A Study of the Photo-Electric Efficiency of Dye-Sensitized Solar Cells Under Lower Light Intensity

Hee-Je Kim*, Yong-Chul Kim*, Ji-Tae Hong*, Mi-Jeong Kim*, Hyun-Woong Seo*, Je-Wook Park* and Jin-Young Choi†

Abstract – To elucidate possible challenges for outdoor practical use of dye-sensitized solar cells (DSCs), we compared conventional Si solar cells with DSCs. DSC modules still require a larger area than conventional Si solar modules to attain the same rated output because of lower photoelectron-chemical conversion efficiency. However, in backup systems by using batteries, the measured data shows that DSCs generated 15% more electricity than Si solar cells of the same rated output power in the same interval of cloudy daylight. Moreover, the battery charging time of DSCs is about 1 hour faster than the same rate of Si solar cells under outdoor cloudy daylight. This result also indicates that conversion efficiency obtained by the certified condition less than AM 1.5 condition does not always coincide with the electricity generated outdoors daily, and it is not a crucial measure to evaluate the performance of solar cells.

Keywords : Cloudy daylight, Dye sensitized solar cells, Si solar cells, Outdoor experiments

1. Introduction

Although single-crystalline or poly-crystalline Si solar cells play the lead for practical use now, difficulties in their cost reduction still stand in the way of popularization. Thus, solar energy has been left in a lethargic state. The shortage of Si resources, the raw material needed to manufacture solar cells, is also coming just around the corner. Therefore, new types of low cost solar cells are necessary.

In 1991, O'Regan and Gratzel of the Swiss Federal Institute of Technology at Lausanne introduced dye sensitized solar cells (hereinafter referred to as DSCs) as a new class of low cost solar cells [1], whose solar energy conversion efficiency (hereinafter referred to as Eff) was reported to be as high as 7.1% in simulated solar light, and 12% in diffused daylight. Recently, DSCs possess efficiencies of 8~11% in small devices (area less than $1cm^2$) [2] and 5~6% in $100cm^2$ modules under AM1.5 condition. According to this report, the performance of DSCs was almost as good as that of conventional Si-based solar cells despite its simple fabrication process. The raw materials are cheap, very abundant in natural resources, and harmless to human beings. It is neither necessary to have high temperature thermal treatments nor vacuum treatment in the production line, which enables remarkable cost reduction in comparison with conventional solar cells. All these features were enough to attract attention because it can overcome the present sluggish situation and accelerate popularization of solar energy conversion if DSCs are manufactured at a much lower cost than conventional solar cells.

In general, Si solar modules strongly depend on light angle of incidence. So, it needs light tracing systems. Although it uses light tracing systems, it is weak at diffused daylight or input of low power light such as cloudy daylight. However, DSCs are less affected than conventional cells under diffused lighting conditions because the DSC solar system is less sensitive to installation constraints.

In this paper, we compared photoelectric characteristics of the DSC with those of the Si solar cell under indoor A.M 1.5 condition and outdoor cloudy daylight condition. As well, charging characteristics of DSC and Si cells were experimented by using a DC-DC converter battery charging circuit.

2. Preparing DSCs

The manufacturing technique of monolithic DSC is presented [3]. DSCs use a titanium dioxide, TiO_2 semiconductor coated with a ruthenium dye that absorbs light in the visible spectrum [4]. The basic DSC consists of a sandwich of TiO_2, dye, electrolyte and catalyst between conducting transparent electrodes (see Fig. 1).

