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Letter

Design of DSC panel with efficiency more than 6%[☆]

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Abstract

Dye sensitized solar cells (DSCs), as a new innovative technology, were developed very quickly in the past decade since Prof. M. Grätzel (EPFL) made the breakthrough in 1991 (Nature 353 (1991) 737). While photoelectric conversion efficiency of 11.04% was achieved last year in EPFL (J. Photocem. Photobiol. A: Chem. 164 (2004) 3), 8.2% was achieved with a size of 2.36 cm² in 2001 by the ECN group (Sol. Energy Mater. Sol. Cells 84 (2004) 125), which is a very exciting result for large scale DSCs. As potential low cost solar cells, DSC module and the panel's efficiency and stability are still critical problems to the way of marketing. We show our research in the test and design of modules and panels in the past few years at our institute. We have achieved photoelectric conversion efficiency around 6% with 15 × 20 cm² module, and our future primary 500 W DSC power station with the same performance 40 × 60 cm² panel is under way.

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1. Introduction

Due to undue consumption of fossil fuels during the past half century and unbalanced distribution of fossil fuels in the world, we have been confronted with serious global environmental problems, such as Greenhouse effect and environmental pollution. To overcome these problems, development of renewable, clean energy sources are imperative common challenges for mankind to live in the future. Among them, solar energy is the best choice as a safe and clean alternative. Solar cell has been considered as an economical and easy method to convert solar energy directly to electricity because solar cell has proved its preponderance in areas which are remote and far away from electrical net, even as a compensation for daily use since the invention of single crystalline Si in 1954. But the high price and cost of Si-based solar cell were the big obstacles for the utilization universally.

Dye sensitized solar cells (DSCs), as a new innovation technology, were developed very quickly in the past decade since Prof. M. Grätzel (EPFL) made the breakthrough in 1991 [1], as an efficient and environmentally benign alternative to silicon-based photovoltaic cells, has attracted an increasing interest during the past years. Industrial researchers have led the way with teams from Germany, Australia, Switzerland, European group, USA and Japan. New photo-electric conversion efficiency record up to 11.04% was achieved by the EPFL group last year [2], and it well competes with a-Si solar cell. DSCs are expected to become even more popular solar cells because of their potential production in low-cost and efficiency.

Several technologies, to bring practical performances of long life and low cost of DSC modules, have been investigated recently. For example, studies of ionic liquid electrolytes [3,4], quasi-solids [5–7] and solid hole transfer materials [8] are investigated to realize long-life and safe DSC modules. Studies of low-temperature fabrication of TiO_2 on a flexible conductive film [9–11] are investigated to realize a high-speed and low-cost manufacturing process of DSC modules. Upscaling DSC modules is also one of the important technologies to bring about the commercialization of DSCs. Cell size and conductivity of substrates influence the internal resistance of solar cells and, consequently, their fill factor and conversion efficiency. For these reasons, small size cells are normally used to obtain high conversion efficiency on non-industrial studies, however, only less than 1% efficiency was achieved when $100\text{ mm} \times 100\text{ mm}$ large cell was fabricated with TCO glass without any collective electrode as was used for mini-size cells [12].

To upscale DSC sizes, three different module designs have been considered: the parallel grids module, series interconnect Z and W designs module, monolithic series interconnect [13]. Each design has its superiority and defects, proved in the past research.

The first parallel module design, tested in 1995, utilized conductive fingers protected by polymer or ceramic glazes to collect current in a $100\text{ mm} \times 100\text{ mm}$ glass substrate module, even pinhole and leakage at the interface overcoated with the substrate, this type of design has been suspended until 2001. Although the parallel modules need to be connected to achieve the design voltage, and high current in one

module will result in a little low fill factor, however, high active area and high efficiency are the merits of this design [13].

In the series interconnect design, we can obtain identical output when illuminated from either side in each separate single cell, and this design still requires separation of the cells by an effective seal. Easy assembly is the advantage of this design, but the resistance of the interconnection material and the big gap between the two electrodes will also affect the fill factor, and the low active area will increase the production cost.

