Theoretical analysis and comparison of Third Generation Solar Cells

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Abstract: Under the condition that the traditional energy is continuously exhausted, the new round of energy crisis has formed a hot topic of discussion. So nowadays lots of scientists are devoted to recyclable energy area and solar cell, a kind of clean and recyclable energy, has become an academic which is worth studying. Solar cell has experienced major revolution for three times and now we have entered the era of the third generation of solar cells. In this essay, we firstly introduce three kinds of the third generation of solar cells in details then we get the conclusion that quantum dot is the most suitable and promising material to produce and doing further research for the third generation of solar cells by using some scientific manners and comparing their advantages and disadvantages. We hope that some drawbacks of quantum dot solar cell can be improved and practical quantum dot solar cell can be successfully manufactured in the following study.

Keywords: Third Generation Solar Cells, perovskite solar cells, Quantum dot solar cells, dye-sensitized solar cell.

1. Introduction

Because of the explosion of population in the world nowadays and the running-out trend of traditional energy, scientists now are trying to take advantages of every recyclable energy to meet the basic demand of energy for people. And Solar cells, related to recyclable energy area, have developed swiftly with the effort made by scientists. It is common knowledge that PN junctions can generate photovoltaic effect, and semiconductors can be used to produce solar cells [1]. Solar cells have influenced our daily life greatly: they have become the important long-term energy for aerospace field. Solar cells are also widely applied for some devices on streets, for example, they become the main power supply for unmanned weather stations, household power, street lamps and monitoring equipment. The development of solar cells has undergone three generations of big changes. The first generation of solar cell is made of crystalline silicon and it is the most commonly used nowadays because of its simple manufacturing technique and its considerable conversion efficiency (generally 15%-25%) [2]. However, due to the application of crystalline silicon, there is limited space for lowering its weight and cost. The thin films' solar cells are all classified as the second generation of solar cells and they are all made on glass substrates. Although its materials and manufacturing technique are very cheap, its conversion efficiency is very low(generally 6%-10%)[3].

Now we have entered the era of the third generation of solar cells, and target is to improve the conversion efficiency, decline the cost and enhance its function for more convenient application. In the following paragraph, we firstly discuss three materials applied for the third generation of solar cells in chapter 2-4.We will express their backgrounds, structures, working principles, advantages and drawbacks , significant researches and future development in details. We will compare their functions by using scientific methods and analyzing their advantages and disadvantages to pick out which material is the most suitable and promising for producing and doing research for the third

generation of solar cells [4].Our essay will help researchers to find the material which is most worth studying and clear researching target of the third generation of solar cells.

2. Perovskite solar cells

2.1 Present situation

Perovskite is a kind of material structure with great optical electrical conversion efficiency, which has been widely used with high attention. The perovskite structural materials have been greatly applied in the third generation solar cells, and its related area has been becoming more and more popular not only the raising awareness of developing recyclable energy in face of population explosion, but also the Perovskite structure has strong designability and perovskite solar cells have huge potential to be developed.

It is estimated in the industry that the conversion efficiency of perovskite solar cell devices using new materials can reach about 50% in the future, which is about twice as big as that of commercial solar cells at present. With the continuous improvement of conversion rate, perovskite photovoltaic cells are expected to usher in large-scale commercial applications. Some experts predict that it is possible to achieve gigawatt level mass production of perovskite photovoltaic around 2025.

2.2 Structure

Figure 1 demonstrate the structure of perovskite crystal and perovskite crystal becomes the most well-known material for making light-absorbing layers for perovskite solar cell because of its simple manufacturing process and low cost. The chemical formula of perovskite crystal is ABX3,where A refers to organic cation and CH3NH3+ is the most commonly used, and B refers to meat lion(i.e: Pb2+ or Sn2+) and X is Halogen group(i.e: I-;Cl-;Br-). In the structure shown in Figure 1,mental ion B locate in the center of the whole structure, organic cation A occupies all cube vertexes and X sets in the middle of all faces of cube, compared to the structure gathering A,B,X in one lines or faces, The structure of perovskite crystal is more stable, which will benefit the diffusion and drift of carriers.

