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Research on solar cells based on electron transport layer

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Abstract. In today ' s world, the energy crisis and environmental pollution are becoming more and more serious. As a renewable energy, solar energy has become one of the important means to meet the global energy demand. Making solar cells using volt effect is an effective way to convert solar energy into electricity. In order to employ solar photovoltaic power generating technology with high efficiency and cheap cost, new solar cell research and development is being done. Among them, organic solar cells are considered as one of the promising solar photovoltaic technologies because of their light weight, simple preparation process, good flexibility and easy to achieve large area processing. While perovskite solar cells are developed in a high speed in recent year because of their simple production and long service life. The urgent problem in this field is further improve the energy conversion efficiency of solar cells. In order to solve these problems, we study the structure principle and electron transport layer of solar cells, and get solutions by analyzing these problems.

Keywords: solar cell, electron transport layer, PSCs, OSCs.

1. Introduction

Since the beginning of the 21st century, with the continuous growth of the world's population, the acceleration of industrialization and urbanization, the speed of energy consumption is getting faster and faster. In the case of less and less non-renewable energy reserves of coal, oil and natural gas, solar energy -- a huge and inexhaustible new renewable energy has been widely concerned by the industry. Today, the most common way to harness solar energy is through solar cells.

So far, solar cells can be divided into three generations, the first generation of solar cells for silicon-based solar cells. With its mature technology and high photoelectric conversion efficiency, it has found a huge 89% share in the photovoltaic market. However, due to its high production cost, its application in mass production is limited. The second generation of solar cells are thin film solar cells. It had the same problems as the first generation. The third generation of solar cell is a new type of solar cell emerging in recent years, such as perovskite solar cells. It has the advantages of low cost and simple preparation, but its conversion efficiency needs to be improved.

The electron transport layer (ETL) is an important part of improving solar cell efficiency. The energy level of the perovskite absorption layer should meet the function of the electron transport layer, which has the qualities of high electron mobility and high light transmittance. Currently, there are two main categories of electron transport materials: metal oxides and organic compounds.

Metal oxide electron transport materials have many advantages, for example adjustable band width, high transmittance and strong carrier transport capacity. It is widely used in all kinds of solar cells. At present, the common metal oxide electron transport materials are mainly TiO_2、ZnO、SnO_2.

Due to the fact that organic electron transfer materials' semiconductor photoelectric characteristics may be changed by altering their chemical structure, they exhibit superior moisture resistance and flexibility than metal oxide layers in organic compounds. Such as PCBM, FDDI, CPE...

In summary, both metal oxides and organic molecules have certain benefits, it is possible to mix the two in the future. The efficiency of solar cell can be further improved. This research is based on the electron transport layer to study solar cells.

2. Literature review

Solar cell is a kind of photoelectric semiconductor chip, also known as ' solar chip ' or ' photocell ', which uses solar light to generate electricity directly. In the case of the circuit, it may output voltage and create current instantly as long as it matches specific lighting requirements. In physics, solar photovoltaic (PV) is referred to devices that use photoelectric or photochemical processes to transform light energy directly into electricity. In a solar cell, the light absorption layer absorbs sunlight to generate electron hole pairs, which are separated and exported to the electrode through the electron and hole transport layer respectively. The conduction and composite rate of electrons and holes in the transport layer affect the current density and voltage of the cell, thus affecting the photoelectric conversion efficiency of the cell. The electron and hole conduction and recombination rate are mainly determined by the type, crystallinity and defect density of the transport layer material. So the electron is one of the important contents in the research of solar cell materials.

