepared on the flexible folding substrate flexible wearable thin film photovoltaic cells, and can through the volume of volume process of mass production. Organic thin film photovoltaic cells now have a PCE of 3%, and the open-circuit voltage can reach 0.9V. The organic materials are Basically safe for human use, with a promising future for advancement in the realm of wearable and civil photovoltaic cells.

The structure of the organic photovoltaic cell is shown in Figure 2, in which FTO is fluorine-doped tin oxide, and the active layer with light absorption is the core part of the organic photovoltaic cell. The active layer is generally composed of donor materials and acceptor materials.Donor materials are generally organic small molecules or polymers with photovoltaic characteristics, and acceptor materials are generally fullerene materials (such as PCBM) or small molecule non-fullerene materials (such as N2200).

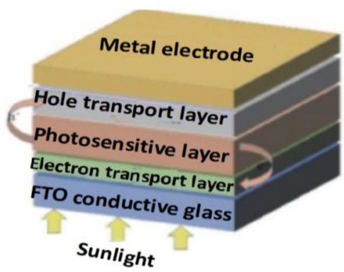

Figure 2. Organic photovoltaic cell structure [1].

DOI: 10.54254/2755-2721/58/20240678

At present, there are two main problems facing organic thin film photovoltaic cells: ① Due to the low charge mobility of organic semiconductors, its PCE is lower than silicon-based photovoltaic cells and inorganic semiconductor photovoltaic cells; the stability of ② organic photovoltaic cells mainly affects the active layer material. The organic semiconductor materials that constitute the active layer usually chemically decompose in the case of air, water and light. At the same time, the fullerenes are somewhat chemically active and unstable in the air. For example, PCBM can react with oxygen and water under light, so that its work function is reduced, so that the stability of the battery decreases, its efficiency is greatly reduced under the condition of long sunlight exposure, and the service life is short. Therefore, organic photovoltaic cells need to seek high charge mobility active layer organic compounds are needed to further increase conversion efficiency and address stability issues. so as to go further on the road of commercialization [6].

2.2.3. Dye-sensitized photovoltaic cells. Dye-sensitized photovoltaic cells (DSSCs) offer the benefits of a straightforward approach and affordable price. The dyes used as dye sensitizers can be extracted from various natural resources, with low raw material cost and no pollution to the environment, which meet the requirements of current environmentally friendly devices. Because DSSCs are insensitive to environmental pollutants and have no special requirements for processing ambient temperature,They are ideal for producing continuous roll-to-roll prints on flexible substrates. In addition, DSSCs are a great option for inside applications, such as mounting on windows and skylights to provide indoor power supply, as they utilize diffuse reflection effectively, perform well even in darker situations, and guarantee good efficiency at dawn and dusk or cloudy days. A type of solar cell that is currently garnering increasing interest is the DSSC, which has a maximum efficiency of more than 13% to 15%.

The structure of the dye-sensitized photovoltaic cells is shown in Figure 3. DSSCs are mainly composed of five parts: transparent conductive substrate, photoanode, photosensitizer, electrolyte and counterelectrode. The photoanode is generally deposited on a transparent conductive glass substrate by a mesoporous oxide layer (usually titanium oxide TiO_2) for conducting electrons; the photosensitizer is stimulated by the light to generate electron injection semiconductor conduction band, generally including organic and inorganic dye sensitizer and pure natural dyes; electrolytes contain redox electropair (usually organic iodine ions I/I_3) for electron transmission and dye regeneration; the electrodes are generally metal electrodes (such as platinum) or carbon material.