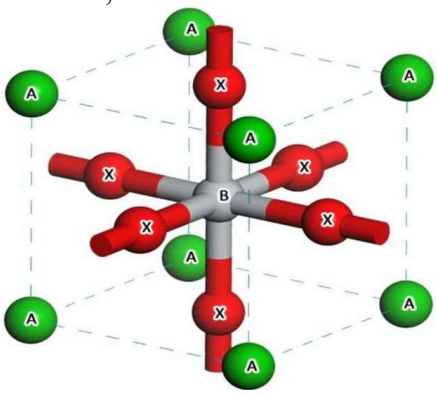


Figure 1.the structure of perovskite crystal

As shown in figure 2, one of the most common the perovskite solar cells with pore structure is mainly composed of: Glass substrate; FTO conductive glass; TiO2 layer; Perovskite layer; Spiro-OMeTAD; IZO; Voltage [5].

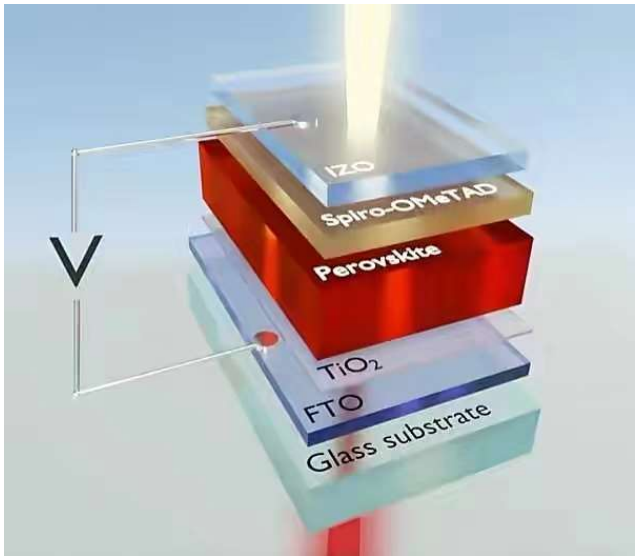


Figure 2. the structure of perovskite solar battery

2.3 Working principle

When the surface of the perovskite solar cells are exposed to the sunshine, the perovskite structure will firstly absorb photons and electron-hole pairs will be generated, these carriers will become free carriers or form excitons. What is more, these carriers have a long diffusion length and lifetime.

In the second step, the electron transport layer and hole transport layer will respectively gather these electrons and holes which fail to recombine, which means that the electrons from previous perovskite structure are transported to the electronic transport layer, Then, they will be collected by FTO conductive glasses, which is doped with fluorine and SnO2, FTO conductive glasses have greater functions compared to ITO conductive glasses used in previous perovskite solar cells. In the meantime, the holes from perovskite structure are transported to the hole transport layer, and metal electrode will collect these holes. Finally, the photoelectric current is gained by linking the circuit of FTO conductive glasses and metal electrode together. The working principle can be seen in figure 3. It is unavoidable that the processes of transporting carriers will get a little damage because of the carriers' losses, the main causes can be concluded by the following reasons like (1) the reversible recombination of electrons and holes (2) the case of non-compact perovskite structure. It is clear that the carriers losses will definitely and badly influence the output efficiency of perovskite solar cells. So if we want to enhance the whole efficiency of this type of solar cell , some ways needed to be figured out to minimize the losses of the carriers[6].

