Comparison and Analysis of the third generation of the solar cells

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Abstract: Since the current energy crisis, the efficiency of using solar cell energy has become increasingly important. In order to get a high efficiency, new kinds of solar cells would be needed, which called the third generation of solar cells. This paper review three kinds of solar cells, including the perovskite solar cells, the quantum dots solar cells and the organic solar cells. Firstly, the structure of perovskite solar cells is composed of a FTO conducting glass, a TiO2 blocking layer, a TiO2 mesoporous layer, a perovskite layer, a HTM (Hole Transport Material) layer, and mental electrode. Then, I sum up the manufacture and the development of the perovskite solar cells. Secondly, this paper analysis the structure, manufacture, and development of quantum dots solar cells. The structure of quantum dots solar cells includes the transparent conducting oxide, wide bandgap oxide semiconductor film, quantum dot sensitizer, electrolyte, and counter electrode. The third one is the organic solar cells. The structure of the organic solar cells includes layer, cathode, anode, and transparent substrate. Finally, this paper reviews the merits and defects of each solar cells.

Keywords: The third generation of the solar cells, Perovskite, Quantum dots, Organic.

1. Introduction

Solar energy is becoming the increasingly important power around the world. It can be a solution to face the current energy crisis and environment pollution. There are three generations in the development of solar cells. The first generation is the silicon solar cells. The second generation is the membrane solar cells and the third generation is the highly-effective solar cells. However, the third generation's solar cells are still in the laboratory, and many researchers are trying to bring this kind of solar cells into every family's home. This article is the review about perovskite solar cells, quantum dots solar cells and organic solar cells. In the content of the perovskite solar cells, I sum up the structure of perovskite solar cells, which is composed of a FTO conducting glass, a TiO_2 blocking layer, a TiO_2 mesoporous layer, a perovskite layer, a HTM (Hole Transport Material) layer, and mental electrode. Besides, I also sum up the manufacture of the perovskite solar cells, which includes the acid corrosion of FTO layers, spin coating the FTO layers with TiO_2, producing the HTM and making electrodes. I also write about the development of the perovskite solar cells. In the future, researchers are finding the low-cost way to produce ETM and HTM layers. In the second part, I sum up the quantum dots solar cells. The structure of quantum dots solar cells includes the transparent conducting oxide, wide bandgap oxide semiconductor film, quantum dot sensitizer, electrolyte and counter electrode. The manufacture of the quantum dots solar cells includes producing the light positive electrode and quantum dots. The development of quantum dots solar cells includes optimizing the producing process of the quantum dots and researching the new-type quantum dots material. In the third part, I sum up the organic solar cells. The structure of the solar cells includes layer, cathode, anode and transparent substrate. The manufacture of the organic solar cells mainly includes the corrosion and cleaning of ITO glass, spin coating of PEDOT: PSS, annealing, spin coating of organic active layer and the vapor deposition and annealing of metal electrode. In the last part, I introduce the merits and defects of these three different kinds of solar cells. This article reviews three of the third generation solar cells, introduces the structure, manufacture and development of them, and finally sums up the merits and defects of them.

2. Perovskite solar cells

2.1 The structure of perovskite solar cells

The structure of the perovskite crystal is ABX_3 structure. In this structure, A ion located in the center of a unit cell. There are 12 X ions around A ion located in the middle point of the side of the cubic and 8 B ions around A ion located in the point of the cubic [1]. The structure is shown in figure 1.

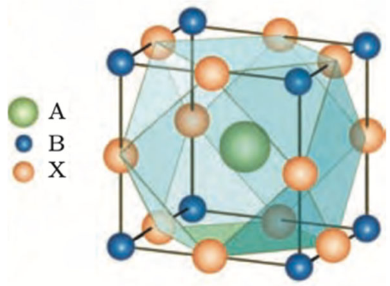

Figure 1 The structure of the ABX_3

The structure of the perovskite solar cells is composed of a FTO conducting glass, a TiO2 blocking layer, a TiO2 mesoporous layer, a perovskite layer, a HTM (Hole Transport Material) layer, and mental electrode. The structure is shown in figure 2.

