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Research into Fabrication and Popularization of Organic Thin Film Solar Cells

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An analysis was conducted herein on the research status of several popular solar cells at the present stage, including silicon solar cell, thin film photovoltaic cell, and dye-sensitized solar cell (DSSC). In doing so, we concluded that the current situations provide a favorable objective environment for the popularization of organic thin film solar cells. Finally, we reviewed the merits and demerits of the organic thin film solar cell together with the major research focus on and progress of it, and summarized obstacles to and development trails of the popularization of organic thin film solar cells.

1. Introduction

As the energy crisis further deepens in the 21st century, the existing development level for solar cells has already failed to satisfy increasing social demands for energy. This phenomenon is mainly reflected in the costly high-purity silicon solar panels, in the defects at new amorphous silicon (a-Si) during energy conversion, and in the limited theoretical energy conversion efficiency (around 25%) of silicon solar panels as well. As a result, there emerge bottlenecks for development of traditional silicon solar panels. Recently, along with the progress of materials science, mounting new thin film photovoltaic cells has been developed and applied for practical use. The organic thin film solar cell draws the attention of researchers accordingly. Characterized by low cost, strong plasticity, and simple fabrication, organic polymers have gradually been highly praised by research staffs for its performance in the realm of solar cells (Aissa et al., 2015; Bernardo et al., 2016; Giuliante et al., 201).

2. Research status in the solar cell field

Silicon materials, including conventional high-purity silicon, new-type a-Si, and new-style polycrystalline silicon (poly-Si), are mainly applied for fabrication of solar cells at the current stage. Crystalline silicon solar panels have helped silicon solar cells that are equipped with them gain international popularity in the solar cell field with such advantages as relatively high energy conversion efficiency which reaches 20% for monocrystalline silicon of single material and 15% for poly-Si, respectively (Ruiz-Vega et al., 2015). However, the disadvantages of elaborate manufacturing techniques and high cost restrict the application of silicon solar cells to satellite, aerospace industry, and other national high-tech domains. In this connection, there is still a long way towards commercialization for silicon solar cells to go. One of the present studies on silicon solar cells is reducing development and manufacturing cost. Through research into the development status of domestic silicon solar cells, Zhang (2011) a Chinese researcher, suggested to reduce cost by thinning silicon wafers or by broadening the surface of silicon crystal. It is his expectation that the cost will have dropped to one third of the present one for over ten years, followed by the reduction of solar power generation cost to as similar as the cost of conventional energy generation. Therefore, to his understanding, it is likely that solar power acts as the source of daily power supply. Moreover, Zhang found out through research that the addition of foreign substances (Er, a rare earth element, for instance) helped improve the energy conversion efficiency of solar cells.

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Given that the fabrication of silicon solar cells has high cost and theoretical energy conversion limits, more and more researchers and scholars turn their attention to studies on thin film solar cells which mainly contain a-Si thin film solar cells, CdTe solar cells, GaAs solar cells, Cu (In, Ga) Se2 solar cells (CIGS, for short), and Nano-crystalline TiO2 DSSC (Leonardo, 2014).

Despite lower conversion efficiency than crystalline silicon and monocrystalline silicon, as well as the disadvantage of light attenuation, a-Si thin film solar cells are deemed to be put into large-scale application in the human society due to the simplicity and low cost for its fabrication. Actually, among various thin film solar panels of nations which have been brought into real production for now, a-Si thin films have achieved mass production by and large. As there are some flaws in silicon thin film solar cells, Zhong predicted the future trend of corresponding technical progress from three perspectives:

(1). Access to high quality thin films by controlling surface reactions;

(2). Development of alloy materials absorbing broader solar spectra, so that silicon thin film solar cells have larger maximum energy conversion efficiency;

(3). Research into solar cells of composite materials, of a-Si and poly-Si for example, such that the advantages of all the materials can be taken (Zhong, 2001).

