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Current status and prospects of flexible solar cells

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Abstract. With the increasing global demand for clean energy, solar cells, as a renewable and pollution-free clean energy source, have attracted much attention. In the past, solar cells have always used rigid materials as substrates. However, this rigid solar panel is not only bulky and limited in layout, but also susceptible to external impact and damage, which is not conducive to its application in various scenarios. Flexible solar cells, developed from rigid solar cells, have the advantages of light weight, small size, high safety, and strong adaptability, gradually becoming the development trend of solar cells. The research and development of flexible solar cells benefit from the rapid development of materials. In recent years, the emergence of various new materials and preparation technologies, such as carbon fibers, polymers, organic materials, and nanostructures, has provided a better foundation for the preparation of flexible batteries. At the same time, flexible batteries can also be processed through printing, spraying and other processing methods, improving manufacturing efficiency. In addition, the demand for wearable devices, smart homes and other emerging scenarios in society has also accelerated the research and application of flexible solar cells, providing broad application prospects for their development. However, its cost is usually higher than that of rigid solar cells, and market regulation under new categories requires time to adapt. The development of flexible solar cells is benign, but it requires the market to test its standardization.

Keywords: flexible solar cells, thin-film materials, preparation technology.

1. Introduction

The traditional solar cell, also known as a photovoltaic cell, is a kind of device that converts solar energy into electric energy. It is huge and made of rigid materials such as silicon. The earliest solar cell was made by American inventor Charles Fitz in 1883. However, the development of early solar cells was limited due to their low efficiency, high cost and lack of reliable materials. Nowadays, rigid solar cells are not only used in large-scale power generation projects, but also widely used in homes and commercial units. However, these solar cells still have limitations, such as heavy weight, large volume, difficulty in flexibility, and insufficient adaptability and stability.

In the past decade, the research and development of flexible solar cells have surged, mainly due to the growing demand for lightweight, portable and easy-to-install solar panel systems. Different from traditional solar panels with huge volume and strong rigidity, due to the use of flexible substrates such as plastics, metal and fabrics, these substrates enable solar cells to bend and adapt to different surfaces.

The development of flexible solar cells began in the 1960s. The first batch of flexible solar cells was made of amorphous silicon, cadmium telluride and copper indium gallium selenide thin films. In the

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mid-1990s, the invention of organic solar cells using polythiophene and other polymers made solar cells more flexible and portable [1]. Organic solar cells are easier to manufacture and portable, and improve the efficiency of converting sunlight into electricity. In the latest development, the materials experimental team of Soochow University in China used functional bis ((3- methyl oxetane -3- yl) methyl) thiophene-2,5-dicarboxylate (OETC) as an in-situ crosslinking monomer in the research of perovskite flexible solar cells, which improved the efficiency of this kind of flexible solar cells with thiophene added to the certification to 22.9%. The power conversion efficiency of the flexible solar cell is greatly improved [2]. The development and iteration of flexible solar cells are ongoing.

Although the development of flexible solar cells has made remarkable progress, there are still some challenges in expanding production and improving efficiency. With the increasing demand for flexible solar panels and the continuous progress of solar cell technology, the future prospect of flexible solar cells is bright. This paper will discuss the research status of flexible solar cells and their future development and application potential.

2. Classification

Common types of flexible solar cells include organic solar cells, dye-sensitized solar cells and thin film solar cells. They all have the advantages of light weight, and each type of solar cell has its own advantages and disadvantages. Because of the use of organic materials, organic solar cells are of low cost, and are an ideal choice for flexible portable devices. They can be also made transparent, allowing them to be placed in a window or other surface without blocking the view. However, compared with traditional solar cells, the efficiency is lower, which means that less energy is generated per unit area; their life span is shorter, which means that they may need to be replaced more frequently and are easily damaged by moisture and oxygen, leading to degradation over time.