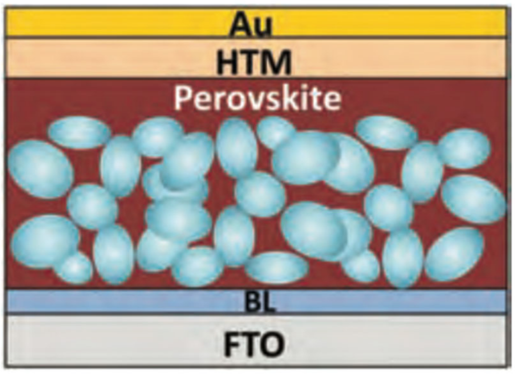

Figure 2 The structure of the perovskite solar cells

In a perovskite solar cell, the TiO2 BL forms a Schottky barrier potential, which can effectively stop electrons from flowing from FTO to TiO2, and holes from flowing from HTM to FTO.[1] The perovskite acts as an absorbing layer, which is very important in solar cells. Perovskite crystal has a high absorbing coefficient and almost perfect crystallinity, reducing the combination of the carriers. HTM (Hole Transport Material) can have a good contact with the perovskite layer, achieving a better hole transformation. In order to get a good device efficiency, which is about 20%, HTM would be essential to achieve this, but HTM is quite expensive and very difficult to synthesize. Therefore, the perovskite solar cells without HTM layer are produced. In 2012, Etgar's group proved that the perovskite layer can not only act as a light absorbing layer, but also as a function of transforming holes. And Han and his group successfully produced no-HTM perovskite solar cells, whose efficiency achieved 12.8% [2]. However, it can be seemed that the efficiency of no-HTM perovskite solar cells is much lower than the efficiency of HTM perovskite. That is mainly because of the poor ohm contact between the perovskite layer and electrode layer, which causes large amounts of recombination.

In addition to the mesoporous structure, perovskite solar cells have the plain heterojunction structure. Compared to the mesoporous structure, the plain heterojunction structure is simpler and still has a good efficiency. The mesoporous structure is composed of the glass, ITO electrode, HTM layer, perovskite layer, ETM layer and negative electrode [3]. The difference between two different kinds of structure is that there is no complex mesoporous part in the plain heterojunction structure's layer. Using the simple plain structure can also get high efficiency in a lower cost. Due to the fact that the simple plain structure cannot have complex structure, the manufaction of the perovskite layer becomes quite important. Michael Gratze and his group used PEDOT:PSS to form a continous membrane, which helps increase the efficiency of the perovskite layer.

2.2 The manufacture of perovskite solar cells

The first step is to process the FTO base. Using acid to corrode part of the FTO in the surface and cleaning FTO by ultra-sonic cleaning method. The second step is to produce TiO2 blocking layer. Spin coating the FTO with the TiO2 precursor solution, and annealing it in 500 Celsius Degree. In the third step, using spin coating to produce the perovskite layer. After spin coating PbI_2 on the base of TiO2 blocking layer, soaking it in the perovskite solution for 10mins. After drying and annealing, we can have the perovskite layer. The fourth step is to produce the HTM. Spin coating the material solution over the perovskite layer and get the membrane of HTM. The fifth step is to make electrode. Putting the device into the membrane deposition machine and produce the electrode in a high pressure.

In these five steps, the manufacture of perovskite has many ways, such as one-step method, two-step method, evaporation method and CVD method. The method I mentioned above is the two-step method, which could control the surface shape of the perovskite membrane. The one-step method is the most used method, which mixes the PbX_2 and CH_3NH_3I, solves them in the DMF solution and then, spin coats it to the base. In the evaporation method, researchers control the composition of perovskite membrane by controlling the evaporation speed of PbI_2 and CH_3NH_3I, making the surface of the membrane more even.