CIGS, another commonly-used thin film solar cell, has less energy conversion efficiency than silicon thin film solar cells (Ferioli and Coudun, 2011). However, with stable performance and reliable resistance to light attenuation, CIGS is studied and used all over the world. By analyzing the characteristics of CIGS, Zhuang and Zhang (2004) revealed several advantages of it:

(1). Thanks to the thickness as small as around 2μm, CIGS thin films have a relatively large range of spectrum absorption and a higher energy conversion efficiency of over 50 percentage point than the mere 25% or so efficiency of silicon thin films.

(2). There is no light attenuation for CIGS thin films due to the strong radiation resistance of copper pyrites, which is the reason why the CIGS solar cell has the longest service life among solar cells.

Also, through research into the current development conditions of extension CIGS solar cells by nations, they concluded that it is feasible to develop the CIGS solar cell in China, and described the application prospect of it in providing electricity for urban use, for irrigation use in northwestern deserts, and for illumination use in Chinese cities. In terms of CIGS fabrication methods, Guo et al., (2008) reviewed the major fabrication processes of the absorption layer of the CIGS thin film solar cell, covering reactive sputtering and hybrid sputtering, selenization & sulfurization, co-evaporation, co-sputtering, screen print, and electrodeposition. Through summarization of the CIGS fabrication processes used by dominant CIGS manufacturers, they found that pre-sputtering and selenization enjoyed a wider application. At the end of their paper, it was noted that the orientation of research into CIGS absorption layer should bethining absorption layers, simplifying fabrication processes, and lowering down film formation temperature.

Table 1: Highest photoelectric conversion efficiencies of various solar cell modules

Classification	Effic. (%)	Area (cm^2)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	Test Center (and date)	Description
Si(crystalline)	22.7 ± 0.6	778(da)	5.60	3.93	80.3	Sandia(9/96)	UNSW/Gochermann
Si(multicrystalline)	15.3 ± 0.4	1017(ap)	14.6	1.36	78.6	Sandia(10/94)	Sandia/HEM
Si(thin-film polycrystalline)	8.2 ± 0.2	661(ap)	25.0	0.318	68.0	Sandia(7/02)	Pacific Solar 1~2 μm on glass
CIGS	13.4 ± 0.2	3459(ap)	31.2	2.16	68.9	NREL(8/02)	Showa Shell (Cd free)
CdTe	10.7 ± 0.5	4874(ap)	26.21	3.205	62.3	NREL(4/00)	BP Solarex
a-Si/a-SiGe/a-SiGe	10.4 ± 0.5	905(ap)	4.353	3.285	66.0	NREL(10/98)	USSC

Aside from silicon and inorganic compounds, dye-sensitized materials such as the commonly-used nano-crystalline TiO2 and zinc oxide can also be applied to thin film fabrication for solar cells. Shi, et al. (2002) studied the structure and energy conversion principle of nano-crystalline TiO2 DSSC, based on which they suggested three key factors in developing and fabricating nano-crystalline TiO2 DSSC:

(1). Selection of micro structure of nano-crystalline TiO2. Thin films fabricated with different processes that require different micro structures of nano-crystalline TiO2will exert various influences on conversion efficiency, thus optimal grain size ranges of nano-crystalline TiO2 should be determined in selecting fabrication processes.

(2). Selection of dye-sensitized materials. During selection of dye-sensitized materials, multiple factors should be taken into account in a way that ensuring effective absorption of solar energy, enough conversion efficiency, and favorable charge transfer efficiency.

(3). Selection of carrier transfer materials. Proper P-type semiconductor materials picked out are an important part of nano-crystalline TiO2 thin film solar panels. There are some deficiencies for solid-state dye-sensitized nano-crystalline TiO2 thin film solar cells. On the one hand, it has low energy conversion efficiency; on the other hand, if electrolyte of organic solvent leaks or volatizes, the solar cells filled with it will be seriously corrupted, which leads to a short service life. To address the problem of short lifespan resulting from leakage and volatilization of present liquid electrolytes, Lin, et al. (2006) designed and synthesized a series of solid state polymer electrolytes of DSSCs by introducing various functional polymer groups that strengthened the contact between electrolytes and TiO2 thin films, aiming to offset the disadvantages of solid-state polymer electrolytes, namely poor electrical conductivity and low conversion efficiency. In addition, the theoretical simulation of dye-sensitized nano-crystalline solar cells conducted by them proved that the conversion efficiency can be enhanced with the adoption of the nano-crystalline TiO2 thin film, and that the structural optimization of nano-crystalline TiO_2 thin film electrodes and counter electrodes helped improve the efficiency of light absorption.