The monolithic interconnect module is recognized as an alternative design that has significant advantages for volume production and for relatively small cells. It effectively eliminates one substrate by connecting both electrodes to one conductor substrate, affects the cell by electrical isolation on that substrate, and the thickness is controlled by the printing process. But high resistance interconnect electrodes are still the big obstacle in the monolithic interconnect module series interconnect. The problem of low efficiency and stability will limit the use of this design in big modules and outdoor use.

The difference of the DSC module in series interconnect and in parallel design has been discussed and tested in our past work [14].

In any case, the performance of a single cell is very important to the module, even to the panel. Efficiency up to 8.2% has been achieved with a size of $0.8 \times 5 \text{ cm}^2$ in 2001 by the ECN group [15] in masterplate design, this is a very exciting result for the big DSCs. The ECN group also confirmed a stable performance in past research [16]. However, this is still not good enough for module design, not only regarding the size, but also the performances. To match the future manufacture production performance, even bigger strip cells, without depressing performance, should be developed. STI in Australia has finished its showcase with 200 M^2 in 2003 [17].

This paper shows our research in the test and design from the single cell, the modules, to the panels, and our future design of 500 W primary DSC power station. We have achieved photoelectric conversion efficiency around 6% with a size of $15 \times 20 \text{ cm}^2$ module and an active area larger than 60%, and almost same performance with a size of $40 \times 60 \text{ cm}^2$ panel for our future primary 500 W DSC power station.

2. Materials

TEC-15 glass(LOF, 2.3 mm, $15 \Omega/\text{square}$, USA) was used both as the working and counter transparent electrodes. Cis-di(thiocyanato)-N,N-bis(2,2'-bipyridyl-4,4'-dicarboxylate) Ru(II)bis-tetrabutylammonium (N719) was the sensitizer. Electrolyte composition was as follows: 0.1 M LiI, 0.1 M I_2 , 0.5 M tert-butylpyridine (TBP) and 0.6 M 1,2-Dimethyl-3-propylimidazoliumiodide (DMPII) in the mixture solvent of Acetonitrile/Valeronitrile/3-Methoxypropionitrile. Nanoporous TiO_2 films was prepared as reference [18,19]. Platinized counterelectrode was printed using a paste based on H_2PtCl_6 dispersed in a mixture of terpeneol and ethylcellulose. Surlyn and Bynel polymer (Dupont) hot-melt foil have been used as primary sealing materials.

Electrode finger was printed using silver paste (BYD1065, Shanghai Bao Yin Electronic Materials Company, China).

I – V characteristics of the DSCs (I_{sc} , V_{oc} , FF and η) are derived with a Keithley 2400 source meter under a Xenon lamp (1000 W/m^2 , uniform illumination is less than 3% in an active area of $30 \text{ cm} \times 30 \text{ cm}$, Changchun Institute of Optics Fine Mechanics and Physics, Chinese Academy of Sciences, calibrated with standard crystalline silicon solar cell, spectral mismatch was not considered), DSCs panel outdoor test was finished in a clear day calibrated by standard crystalline silicon solar cell and pyrometer.

3. Experiments

3.1. DSCs assembly

Strip cells were normally used to test the performance of DSCs materials, such as TiO_2 , dye, platinum paste and electrolyte, before assembling DSC module and panel in our laboratory. A new concept of lamination has been developed by the ECN group and used for our DSCs assembly [16]. A circulation pump was used to color the photoelectrode after lamination, the small holes were sealed by surlyn with a hot-stamp after injecting electrolyte. It is an easy way to assemble strip cell by using the same process as that of DSC module, and cover the working electrode with black mask to make sure the exact active area during the test, as shown in Figs. 1 and 2,

