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Research Article

Synthesis and Characterization of a Photoelectrode with a Novel 3D Structure for Dye-Sensitized Solar Cells

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This study designs a novel dye-sensitized solar cell (DSSC) in which the photoanode is derived from its three-dimensional (3D) structure. The inside of the cell has a positive illumination structure, with the purposes of increasing the area of photoelectrode thin film and of increasing the illuminated area within a fixed area in order to achieve the objective of enhancing the photoelectric conversion efficiency of cell. For the cell structure experiment, the study uses graphite paper, carbon and platinum as counter electrode materials, and then conducts measurement with cell heights of 3 mm, 5 mm, and 7 mm. The electrolyte used is a gel polymer electrolyte. The assembly of the cell is divided into vertical assembly, inclined assembly, and tandem assembly. In the 3D tandem cell experiment, the counter electrode material is platinum. Experimental results show that when cell height is 7 mm and illuminated area is 0.28 cm^2, open-loop voltage is 0.662 V, short-circuit current density is 18.42 mA/cm^2, fill factor is 0.31, and the photoelectric conversion efficiency is 3.85%, which is 1.65 times that under vertical assembly (2.34%) and 2.15 times that of the flat cell (1.79%).

1. Introduction

In 1954, the first silicon solar cell was introduced at Bell Laboratories. Since then, solar cells have been under development for decades [1]. In 1990, M. Gratzel et al. developed a dye-sensitized solar cell (DSSC), which employed titanium oxide (TiO_2) as the photoanode and was attached with a piece of glass coated with transparent conductive oxide (TCO) thin film. The efficiency of the resulting solar cell was tremendously enhanced, and the manufacturing process was effectively shortened, making it much cheaper than other kinds of solar cell [2]. Through continuous improvement and progress, the effectiveness of DSSCs has been further enhanced. However, even though a lot of research energy had been carried out in the selection and preparation of photoanode materials and dyes, the enhancement of the effectiveness of DSSCs is still quite limited.

In addition to improving materials, enhancement of DSSC effectiveness has been another important issue of study. In recent years, many studies of the enhancement of solar cell effectiveness have emphasized cell structure. In 2006, Liska combined a copper indium gallium selenide (CIGS) cell with a DSSC, with the upper-layer cell being DSSC and the lower-layer cell being a CIGS cell [3]. Experimental results showed that the open-loop voltage of cell reached 1.45 V and the effectiveness of the cell was enhanced by 15%. In 2007, Ahna made tandem DSSCs and applied series connection as the wire connection method [4]. The solar cell was applied in electrochromic (EC) equipment. The open-loop voltage of the cell was 1.35 V and the short-circuit current density was 3.96 mA/cm^2. Experimental results showed that the chromic and reduction response times of equipment with the proposed cell were around 60 seconds and 45 seconds, respectively. When the wavelength of light was 750 nm, the optical density difference was 1.2. Therefore, this cell set was successfully applied in EC equipment. In 2010, Fan made tandem DSSCs, where the upper-layer cell was absorbed with JK2 dye and lower-layer cell was absorbed with synthetic

dyes of SQ1 and TT1, with the intention of strengthening the sensitizer's ability to absorb sunlight wavelength; parallel connection was used as the wire connection method [5]. Experimental results showed that the photoelectric conversion efficiency of the cell reached 8.33%. In 2011, Ito made a tandem cell using a GaAs/AlXGa(1–X)As graded solar cell (GGC) and a DSSC, with the upper-layer cell being DSSC and the lower-layer cell being GGC, using series connection as the method of wire connection [6]. Experimental results showed that the open-loop voltage of the GGC was 1.11 V, the open-loop voltage of the DSSC was 0.76 V, the open-loop voltage of the tandem cell was 1.85 V, and photoelectric conversion efficiency of the tandem cell was 7.63%. Although its efficiency was lower than that of the single GGC (7.66%), the effectiveness of this cell was sufficient for application to electrolysis of water. In 2011, Jeong made a tandem solar cell comprising CIGS and DSSC, using series connection and parallel connection as the methods of wire connection [7]. Experimental results showed that the photoelectric conversion efficiency of the tandem cell reached 12.35%, surpassing that of the single CIGS cell (11.71%).

Tandem cells have shown good performance in the various studies mentioned above. Through combination of dyes of different light absorption wavelengths, as well as series connection or parallel connection of cell circuits, the light is transmitted to the cell body, without being absorbed, so it can be absorbed and used again. However, since the iodide used for preparation of electrolyte fluid and photoanode just resembles the protective color used in sunglasses, part of the light can be absorbed by electrolyte fluid and the photoanode body in the process of sunlight transmittance to tandem cell, leading to the dissipation of heat energy. Lower-layer cells form back illumination, causing energy loss. Therefore, even though tandem cells can recycle the transmitted light energy, enhancement of cell effectiveness is still very limited. If incident light can reach the photoanode before going through electrolyte fluid, it can help enhance the useable degree of incident light and achieve the objective of the enhancement of effectiveness.

As we know, for all kinds of solar cells, cost reduction is all the time crucial for their future development [8]. Carbon materials are widely used in batteries, such as disordered carbon, hierarchically porous carbon monoliths, and acid treated graphite [9]. In DSSCs, as a promising low-cost replacement of Pt counter electrode, carbon counter electrode has been widely investigated [10–12]. This study uses graphite paper, carbon, and platinum as counter electrode materials to compare the effects of these three materials on the performance of DSSCs.