Upon illumination of the cell, charge separation occurs

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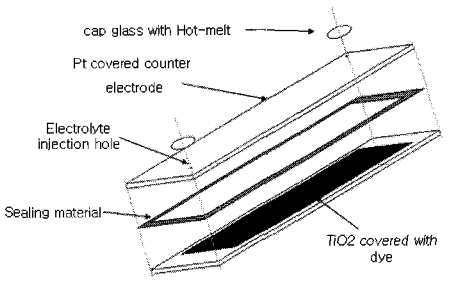


Fig. 1. The structure of DSC

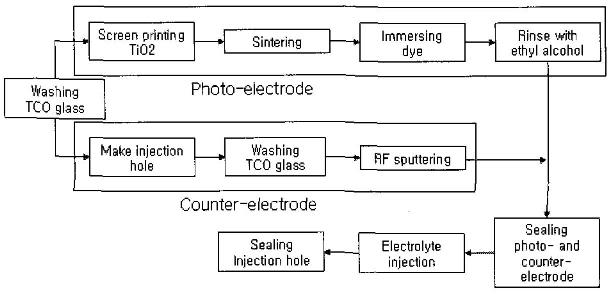


Fig. 2. Fabricating process of DSC

by electron injection from the excited dye molecules in the conduction band of TiO_2. The dye is oxidized by a redox electrolyte.

An overview of all production steps to fabricate the cell preparation is shown in Fig. 2.

The photo-electrodes were printed 50μm thickness TiO_2 pastes on TCO (transparent conducting oxide) glass plates. After printing, the photo-electrodes were sintered at 450℃ for 2 hours (thickness goes down 20μm), before they were immersed in a 0.3mM dye sensitizer ethanol solution at a temperature of 25℃. As for the sensitizer, ruthenium complex (N719) was employed. The photo-electrodes were left in the dye solution overnight, rinsed with ethanol, and dried using a low temperature heat blower. The counter electrodes were coated with Pt using RF sputtering. As encapsulation material, thermoplastics (Hot-melt, thickness: 60μm) were used. Fig. 3 shows one of the fabricated DSCs (Isc: 43.5mA ~46.5mA, Voc : 0.79V~0.83V, fill factor : 0.61).

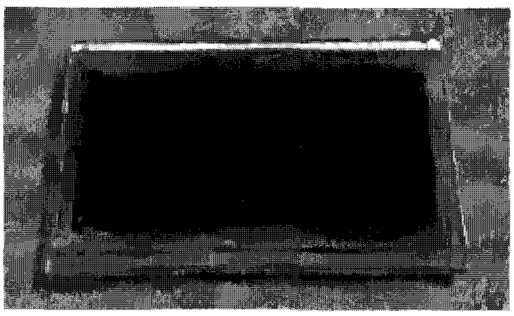


Fig. 3. The fabricated DSC solar cell (active area: 16.5 cm^2, Isc: 45mA, Voc: 0.8V E_{ff}: 75.7%)

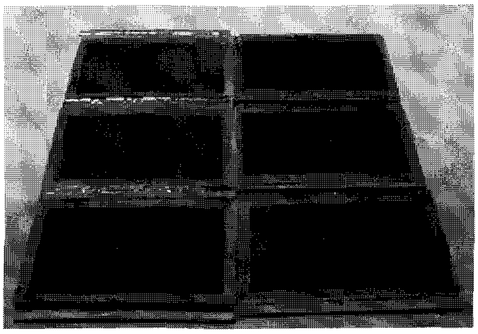
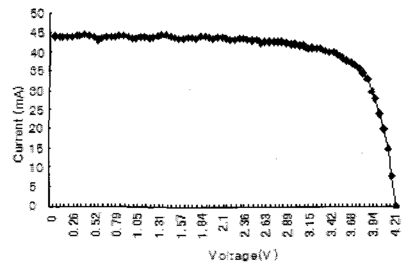


Fig. 4. The 6 serialized DSCs module (AM 1.5 condition – Pmax: 137mW)

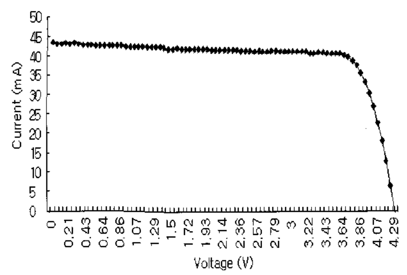
3. Experiments

The Si solar cell doesn't work under diffused light or low power light because of its structural and electrical characteristics. However, in case of the DSC, there are many differences in comparison with Si solar cells. Our experiments show that DSC works under diffused light or low power light conditions such as sunset or sunrise time. For measuring the performance of DSCs, a conventional Si solar cell was prepared as a control. The 6 serialized DSCs were prepared having the same MAX power rate as the counter Si solar module (Fig. 4).