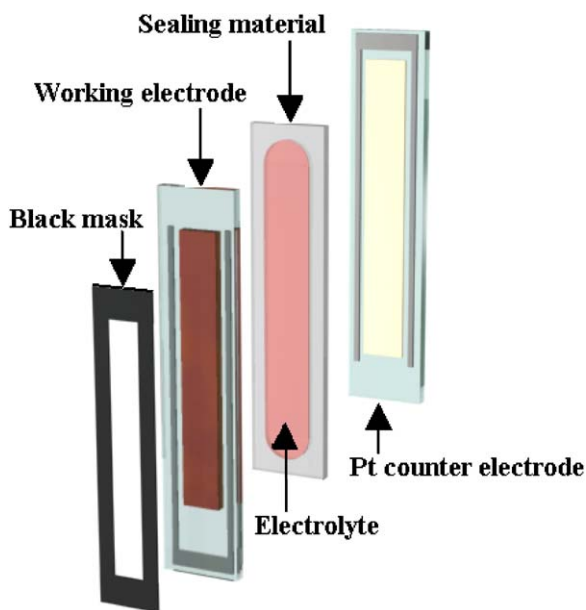


Fig. 1. Design scheme of strip cell.

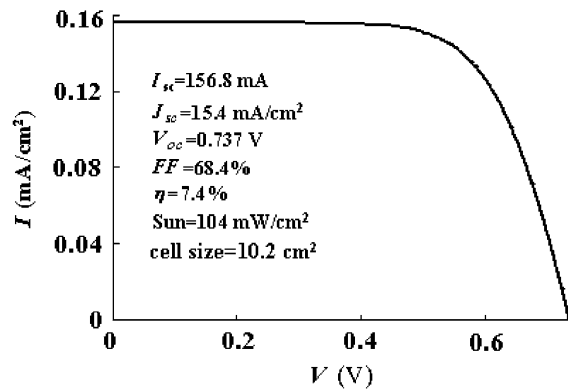
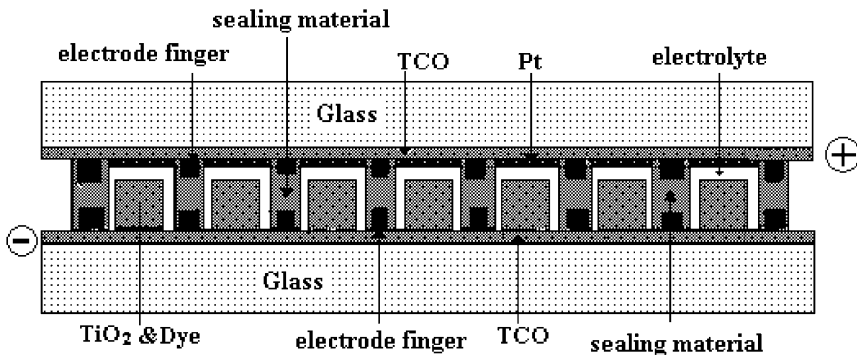
Fig. 2. Indoor test I - V characteristics of strip cell.

Fig. 3. Cross section of parallel module.

which illustrates the design scheme of strip cell and I - V characteristic performance of this strip cell.

Figs. 3 and 4 give the design scheme and cross section of the parallel grids module. It is a critical step for DSCs to achieve an optimum and long-running module in the laboratory before its entry to the commercial market. Fig. 5 gives the I - V characteristics of the parallel module. The short current density and fill factor decreased with enlarging the area of working electrode, so as the efficiency. It is very clear that the module performance is very sensitive to the resistance of silver finger and the silver bus-bar. The fill factor decreased from 68.4% to 59% with the increasing of active area from strip cell to module, as shown in Figs. 2 and 5.

