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Improving Efficiency of Dye-Sensitized Solar Cell by Micro Reflectors

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Dye-sensitized solar cells (DSSC) are 3rd generation solar cells that have a low manufacturing cost that is 1/3 to 1/5 that of a conventional silicon solar cells, and accordingly, DSSC is currently being developed around the globe. In this study, we investigated a reflector that can recover light that is lost in order to improve the conversion efficiency of DSSCs. The angle of the reflector was determined by using an optical analysis program. Micro pyramid patterns at an angle of 112.6º were fabricated using an ultra-precise shaping machine, and these structures maximize conversion efficiency by increasing the light distance. A comparative study was carried with respect to the conversion efficiency. We build a DSSC attached to a reflector with a mirror angle of 112.6º and measured the conversion efficiency of solar cell by using a solar simulator that can irradiate 100 mW/cm^2 (1Sum, AM 1.5). The results of the experiment indicate that the DSSC with the micro pyramid mirror exhibits an efficiency that is about 2% better than that of a DSSC with a black plate. The reflected light can cross more of the dye in the TiO_2 Layer. Therefore, the voltage at maximum power (VMP) is greater than that of other reflectors with a different mirror angle.

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NOMENCLATURE

AM=Air Mass
Sun=Solar density(100mW/cm^2)
IMP=Max Power Current (mA)
VMP=Max Power Voltage(V)
FF=Fill Factor
cb/vb=Conduct band / Valence band
Eg= Energy band gap
$S/S^*/S^+$=Ground state/excited state/oxidation of photosensitizer
HOMO=The ground state of the photosensitizer
LUMO= The excited state of the photosensitizer

1. Introduction

Modern life depends on acquiring energy and using it efficiently, and energy from solar light is practically infinite since one hour's worth of radiation onto Earth is equivalent to what the entire globe consumes in a year. Solar energy can be produced anywhere without any additional pollution, and it has become popular as a new source of energy to substitute current energy sources. Organic solar cells in particular have attracted much attention due to their portability, flexibility, mass production through a continuous process, potential for affordability, etc. Dye-sensitized solar cells are organic solar cells that have the advantage of being produced at a very low cost of about 1/4 to 1/5 that of existing silicon solar cells. Furthermore, the size of the nanoparticles and the thickness of the film can be controlled to manufactured transparent solar cells, which are expected to have a wider range of applications than existing solar cells. However, these have the disadvantage of lower conversion efficiency than existing solar cells.[1-3]

We propose a new method that improves the light conversion efficiency by using a reflector to collect light that would otherwise be lost due to permeation through the dye-sensitized solar cell. The goals of this study are to

- Fabricate a reflector with the appropriate micro structure
- Improve the working distance of the scattered light
- Control the mirror angle to provide the optimum design

