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Research on Preparation and Progress of Two-Dimensional Perovskite Solar Cells

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Abstract: Two-dimensional perovskite solar cells are considered as the most promising new type of solar cells due to their unique advantages such as strong spectral absorption, low cost, adjustable composition, excellent structure, excellent photoelectric characteristics and simple preparation through various processes. This paper will briefly introduce the structure and principle of two-dimensional perovskite solar cells, and introduce the research progress of top electrode materials in detail, including improving the preparation method of metal top electrode materials, repairing and introducing buffer layer and cathode intermediate layer for interface modification. High-performance perovskite solar cells use lead-containing perovskite materials as the light absorbing layer. Even if the device packaging process is perfect, lead-based perovskite materials still have the possibility of causing pollution to the environment, especially when the battery is damaged or the failed solar cells are improperly recycled. Therefore, in this paper, we can obtain high-quality perovskite films by improving the preparation process, solvent engineering and annealing engineering.

Keywords: Two-dimensional perovskite, Solar cell, Preparation and progress.

1. Introduction

With the increasing demand for energy, a lot of energy is consumed, and energy shortage has become an important factor restricting economic development. Countries all over the world pay more and more attention to energy security. Among many kinds of renewable energy, solar energy is undoubtedly the most promising. First of all, solar energy is widely distributed on the earth. Photoelectric conversion is one of the most effective ways to utilize solar energy resources. In short, it is to use solar energy to generate electricity and convert solar energy into electricity. Solar cells are an effective medium for this transformation process. Solar energy is a renewable and pollution-free energy source, which can be converted into electric energy by solar cells. Among them, monocrystalline silicon cells have high efficiency and good stability, but the preparation process of devices is complicated, the time period is long and the cost is high. Amorphous silicon battery has low preparation cost and market price, but its photoelectric conversion efficiency is low. Polysilicon battery, on the other hand, combines the advantages of the above two kinds of batteries, with considerable market price and high photoelectric conversion efficiency, and provides people with the energy they need [1]. It is important that the semiconductor material of perovskite solar cells has an appropriate band gap. Semiconductors with different band gaps only absorb part of solar radiation energy to produce electron-hole pairs. The smaller the band gap is, the usable part of the solar spectrum will be absorbed, and at the same time, the amount of energy wasted near the peak of the solar spectrum will be greater.

At present, there are two main ways to apply solar energy technology: one is to directly convert solar energy into other forms of energy, such as solar cookers and solar water heaters based on photothermal action; Another common application is to use photoelectric conversion technology to convert solar energy into electric energy and then into other forms of energy for utilization. The most common photoelectric conversion device is solar cell [2-3]. Perovskite solar cells have obvious development and application prospects because of their unique advantages such as strong spectral absorption, low cost, adjustable composition, excellent structure, excellent photoelectric characteristics and simple preparation through various processes, and are considered as the most promising new solar cells [4]. In this paper, the structural principle of perovskite solar cells will be briefly introduced, and the research progress of top electrode materials will be introduced in detail, including improving the preparation method of metal top electrode materials, repairing and introducing buffer layer and cathode intermediate layer for interface modification. The stability of two-dimensional perovskite solar cells and the prospect of commercialization of two-dimensional perovskite solar cells are also discussed.

2. Structure and Principle of Two-dimensional Perovskite-type Solar Cells

2.1. Crystal structure of two-dimensional perovskite materials

Compared with other components in two-dimensional perovskite materials, the top electrode usually receives less attention. However, the excellent performance of perovskite solar cells cannot be separated from the role of the top electrode. A good top electrode material can simultaneously improve the photoelectric performance and long-term stability of the device. The basic structure of a two-dimensional perovskite type solar cell consists of five parts: a transparent conductive glass, an electron transport layer, a perovskite active layer, a hole transport layer, and a counter electrode. In recent years, researchers have obtained efficient and stable new perovskite-type solar cells from the perspective of new battery structure design. Under the action of a built-in electric field, electrons and holes move to the N-type and P-type semiconductor sides, respectively, and charge accumulates at the battery poles to generate a photogenerated voltage. Once the external circuit is connected, there can be power output. The electron/hole transport layer material directly contacts with the calcium titanate layer to improve the efficiency of carrier extraction.