3.2. Reproducibility of the DSC module

The reproducibility of the DSC modules has been tested based on our laboratory procedure by 22 modules in one batch. The distribution of J_{sc} , V_{oc} , FF and η for the 22 modules is shown in Fig. 6. The conversion efficiency of 18 cells in 22 modules

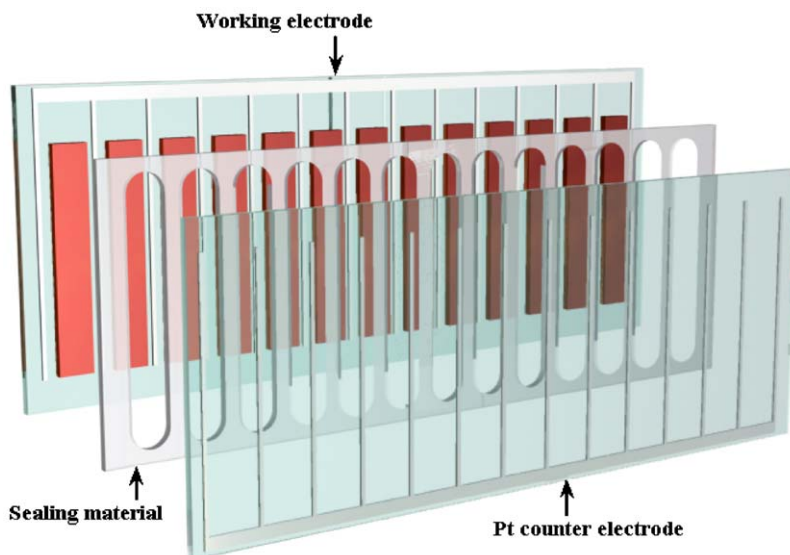
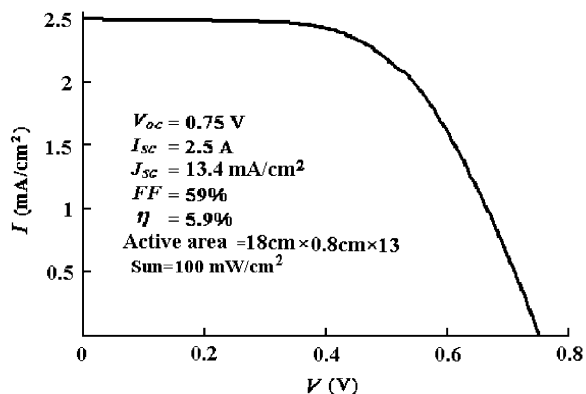


Fig. 4. Design scheme of parallel module.

Fig. 5. Indoor test I - V characteristics of parallel module.

was over 5.5%, and the best is 5.9% under one Sun, only one cell's efficiency was 4.48%, due to a little shortage between electrodes, and very bad fill factor (only 49%). There is a very good prospect that the J_{sc} , and FF still have the potential to improve in the near future. From this it can be concluded that the reproducibility of the baseline process is good.

3.3. DSC panel primary design

For future commercial production the module is just one element for the design of the panel and the mechanical and aesthetic elements are also critical.