Therefore, the experiment in study improves upon the tandem structure used by previous scholars before and adds another structural design outside the cell. Multiple solar cells are connected in series in a three-dimensional (3D) direction, and a set of cells with completely positive illumination structure is made to lengthen the illuminated area of a DSSC, in an attempt to enhance the short-circuit current density and the effectiveness of the DSSC.

2. Experimental Details

The photoanode material used in the experiment is Degussa P25 TiO_2 powder. First of all, 25 g of Degussa P25 TiO_2 powder is added with 0.8 g of polyethylene glycols (PEG) and 2 mL of dispersant (Triton X-100), and then 0.1 moles of nitric acid solution is added. The compound is vibrated in an ultrasonic vibrator for about 1 hour, and then stirred by a magnetic stirrer for 24 hours, resulting in an evenly dispersed TiO_2 paste.

The conductive glass used in the experiment is fluorine doped tin oxide (FTO) conductive glass, with thicknesses of 0.7 mm and 2.2 mm, used in the photoanode substrate and platinum-coated counter electrode, respectively. The counter electrodes of the experiment are composed of 3 different materials, including graphite paper with a thickness of 0.4 mm, carbon with a thickness of 1 mm, and platinum with a of thickness 20 nm. Platinum is prepared by sputtering a layer of platinum on FTO conductive glass. The sputtering parameters are set with the vacuum degree at 6 Pa, electric current at 30 mA, and sputtering time at 120 seconds. After completion of sputtering, platinum with a thickness of 20 nm is made.

In this study, the photoanode of cell is made into a 3D structure. First of all, conductive glass is cut into appropriate dimensions. The cut conductive glass is washed by deionized water to clear away the glass fragments from the surface. Then it is placed in anhydrous ethanol to carry out ultrasonic vibration for about 1 hour to clear away the oil from the surface. Next, it is placed in oven for drying. After that, adhesive tape is stuck on the conductive side of the conductive glass, leaving a suitable area for the coating of TiO_2 paste. Then the coating of the blended TiO_2 paste is carried out by a spin-coater at a spinning speed of 1000 rpm for a set time of 5 seconds. The coated conductive glass is placed in an oven for drying at 50°C for 10 minutes. After that, it is placed in a sintering furnace. The rate of temperature increase in the sintering process is set at 10°C/min. The temperature of the sintering furnace is increased to 70°C and kept unchanged for 15 minutes. The temperature of the sintering furnace is increased to 400°C at the same rate of temperature increase as above and kept unchanged for 30 minutes. After completion of sintering, the glass is still left in the furnace for natural cooling until it reaches room temperature, thus completing the preparation of the photoanode TiO_2 thin film.

At this stage of the experiment, the electrolyte used is a gel polymer electrolyte. The main reason for using a gel polymer electrolyte is that, in the experiment, the cell is prepared to have 3D structure. To date, a number of research teams have studied gel polymer electrolyte [13, 14]. Using a gel polymer electrolyte can avoid some of the shortcomings faced when using a liquid electrolyte, such as easy leakage of the electrolyte, high volatility of the organic solvent, and difficult packaging. Moreover, packaging by liquid electrolyte will be taken as an experimental goal in future studies.

The electrolyte material is composed of iodide, macromolecule material, and solvent. First of all, iodide is blended with the solvent to form a liquid electrolyte. In the blending process, iodide is added to the solvent and the compound is

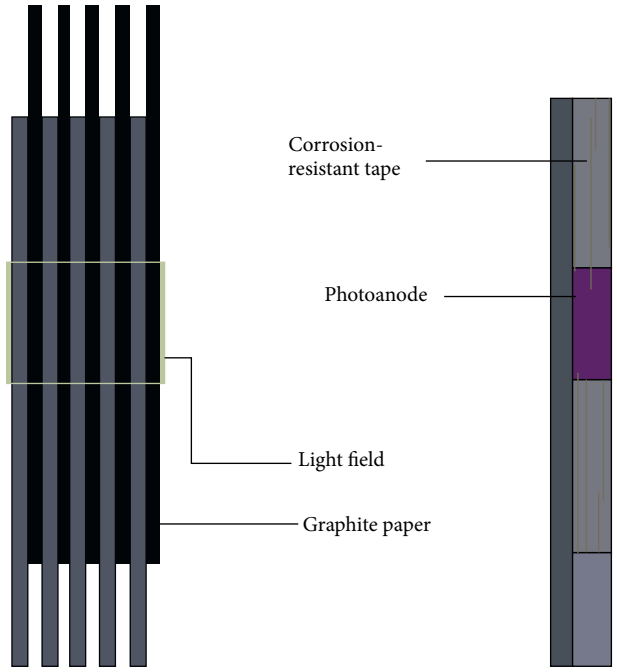

Figure 1: Schematic diagram of vertical DSSC assembly.