Dye-sensitized solar cells use low-toxic materials, which are flexible and of low cost, easy to install in various settings, and can be made transparent, allowing them to be placed in windows or other surfaces without blocking their high efficiency under low light conditions, making them effective in cloudy or shadowy environments, but their service life is shorter than that of traditional solar cells, which means that they may need to be replaced more frequently, which leads to lower degradation efficiency under high light conditions than some other types of solar cells.

Thin-film solar cells can be made into large sheets, which makes their manufacturing cost lower, they are also lighter and more flexible than other types of solar cells, which is convenient for installation in various settings. They have high efficiency in low light conditions, good performance and durability, and are very suitable for outdoor use. But the efficiency is lower than that of traditional solar cells, which means less energy is generated per unit area. It is easy to be damaged by moisture and oxygen, which leads to degradation over time and is more difficult to recycle than other types of solar cells because they contain toxic substances such as cadmium and selenium [3].

Generally speaking, the choice of flexible solar cells will depend on the specific needs and limitations of the project. Factors such as cost, efficiency, life span and environmental impact should be considered when selecting specific types of solar cells.

3. Production and generation technology

Flexible solar cells are manufactured using various materials and technologies. Flexible solar cells are usually made of thin-film materials, such as amorphous silicon, perovskite and copper indium gallium selenide (CIGS). The first scientific research team to use these materials is in the National Renewable Energy Laboratory. Led by Dr. Jerry Olson, the team began to study CdTe, InGaN, ZnO/Cu/ZnO/ and organic solar cells in the 1970s [4]. These materials are flexible and light, and can be deposited on various substrates. When photons from sunlight reach the solar cell, they are absorbed and a pair of electron holes are generated. Different types of impurities are added to the P-type and N-type layers to form a positive charge region and a negative charge region, which leads to the difference between the two Fermi levels. However, when combined with the source layer, the Fermi level should be the same. Therefore, there is a slope, which is a potential gradient, an electric field and allows drift to work.

Electron pairs and holes are separated by an electric field, and electrons move to the P layer and holes move to the other layer. This separation prevents the direct composition of the carrier. Then, the individual electrons and holes are collected into the corresponding solar cell electrodes, which are connected to the P and N layers respectively to facilitate the carrier extraction. Then, they are connected to the battery for storing energy through an external circuit to generate current [5].

The production of flexible solar panels is mainly divided into four steps. The first step of substrate preparation is to select suitable flexible substrates such as polyimide and Polyethylene terephthalate (PET), and carry out stain removal, polishing, deionization and other treatments. Second, film preparation is to prepare the required films on the substrate, including transparent conductive films, P-type and N-type material films, etc. There are many ways of film manufacturing technology. Roll-to-roll technology is to use continuous roll-to-roll processes to deposit film materials on flexible substrates. Inkjet printing technology refers to the use of a nozzle as the medium to control the injection of ink in the ink bag through circuits and controllers. Each nozzle is usually composed of hundreds of tiny spray holes, which gather together to form a rectangular array for ink spraying. The computer will generate inkjet modules to generate patterns based on computer settings [6]. This process is very accurate and can be used to create complex patterns and shapes. Vacuum deposition technology is a technology that utilizes evaporation, sputtering, chemical reactions, and other methods in a high vacuum environment to prepare thin films. Vacuum deposition technology includes many methods, the common ones are Physical vapor deposition (PVD) and chemical vapor deposition (CVD). PVD mainly uses evaporation or sputtering to heat the material to a certain temperature, so that it can be evaporated or sputtered into the vacuum chamber. As the atomic molecules of the material escape, they will diffuse and deposit on the substrate surface to form a thin film. CVD involves the formation of thin film materials by chemically reacting the reaction gas, which is then deposited on the surface of the substrate. Vacuum deposition technology can prepare thin and uniform high-quality films [7]. Laser scribing technology includes using a laser to selectively remove thin film materials from the substrate. This technique can be used to create complex patterns and shapes in thin films. The third step is ion implantation, that is, P-type and N-type semiconductor materials are ion-implanted to form a p-n junction, so that the solar panel can convert sunlight into electric energy. The final step is encapsulation, which means packaging the device with PTFE, PET and other materials, and installing wires and other required devices [8].