During the preparation of perovskite materials, auxiliary reagents are used to extract the solvent of perovskite precursor solution, thus accelerating the precipitation of perovskite materials, so as to form a perovskite film with uniform surface and high density. Because the preparation process of planar perovskite-type solar cells is simple and the preparation temperature is low, planar structure is generally used in flexible perovskite-type solar cells[5-6]. The perovskite-type solar cells with planar structure can be produced in a large area by the roll-to-roll process. This kind of battery creatively carries out light absorption and carrier transmission in different functional layers, greatly reducing the probability of carrier recombination in the device. However, this kind of battery also has many problems such as unstable sensitizer, poor light absorption and high price.

2.2. Working principle of battery

When the perovskite solar cell device operates under light, the perovskite thin film photoactive layer absorbs the photons with energy higher than the semiconductor gap width. The valence band electrons absorb enough energy and then jump to the conduction band. At the same time, holes are formed in the valence band, resulting in electron-hole pairs. Since the perovskite layer has the bipolar effect of producing electron hole pairs and transmitting electrons, the photoelectric conversion efficiency of perovskite type solar cells without electron transmission layer can also achieve more than 14% [7]. Under the irradiation of sunlight, the perovskite absorption layer converts the exciton into an electron-hole pair, in which the electron moves to the transparent bottom electrode through the electron transport layer, and the hole moves to the top electrode through the hole transport layer, and finally forms a closed circuit under the external wiring, and finally generates a current. Figure 1 shows the structure of two-dimensional perovskite solar cells.

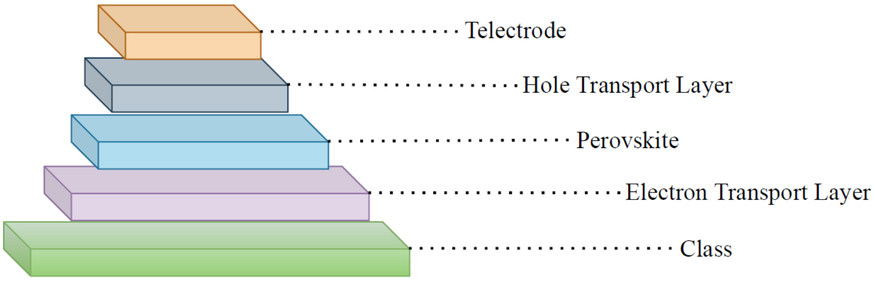

Figure 1. Structure diagram of two-dimensional perovskite solar cell

It shows good light transmittance and absorption rate in the visible light wavelength range; Its energy level position matches that of perovskite layer, which improves carrier mobility and can hinder hole transmission. The efficiency of this kind of solar cells has been continuously broken through, but the liquid electrolyte used in this kind of solar cells will dissolve and decompose perovskite materials, making the internal light absorption layer extremely unstable, which leads to the extremely short life of the device[8]. Therefore, if we want to further improve the stability of solar cells, the key point is to find a substitute for liquid electrolyte.

3. Preparation of Two-dimensional Perovskite-type Solar Cells

3.1. Preparation of electron transport layer

In the structure of two-dimensional perovskite-type solar cells, the main role of the electron transport layer is to extract and transport electrons from the perovskite-type photoactive layer, and block the injection of photogenerated holes in the perovskite-type photoactive layer. The excited electrons are transferred from the perovskite layer to the electrode. Therefore, the conduction band should be smaller than the conduction band of perovskite and larger than the conduction band of the electrode to facilitate the capture of electrons [9]. While improving efficiency, researchers also focus on simplifying the structure of solar cells and reducing the preparation cost. The traditional vapor phase method for preparing perovskite thin films has a uniform and dense shape, but this method has high instrument costs and cannot be prepared at low temperatures, which limits its development towards flexibility.