2.3 The development of perovskite solar cells

In the future, finding low-cost, good performance ETM, HTM layers and simplify the structure of solar cells would be a goal of researching. For example, some researchers used ZnO, Al_2O_3, ZrO_2 to substitute TiO2 to acting as the blocking layer, or used CZTS(Cu_2ZnSnS_4) to substitute spiro-OMeTAD which is quite expensive to acting as HTM layers [4].

Besides, producing the solar cells with efficiency and modifying the synthesize method to manufacture the solar cells in a large area would also become a main goal in future study, which require people to have a deeper understanding about the material's properties.

3. Quantum dots solar cells

3.1 The structure of quantum dots solar cells

The structure of quantum dots includes the transparent conducting oxide, wide bandgap oxide semiconductor film, quantum dot sensitizer, electrolyte and counter electrode.The transparent conducting oxide, wide bandgap oxide and semiconductor film can also be called light positive electrode [5]. The solar cells are just like sandwiches. The structure is shown in figure 3.

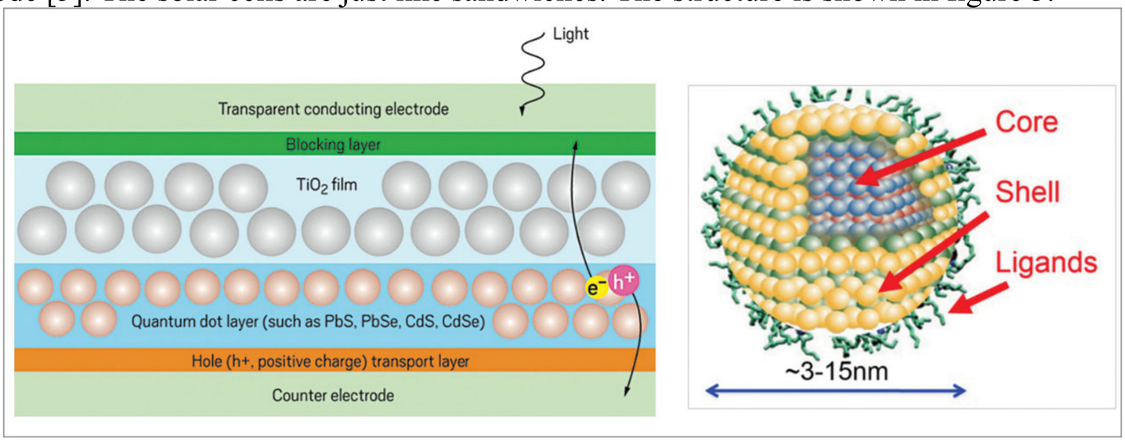

Figure 3. The structure of quantum dots solar cells

The transparent conducting oxide can collect electrons and act as a carrier of the light positive electrode. It has a high light transparency and great conductivity. In the process of making quantum dots solar cells, FTO(Fluorine doped Tin Oxide) and ITO(Indium doped Tin Oxide) are often used to produce TCO(transparent conducting oxide).

Wide Bandgap Oxide Semiconductor Film mainly acts as the function of the resistor sensitizer and transport the electrons. Normally, we use TiO_2, ZnO and SnO_2. TiO_2 has the strong ability to be against the corrosion of acid and alkali, great optic stability. It also can be easily controlled in the process of manufacture and without any poison. Therefore, TiO2 becomes the most popular material. Quantum Dot Sensitizer act as the function of absorbing light in solar cells. Therefore, the absorbing range of the spectrum should be very large. There are many kinds of quantum dot sensitizers, like CdS, CdSe, CdTe, PbS. Electrolyte includes many oxidizing and deoxidizing process, mainly using electrons and holes to construct the whole circuit. Besides, electrolyte should have great optic and thermal stability. Counter Electrode is mainly used to catalyze electrolyte, so it needs to have a great catalysis property [6]. The popular counter electrode has Cu_2S, Pt, CoS and Au.