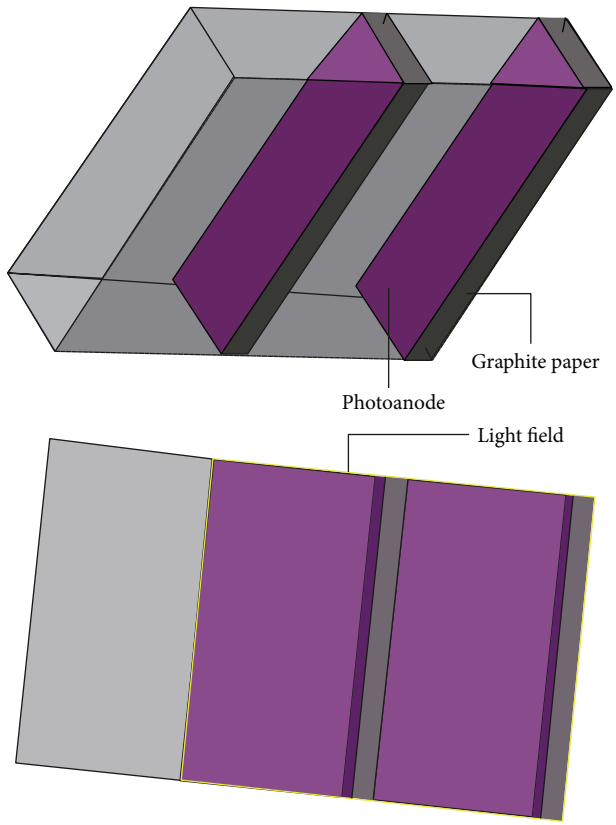

Figure 2: Schematic diagram of inclined DSSC assembly.

vibrated in an ultrasonic vibrator for 30 minutes to complete the preparation of the liquid electrolyte. After that, 40 wt% PEG is added to the liquid electrolyte, which is then heated and stirred by a magnetic stirrer for some time until the macromolecule material is completely solved in the liquid electrolyte. The iodide selected for use in this study is 0.1 M KI + 0.01 M I_2 + 0.05 M 1-butyl-3-methyl-imidazolium iodide (BMII), the solvent is ACN, and the macromolecule additive is PEG. All of them are combined together to prepare a gel polymer electrolyte, which is then heated and stirred by a magnetic stirrer and finally placed at room temperature to let it cool down naturally, completing the preparation of gel polymer electrolyte. In addition, the prepared gel polymer electrolyte has to be stored in a brown glass container wrapped in aluminum foil, and the container has to be kept in a dark place to avoid contact with any light from the outside.

After N719 dye is placed in a Petri dish, calcinated photoanode thin film is soaked in the dye. In the soaking process, the Petri dish has to be wrapped in aluminum foil to avoid direct light illumination and set aside for 24 hours for the dye to completely soak in. The 3D cell structure of the experiment is assembled in 3 ways: vertical assembly, inclined assembly, and tandem assembly, as shown in Figures 1, 2, and 3, respectively.

For vertical assembly, the counter electrode materials are graphite paper, carbon, and platinum. Strips of photoanode are distributed in the illumination zone and nonillumination zone, with the yellow frame area being the illumination zone. During assembly, brown corrosion-resistant adhesive tape at thickness of around 20 μm is stuck in nonillumination zone to prevent the photoelectrode and counter electrode from being short-circuited. The well blended gel polymer electrolyte is applied on the illumination zone by a scraper. Then three kinds of counter electrodes are combined together like a sandwich. Several of the same solar cells are piled up vertically. Between the photoanode and photoanode, a parallel connection is performed, and between the counter electrode and counter electrode, a parallel connection is made. Once these connections are made, assembly is completed. This assembly method is employed because a gel polymer electrolyte is used, and no leakage problem occurs when the cell is vertically placed. After a tandem cell is made, electrical testing can be carried out directly.

Regarding the inclined assembly experiment, FTO glass at a thickness of 2.2 mm is used as the photoanode, and graphite paper is used as the counter electrode. When cutting the glass, the tip of the glass is cut at an angle of around 30 degrees. Make sure that assembly is undergone in one direction only and cannot be undergone reversely; otherwise the assembled cell will take on back illumination structure. The height of the geometrical shape of glass being cut is around 4.4 mm, and the hypotenuse of the glass top is 2.54 mm. After washing, spin coating, sintering, and soaking, the dye can carry out assembly, through the method shown in Figure 2. The figure shows the front view and top view of the inclined assembly method. The yellow frame area is the illumination zone, with a length of around 5.88 mm and a width of 5 mm. The inclined angle is designed to prevent sunlight from creating refraction after going through the glass and directly illuminating the surface of the photoanode after the dye has soaked in.

