

Reduction of temperature in silicon photovoltaic module using thermal radiation coating

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Abstract. The temperature of solar cells increases under the actual operating conditions, and the conversion efficiency of solar cells decreases with increasing temperature. In this study, a thermal radiation layer was coated on the back sheet of the PV module by a spray coating method and the effect was evaluated. The thickness of the layer was 30 μm . The temperature of the PV module with the thermal radiation coating was lower than that of the PV module without the thermal radiation coating. And the operating temperature range of the PV module with the thermal radiation coating was decreased by 2~3°C. The open-circuit voltage of the PV module with the thermal radiation coating was 0.1 V higher than that of the module without the coating due to the thermal radiation coating.

1 Introduction

Photovoltaic (PV) power generation is becoming widespread as a clean and gentle energy source for the earth. Though the performance of solar cell is mainly evaluated under the standard test condition (STC: 1kW/m² irradiation, 25°C module temperature, and AM1.5 global spectrum), operation under various environments is required for PV systems, and environmental factors such as solar irradiation and module temperature seriously influence the generating performance of the systems

The temperature of solar cells increases under the actual operating conditions, and the conversion efficiency of solar cells decreases with increasing temperature [1-11]. It is therefore very important to reduce the cell temperature in PV modules.

In this study, a thermal radiation layer was coated on the back sheet of a PV module and the effect was evaluated.

2 Experimental procedure

Figure 1 shows the single crystalline silicon PV modules (area: 1200 mm \times 527 mm) evaluated in this study. The output characteristics of PV modules with and without thermal radiation coating were compared. A thermal radiation layer (Pelcool (R), PELNOX Ltd.) was coated on the back sheet of the PV module by a spray coating method. The thickness of the layer was 30 μm . The thermal radiation layer consisted of acrylate resin and inorganic fillers. The fillers were selected to radiate the heat, particularly in the temperature range from 40 to 100°C, which is the main range of operating temperature

for the PV module. The thermal emissivity of the layer is 0.95. In order to detect the temperature of the PV module (T_{mod}), temperature sensors (Pt100) were set on the back surface of the PV modules. The current-voltage (I-V) characteristics were measured using an I-V curve tracer (MP-160, EKO). The modules with and without the thermal radiation coating were evaluated at University of Miyazaki (Miyazaki, Japan).

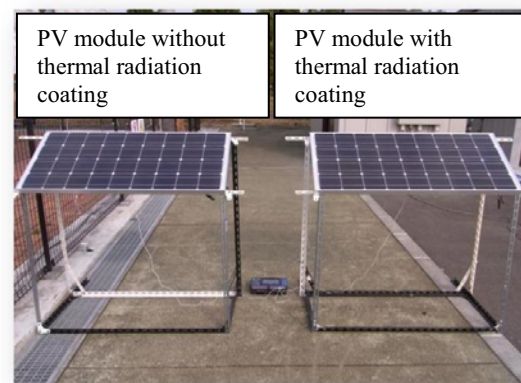


Figure 1. Single crystalline silicon PV modules (area: 1200 mm \times 527 mm) evaluated in this study.

3 Results and discussion

Figure 2 shows the temperatures of the PV modules (T_{mod}) with and without thermal radiation coating. Figure 2 also shows the ambient temperature. The ambient temperature was stable during the measurement period. The temperature of the PV module with the thermal radiation coating was lower than that of the PV module

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without the thermal radiation coating. The effect of the high-radiation layer was remarkable.