3.2 The manufacture of quantum dots solar cells

Firstly, we need to produce the light positive electrode, which includes the FTO's cleaning, making the solution, and manufacture of the membrane. The second step is the process of producing quantum dots. There are mainly two different ways to produce the quantum dots.

The first method is to use the precursor solution, like Successive Ionic Layer Adsorption and Reaction and Chemical Bath Deposition. SILAR soaks light positive electrode in the precursor solution of positive and negative ions, enabling quantum dots to have a in-situ growth, which could achieve a high coverage in the membrane. In CBD method, researchers directly put membrane into the precursor with both positive and negative ions. Besides, the temperature, concentration, pH, and reaction time would influence the synthesis of the quantum dots. The second method is to synthesize quantum dots colloidal particle previously, then link it to the surface of oxide. This method could effectively control the size and shape of the quantum dots, increasing the potential property of quantum dots. It can be seemed that every method has its own advantage. Therefore, some researchers combine two different methods. Y. L. Lee and his group used colloidal particle firstly, then used SILAR to produce CdSe quantum dots, which increased the efficiency of the solar cells [7].

3.3 The development of quantum dots solar cells

The manufacture method of the quantum dots and the synthesis condition would affect the positive electron, so optimizing the producing process of the quantum dots would be very important. The positive electron structure could directly influence the loading of quantum dots, transformation of charge and recombination. By optimizing the design of positive electrode, we could improve the property of solar cells.

New-type quantum dots' development is also the focus of researching. By developing new kinds of quantum dots, we can absorb light in a wider spectrum and get higher efficiency. Besides, the most popular semiconductor material, like Cd, Pb, would cause serious environment damage, so many researches focus on synthesizing environmental-friendly quantum dots material.

In the future, instead of TiO_2, Wide Bandgap Oxide Semiconductor Film may be made from ZnO, which has higher chemical and thermal stability. And the electrons' life in ZnO is longer. ZnO has a higher electron density, and is easier for the growth of nanowire because of its crystal structure, which could increase the transformation speed and collection speed of the electron at the same time, and also can lower the recombination between electrons and holes. Although the nano particle could largely increase the surface area of the material, it cannot be good for the transformation of electrons, because this structure would cause serious charge recombination. Therefore, many researchers started to build 1-D nano structure (nano wire) to increase the transformation ability. P. V. Kamat and his group succeeded to grow 1-D TiO_2 nano bar structure vertically on the transparent conducting oxide, showing the slower recombination speed [8].

4. Organic solar cells

4.1 The structure of organic solar cells

Organic polymer solar cells are composed of photoactive layer, cathode, anode and transparent substrate. The structure is shown in figure 4.

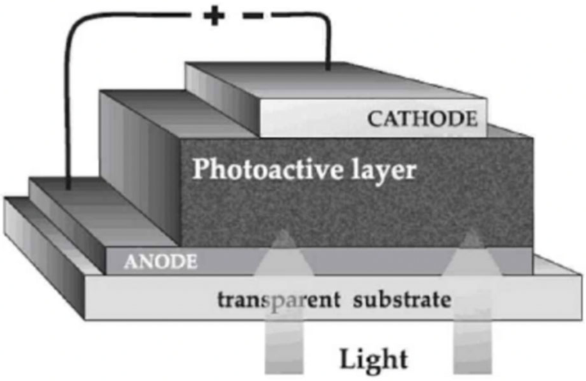

Figure 4. The structure of organic solar cells

When the solar cells are working, photoactive layer absorbs light and complete the transformation from light photon to electron. After that, in the build-in electric field, the electrons are transferred to electrodes and give energy to the outer circuit. The carriers' transformation in most organic material is one direction, so one-layer Schottky structure's carriers is quite unbalanced. In order to improve the transformation ability of carriers, we introduce the two-layer solar cells structure. This kind of structure puts electron acceptor and donor between two electrodes.