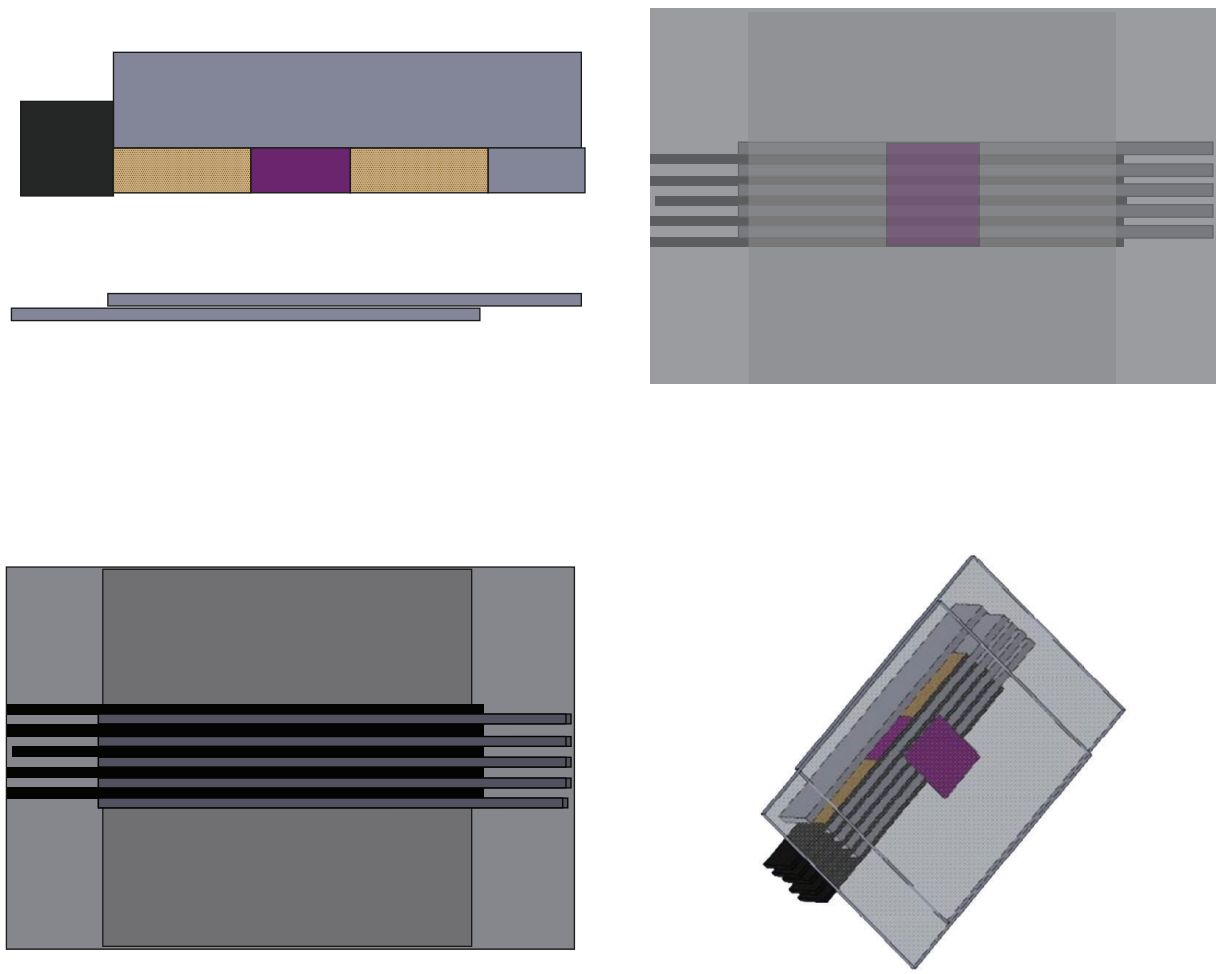

Figure 3: Schematic diagram of tandem DSSC assembly.

The antielectrode materials used in tandem assembly are graphite paper and platinum. These materials are an improvement compared to the structures of tandem cells used by previous scholars. In the design used in this study, the vertical cell is attached to a flat cell for assembly. The principle of tandem cell is that a sensitizer, available to absorb different wavelengths, is distributed to different cell layers, making the cell completely absorb all the light wavelengths provided by sunlight. However, in the process of sunlight transmittance to a tandem cell, back illumination is created. In the tandem assembly design in this experiment, the entire conversion process from incident sunlight to photoelectricity takes place under positive illumination.

The parameters of a 3D cell include photoanode substrate thickness, counter electrode thickness, cell width, number of parallel connections, and illuminated area. Additionally, another set of parameters are the parameters of height. Height affects the transmittance degree of a cell and thus affects the effectiveness of a cell. Figure 4 is the schematic diagram of the different parameters of a 3D cell. The figure takes an inclined cell as an example and defines all the parameters of a 3D cell. The cell in this example has two parallel connections.

Table 1 shows the experimental group of the study. In addition to 3D cells, this study also designs a set of traditional flat cells to serve as the comparative group in the experiment. Flat cells are tested with 3 different counter electrode materials. As for the 3D cells, they are divided into vertical assembly, inclined assembly, and tandem assembly. Vertical assembly uses three kinds of counter electrode materials as well as three cell heights of 3 mm, 5 mm, and 7 mm for testing. However, under inclined assembly, as restricted by counter electrode thickness, illuminated area, and the difficulty of glass machining, we only use thin graphite paper as a counter electrode material and one cell height of 4.4 mm. Tandem assembly uses platinum and graphite paper as counter electrodes and three cell heights of 3 mm, 5 mm, and 7 mm for testing.

This study uses field emission scanning electron microscopy (FE-SEM) to observe the surface morphology of photoanode thin film, transmission electron microscopy (TEM) to observe the particle distribution of micropowder, and energy dispersive spectroscopy (EDS) to analyze the photoanode surface. Moreover, we use a simulated light source of sunlight to measure open-loop voltage, short-circuit current density, and photoelectric conversion efficiency. The

Table 1: Design dimensions of different parts of the experimental sample.

Assembly manner	Counter electrode	Substrate thickness of photoelectrode (mm)	Thickness of counter electrode (mm)	Number of photoelectrode parallel	Illuminated area (cm^2)
Flat	Platinum	0.7	0.7	1	0.25
Flat	Carbon	0.7	1	1	0.25
Flat	Graphite paper	0.7	0.4	1	0.25
Vertical	Platinum	0.7	0.7	4	0.28
Vertical	Carbon	0.7	1	3	0.255
Vertical	Graphite paper	0.7	0.4	5	0.275
Incline	Graphite paper	2.54	0.4	2	0.294
Tandem	Platinum	0.7	0.7	5	0.28
Tandem	Graphite paper	0.7	0.4	6	0.275