DSSCs with low-light power generation, are less influenced by the surrounding temperature and light intensity and angle, advantages of low cost and simple manufacturing, but there are still several problems in the light anode. Currently, the most commonly used material is the anatase phase TiO_2, But the presence of numerous surface states and defects in TiO_2 nanocrystalline films make electrons prone to annihilation during the transport process, thus limiting the electron injection and collection efficiency. This has largely limited the improvement of TiO_2 dye-sensitized photovoltaic cells PCE. Therefore, it is a long way to find and develop new light anode materials 20. In terms of dye-sensitizers, since dyes as light trapping are a critical part of DSSCs, organic dyes also have the problem of poor stability and energy. Therefore, it is necessary to develop more stable inorganic dyes as absorbent materials that can absorb all the solar spectrum from the visible near-infrared region to the incident light at a wavelength of about 920nm, to maximize its energy absorption. In order to ensure that it has a higher PCE and also has a long service life. In terms of the electrolytes, the most commonly used one right now is the organic iodide ion I/I_3 liquid electrolyte. Liquid electrolyte is difficult to preserve and transport, and the stability of organic iodide ion electrolyte is poor. After repeated use, the ability to transfer electrons is greatly reduced, resulting in poor battery performance and short service life. The inorganic ionic electrolyte also has the problem of PCE of DSSCs when the stability of long-term use. Therefore, to address the issue of present liquid electrolyte DSSCs' electrode stability, stable solid electrolyte must be developed and used [7].

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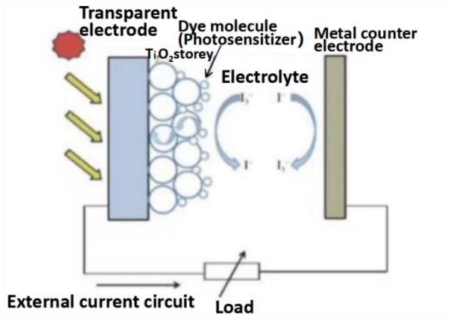

Figure 3. Dye-sensitized photovoltaic cell structure [1]

2.2.4. Quantum dot-sensitized photovoltaic cells. A new type of solar cell that has gained increasing attention is called a quantum dot-sensitized photovoltaic cell (QDSC). They employ quantum dot sensitizer, which has the features of high light absorption efficiency, wide range, adjustable band gap, and low cost, as a light-absorbing material. Figure 4 depicts the composition and operation of quantum dot-sensitized photovoltaic cells. The PCE of QDSCs has surpassed 11% after only a few years of research, and its theoretical PCE is as high as 44%, making it one of the most promising solar cells. The structure of QSCs mainly includes four parts: photoanode, sensitizer, electrolyte and counter electrode. The structure is similar to DSSCs, and the working principle of both is very similar. The difference is that QDSCs use quantum dot sensitized layers as light-absorbing material [8].

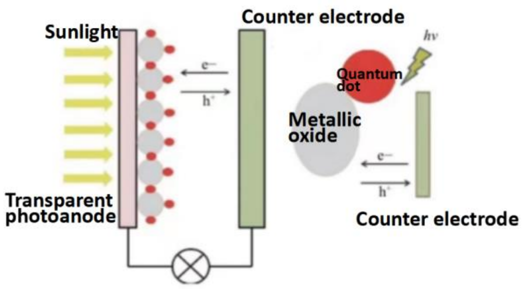

Figure 4. Structure and working principle of quantum dot photovoltaic cells [1]

3. Current status and prospect

3.1. Status quo

The application of solar photovoltaic technology dates back to the early 1950s, but it was not in recent years that the solar photovoltaic industry developed rapidly. Solar photovoltaic energy is currently one of the most significant sources of renewable energy in the world.

First, solar photovoltaic power is becoming more affordable. The cost of solar photovoltaics is decreasing as a result of the industry's growth and the ongoing advancement of technology. The International Energy Agency estimates that during the previous ten years, the cost of producing solar photovoltaic power has decreased by around 80% [9].

Second, there is an increase in the capacity of solar photovoltaic installations worldwide. The International Energy Agency projects that by 2030, there will be 1.4 trillion watts of solar photovoltaic capacity built worldwide. With one-third of the global installed capacity, China is currently the largest solar PV market [10].