4. Application

The application of flexible solar cells uses the advantages of flexible solar cells in different industries, such as aerospace, automobile and consumer electronics. Flexible solar cells can be applied in various ways because of their unique characteristics.

The flexible solar panel on a portable power supply is very suitable for charging mobile devices such as smart phones, tablets and cameras on the move. They are light in weight and easy to carry, making them an ideal choice for hikers, campers and travelers. Flexible solar cells in wearable technology can be integrated into clothes, backpacks and other wearable technology equipment. Among them, Yeojun Yun et al. made good progress in the field of wearable devices based on GaAs III-V semiconductor flexible solar cells. The GaAs thin film photovoltaic technology itself has a high power conversion efficiency (PCE) of 29.1% (Alta Devices). Based on this, this team adopted the epitaxial lift-off (ELO) process and the structure of the sacrificial layer and epitaxial layer, which enabled the active layer to be separated from the gallium arsenide substrate, thus realizing the reuse of gallium arsenide and saving the cost of expensive materials [9]. Flexible solar cells can be used to create building integrated photovoltaic (BIPV). These solar cells can be installed on roofs, walls and windows to generate clean and renewable energy for buildings [10]. Flexible solar cells can also be used in transportation applications such as electric cars, ships and airplanes. They can be integrated into the car body to provide power for charging batteries or running electrical systems. In short, the application of flexible solar cells is endless, and they can be used in various industries to generate clean and renewable energy.

5. Restrictions

Flexible solar cells have made great progress in becoming a feasible solution for renewable energy. However, their implementation in the market is still not universal and is limited by some obstacles and limitations. The following are some key challenges faced by flexible solar cells in the market.

Flexible solar cells are still not as efficient as rigid solar cells. Compared with rigid solar cells, flexible solar cells are less efficient, so it is more difficult to generate a lot of electricity. Inefficiency also means that more batteries are needed to store the right amount of electricity. At the same time, flexible solar cells use more precise materials and more complex manufacturing technologies, which makes them worse in durability and applicability than traditional solar cells. Another great challenge is the durability, because environmental conditions can easily damage the structure. Damaged devices will reduce energy output, and some materials used in the production of flexible batteries are easily degraded over time, thus further limiting their performance [11]. The cost of mass production of flexible solar cells is still higher. Companies that produce flexible solar cells still have high manufacturing costs, which limits their competitiveness in the market. Flexible solar cells need high-performance batteries to store the energy they generate. However, the cost of these batteries has not yet become an affordable cost for large-scale implementation. And solar cell manufacturing companies must also meet regulatory challenges. Regulations make it challenging to establish a large-scale solar cell manufacturing industry with economies of scale [12].

Solving these limitations will probably bring more economical, durable and low-cost technologies for mass production, so that consumers can obtain these technologies at any time.

6. Conclusion

Flexible solar cells have great potential in a wide range of applications because of their light weight and flexibility, including wearable electronics, medical and building materials. The development of these devices has been focused on improving their efficiency, durability and cost-effectiveness, while exploring new materials and manufacturing processes. Researchers are also studying the integration of these batteries with energy storage systems to improve their reliability. Furthermore, the research on higher conversion efficiency and higher applicability in the flexible solar cell industry has become the development goal of the new flexible solar cell industry in the new era. From the material base to the processing technology, every part is developing hard.

However, the commercialization and mass production of flexible solar cells still face challenges such as scale, stability and standardization. Nevertheless, driven by the increasing demand for renewable energy and the shift to sustainable development, the global flexible solar cell market is expected to grow in the next few years.

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