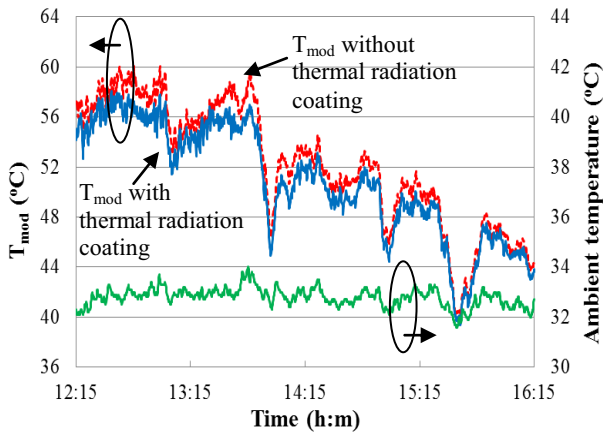


Figure 2. Temperatures of the PV modules with and without thermal radiation coating.

Figure 3 shows the T_{mod} of the PV module without the thermal radiation coating and the difference in temperature between T_{mod} of the PV modules with and without thermal radiation coating (T_{mod} without coating – T_{mod} with coating). The maximum difference of 3.38°C was observed at 12:57. It is found that the difference in temperature between T_{mod} of the PV modules with and without thermal radiation coating increases with increasing T_{mod} of the PV module without thermal radiation coating.

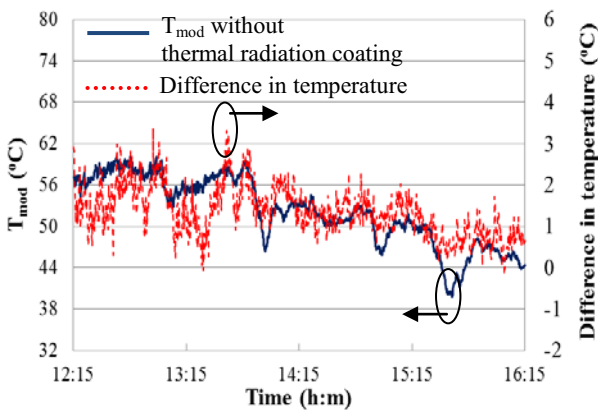


Figure 3. T_{mod} of the PV module without thermal radiation coating and the difference in temperature between T_{mod} of the PV modules with and without thermal radiation coating.

When we define a backside of PV module [area: A_1 (m^2), emissivity: ε_1] and an environment [area: infinite], the radiation heat from the backside of PV module to the environment Q_{12} (W) is given by

$$Q_{12} = A_1 \varepsilon_1 \sigma (T_1^4 - T_2^4) \quad (1)$$

where σ , T_1 , and T_2 are the Stefan–Boltzmann constant ($5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$), the absolute temperature (K) of the PV module, and the absolute temperature (K) of the environment, respectively. It was found that the radiation heat increased with increasing emissivity, and the high emissivity of the thermal radiation layer enhanced the heat radiation from the module to the environment. Q_{12} (W) is higher when T_1 is higher. Therefore, the difference in temperature between T_{mod} of the PV modules with and without thermal radiation coating increased with increasing T_{mod} of the PV module without thermal radiation coating.

Figure 4 shows the open-circuit voltage (V_{oc}) of the PV modules with and without the thermal radiation coating. V_{oc} of the PV module with the thermal radiation coating was 0.1 V higher than that of the module without the coating during the test period. The V_{oc} of PV modules decreases with increasing temperature.

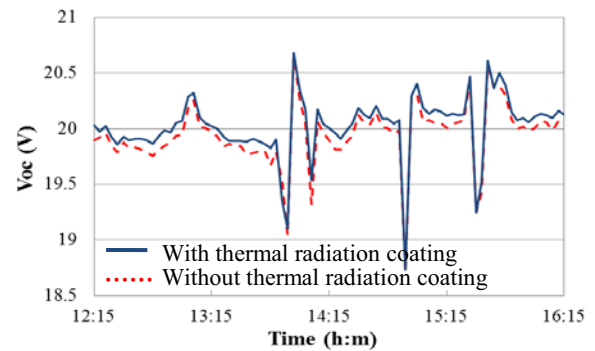


Figure 4. Open-circuit voltage (V_{oc}) of the PV modules with and without the thermal radiation coating.