Finally, solar photovoltaic technology continues to innovate. High efficiency, low cost, high stability, and reliability are the main priorities for solar photovoltaic technology development. The efficiency of solar cells has been continuously improved, from around 10% initially to more than 20% now. In addition, research on new solar cell technologies is also advancing, such as organic solar cells, perovskite solar cells and others [11].

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3.2. Prospects

First of all, the future prospects of the solar photovoltaic industry are very broad. First of all, solar photovoltaic power generation will become one of the most important sources of energy in the future. As global energy demand continues to increase, solar photovoltaic power generation will become increasingly important.

Second, the solar photovoltaic industry will usher in rapid growth. With the continuous innovation of technology and cost reduction, the solar photovoltaic industry will usher in rapid growth. The global solar PV market is expected to reach $1.5 trillion by 2030.

Third, the solar photovoltaic industry will promote sustainable development. Solar photovoltaic power generation is a green and clean energy source that does not produce pollution or greenhouse gases, and can help reduce dependence on fossil fuels and promote sustainable development.

Fourth, the solar photovoltaic industry will drive employment growth. The rapid development of the solar photovoltaic industry will drive employment growth in related industries, such as solar cell manufacturing, construction and operation of photovoltaic power stations.

3.3. Problems and Challenges

Despite the solar photovoltaic industry's tremendous progress, there are still some problems and challenges. First, the solar photovoltaic industry needs to face a changing policy environment. The policy environment has an important impact for information on the growth of the solar photovoltaic business. The policy support of some countries has played a positive role in promoting the development of solar photovoltaics, but the policy uncertainty and changes may have a certain impact on the industry. Second, the solar photovoltaic industry also needs to face technical bottlenecks. Although the solar photovoltaic technology continues to innovate, there are still some technical bottlenecks, such as the solar cells' life and conversion efficiency.

Finally, the solar photovoltaic industry needs to address the sustainability issue. Although solar photovoltaic power generation is a green and clean energy source, it still needs to consume certain energy and resources in the production process. Therefore, the solar photovoltaic industry needs to make more efforts in terms of sustainability, such as promoting the circular economy, reducing resource consumption and others [12].

4. Conclusion

In 1954, the photovoltaic cell was born as the world's first solar cell, the photovoltaic cell technology iteration has gone through three generations. This paper mainly introduces the development process of the technology of third-generation photovoltaic cells, and comprehensively analyzes the advantages and disadvantages of the third generation of photovoltaic cells from the aspects of production materials, conversion efficiency, manufacturing cost, application value and environmental pollution. This paper introduces the third generation photovoltaic cell technology, analyzes in detail the technical characteristics of four types of representative photovoltaic cells, including inorganic thin film photovoltaic cells, organic thin film photovoltaic cells, dye-sensitized photovoltaic cells and quantum dot sensitized photovoltaic cells, and has a clearer understanding of the latest development of photovoltaic cell technology. Compared with the first and second generation, the third generation photovoltaic cells have the advantages of higher efficiency, stronger stability and longer service life, and they have stronger technical advantages and a broader market prospect. Although the photovoltaic industry still has problems such as conversion efficiency, economic benefits and service life, but with the continuous progress of photovoltaic technology and the corresponding policy support, these challenges and problems will be solved. It is an unavoidable trend that the price of photovoltaic power generation will continue to decline., and its position in the energy industry will become increasingly important.

There are still some problems with this study. Due to the limitations of objective conditions and personal cognitive ability, the literature referenced in this study is not comprehensive and sufficient, and the analysis of the development process and technical characteristics of photovoltaic cell

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technology is not in-depth enough. Because of the lack of actual investigation and research on the photovoltaic cell industry, and the lack of more detailed data, the current situation analysis and prospect forecast of the third generation of photovoltaic cells are not in-depth enough, etc. The development of the latest photovoltaic cell technology needs more in-depth understanding and research. In the future, further research will be conducted on high-efficiency photovoltaic cell technology, photovoltaic system intelligent technology, photovoltaic energy storage technology and other aspects.

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