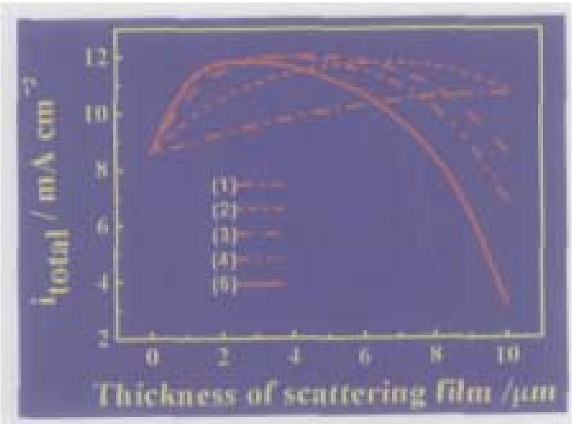

Figure 1: The relationship between photocurrent density and thickness of TiO_2 s cattering layer

3. Research status of organic thin film solar cells

Through the above analysis, it can be seen that either the first-generation silicon photovoltaic cells or the second-generation solar cells of various thin films have certain flaws. Against this backdrop, organic thin film solar cells come into the view of researchers. Compared to silicon solar cells, CIGS, and dye-sensitized nano-crystalline TiO_2 solar cells, organic thin film solar cells are characterized by low manufacturing cost, light weight, and good flexibility. Guo, et al., (2011) studied on the device structure and working principles of two main organic thin film solar cells, namely double heterojunction thin film solar cells and bulk heterojunction thin film solar cells. Through the comparison between their power conversion efficiency and service life, Guo Jun et al. concluded that the bulk heterojunction thin film solar cell had a higher conversion efficiency and yet much shorter lifespan than the double heterojunction thin film solar cell. The main current research focus on organic thin film solar cells by researchers at home and abroad is improving energy conversion efficiency. The reason for this is that the mass production of organic thin film solar cells will come true in a short time due to low cost and handy manufacturing process once the energy conversion efficiency is improved to such a degree that satisfying actual requirements (Michele et al., 2016).

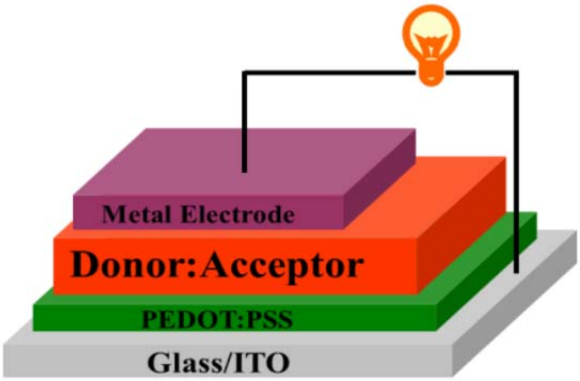

Figure 2: Schematic diagram of single layer organic solar cells

The energy conversion efficiency as low as around 1%-5% is the largest shortcoming for application of organic thin film solar cells compared to other inorganic thin film solar cells. Through analysis, Shen (2009) summarized three reasons for energy loss during operation of organic thin film solar cells:
(1). Intermolecular forces were relatively weak due to changeable structures of amorphous polymer materials, which impaired photoelectric effects.
(2). Polymer materials had relatively high band gaps.
(3). The high doping density of polymers rendered the occurrence of charge carriers short.