Compared to Schottky structure, although two-layer structure has a higher transformation efficiency, it has a low composite and mobility. And the manufacture of this structure is also quite complex [9]. Bulk heterojunction's structure is like this: Anode/ MDMO-PPV: C60/cathode. In the structure, acceptors and donors would be disperse from each other, which could solve the short diffusion length of exciton in polymer materials. Besides, if one of material has the ability to form film, there is no need for researchers to produce it in vacuum, which simplified the manufacture process of the device. Diffusion two-layer heterojunction solar cells are between the two-layer heterojunction and bulk heterojunction. The structure is shown in figure 5.

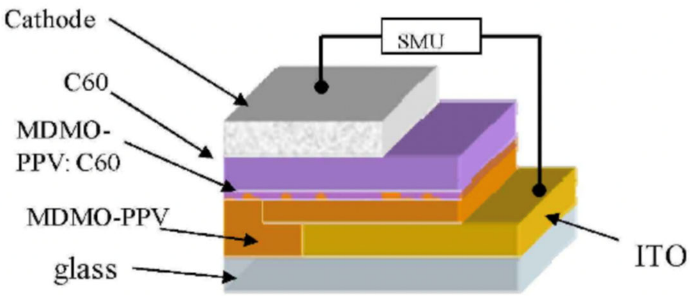

Figure 5. The structure of diffusion two-layer heterojunction solar cells

Firstly, it has a two-layer structure, which is the acceptor and donor. But in the interface, these two materials also combine with each other. This kind of structure could not only have large area of interface, but also have the transformation tunnel to transform continuous current. However, this structure doesn't have a high efficiency, so it's not popular for this kind of solar cells.

4.2 The manufacture of organic solar cells

The organic solar cells' manufacture mainly includes the corrosion and cleaning of ITO glass, spin coating of PEDOT: PSS, annealing, spin coating of organic active layer and the vapor deposition and annealing of metal electrode. The corrosion of ITO glass is using insulation to stick the 13mm*25mm part in the middle, and put it into the mixture solution of 37% H_2SO_4 solution and deionized water [10]. After that, using ultrasonic to clean the impurity, oil and some organic impurity. The second step is to produce the PEDOT: PSS cushion layer. It has a good conductivity and a great stability. The researchers spin coat the PEDOT: PSS to the ITO glass, and anneal it on the heating station. In the third step, the organic small molecule often uses vacuum vapor deposition to produce membrane. In order to get even thickness, the vapor deposition's speed should be stable. The property of the material would also influence the quality of the membrane.

Annealing method is to control the surface shape of the membrane, improve the transformation ability of carriers. Researchers put it into the vacuum bake oven to reduce the water and other solution on the membrane and then, increase the temperature to anneal the sample. The mental electrode is made from vapor deposition. Firstly, researchers put battery sample into the vacuum room. Secondly, using 10% NaOH solution to erase the oxide layer. Then, open the recycling water and start to extract vacuum. When the evaporation speed and thickness become stable, the vapor deposition would start. The package of organic solar cells would very important, because organic solar cells are very sensitive to the light, oxygen, and water vapor. Besides, the active layer material would be oxidized and therefore, their carriers' ability to transformation and efficiency would slow down.

4.3 The development of organic solar cells

The organic polymer solar cells' material is always big molecule polymer, which requires polymer to have wide spectrum and high absorption efficiency, and have great ability to form membranes. The mainly acceptor material is PCBM, which has low LUMO potential level, and high electron mobility. However, its absorption in visible light is quite low. In order to overcome this drawback, researchers use other materials (derivation) to replace PCBM as the acceptor material. The core of the organic device is the organic semiconductor. Many researchers use doping method to increase the conductivity and thermal stability. Alivisatos and his group in UCB used CdSe semiconductor as the acceptor, mixing it with P3HT to produce polymer solar cells [11].

From 1990s, the researches based on organic big molecule become develop fast. Fullerene and its derivative are great electron acceptor, but the lower ability to be solved limits its process to be applied into polymer solar cells devices. Chang and his group used MEH-PPV and PCBM as active material to manufacture the solar cells. However, C_{60} and its derivative's absorption ability is quite low around the spectrum of visible light, so some donor materials which have great ability to absorb light should be chosen. PVV and its derivative are also studied very much and often act as donors. The most representative material is MEH-PPV, which has a good solubility. MEH-PPV has a high hole mobility but low electron mobility.