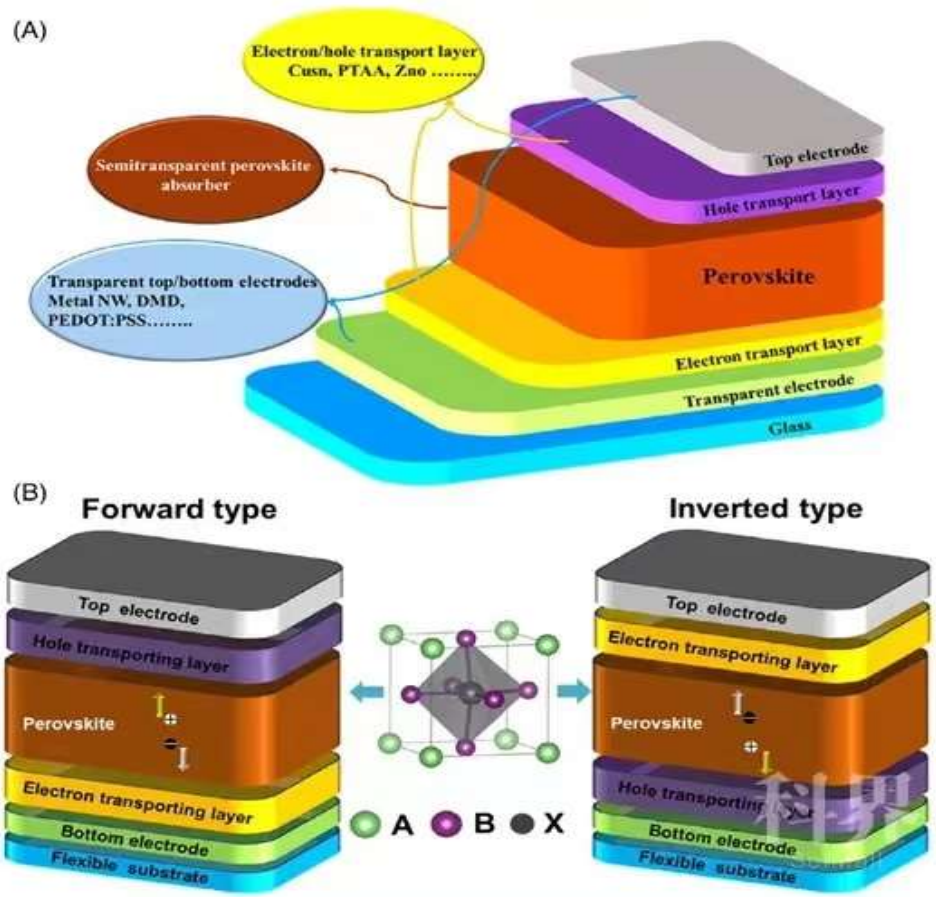


Figure 3. The working principle of perovskite solar cells

2.4 The drawbacks and future

Firstly, the perovskite solar cells contain poisonous materials which may do harm to its production staff because some perovskite battery contain Pb2+. Secondly, the working condition of the most perovskite solar cells are unstable, Pb2+ in perovskite can be easily oxidized and volatilized, and it can be easily divided when the perovskite crystal meets water. If perovskite solar cells are applied to generate electricity, some harmful materials will infiltrate into roof or soil and pollute the environment. Last but not the least, the working efficiency of the most perovskite solar cells is extremely low compared to that of traditional silicon solar cells which have mature technology, the short life and huge carriers losses are the main cause of low working efficiency of perovskite solar cells and this problem remains to be handled [7].

Researchers from the NREL have made key technological breakthroughs and built a perovskite solar cell with dual advantages of high efficiency and high stability. The research results have been published in the journal Nature recently in 2022.The researchers said that the newly developed perovskite solar cell has a photoelectric conversion efficiency of up to 24%[8], which is the highest in similar reports, and also has stability. After 2400 hours of operation at 55, the battery can still maintain 87% [8] of its original efficiency.

3. Quantum dot solar cells

3.1 Present situation

Solar energy is a renewable resource with great potential, but because of the high cost of solar cells, relying on solar energy to generate electricity can't compete with other power generation methods. However, in recent years, with the rise of quantum dot technology, quantum dot solar cells have become the research focus of solar cells in the world. Quantum dot solar cell is a new type of cell with

quantum dots (inorganic semiconductor nanocrystals) as light absorbing materials. Quantum dots are tiny semiconductor particles with a size of several nanometers. [9]The unique ability of quantum dots to interact with light makes scientists think that quantum dot material structure has the opportunity to make the cost of solar power generation at the same level as that of fossil energy power generation.

3.2 Structure

Quantum dots (QDs) are important semiconductor materials. Their three-dimensional dimensions are less than twice the Bohr radius of excitons in related semiconductor materials. Its shape is usually spherical or nearly spherical, and its size is between 2 and 20 nm. When the energy from a specific electric field or a certain amount of light pressure is obtained for a quantum dot, the electrons in the quantum dot will be excited to release light of a specific frequency. Because the size of the quantum dot can change the frequency of the emitted light excited, the color of light can be controlled by changing the size of this nano semiconductor. This nano semiconductor with the properties of limiting electrons and electron holes is called quantum dot [9].

It should be pointed out that either materials smaller than 100nm are quantum dots, and the real critical dimension depends on the Fermi wavelength of electrons in the materials. A quantum dot is called when all three dimensions are less than one Fermi wavelength.