These solar cells were compared under AM 1.5 condition (Fig. 5). The experiments were practiced in indoor and outdoor conditions. Diffused daylight and low power light condition were used.



(a) DSC module I-V curve Pmax -137mW Eff : 61%



(b) Si solar module I-V curve Pmax – 147mW, Eff : 78.8%

Fig. 5. I-V characteristic of DSC module and Si solar cell at AM 1.5

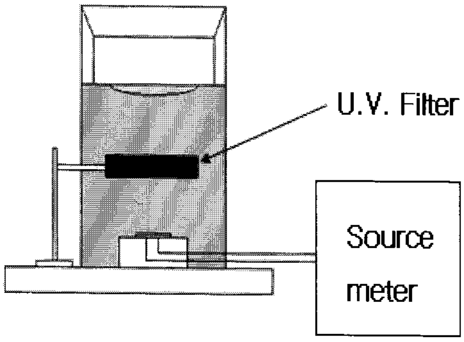


Fig. 6. The structure of artificial solar simulator

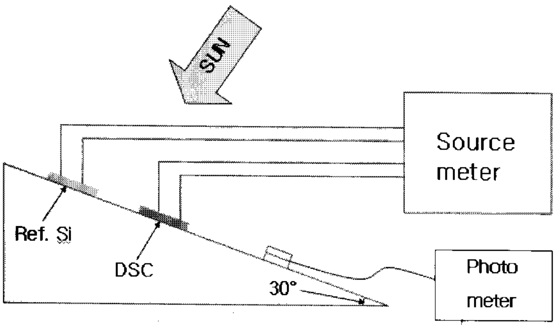


Fig. 7. The solar tracing system for outdoor experiment

In indoor conditions, the composed light variable solar simulator (Fig. 6) and varied light source from 5mW/cm^2 to 25mW/cm^2 for comparing each solar cell in conditions of low power light (sunset or sunrise conditions) were used. A full spectrum solar simulator as the light source was employed (Oriel Co. 300W Xe Model 6258). Measuring instruments were covered for protecting external light interference.

Diffused day outdoor experiments were practiced for measuring 1 day generation differences in each solar cell because of the light angle of incidence affect on Si solar cells generation. The outdoor experiments were performed by using the solar tracing system (Fig. 7).

In outdoor conditions, the composed systems were placed on flatland kept away from a shadow. The place of the outdoor test was located at Busan, Korea at 35°10'N latitude, 129°03'E longitude (weather: -2℃ ~ 14℃, humidity: 37%). The experiments were practiced from A.M. 6:30 to P.M. 6:30 (sunrise time – a.m. 6:20, sunset time – p.m. 6:50). Input of light power and output of solar cells electric power were measured with 1 hour interval by using V-I meter.

Fig. 8 and Fig. 9 indicate the battery charging system by using solar cell and DC-DC converter for outdoor battery charging test. Switching frequency of battery charger is set at 1.2MHz and output voltage was 3.3V for 1 battery charging. This frequency minimized solution footprint by allowing the use of tiny and low profile inductors and ceramic capacitors. DSC and Si solar modules connected with each DC-DC converter and measured voltage at 1 hour intervals.