Although the efficiency of organic solar cells is up to 6.77%, but compared to mature non-organic solar cells' efficiency, the organic solar cells' efficiency is still quite low [12]. Combining organic and non-organic material to improve the comprehensiveness property of solar cells would become the future of solar cells' researches.

5. Comparation of three different solar cells

5.1 The merits of different solar cells

Perovskite solar cells can have a high absorption coefficient, high carrier mobility, high exciton diffusion coefficient and can be manufacture in low temperature. Perovskite solar cells have a high efficiency to transform from light to electric power. Its low cost, good flexibility and transparency enable it to attract great attention around the world. Its unique defection gives perovskite solar cells abilities to present both n-type and p-type properties.

Quantum dots solar cells have become the hot pot around the world. Firstly, the absorption spectrum can be changed by controlling the size of particle and chemical composition, which could change from visible light to ultrared rays. They have a great chemical stability and are easy to produce. Besides, their ability to absorb light is quite strong. In theory, the efficiency of quantum dots to transform light can achieve as 44%, so they have great development potential [13]. As a '0-demention' material, carbon quantum dots can not only have the light ability and small size, but also have a great solubility, low poison, and a great conductivity.

Organic solar cells have the advantage of low cost, simple procedures to produce and light weight. Besides, organic solar cells have a great flexibility and are easy to form membrane. Their produce can in a low temperature condition. Organic solar cells also have the potential to manufacture in a large area and are easy to carry, which can be used in watches and laptops. More importantly, they are beneficial to the environment.

5.2 The defects of different solar cells

Perovskite solar cells have stability problem, which mean that their efficiency would decay largely in the atmosphere. There is many Pb which has a great solubility and could cause environment problems. Besides, the most popular way to produce perovskite solar cells is using spin-coating, which cannot produce large area and continuous membranes at the same time. People are still lack of deep understanding about the physical principle in a microscopic view.

Carbon quantum dots solar cells' principle still cannot be explained thoroughly. Although the theoretical efficiency can be up to 44%, there is still no perfect structure to achieve this number.[10] The development of quantum dots solar cells is now mainly around improving their efficiency and stability, which including the choosing of material, the process of manufacture and the optimization of device.

The organic solar cells can be classified into two catalogs, which are big molecules and small molecules. Big molecules don't have a stable shape, making carriers difficult to move between molecules, lowing the efficiency. Small molecules have a poor solubility in many organic solutions, so making this kind of solar cells requires the vacuum condition, which is high cost and difficult to gain large area of results.

6. Conclusion

In this article, there are three different kinds of third generation solar cells introduces. The first is the perovskite solar cells. Its structure is composed of a FTO conducting glass, a TiO2 blocking layer, a TiO2 mesoporous layer, a perovskite layer, a HTM (Hole Transport Material) layer, and mental electrode. The acid corrosion of FTO layers, spin coating the FTO layers with TiO2, producing the HTM and making electrodes are the steps needed to manufacture the perovskite solar cells. The second is the quantum dots solar cells. The structure of quantum dots solar cells includes the transparent conducting oxide, wide bandgap oxide semiconductor film, quantum dot sensitizer, electrolyte, and counter electrode. The manufacture of the quantum dots solar cells mainly includes producing the light positive electrode and quantum dots. The third is the organic solar cells. The structure of the solar cells includes layer, cathode, anode, and transparent substrate. The manufacture of the organic solar cells mainly includes the corrosion and cleaning of ITO glass, spin coating of PEDOT: PSS, annealing, spin coating of organic active layer and the vapor deposition and annealing of metal electrode. In this article, I write the review of the third-generation solar cells, including the perovskite solar cells, quantum dots solar cells and organic solar cells.

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