Then comes the solution spin-coating method, which has become the most common and common method to prepare perovskite through continuous research, development and optimization, from one-step method to two-step method and then to wash the solvent. Compared with traditional three-dimensional organic-inorganic hybrid perovskite, due to its organic interlayer, two-dimensional perovskite materials not only have excellent humidity stability, but also can inhibit the ion migration inside the perovskite materials, thus alleviating the decomposition of perovskite materials and electrode corrosion caused by ion migration, which greatly improves the stability of perovskite solar cells [10].

3.2. Preparation of two-dimensional perovskite absorption layer

Morphology design of two-dimensional perovskite materials is an important condition for obtaining efficient perovskite solar cells. The morphology and crystallinity of perovskite films directly affect the light trapping efficiency and short-circuit current density. At present, high-performance perovskite solar cells all use lead-based perovskite materials as light-absorbing layers. Even if the packaging process of devices is perfect, lead-based perovskite materials will still cause environmental pollution, especially when the batteries are damaged or the failed solar cells are improperly recycled. Therefore, in this chapter, high-quality perovskite films are obtained by improving the preparation process, solvent engineering and annealing engineering.

3.2.1. Optimization of preparation process

The low crystallinity of two-dimensional perovskite films will reduce the generation of charge carriers and increase their defect state density. Therefore, by optimizing the preparation process of perovskite thin film, we can prepare large grain, no pinhole, uniform perovskite thin film, and then obtain efficient and stable perovskite type solar cells. At the same time, it also plays the role of blocking the hole, so that the hole cannot be compounded through, and the valence band of the electrode should be smaller than that of perovskite. For perovskite materials, they will slowly decompose into. This problem can be improved by packaging technology, so it is not the biggest problem hindering the commercialization of perovskite solar cells.

For perovskite, due to the existence of internal defect states, light and heat will become catalytic factors to accelerate the degradation of the material itself. The biggest difference between two-dimensional perovskite materials and traditional three-dimensional perovskite materials is the spatial structure. Due to the insulation of long-chain organic amines and the conductivity of perovskite material conductor layer, the natural multi-weight quantum well structure as shown in Figure 2 will be formed. The perovskite layer acts as a "trap", and the long-chain organic amine acts as a "wall". Due to the existence of this quantum well structure, the quantum confinement effect will be formed, resulting in the increase of the internal binding energy of two-dimensional perovskite materials.