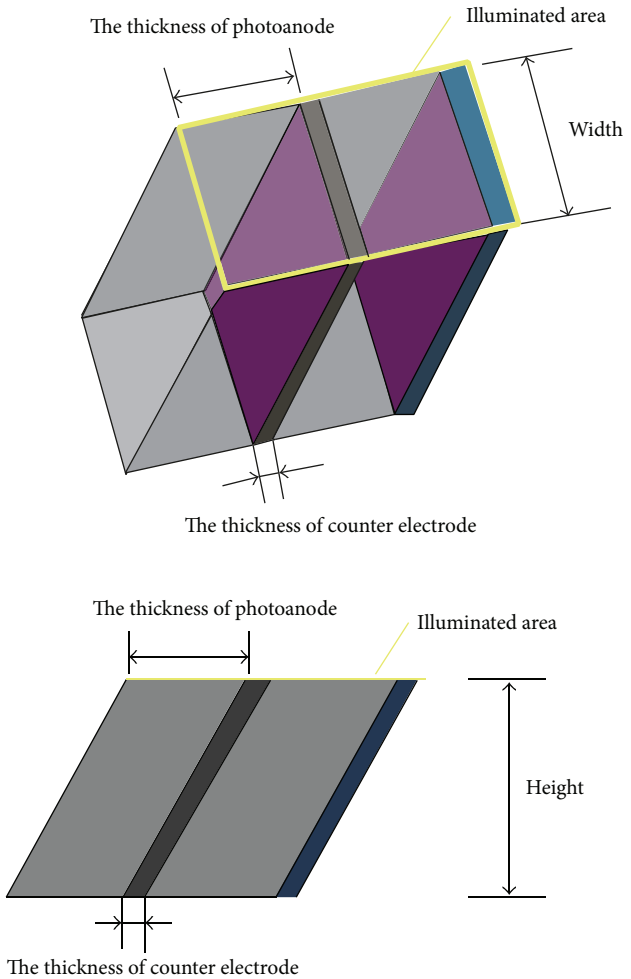

Figure 4: Schematic diagram of different parts of 3D structured DSSC.

parameter for the simulation of sunlight is AM1.5, with a 100 mW/cm^2 light.

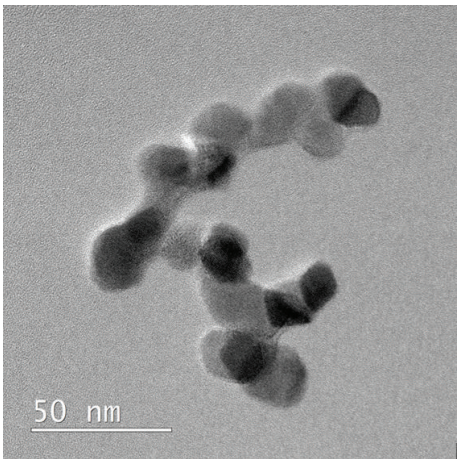

Figure 5: TEM image of Degussa P25 TiO_2 nanoparticles.

3. Results and Discussion

The experiment takes Degussa P25 TiO_2 as the photoanode thin film of DSSC. It is composed of 80% anatase and 20% rutile. Before analysis, 100 mg of TiO_2 is added to 3 mL of anhydrous ethanol and ultrasonic vibration is carried out for about 1 hour to let particles disperse evenly. We absorb the solvent with a dropper and titrate it on a copper net containing carbon film. After vacuum dusting for 10 minutes, TEM analysis is carried out. As shown in Figure 5, the TiO_2 under analysis by TEM appears to be nearly spherical, with a particle size of around 20 nm. The particles are in monodispersed form.

Before sintering of TiO_2 thin film, a macromolecule organic additive, like PEG, is added and the thin film is stirred evenly. This kind of material has a plasticizing feature, which can effectively prevent thin film, when being dried, from cracking and affecting the efficiency of the cell. When the thin film temperature rises to around 200°C, organic additives are evaporated gradually, producing many pores on the thin film surface. These pores increase penetration on the photoanode

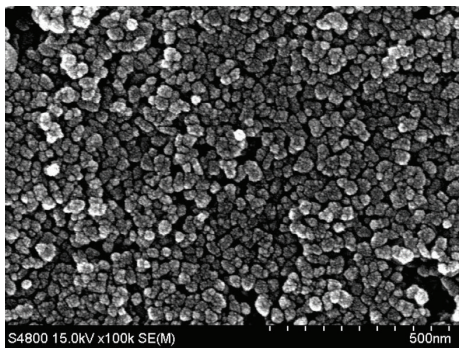

Figure 6: FE-SEM image of TiO_2 thin film.

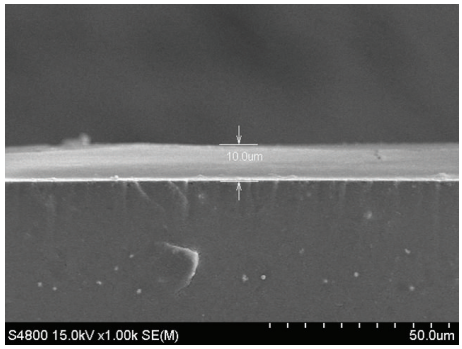

Figure 7: Cross-sectional FE-SEM image of photoelectrode thin film.

surface, further enhance the absorbance amount as dye is soaking in, and increase the contact area with the electrolyte after assembly of the cell. Figure 6 shows the analysis of the photoanode surface by SEM. Figure 7 shows the analysis of the lateral side of the photoanode by SEM. In the experiment, the coating of the photoanode is carried out by spin coating. As seen in the figure, there is a slight difference in film thickness between the left and right sides. The left side is far from the spinning center, and the right side is close to the spinning center. Due to centrifugal force, the outer circle is thicker and the inner circle is thinner. Throughout the entire course, the thin film is 6.5 μm ~ 10 μm thick. Under microobservation, the photoanode thin film takes the shape of an inwardly depressed arc.