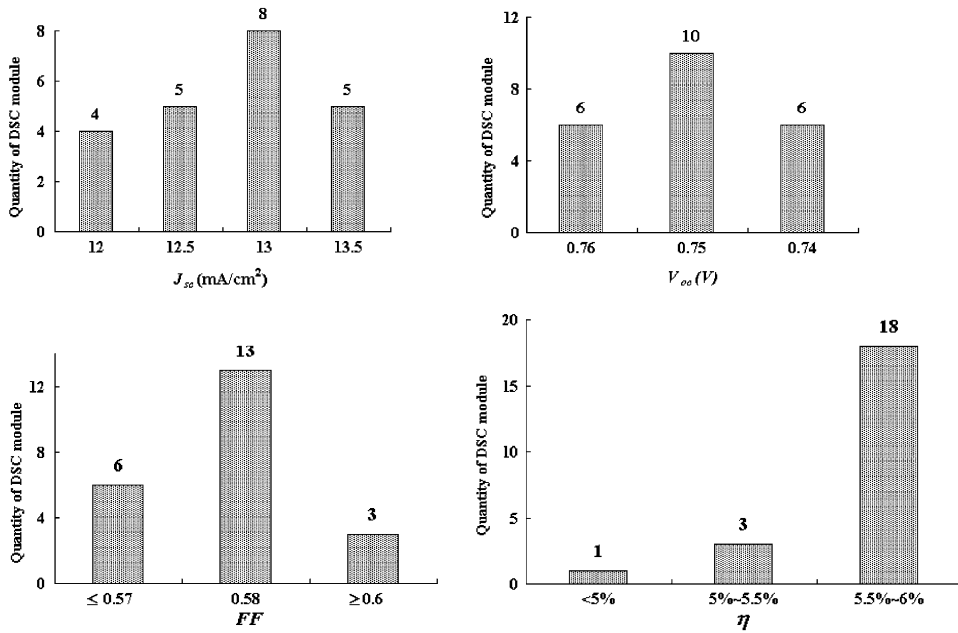


Fig. 6. The distribution of I - V characteristics in one batch of module.



Fig. 7. Picture of the 60 W DSC primary power station.

Above all, electrical performance of the panel is the most important currently. As shown in Fig. 7, we fabricated a panel by using eight DSC modules with similar performance and tested them outdoors. Photoelectric efficiency of 5.7% under 0.95 Sun and efficiency of 6.2% under 0.78 Sun have been achieved, the I - V characteristic performance is shown in Fig. 8, the loss of the protect glass outside is not included. In the same way, five more panels were finished, and almost 60 W output power in total was used for charging the battery.

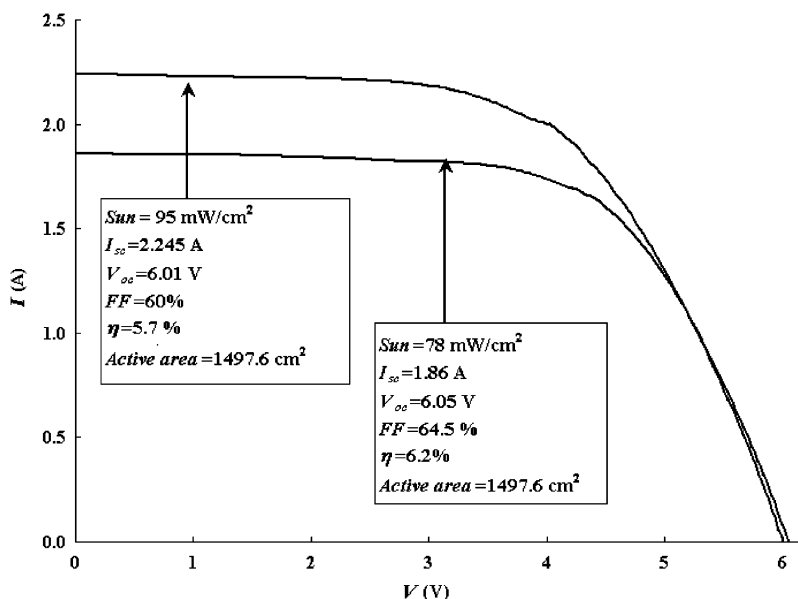


Fig. 8. Outdoor test I – V characteristics of the panel.

4. Conclusion

In the past decade, many researchers were involved in the design of the modules, as well as panels for commercial production, but performance and stability are the two major obstacles. Here we introduced our primary test results in designing high efficiency modules and panels for outdoor use. Photo-electric conversion efficiency of 7.4% under 104 mW/cm^2 incidence light intensity by using both TCO glass for photoelectrode and counterelectrode with active area of 10.2 cm^2 was reported, 5.9% photoelectric conversion efficiency under 100 mW/cm^2 with active area of 187.2 cm^2 was achieved, and 5.7% photoelectric conversion efficiency under 95 mW/cm^2 and 6.2% photoelectric conversion efficiency under 78 mW/cm^2 with an active area of 1497.6 cm^2 were obtained in our lab. Six similar performance panels with a size of $40 \text{ cm} \times 60 \text{ cm}$ were used for charging battery since April 2004 as a 60 W primary power station.

From our test results, it is possible to obtain 7% photoelectric conversion efficiency in the near future if you could get the optimum design and best performance, and the potential low cost and feasibility for the power station as a means of generating electricity in the near future.

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