Taking the metal enhanced quantum dot solar cell with p-i-n longitudinal layered structure as an example, as shown in Figure 4, from the bottom up, the first is a 300 nm thick GaAs substrate and a 60 nm thick metal reflective layer, followed by a four cycle quantum dot composite layer, where the quantum dot is a GaAs cone with a height of 80 nm, and the top and bottom radii are 20 nm and 40 nm respectively; The thermal barrier layer is 80 nm thick AlGaAs, followed by 80 nm thick E-type AlGaAs and 20 nm thick cross grid metal gratings. The grating at the top of the enhanced solar cell is a periodic structure formed by digging cross on the metal gold layer, and the width of the dug cross grid is 960nm [10].

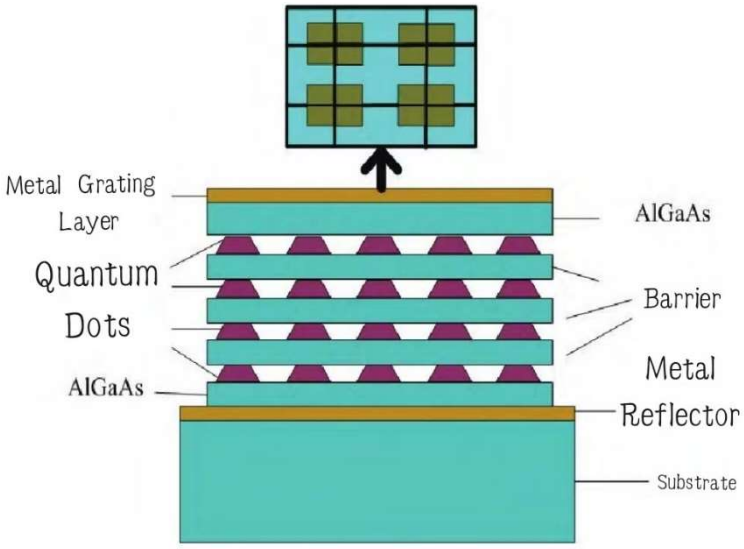


Figure 4. Metal enhanced quantum dot solar cells

Figure 5 shows the structure of the conventional quantum dot solar cell. The main part is the same as the enhanced quantum dot solar cell, but the difference lies in their different electrodes. The ring electrode introduced into conventional quantum dot solar cells only serves as a memory link; The metal grating and metal reflector introduced by metal enhanced solar cells not only have the role of electrode connection, but also use the surface plasmon effect and secondary reflection to enhance the solar cell absorption.

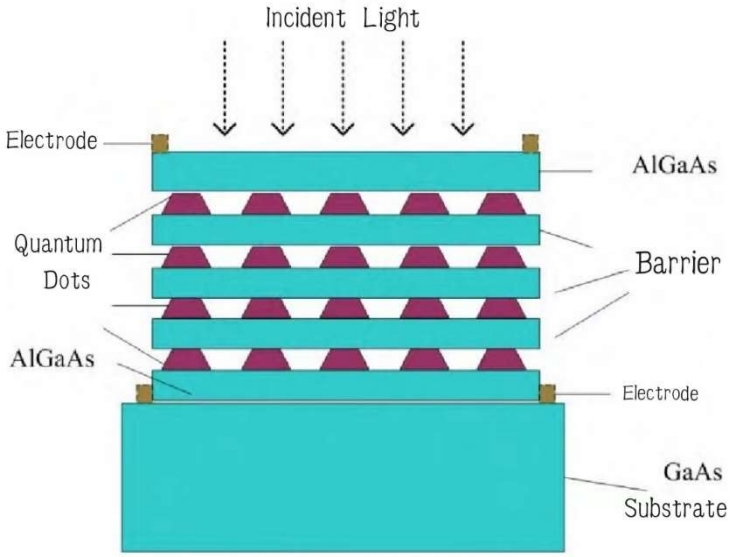


Figure 5. Conventional quantum dot solar cell

3.3 Working Principle

The properties of quantum dots are between bulk semiconductors and discrete atoms or molecules. They have different photoelectric characteristics from LED particles, and their photoelectric characteristics will change with the change of size and shape. When a quantum dot is irradiated by light above a certain frequency, once the electrons inside the quantum dot absorb enough energy, they can leave their atoms and move around the nanoparticles continuously, forming a conductive band, in which the electrons can freely pass through the material and conduct electricity.