In 2009, Miyasaka [1] et al. first applied TiO_2 mesoporous nanoparticles in the electron transport layer of perovskite solar cells to assist the extraction and transmission of charge, and obtained a photoelectric conversion efficiency of 3.8% battery components. Lakhdar [2] carried out studies on using TiO_2 as the electron transport layer of Ge based planar perovskite solar cells, and achieved a power conversion efficiency (PCE) of 13.5%. In 2013, Kumar et al. [3] applied nanostructured ZnO as a transport layer in perovskite solar cells for the first time and obtained 8.9% PCE. In 2014, Kim [4] prepared ZnO electron transport layer by low temperature sol-gel method. By adjusting the thickness of ZnO layer, the PCE obtained was 16.4%. In 2019, Yun [5] used SnO_2 nanoparticles to prepare a uniform electron transport layer for perovskite solar cells, which showed ideal short-circuit current, open-circuit voltage and filling factor, and the highest photoelectric conversion efficiency reached 19.0%. Chen's research group [6] used two types of polymers PBTI and PDTzTI as ETL due to their high electron mobility and well-matched energy level arrangement and interface trap/defect passivation. Devices with PDTzTI ETL showed 20.86% optimal PCE. In 2019, Chaudhary et al. [7] studied the application of TiO_2 in THE $CH_3NH_3PbBr_3$ perovskite photodetector, and the results show that the device based on the planar TiO_2 electron transport layer has high photocurrent, response rate and photoelectric conversion efficiency.

3. Discussion

3.1. Electron transport layer of organic solar cell

Organic solar cells (OSCs), or organic photovoltaic cells (OPVs), consist of an absorbent layer of organic materials. Compared with inorganic solar cells, it has low cost, the thickness of thin, light quality, simple manufacturing process, the sunlight absorption band is adjustable, can be made into large area the advantages of flexible components, has wide development and application prospects, has become the new material and new energy fields today one of the most dynamic and vital research frontiers.

Principle of solar cell

(1) Exciton production - light absorption process

Under the solar radiation, the organic photoactive layer absorbs photons, when the photon energy ($h\nu$) is greater than the energy gap of organic materials (Eg), the organic photoactive layer material absorbs the energy of photons, making electrons jump from the highest occupied molecular orbital (HOMO) orbital to the lowest unoccupied molecular orbital (LUMO), and form holes on the HOMO. The result is an electron-hole pair that binds each other, called an exciton

(2) Exciton diffusion

In general, an effective electron acceptor is required in organic photovoltaic devices to assist electron transfer in strongly binding excitons, that is, the donor/acceptor (D/A) interface usually exists in organic cell structures. The difference in LUMO energy levels between the two materials at the interface forms a built-in electric field that drives the transfer of charge in the exciton

(3) Dissociation of excitons (charge transfer and separation)

In organic solar cells, excitons formed in donor materials at D / A interface can be separated. The energy level transfer between donor LUMO and acceptor LUMO provides the force needed to overcome the exciton binding energy, which belongs to the excited state energy transfer. The force required to separate the excitons generated in the receptor material is provided by the energy transfer between the HOMO of the donor and the receptor, specifically the ground state energy transfer. Because the interface between the donor and acceptor is where this energy transfer-induced exciton dissociation takes place, the configuration of these two materials in the active layer is essential for the device's efficient operation. Electrons can be moved to the reception material and then taken to the cathode charge collection after being separated.

(4) Carrier transport

In OPVs, overcoming binding energies (Frenkel excitons range from 0.3 to 1 eV) and separating tightly bound excitons into free carriers has been considered a critical challenge for achieving high optical currents. After photoinduced charge transfer at the end of the interface, charge dissociation occurs and free charge is obtained, in which the hole is transferred at the interface and transported to the positive pole, while the electron is transported to the negative pole. When the carrier mobility is lower than 10^{-4} cm^2 V^{-1} S^{-1}, the charge transport to the electrode will recombine, resulting in photocurrent loss, resulting in a lower short-circuit current of OPVs.

(5) Collection of charge

The holes are transferred at the interface and collected at the positive electrode, while the electrons are transferred to the recipient material and transported to the negative electrode for charge collection.

The electron transport layer of an organic solar cell is also unique because of how it works. In organic solar cell devices, the electron transport layer can form ohmic contact with the active layer to promote electron transport, thus improving the PCE of OSCs. Conjugated polyelectrolytes (CPEs), non-conjugated polyelectrolytes (N-CPEs), small molecules] and inorganic - organic hybrid compositions can be used as electron transport layers in organic solar cells

Among them, metal oxide, as a new ETL material in OSCs, has high optical transparency, excellent charge transfer performance, low price and abundant storage, which can effectively reduce the manufacturing cost of OSCs. At present, the research of OSCs electron transport layer is mainly focused on zinc oxide (ZnO), and the efficiency of more than 7% has been achieved in OSCs devices based on PTB7-TH: PC71BM active layer system.