Figure 8 shows the *J-V* curves of cells with cell heights versus the counter electrode material of the graphite paper. When cell heights are 3 mm and 5 mm, the *J-V* curves are very close to each other. Although the illuminated area of the cell at a height of 5 mm is greater than the cell at a height of 3 mm, the depth of its light enlarges gradually, and the problem that the light cannot transmit to the inside of cell easily starts to emerge. Hence, its short-circuit current density has limited room for lengthening. When the cell height is 7 mm, short-circuit current density does not increase, but rather decreases, and the degree of reduction is very obvious. Table 2 shows the experimental numerical values of cells with cell heights versus the counter electrode material of graphite paper. When the cell height is 5 mm, open-loop voltage can reach 0.425 V, the

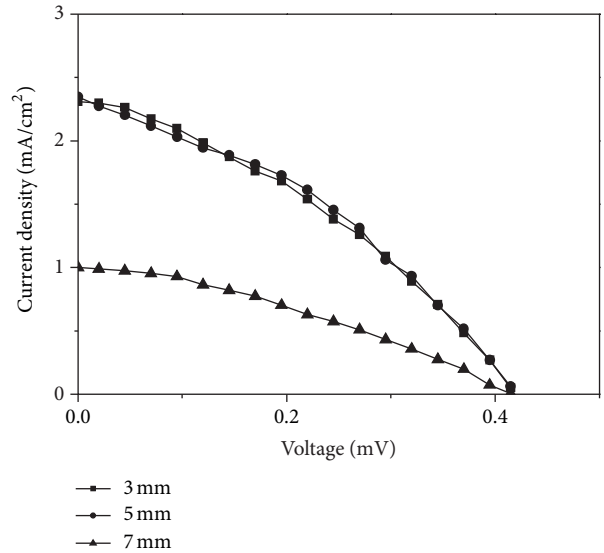

Figure 8: Photovoltaic curves (*J-V*) of the prepared 3D DSSC made by a graphite counter electrode at different cell heights.

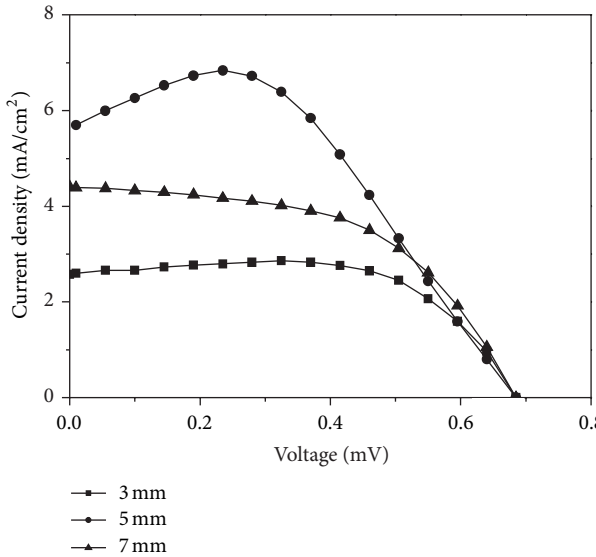

Figure 9: Photovoltaic curves (*J-V*) of the prepared 3D DSSC made by a Pt counter electrode at different cell heights.

Table 2: Photovoltaic parameters of the 3D DSSC made by a graphite counter electrode at different cell heights.

Height (mm)	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF	η (%)
3	0.42	2.31	0.35	0.34
5	0.425	2.35	0.37	0.37
7	0.47	1.02	0.36	0.17

short-circuit current density is 2.35 mA/cm^2, the fill factor is 0.37, and the photoelectric conversion efficiency is 0.37%.

Figure 9 shows the *J-V* curves of cells with cell heights versus the counter electrode material of platinum. When the cell height is adjusted from 3 mm to 5 mm, the *J-V* curve

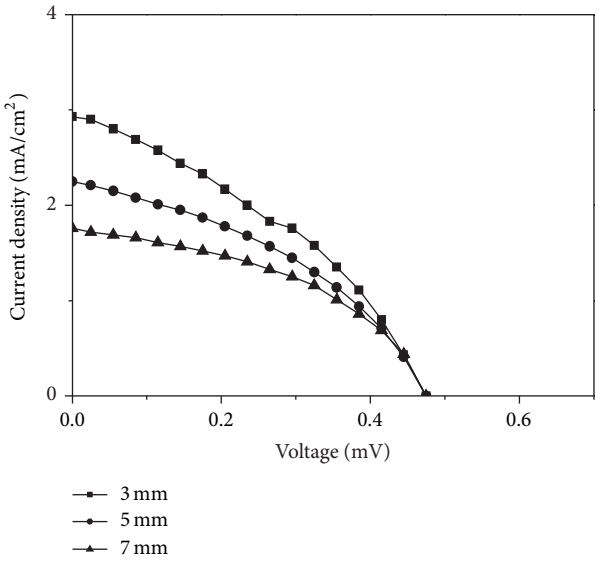

Figure 10: Photovoltaic curves (*J-V*) of the prepared 3D DSSC made by a carbon counter electrode at different cell heights.