Schottky solar cells, quantum dot sensitized solar cells, organic-inorganic heterojunction solar cells, depletion heterojunction solar cells, ultra thin-layer solar cells, and bulk heterojunction solar cells are the primary categories of quantum dot solar cells at the moment.

Three components make up a QDSC: a counter electrode for depositing quantum dots, an electrolyte, and a photoanode. Its working principle is similar to that of DSCs. As shown in Figure 6, in the light condition, when quantum dots collide with photons, they absorb enough energy and are excited to generate electron hole pairs and separate, the excited electrons quickly flow into the TiO2 conduction band and are collected by the external circuit, the holes of quantum dots are reduced to the ground state by the electrolyte, and the electrolyte receives the electrons flowing from the external circuit at the opposite electrode to complete regeneration, thus completing a cycle [9].

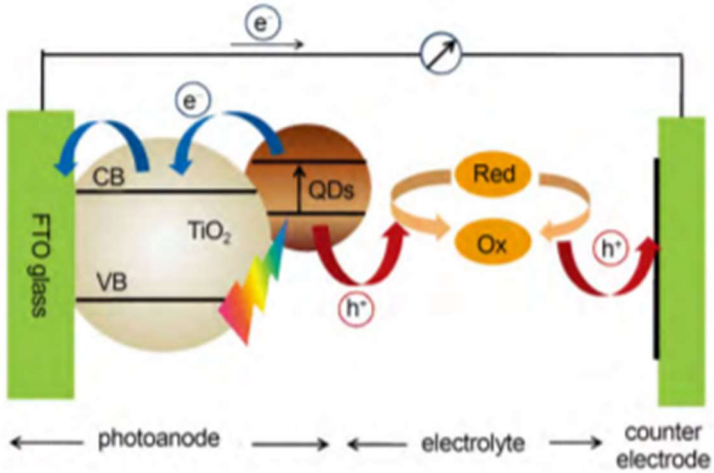


Figure 6. Structure and working principle for the QDSC

Photoelectric conversion is mainly completed through three interfaces: (1) interface between quantum dots and metal oxide semiconductor; (2) Interface between quantum dots and electrolyte (3)

interface between electrolyte and counter electrode. Specifically, the photo anode is composed of a wide band gap semiconductor oxide (TiO2, SnO2, ZnO) film with a mesoporous structure and quantum dots deposited on the film;

3.4 The drawbacks and future

Advantages is as follow: (1) Because the light absorption range can be changed by adjusting the composition and size of particles, its light absorption range is extremely large, including visible light to infrared light; (2) Very stable chemical properties; (3) the synthesis process is simple, and the synthesis cost of light-absorbing materials is low; (4) Because the extinction coefficient and intrinsic dipole moment are high enough, the light absorption layer of quantum dot battery can be made extremely thin, which can further reduce the manufacturing cost of the battery; (5) Compared with bulk semiconductor materials, quantum dots are easier to match the energy levels of electron donor and acceptor materials [11].

Disadvantages is as follow: (1) In vivo imaging technology of quantum dots has been continuously optimized and improved, but the sensitivity of fluorescence imaging technology to deep tissues in vivo is low; (2) Metal-organic chemical method for preparing nanoparticles has harsh preparation conditions, complicated reaction steps, high reagent cost and high toxicity; (3) The inertia of quantum dots in vivo, that is, the long-term toxicity to organisms, remains to be verified.

Quantum dot solar cells have an incalculable potential worth and plenty of room for growth. However, there is currently no functional solar cell and the quantum dot battery research is still in the early stages of theoretical discussion and fundamental study. The efficiency and stability of quantum dot solar cells are the main areas of attention for research and development. Theoretical studies demonstrate that the energy conversion efficiency of quantum dot solar cells developed and produced by using quantum dots with notable quantum confinement effect and discrete spectral characteristics as active regions can be significantly improved, and its limit value can reach about 44% [11].

Although this practical solar cell with super high conversion efficiency has not yet been made, a large number of theoretical calculations and experimental studies have confirmed that quantum dot solar cells will show great development prospects in the future solar energy conversion. Most people are optimistic about the future of perovskite solar cells, and believe that researchers will find the best solution to replace the existing technology. But if you ask when it can come, many things are uncertain.

