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Improved heat dissipation in a crystalline silicon PV module for better performance by using a highly thermal conducting backsheet

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ABSTRACT

The temperature of a crystalline silicon photovoltaic module has a strong impact on the electrical performance of the module. The performance can be improved by reducing the temperature of the module. In this study, a highly thermal conducting backsheet was integrated to the mini module, consisting of one single crystalline silicon solar cell, to investigate the temperature and performance changes in the module. By applying a backsheet with graphite and aluminum film, it was found that the final temperature was decreased, compared to a solar cell with a reference backsheet. In addition, providing a suitable heat path for thermal dissipation in the frame of the module has an influence on the effectiveness of the highly thermal conducting backsheet.

1. Introduction

A photovoltaic module converts radiation energy from the sun into electricity. Energy from the sun is a form of electromagnetic radiation having a wide range of wavelengths. In the case of crystalline silicon, the photovoltaic (PV) cells convert only a small fraction of the wide spectrum of solar energy, mainly from wavelengths of 400–1100 nm [1,2]. In addition, in the case of the wavelength specified above, the solar cell cannot convert all the energy into electricity, and the external quantum efficiency of the crystalline silicon cells for this wavelength range is approximately from 20 to 90%, as reported in other references [3,4]. The energy from other wavelengths, and the unused energy in the 400–1100 nm wavelength range, induces a temperature rise in solar cells including a PV module. Light that has energy below that of the band gap of crystalline silicon solar cells cannot be converted into electrical power. This light significantly contributes to the temperature rise in a solar cell if it is absorbed by the solar cells or by the module. It is known that the performance of solar cells is sensitive to temperature like all others semiconductor devices [5–8]. As the temperature of the solar cell increases, the band gap of the device decreases, resulting in an increasing short circuit current and a decreasing open circuit voltage, as reported previously. This phenomenon occurs because the thermally excited electrons begin to dominate the electrical properties of the silicon cells [5]. The detailed physics of the temperature impact on the performance of solar cells can be found in other references [9–11]. Hence, there are many reported correlations expressing the electrical efficiency of solar cell, η_c, as a function of the cell temperature, T_c. Below is one of equations expressing the effect of Tc on η_c.

$$\eta_c = \eta_{T_{ref}}\left(1 - \beta_{ref}\left(T_c - T_{ref}\right) + \gamma log_{10}G_T\right) \quad (1)$$

where η_{Tref} is the module's electrical efficiency at a reference temperature (T_{ref}) and a solar radiation flux of 1000 W/m^2 [5,12]. β and γ are the temperature coefficient and the solar radiation coefficient, which have values of approximately 0.4%/°C[1] and 0.12, respectively, in the case of crystalline silicon solar cells. G_T is the solar radiation flux (irradiance) on the module plane (W/m^2). As listed, both coefficients are relatively small, so the latter term in Eq. (1) is usually neglected [5,12]. As explained by the above equation, the performance of the PV module can be improved by decreasing the temperature of the module. To quantify the effect of the

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temperature on the performance of the solar cell, the temperature coefficient is generally used. It is reported that the coefficient of a crystalline silicon solar cell is −0.4 ~ −0.5%/°C ([11–13]. Additionally, decreasing the temperature of the module can increase the reliability of the PV module because some of the materials in PV modules are polymers, such as EVA (Ethylene-vinyl acetate), PET (Polyethylene terephthalate), PVF (Polyvinyl fluoride), PO (Polyethylene), and PVDF (Polyvinylidene fluoride), and these materials degrade rapidly with higher temperature, as reported in other references [14–18].

To decrease the temperature of the PV module, different types of approaches have been used, such as applying structured glass in the front side of the module and a V shape fin in the back side or filling the thermal conductivity filler in encapsulant to enhance the heat dissipation [11,13,19,20]. Other approaches include combining other systems, such as a thermal solar panel for heating water and a cooling PV module, or devices such as a thermoelectric device for generating electricity from the temperature difference between the airside and the PV module [21–27]. In this study, a backsheet with improved thermal conductivity, especially in the plane direction, was integrated to one cell mini module to investigate the effectiveness of the improved thermal conductivity of the backsheet and its impact on the performance parameters of solar cells. For this, one cell mini modules with a commercially available backsheet with a PET-based structure and a newly developed backsheet with improved thermal conductivity were compared.