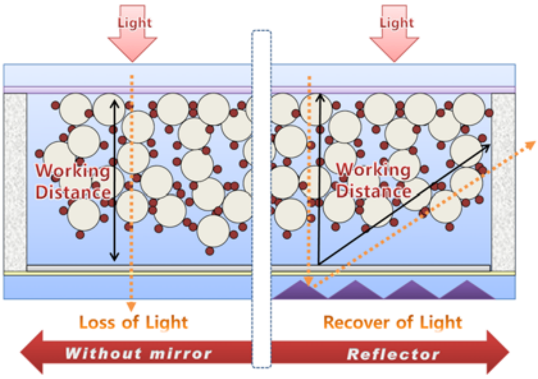

Fig. 1 DSSC with reflector

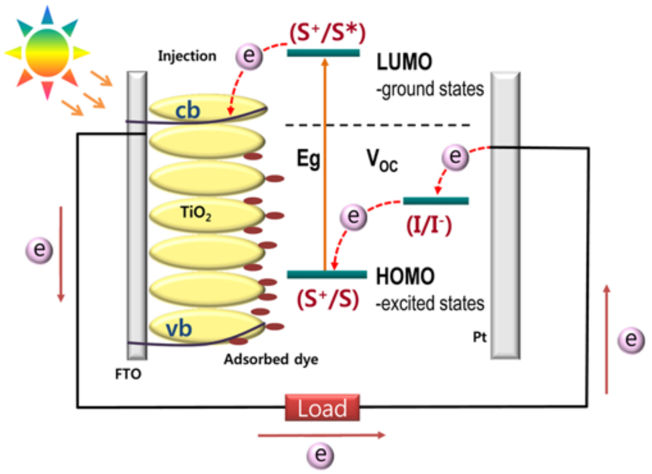

Fig. 2 Working principle of the DSSC

- Improve the photoelectric efficiency with a micro pyramid arrayed mirror

2. Background

2.1 Dye-sensitized Solar Cell (DSSC)

Fig. 2 shows the operating principle and the structure of the DSSC. Visible rays are absorbed in TiO_2 by n-type nanoparticles. The dye molecules are chemically absorbed on the surface and generate electron-hole pairs with electrons injected into the conduction band of the semiconductor's oxides. These electrons that are injected into the semiconductor's oxide electrode generate a current through each of the interfaces of the nanoparticles. The holes made from the dye molecules are deoxidized by the receiving electrons, and thus, the DSSCs begin to operate.

The dye becomes saturated after absorbing solar light, and the electrons that are generated are in turn transferred to the TiO_2 conduction layer and then flow out through a transparent electrode to carry electrical energy. When solar light is absorbed, the oxidized dye is deoxidized after electrons are supplied from the electrolyte. At that moment,

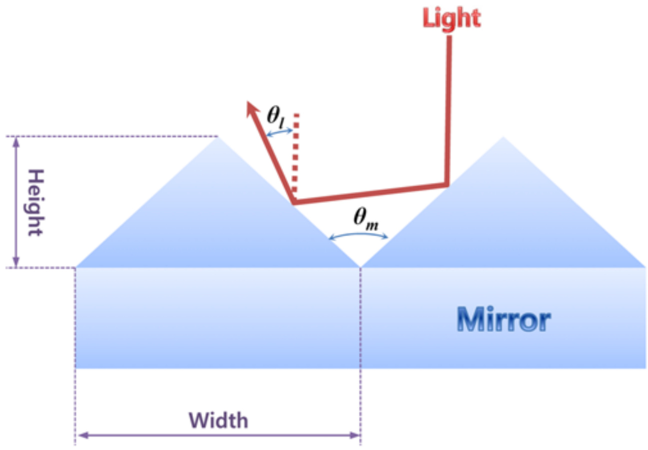

Fig. 3 Light path and mirror angle

electrolysis mainly occurs as the oxidation/deoxidation pair of I-/I3- that receives electrons from the relative electrode in order to transfer them to the dye.[4]

2.2 Relation between light scattering distance and efficiency

The processes that are used to generate and transfer electrons play an important role in determining the performance of the cell. At first, the time span during which electrons that are generated from the dye are fed to TiO_2 should be shorter than that during which they recombine with the holes and disappear. Normally the time to feed electrons is very fast, from femto-seconds to pico-seconds, and oxidized dye is regenerated within several nano seconds.[5]

The electrons that enter into a conduction layer of TiO_2 should not be recombined with oxidized ions during electrolysis either. In general, the recombination is slower by a few microseconds to milliseconds. Thus the loss due to the recombination of electrons-hole pairs is not considerable, but even small amount of it reduces the efficiency of the cell.

One method that can be used to increase the efficiency of the dye-sensitized solar cell is to expand the surface area of the semiconductor oxide, which is TiO_2 in this case. Since the dye molecule has a high efficiency when absorbed on the semiconductor as a single layer of molecules, the solar light absorbed becomes larger as the surface area of the semiconductor on which the dye molecule is absorbed increases. Consequently the efficiency of the cell improves since the TiO_2 particles are small and the porousness is high.

This study investigates the conditions under which the dye produces as many electrons as possible by reflecting the solar light that enters to increase the scattering distance rather than by expanding the surface area of the oxide.

3. Experiment

3.1 Light simulation

We used a light analysis program to design a micro reflector in order to increase the scattering distance of the solar light that is reflected on the dye layer of the dye-sensitized solar cell.