3.2. Electron transport layer of perovskite solar cell

In order to solve the problem of solar cell consumption. In 2009, a solar cell based on perovskite structure ($CH_3NH_3PbX_3$, X is the halogen element) has attracted worldwide attention. There are many kinds of compounds satisfying the structure of perovskite, and hybrid metal halide perovskite materials are emerging in the field of solar cells. A typical three-dimensional (3D) perovskite is composed of three main ions, the chemical formula is ABX3, where the A site is A monovalent cation with A large radius, such as inorganic metal ions Cs^+, Rb^+, and organic ammonium ions $CH^3NH_3^+$ (MA). The B site is usually composed of divalent metal cations of smaller radius (e.g. Pb_2^+, Sn_2^+, Ge_2^+, Mg_2^+, Ca_2^+, Sr_2^+, $Cu_2^{+,}$ Ni_2^+, etc.), and X is the halogen anion (e.g. I^-, Br^-, or Cl^-).

Perovskite solar cells (PSCs) are based on DSSCs and OPVs. The PSCs developed based on DSSCs are generally called formal N-I-P structure, while trans-P-I-N structure is PSCs based on OPVs.

Mesoscopic PSCs are developed based on DSSCs through research. It consists of glass substrate, transparent conductive oxide, dense electron transport layer, mesoporous electron transport layer, perovskite photoelectric conversion layer, hole transport layer and back contact electrode. In subsequent developments, researchers found that even after the removal of the mesoporous electron transport layer, PSCs still showed excellent photoelectric conversion performance, and thus derived the planar formal PSCs structure, the trans-P-I-N structure PSCs is developed on the basis of OPVs, and OPVs are similar in structure.

Because perovskite solar cells have a series of advantages such as low cost, simple preparation process, flexible, transparent and laminated cells, it has been developed rapidly.

To improve the efficiency of perovskite solar cells, the researchers used a variety of methods. By substituting solid hole conduction material spiro-Meotad for liquid electrolyte, the problem of dissolution of perovskite spot adsorbed on TiO_2 surface in iodide and iodide based liquid electrolyte was solved. The efficiency of the solar cell was increased from 9.7% to 25.5% by using perovskite material assembled with mixed cations and halogen anions instead of pure $MAPbI_3$ devices.

4. Conclusion

The working principle, structure and composition of organic solar cells and perovskite solar cells are studied in this paper. By analyzing their principle and composition structure, we get their advantages, which makes us have an understanding of the present stage of solar cells.

For perovskite solar cells, it is a new type of stable solar cell. However, there is still a long way to go for affordable Internet access of PSCs, and many problems still need to be solved. Based on my understanding of this field, I put forward some prospects for future research of PSCs:

(1) In PSCs, the interface is accompanied by the recombination of carriers, and the extraction efficiency and transport capacity of electrons and holes in PSCs can be further improved through interface regulation, thus reducing the recombination of carriers. This also guarantees high efficiency and high stability.

(2) The industrialization of PSCs requires a process that can prepare perovskite film in a large area. At present, it is difficult to prepare perovskite film in industrial application. Therefore, in the future, it is more necessary to combine the development of industrial technology to prepare high-quality perovskite film in a large area.

(3) Considering that Pb commonly used in perovskite is a toxic heavy metal, there is a crisis to the environment and human health. At present, the performance of pure Sn perovskite photovoltaic devices has been greatly improved, but the preparation of perovskite materials based on Cu, Fe, Bi and other metal elements and the performance of photovoltaic devices need to be further studied. Therefore, the development of some metal elements rich in nature and harmless to the environment to replace Pb is also an important direction of the development of perovskite materials in the future.

For organic solar cells, the main problem is that their photoelectric conversion efficiency and lifetime have not been a great breakthrough, which limits the wide application. In order to solve these two key problems, people have tried various methods, such as looking for new organic semiconductor materials, new structures and so on.

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