2. Experiments and details

To enhance the heat dissipation in the PV module, a highly thermal conducting backsheet was developed by laminating 500 μm thick graphite with a 150 μm thick aluminum sheet. To compare the impact of the highly thermal conducting backsheet on the performance of the silicon solar cell, one of the typical structures of a backsheet consisting of PET was also used as a reference backsheet. The cross-section of the backsheet for both highly thermal conducting and PET-based backsheets, including their thickness and the materials used, are shown in Fig. 1 to compare the two different structures. The detailed process for the materials and laminating process, including characterization for the highly thermal conducting backsheet, can be found in the next report [28]. To investigate the impact of the incorporation of the highly thermal conducting backsheet, a one-cell mini module with an electrical contact was prepared, as shown in Fig. 2(a), instead of a full scale PV module. A single crystalline silicon cell of 6 inches was laminated with an EVA encapsulant (67% mass fraction of ethylene and 33% mass fraction of vinyl acetate) at 150 °C for 12 min, as suggested by the material supplier. Low iron glass in the front side for low reflectance and two different types of backsheets in the back side were used to investigate how different thermal conducting backsheets impact the performance of crystalline silicon solar cells. Three mini module samples were prepared for each backsheet type to investigate the consistency of the measurement. The performance of the one-cell mini module was characterized by a continuous type solar simulator (K201 Solar Simulator LAB 200, McScience). The temperature of the solar cells, including both their distribution and the change as a function of time, were monitored using an infra-red (IR) camera (FLIR Systems, ThermoVision™ A-20 M), as shown in Fig. 3. The temperature from the IR camera is that of the surface of the front glass. It was reported that the surface temperature of the glass is slightly lower than that of the silicon cell [29]. This difference is not significant, so the temperature of the front glass was used in this study. Additionally, for accurate measurement, nine points of the mini module were monitored and averaged, as shown in Fig. 3. This figure includes the experimental set-up for the I-V characterization and temperature measurement using the IR camera. The room temperature was monitored during the experiment and the ambient temperature of laboratory was maintained as 28.0–29.0 °C.

During the experiment for monitoring the temperature and the performance of the two types of modules, it was found that the temperature difference of the two modules with different backsheets vary according to the frame of the module. This finding has a dominant impact on the experimental results. Hence, the laminating solar cells and the laminating solar cells with an aluminum frame were prepared to make a heat path that is similar to an actual PV module, as shown in Fig. 2(b). This will be discussed more in the next section.

3. Results

As explained in the introduction, illuminating the solar cell by a solar simulator induces a temperature rise in it, as shown in Fig. 4(a). The energy that is not used to generate electricity in the solar cell induces a temperature rise. The temperature of the solar cell increases as the exposure time increases. The different temperature lines in the graph of Fig. 4 indicate the temperature of the different positions in the cells. As explained previously, the temperature of the cell was monitored by an IR camera at 9 points. Although the center temperature of the cell was slightly higher than the other points as shown in Fig. 4(a), the difference was not significant. Hence, the average value from the 9 points was used when the data of the temperature are reported. In this graph, it was also found that increasing the temperature reduces the efficiency of the solar cell, especially the open-circuit voltage (V_{oc}). This phenomenon is also clearly found in the graph of the current-voltage as a function of the exposure time in Fig. 5. This graph shows the effect of the temperature on the current-voltage characteristics of a solar cell. Based on the data in the graph, V_{oc} decreases, but the change in I_{sc} is insignificant as the temperature of the cell increases, as

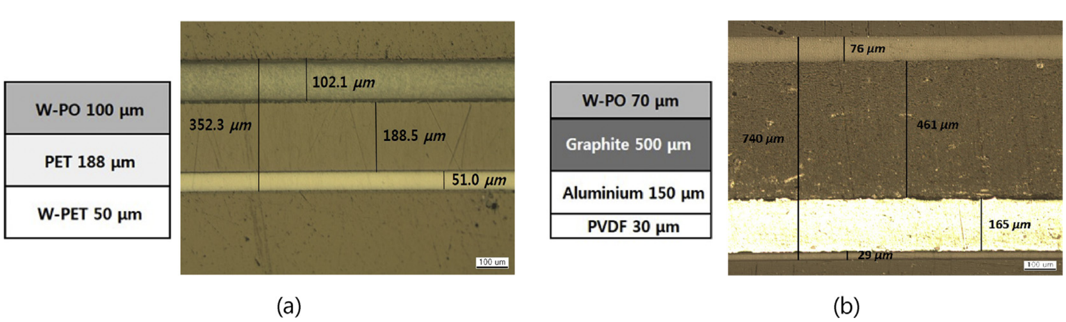

Fig. 1. Images of the cross-sections for the reference backsheet (a) and the highly thermal conducting backsheet (b), including their structures.