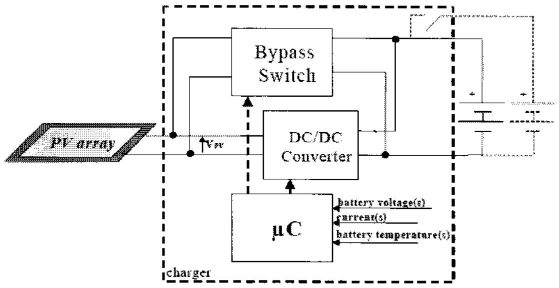


Fig. 8. The battery charger system architecture

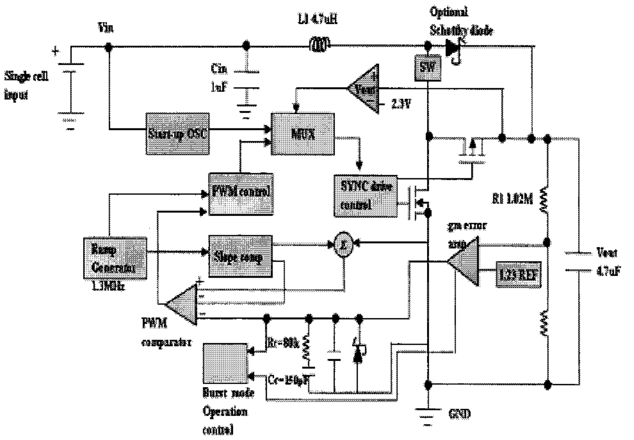


Fig. 9. DC-DC converter for battery charging system

4. Results & Discussions

Fig. 10 contains DSC output power rate and Si solar cell output power rate when input light varied from 5 to 25mW/cm^2. These results suggest that the DSC output is higher than that of the Si solar cell under low light conditions and it is not related to the angle of incidence. The current density slope of DSC is 2.7 times higher than that of Si solar cells. It shows us that the output of DSC reached the maximum faster than that of the Si solar cell.

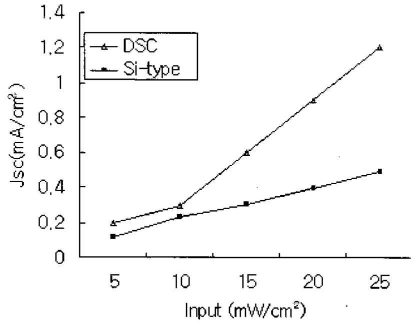


Fig. 10. Indoor testing of each cell from 5mW/cm^2 to 25mW/cm^2

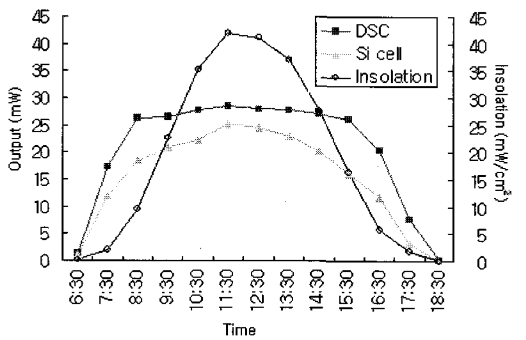


Fig. 11. Output characteristic of DSC and Si solar cell in one day insolation

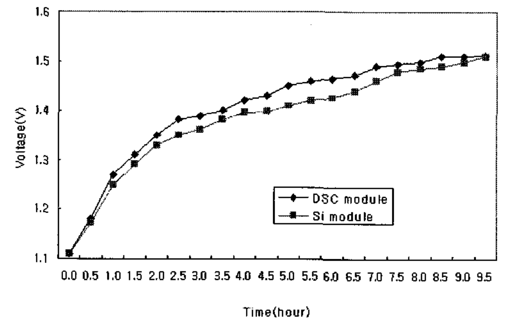


Fig. 12. Battery charging characteristics of DSC module and Si solar module

Fig. 11 shows a typical example of a variation of insolation and generated electricity from sunrise to sunset. Since the output powers are different between the DSC module fabricated here and the commercially available single crystalline silicon module, the generated electricity was converted into the J_{sc} value for ease of comparison. The outdoor condition is diffused. As such, the output power of DSC is 15% higher than the Si solar cell. It shows that the DSC module generated more electricity than the Si module throughout the day. Especially, DSC has advantages over Si solar cells at mid-morning and at mid-afternoon.