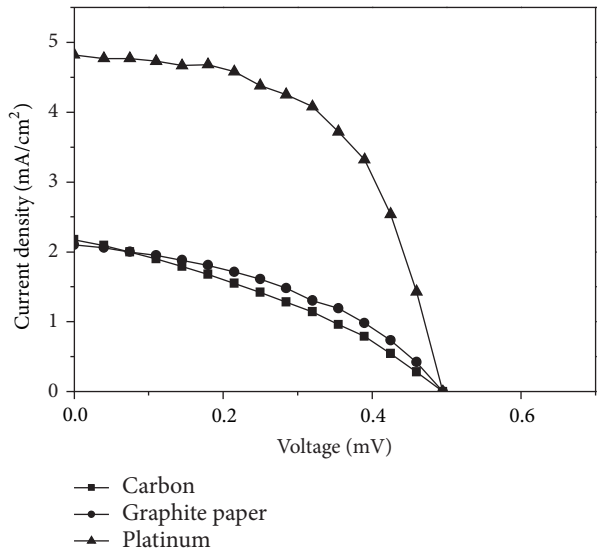

Figure 11: Photovoltaic curves (*J-V*) of the prepared flat DSSC made by different counter electrodes.

Table 3: Photovoltaic parameters of the 3D DSSC made by a Pt counter electrode at different cell heights.

Height (mm)	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF	η (%)
3	0.69	2.57	0.69	1.24
5	0.755	5.69	0.54	2.34
7	0.7	4.40	0.53	1.64

Table 4: Photovoltaic parameters of the 3D DSSC made at different cell heights with a carbon counter electrode.

Height (mm)	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF	η (%)
3	0.48	2.93	0.36	0.52
5	0.48	2.25	0.39	0.43
7	0.48	1.76	0.44	0.38

increases tremendously, but when the cell height is adjusted from 5 mm to 7 mm, the degree of recession of the *J-V* curve is not as great as that of graphite paper. The reason for this is that in this experiment the counter electrode substrate itself is conductive glass and its transmittance is not bad. Even though platinum is sputtered, the counter electrode itself still has a certain degree of transmittance, and is not like graphite paper and carbon, both of which do not transmit light. Therefore, at a cell height of 7 mm, the cell can still accept the light of lateral transmission. Table 3 shows the experimental numerical values of cells with cell heights versus the counter electrode material of platinum. When the cell height is 5 mm, open-loop voltage can reach 0.755 V, the short-circuit current density is 5.69 mA/cm^2, the fill factor is 0.54, and the photoelectric conversion efficiency is 2.34%.

Figure 10 shows the *J-V* curves of cells with cell heights versus the counter electrode material of carbon. As shown in the figure, as cell height increases from 3 mm to 5 mm and then to 7 mm, the short-circuit current density of the *J-V* curves gradually fall. The reason for this is that the carbon material is dark black, and its refraction ability is worse than that of graphite paper. When cell height increases, a great deal of light is absorbed by carbon itself and then turned to be heat energy to be released. In addition, carbon is brittle. As a result, the machining dimensions should not be less than 1 mm, and only 3 sets of parallel connections can be performed within a limited area. Therefore, increasing the parameter of cell height does not enhance the effectiveness of cell, but rather decreases it. Table 4 shows the experimental numerical values of cells with cell heights versus the counter electrode material of carbon. When the cell height is 3 mm, open-loop voltage can reach 0.48 V, the short-circuit current density is 2.93 mA/cm^2, the fill factor is 0.36, and the photoelectric conversion efficiency is 0.52%.

Figure 11 shows the *J-V* curves of cells with different counter electrode materials versus a flat cell. This experiment investigates the comparative group and 3D cells. A flat cell with a counter material of platinum is better than those with counter materials of carbon and graphite paper. According to our tests, the curves of carbon and graphite paper are more or less the same. It can be seen from Figure 11 that the photoelectric conversion efficiencies of carbon, graphite paper, and platinum are 0.37%, 0.44%, and 1.79%, respectively. As for the 3D cells mentioned in the previous section, the photoelectric conversion efficiencies of carbon, graphite paper, and platinum are 0.52%, 0.37%, and 2.34%, respectively, with efficiency of the 3D carbon cell enhanced by 1.4 times; the efficiency of the 3D platinum cell is enhanced by around 1.3 times; the proportion of graphite paper is reduced to 0.8.

Figure 12 shows the *J-V* curve of a cell with a counter electrode material of graphite paper versus an inclined 3D cell. Since it is difficult to carry out inclined machining in an experiment, and under the restrictions of material dimensions and illuminated area, only graphite paper at a thickness of 0.4 mm is investigated in this study. It can be seen from

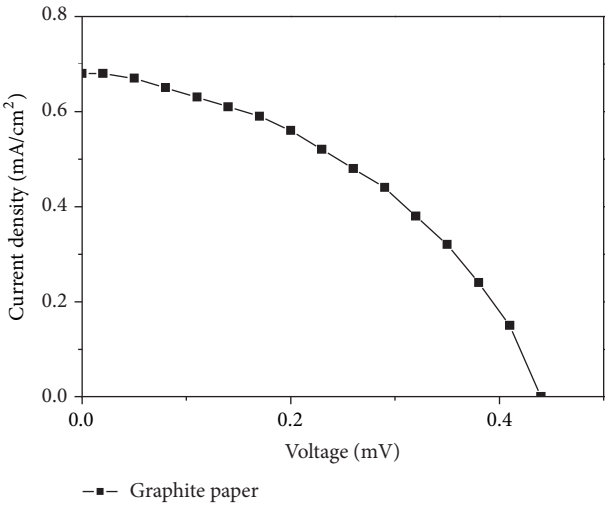

Figure 12: Photovoltaic curves (*J-V*) of the inclined 3D DSSC prepared with a graphite counter electrode.