Table 1 Results of light simulation

Aspect Ratio	Height [μm]	Width [μm]	Mirror Angle [degree]	Light Angle [degree]	Working distance [μm]
2	50	25	28.8	11.6	40.8
1	50	50	53.2	21.2	42.9
0.5	50	100	90.0	0.0	40
0.33	50	150	112.6	67.5	104.5
0.25	50	200	126.9	53.6	67.4
0.2	50	250	136.4	43.8	55.4

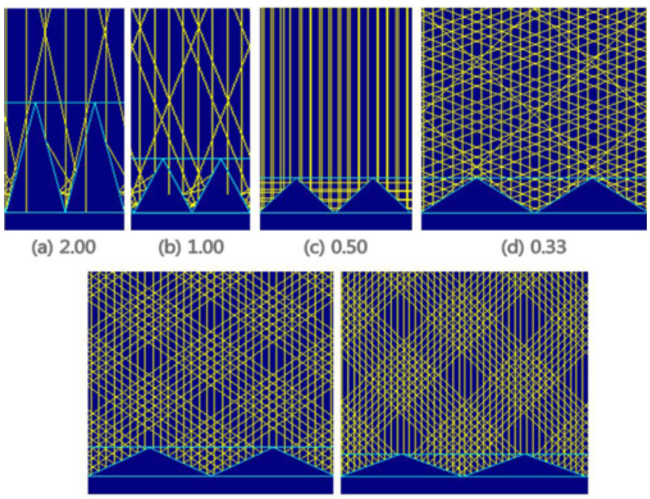

Fig. 4 Simulation results pursuant to aspect ratio

To increase the light scattering distance of the dye layer, we set the light angle (θ_l) to the maximum for the reflected light to be able to spread out widely on the dye layer. The light angle and the mirror angle (θ_m) are indicated on Fig. 3. We measured the light angle according to aspect ratio of the height and width of the micro pattern of the reflector, and we determined the mirror angle as that where the value became the maximum. The resulting values are indicated with respect to the aspect ratio on Table 1 and Fig. 4.

The results of the light analysis indicate that when the aspect ratio was 0.33 and the mirror angle was 112.6°, the light angle had a maximum value of 67.5°. With these conditions, and considering that the thickness of the dye layer in the dye-sensitized solar is 40 μm, solar light can encounter the largest amount of dye with a scattering distance of about 104.5 μm.

3.2 Experiment conditions and measurement method

We produced a DSSC on an FTO membrane coated with 20 μm of TiO_2 paste. The membrane coated with the working electrode was sintered at 450°C and dye (N719) was introduced for a period of about 12 hours.

The micro patterns were formed on the material via micro cutting with a single-crystal diamond tool, and the pattern dimensions including height, width, and length of the micro pattern were dependent on the shape, the cutting depth, and the feeding speed of the machining tool. The shaping material of the machine that used a single-crystal diamond