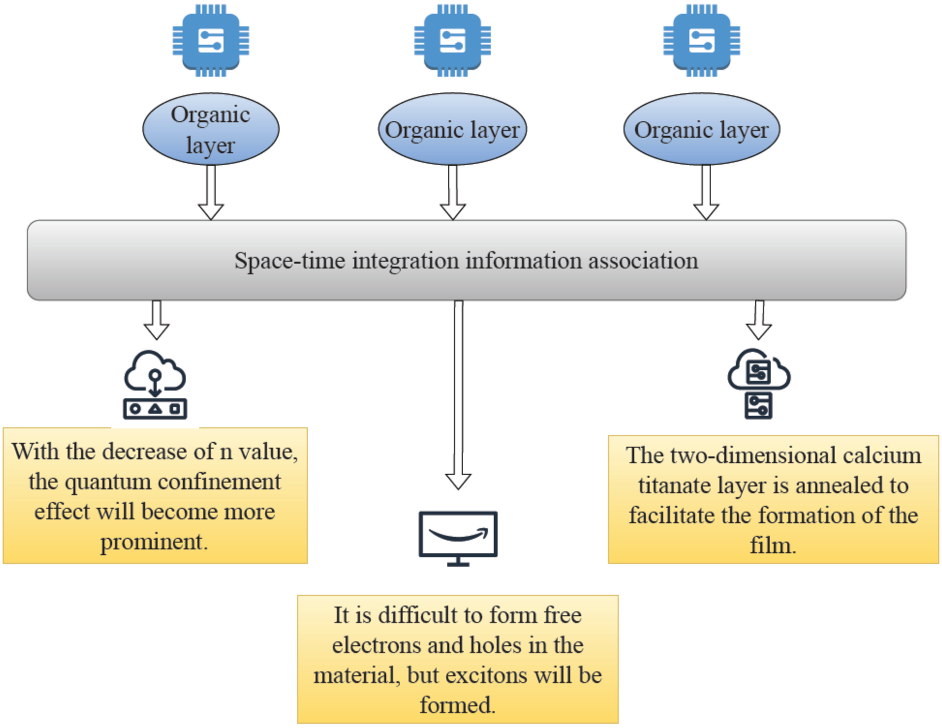

Figure 2. Schematic diagram of two-dimensional perovskite quantum well structure formation

The value of n in two-dimensional perovskite is calculated by the composition of precursor solution, but the purity of the phase in two-dimensional perovskite thin films prepared by this solution ratio is not high. High-quality lead iodide passivated perovskite thin films were obtained by adding hydroiodic acid directly into lead iodide solution and then spin-coating the samples in methylamine atmosphere. The content of lead iodide can be adjusted by adjusting the ratio of hydroiodic acid to lead iodide, and these lead iodide can be located at the interface of perovskite grains, which can effectively passivate and effectively improve the electron transport performance of perovskite films.

3.2.2. Solvent engineering

Optimizing the nucleation effect in the process of preparing perovskite thin films by liquid phase method and improving the smoothness of perovskite thin films and battery performance have become a hot spot. The crystalline quality and morphology of perovskite thin films were improved by solvent engineering, and both hot casting method and vacuum-assisted deposition method belong to one-step improvement methods. The hot casting method was first introduced by Tsai in 2016. Compared with the traditional one-step method, this method needs to preheat the substrate to a certain temperature before spin-coating the two-dimensional perovskite precursor solution, and then spin-coating annealing to form a film. By optimizing this process, the performance of two-dimensional perovskite solar cells has been greatly improved. Using mixed solution as solvent can improve the internal carrier transport ability of two-dimensional perovskite materials, thus improving the device performance of solar cells. The preparation of perovskite thin films usually requires thermal annealing process to promote perovskite crystallization, so perovskite thin films with excellent photoelectric properties can be obtained by optimizing thermal annealing process, thus improving battery efficiency.

4. Conclusions

In recent years, perovskite-type solar cells have been favored by scholars at home and abroad because of their high absorption coefficient and high charge carrier mobility. By passivating the interface defects of the perovskite top electrode, improving the work function and increasing the specific surface area. At present, the maximum efficiency of perovskite-type solar cells has reached 25.1%, which has exceeded the efficiency of amorphous silicon cells and is comparable to the efficiency of polycrystalline silicon cells. The crystal growth direction perpendicular to the substrate is conducive to charge transmission, and is the guarantee of the photoelectric conversion performance of two-dimensional perovskite-type solar cells. The content of lead iodide can be controlled by adjusting the ratio of hydroiodic acid to lead iodide, and these lead iodides can be located at the interface of perovskite grains, which can effectively passivate and effectively improve the electronic transmission performance of perovskite films. The poor stability of perovskite-type solar cells hinders its commercialization. Although the packaging process of the cells can improve the stability of the cells, it also increases the production cost of perovskite-type solar cells. With the continuous deepening of research, the performance of calcium oxide mine batteries has continuously improved. Currently, they have performance comparable to other types of solar energy. Through improving their stability and photoelectric conversion efficiency, they have promoted their widespread application.

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