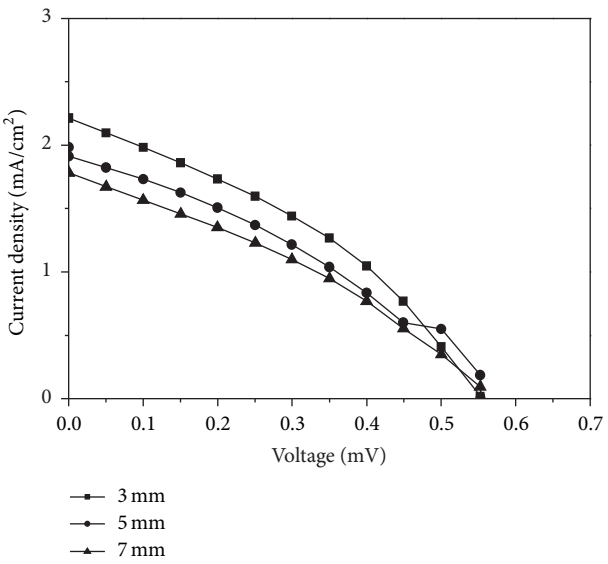

Figure 13: Photovoltaic curves (*J-V*) of the tandem DSSC prepared with a graphite counter electrode.

Figure 12 that open-loop voltage is 0.44 V, the short-circuit current density is 0.68 mA/cm^2, the fill factor is 0.43, and the photoelectric conversion efficiency is 0.13%. Comparing this experiment to the experiment applying the counter electrode material of graphite paper to a vertical 3D cell, the photoelectric conversion efficiency decreases from 0.37% to 0.13%. The reason is that the experiment has only 2 sets of photoanodes with parallel connection. Such a design is limited by the illuminated area measured by a solar cell. Affected by decreased illuminated area, the cell is not sufficiently effective. Although refraction of sunlight can be changed into direct illumination, the grinding method used in this study makes the glass 2.54 mm thick with a cloudy surface, slightly reducing the original transmittance of the cell and affecting the efficiency.

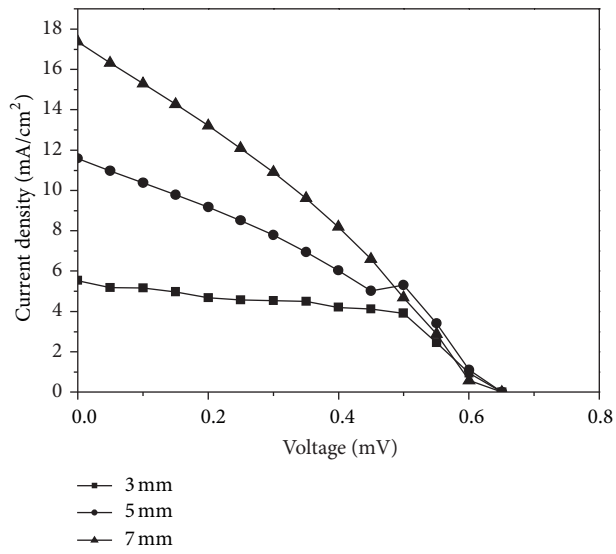

Figure 14: Photovoltaic curves (*J-V*) of the tandem DSSC prepared with a Pt counter electrode.

Figure 13 shows the *J-V* curves of tandem cells with the counter electrode material of graphite paper applied. As shown in the figure, when the cell height increases from 3 mm to 5 mm, the *J-V* curve obviously appears to be crossing. The short-circuit current density of the 3 mm cell is higher than that of the 5 mm cell, and the open-loop voltage of the 5 mm cell is higher than that of 3 mm cell, representing that when the control variable of the experimental parameter is cell height, the optimal height of cell is between 3 mm and 5 mm. It can be seen from Figure 13 that when the cell height is 7 mm, the short-circuit current density obviously tends to decrease, just the same as in the previous experiment with the vertical 3D cell. When cell height is 5 mm, open-loop voltage can reach 0.655 V, the short-circuit current density is 2.00 mA/cm^2, the fill factor is 0.37, and the photoelectric conversion efficiency is 0.49%, which is around 1.44 times that of the vertical experiment (0.34%).

Figure 14 shows the *J-V* curves of tandem cells with the counter electrode material of platinum applied. The figure shows that when the cell height rises from 3 mm to 5 mm and then to 7 mm, the short-circuit current density of the *y*-axis increases by a great extent. With cell heights of 3 mm, 5 mm, and 7 mm, the short-circuit current densities are 5.53 mA/cm^2, 12.16 mA/cm^2, and 18.42 mA/cm^2, respectively. It can be seen from Figure 14 that when the cell height is 7 mm, the open-loop voltage is 0.662 V, the fill factor is 0.31, and the photoelectric conversion efficiency is 3.85%, which is around 1.65 times higher than that of the efficiency previously measured for the vertical 3D cell (2.34%) and 2.15 times higher than that of the flat cell (1.79%). The reason for the immense enhancement of efficiency is that when increasing the receiving area of the cell and under the condition of the same illuminated area, the short-circuit current density increases and, accordingly, enhances the efficiency of the cell.

4. Conclusions

The photoanode of the DSSC designed in this study possesses a unique 3D structure. We use a gel polymer electrolyte as the electrolyte. Assembly is divided into vertical assembly, inclined assembly, and tandem assembly. Research results show that in the tandem assembly experiment, when platinum is taken as the counter electrode, the cell has five parallel connections, the illuminated area is 0.28 cm^2, and the height of cell is 7 mm and the open-loop voltage acquired is 0.662 V, the short-circuit current density is 18.42 mA/cm^2, the fill factor is 0.31, and the photoelectric conversion efficiency is 3.85%, which is 1.65 times higher than that of the vertical 3D cell (2.34%) and 2.15 times higher than that of the flat cell (1.79%).

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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