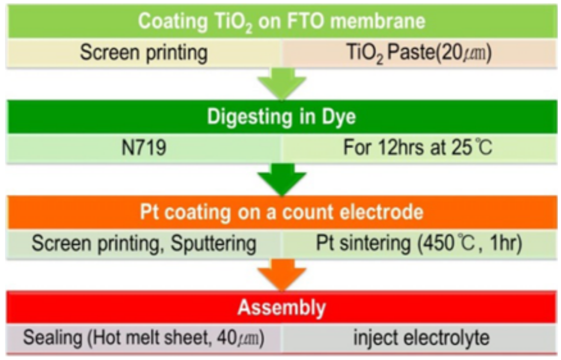

Fig. 5 Manufacturing of dye-sensitized solar cell

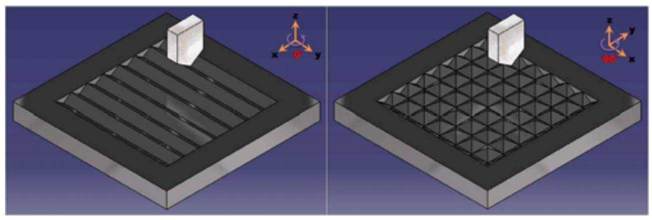

Fig. 6 Machining tool path

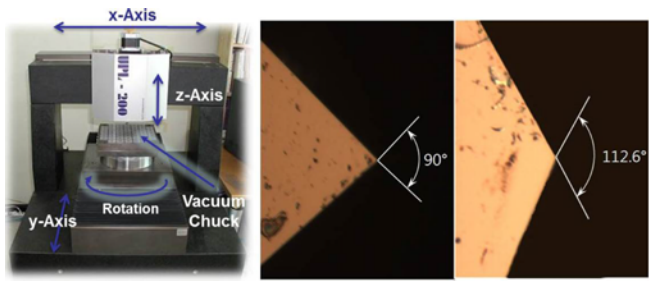

Fig. 7 Shape machine and diamond tools

was set at a certain tool angle to create a 3-dimensional pyramid structure. In order to form the pyramid shape, the process consisted of machining in one axis with the diamond shaping tool and then machining the other axis by rotating the table by 90°.[6]

To machine the sample, oxygen-free Copper (OFHC copper) was mostly used for the general reflector mirror. The results of the light analysis indicated that a single-crystal diamond bite with a 112.6° tool angle would maximize the light angle. The cutting length was a total of 50 μm with 5 μm steps, and the feeding interval was of 100 μm. The height of the mound of the machined material was of about 33.35 μm, and after machining, the material was washed with a supersonic wave to remove micro burr, chips, etc. that could have been generated during machining. Then, the samples were treated with fluoric acid for about 15 seconds and were coated with gold via electrolytic plating.

In order to fully understand the efficiency of the solar cell placed upon the micro reflector, the efficiencies of the gold-coated reflector, pass-through without mirror, and without a reflective black plate were compared by using a solar cell simulator. The simulations progressed under AM (air mass) 1.5 conditions (1sun, 100 mW/cm^2).