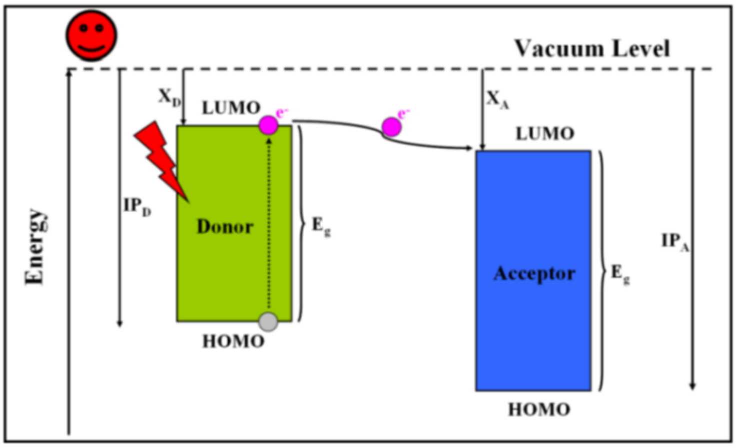

Figure 3: Basic principles of organic solar cells

Along with the release of the low-carbon development report of China in 2012, the country has strengthened efforts to develop high-efficient organic solar cells over the course of the twelfth Five-Year Plan. However, the technological level of organic solar cells in China still lags behind the level in developed countries such as America and Japan. Guo, et al compared the innovation status and development trends of organic thin-film solar cells technology in China, Japan and America through the quantitative analysis of patent distribution in the year, technology lifecycle, and the distribution of patent assignees, whose result showed that there was still a broad gap between China and the other two countries in terms of patent technology application (Guo, et al, 2013). Despite a late start and the technology to be improved in developing solar cells such that there is a long way before organic thin film solar cells realize mass production, China has a strong exploitability of organic thin film solar cells attributable to the consistent trend of research with the one in Japan and America in the field.
The fabrication and popularization of organic thin film solar cells faces with the predominant problem of low conversion efficiency in China. To address this issue, Chen, et al (2014) first established an optical model based on the thin-film interference optical absorption theory, and then conducted simulative analysis on the working principle of organic thin film solar cells with the Matlab simulation model. The result showed that the

thickness of organic thin films played a leading role in optical absorption. Based on it, the method of coating multilayer high reflectance films behind the cathode was proposed by them. Through simulation, they concluded that the number of excitons reached an optimal value when the thickness of active layer was about 150nm.

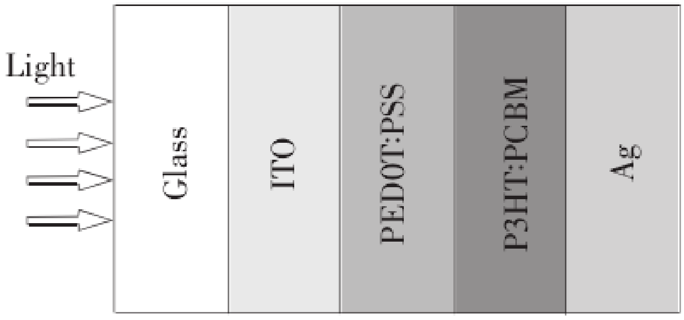

Figure 4: Geometry of organic thin film solar cells structure

In promoting the application of organic thin film solar cells, Mitsubishi Chemical Corporation proposed a possibility of sticking organic thin films to windowpanes to produce electricity at the conversion efficiency of about 3% and at a lifespan of around 5 years. The company announced to make efforts in prolonging the service life for at least another five year. The full promotion of organic thin film solar cells rests on two urgent solutions, namely service life and conversion efficiency, which are also what researchers have been focusing on.

4. Conclusion and outlook

Through the above analysis, it can be concluded that the widely used solar cells at the current stage are silicon thin film solar cells and the solar cells with multi-compound thin films represented by CIGS. Among them, limited by high cost and elaborate manufacturing processing, the silicon thin film solar cell is merely applicable in aviation and other high-tech projects. CIGS solar cell, the most recommended solar cell by researchers, is difficult to realize mass production for civil use due to problems in fabrication processing and corresponding technologies. As a comparison, organic thin film solar cells feature low manufacturing cost, simple fabrication technique, light weight, and broad application fields, thus drawing increasing attention. There has been a series of achievement on the present main research focuses on organic thin film solar cells: improvement of energy conversion efficiency, and extension of service life. Any noticeable breakthrough in these aspects will help realize the dream of achieving mass production of organic thin film solar cells.

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