4. Dye-sensitized solar cell

4.1. Present situation

The dye-sensitized solar cell (DSSC) is an efficient model of an efficient PV cell. This model is an efficient model of a dye-sensitized solar cell (DSSC), which is an efficient model of an efficient PV cell. A transparent oxide (TCO) is usually used on a glass, conducting a transparent oxide (FTO). A nano-porous film is formed by porous nano-size TiO2 particles of about 10 microns in thickness (about 10 ~ 20 nm). Then a layer of dye is coated and attached to the TiO2 particles. Ruthenium polypyridyl complex (Ruthenium polypyridyl complex) is usually used as dye. In addition to using a transparent conductive layer and TCO, the upper electrode is also coated with a layer of platinum as a catalyst for the electrolyte reaction, and the interlayer electrode is filled with Iodide/Triiodide electrolyte. Although the current maximum conversion efficiency of DSSC cells is around 12% [12], the manufacturing process is simple, so it is believed that the cost of production can be reduced even more and the same amount of power can be generated at a lower cost. TCO is a transparent conductive layer that also lessens the energy that light absorbs as it passes through. The majority of commercially available PV systems are based on inorganic materials, which have significant material needs, expensive preparation processes, and energy requirements. Dye sensitized solar cell and semiconductor light absorption and charge carrier transport task has epoch-making difference compared to the conventional solar cells, conventional solar cells materials have specular absorption ability and at the same time demanding carrier transport capacity, and dye-sensitised cells separated

the light absorption and charge carrier transport tasks, Therefore, the only need is to find materials with strong light absorption capacity and materials with strong carrier transport capacity separately. In short, DSSC is an excellent solution to energy problems.

4.2. Structure

The structure of dye-sensitized solar cells consists of five parts :(1) the outer frame of transparent conductive oxide material; (2) wide bandgap semiconductor thin film（generally TiO2）; (3) sensitizers attached to wide bandgap semiconductors; (4) electrolyte (generally iodide ion); (5) Electrodes capable of REDOX reactions (generally Platine), The structural framework is shown in Figure 7.

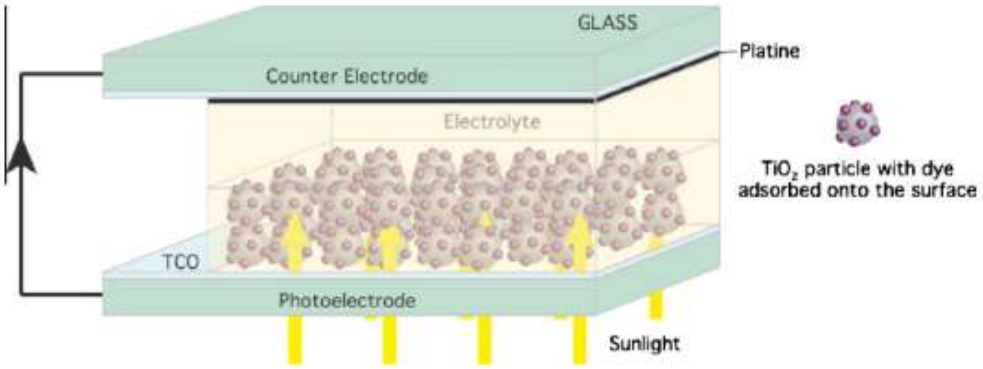


Figure 7. Schematic diagram of dye-sensitized solar cells

4.3 Working principle

The Working diagram of dye-sensitized solar cell is posted in Figure 8.The first process is the sensitizer X absorbs photons of incident light. It causes the sensitizer X to be excited as X* , The excited sensitizer subsequently introduces an electron into the wide bandgap semiconductor's conduction band, changing its state to an oxidized state. The sensitizer's injected electrons then penetrate the semiconductor conduction band to the electrode contact and travel across the external load circuit to the opposite electrode as the electrolyte is being consumed.