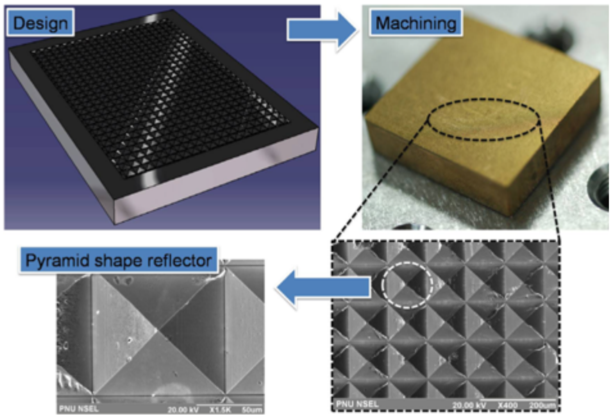

Fig. 8 Machined pattern for reflector

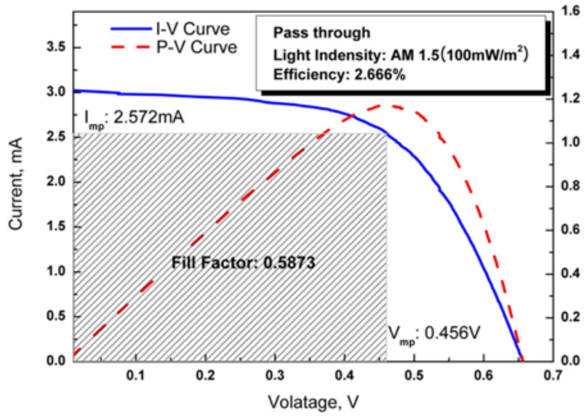

Fig. 10 I-V and P-V curve without a reflector

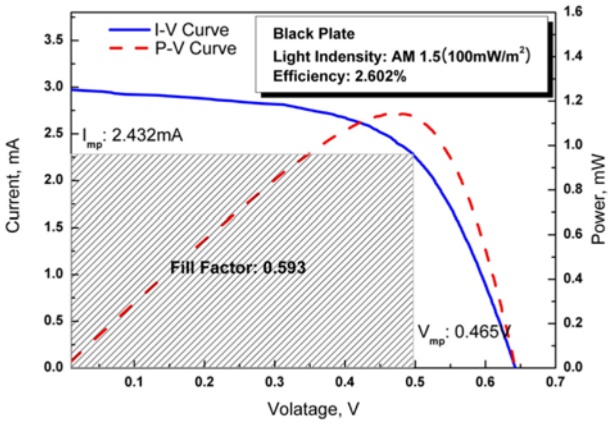

Fig. 9 I-V and P-V curve based on black plate

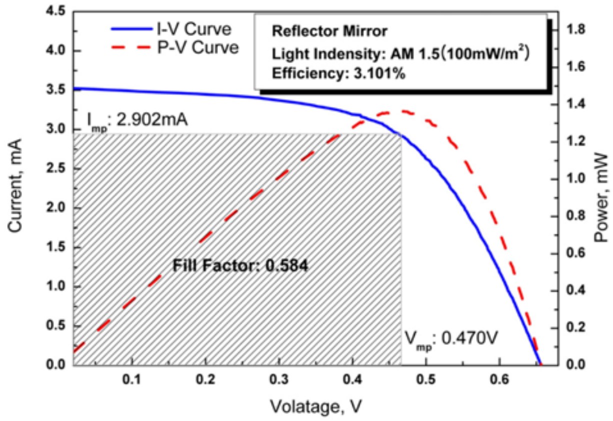

Fig. 11 I-V and P-V curve based on micro pyramid pattern reflector

4. Results and Analysis

The micro pattern machining was performed using a commercial super precision machine. The shape of the micro machined sample was measured using SEM, and Fig. 8 shows that the pyramid-shaped reflector machined to a 100 μm width and 33.35 μm height with a tetrahedral shape.

A burr was generated at the bottom of the micro machined work as a result of the 90° rotation. This is considered in order to study the machining conditions in terms of the cutting amount and the feeding speed.

We made DSSC by hand at a size of 11 mm * 4 mm. This has a smaller area than that from a preceding study that obtained an efficiency of about 0.5%. The size of the mirror is also smaller before.

We compared efficiency of the DSSC in all three cases. Fig. 9 shows the I-V and P-V line of the cell to which the black plate is attached at the bottom of the dye-sensitized solar cell.

The second is for the DSSC where light passed through the solar cell and the solar irradiation then was lost. Fig. 10 shows the efficiency of the DSSC when sunlight is passing through.

Fig. 11 shows the sample where the pyramid-shaped reflector is used to collect the light that is being lost from permeation through the dye-sensitized solar cell.

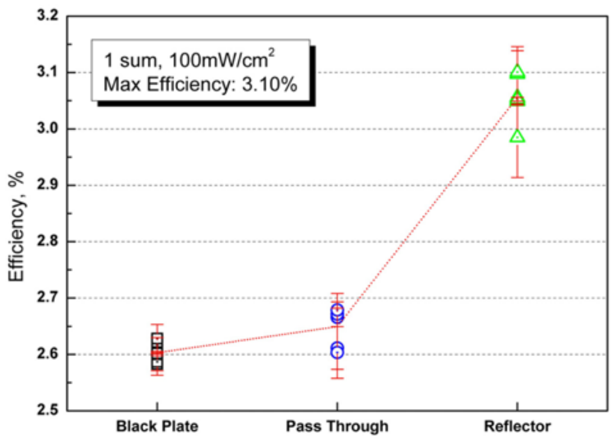

Fig. 12 Comparison of efficiency of different reflectors

5. Conclusions

In this study, a micro patterned reflector was machined to increase the efficiency of the dye-sensitized solar cell, and the conversion efficiency of the solar cell was measured. The results are summarized as follows:

Table 2 Properties of different reflectors

	V_{OC} [V]	I_{SC} [mA]	P_{MAX} [mW]	Fill Factor	Efficiency [%]
Black Plate	0.64	2.40	1.15	0.60	2.603
Pass Through	0.66	3.04	1.17	0.58	2.649
Reflector	0.66	3.54	1.34	0.58	3.056

A light analysis was performed to obtain the optimal reflection angle of 112.6° to increase the conversion efficiency through the reflector and to collect the light that is lost after passing through the dye-sensitized solar cell.

When the pyramid-shaped reflector was used, the energy conversion efficiency was higher by about 17% than that achieved when using a black plate.

In the case of the pyramid-shaped reflector, the maximum inclination lengthened the distance to encounter the dye layer of of the TiO_2 to achieve a maximum power current (I_{MP}) and to bring about an improvement in the efficiency of the entire system relative to the case where there is only a vertical reflection.

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