Fig. 12 shows the battery charging characteristics of DSC and Si solar module. DSC module saturated 1hour faster than Si module. It means the DSC module generated more electricity at the same output rate and same daylight interval.

In the DSC development, much effort has been focused on improving E_{ff} [5 6]. Because of the limitation of electronic conductivity of the TCO layer on the glass electrode, most studies have been done with very small cells with its active area around or less than 1 cm^2 (hereinafter, referred to as "mini-cell"). Recently, several works have been reported on long term stability in some accelerating conditions of degeneration, such as a high temperature (e.g. 85° C) durability test in the dark, and light soaking test under a continuous simulated 1 Sun insolation, although they are still based on mini-cells [7, 8]. Correspondence of these artificial durability tests to outdoor tests like the present study must be examined sooner or later. Putting aside the difference between outdoor test and artificial indoor test, tests on modules and mini-cells may also elucidate different aspects of the phenomena.

Anyway, these fundamental research activities have revealed various properties of DSC. It is often experimented that the generated electricity is not increased linearly with increase in light intensity [9, 10]. Consequently, E_{ff} decreases with increase in light intensity. This phenomenon seems to be attributed to rate limitation of ionic transport or catalytically activated redox reaction on the electrode in DSC, which is effective only in the case of relatively high electric current caused by exposure to an intense light. Since this phenomena has not been experienced in the case of Si cells in which no ionic transport process or catalytically activated redox reaction are involved, difference of E_{ff} between DSCs and Si cells depends on the light intensity. Under the certified condition: 1 Sun, DSCs give relatively low E_{ff} compared with Si solar cells. Since the insolation of 1 Sun condition is only limited for a few hours around noon, it is easily conjectured that DSCs are not usually exposed to so disadvantageous conditions from sunup to nightfall throughout the cloudy day compared with Si solar cells.

6. Conclusion

DSC was prepared in the monolithic way of DSC (Isc: 44.5mA, Voc: 0.82V, fillfactor: 75.7%) and 6 serialized DSCs (Isc: 44.5mA, Voc: 4.21V, E_{ff}: 71.2%) were practiced in experiments and compared with conventional Si modules (Isc: 43.5mA, Voc: 4.29V, E_{ff}: 78.8%) for outdoor testing. Under AM 1.5 conditions, the indoor experiment shows that Pmax of the Si solar module was 9.7% more than W/cm^2, and that DSC slope is better than Si slope, that is, DSC is more sensitive under lower intensity. In outdoor testing, the DSC module generated 15% more electricity than Si solar modules under cloudy daylight. The battery charging test shows that the DSC module reduced battery charging time by about 4 hours, compared with the Si solar module.

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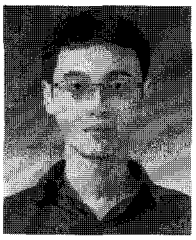

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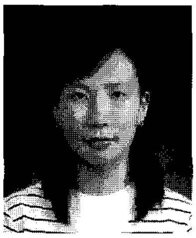

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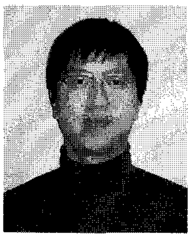

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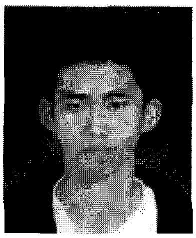

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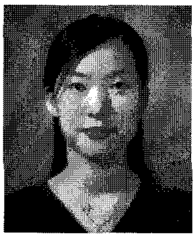

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