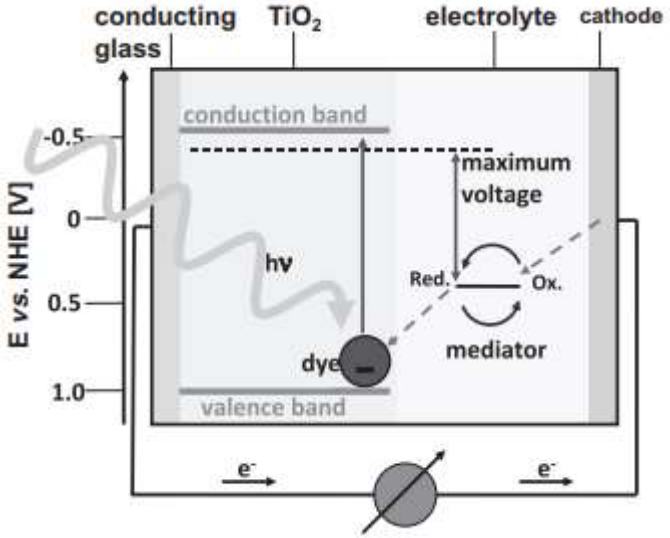


Figure 8. Working diagram of dye-sensitized solar cell

Next, we discuss the dye-sensitized cells efficiency. The level of optimization and compatibility of the aforementioned procedures determines the total efficiency of dye-sensitized solar cells, especially how dyes and semiconductor films react under various lighting. Large surface area and semiconductor film thickness are important for achieving high efficiency, however the modifications needed to meet the aforementioned criteria will surely significantly increase the dye load, which then results in

effective light collection. However, an important feature of the device is the conversion efficiency (IPCE) between photons and current. The sensitizer's ability to absorb light can be compared when devices of the same structure are used. According to the formula below, it is calculated as the sum of the photons absorbed by the incident light as a function of the excitation wavelength divided by the number of electrons produced by the light flowing in the load circuit[13]. Through theoretical analysis, we can find that the open-circuit voltage of dye-sensitized solar cells is mainly determined by the electron transport distance in the REDOX pair, and the main way to develop more efficient dye sensitizers is to improve the efficiency of electron transport and recombination channels.

From what we know above, we can conclude that there are two core elements that determine the performance of devices :1. Photophysical properties of sensitizer 2. Electrochemical properties of sensitizer. The maximum open-circuit voltage is theoretically specified by the oxidation potential, and the short-circuit current of the system is theoretically dictated by the sensitizer's optical absorption properties. One more point: the entire electron transport kinetics will decide the theoretical loss.

4.4 The drawbacks and future

At present, the actual photoelectric conversion efficiency of dye-sensitized solar cells has exceeded 15%, but there is still much room for improvement for large-scale industrial applications. The improvement direction mainly focuses on the upgrade of dye sensitizer. At present, the more common improvement scheme is to improve the charge binding efficiency of oxide, so as to improve the value of open circuit voltage. At present, the most novel material is DSC, which mainly makes use of the diffuse reflection effect in the process of light absorption, making its indoor and outdoor photoelectric conversion efficiency due to traditional silicon solar cells. At present, DSC materials have also been widely used in integrated photovoltaic buildings.

5. Conclusions

In the previous paragraph, we mainly introduce three kinds of the third generation of solar cells in details, It can be learned from the paper that perovskite solar cell doesn’t have obvious advantages and it has the following drawbacks: containing harmful substance like Pb2+;unsteady working condition and extremely low working efficiency. Thus perovskite solar cell is not be recommended . When it comes to Dye-sensitized cell, it has many unique advantages over traditional solar cells, such as the separation of the two core processes of energy conversion, which makes the material requirements less demanding; long service life, service life up to 15-20 years; simple structure, making the production process and large-scale industrial production easy. However, compared with traditional solar cells, DSSC still has several disadvantages: the conversion efficiency of DSSC is lower than that of silicon-based solar cells, and the dye excited state life and the photoelectric conversion efficiency is still not very significant. The quantum dot solar cell introduced in chapter 3 has lots of obvious advantages: extremely large light absorption range; stable chemical properties; simple synthesis process and low synthesis cost of light-absorbing materials; thin light-absorbing layer; quantum dots can more easily match the energy levels of electron donor and acceptor materials compared with bulk semiconductor materials. Since the quantum dot solar cell doesn’t have fatal drawbacks and it has more advantages over disadvantages. The quantum dot solar cell is recommended as the major material for the third generation of solar cells. In the following research, we hope that some drawbacks of the quantum dot solar cell can be improved such as improving the sensitivity of fluorescence imaging technology for deep tissues in vivo and metal-organic chemical method. Besides, practical quantum dot solar cell can be produced and its working efficiency and stability can be further improved with some scientific and technological means.

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