The I-V characteristics of the solar cell are expressed by

$$I = I_0 \left\{ \exp \left(\frac{qV}{n_D k T} \right) - 1 \right\} - I_{sc} \quad (2)$$

where I_{sc} , I_0 , q , n_D , k , and T are the short-circuit current, saturation current, elementary charge, diode ideality factor, Boltzmann constant, and absolute temperature, respectively [12].

From Eq. (2), V_{oc} ($I = 0$) is given by

$$V_{oc} = \frac{n_D k T}{q} \ln \left(\frac{I_{sc}}{I_0} + 1 \right) \quad (3)$$

From Eq. (3), the temperature characteristic of saturation current (I_0) markedly influences the temperature

characteristic of V_{oc} . The saturation current density (J_0) is given by

$$J_0 = qn_i^2 \left(\frac{D_e}{N_A W_p} + \frac{D_h}{N_D W_n} \right) \quad (4)$$

where n_i is the intrinsic carrier concentration, N_A and N_D are the acceptor and donor concentrations, respectively, W_p and W_n are the thicknesses of the p and n neutral regions, respectively, and D_e and D_h are the diffusion constants of electrons and holes, respectively [13]. J_0 strongly depends on T through its proportionality to the square of n_i , which is expressed by

$$n_i^2 = 4M_c M_v (2\pi kT/h^2)^3 (m_e^* m_h^*)^{3/2} \exp(-E_g/kT), \quad (5)$$

where M_c and M_v are the number of equivalent minima in the conduction and valence bands, respectively, h is Planck's constant, and m_e^* and m_h^* are the effective masses of electrons and holes, respectively [14].

From Eqs. (3)–(5), it is found that the decrease in V_{oc} with increasing temperature arises mainly from the change in n_i . The value of J_0 increases exponentially with decreasing $1/T$, and V_{oc} decreases linearly with increasing T .

V_{oc} of the PV module with the thermal radiation coating was higher due to the cooling effect of the thermal radiation coating.

Figure 5 shows the conversion efficiency of the PV modules with and without the thermal radiation coating. The conversion efficiency decreased linearly with increasing temperature. The data for the PV module with the thermal radiation coating existed in the low temperature range owing to the heat-release effect of the coating. As shown in Fig. 3, the cell temperature of the PV module with the thermal radiation coating was 2–3°C lower than that of the module without thermal radiation coating. Eventually, the temperature range of the PV module with the thermal radiation coating was decreased by 2–3°C.

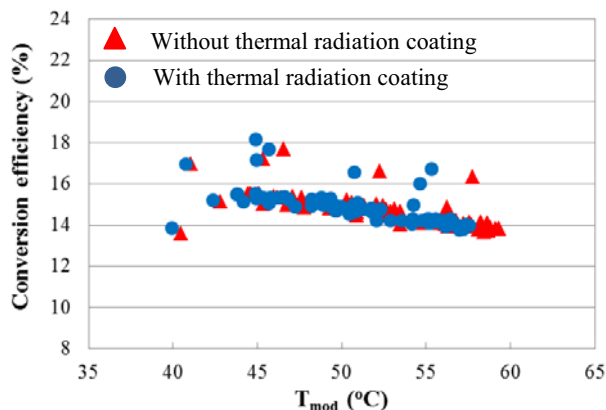


Figure 5. Conversion efficiency of the PV modules with and without the thermal radiation coating.

A high-efficiency PV module can be achieved with a combination of cell and module technologies. In this study, a new simple coating technology for handling heat radiation was developed. By adopting the thermal radiation coating for the PV module fabrication, the module efficiency was easily improved.

4 Summary

Single crystalline silicon PV modules (area: 1200 mm × 527 mm) were prepared and evaluated. A thermal radiation layer (Pelcool (R), PELNOX Ltd.) was coated on the back sheet of the PV module. The thickness of the layer was 30 μm. The thermal radiation layer consisted of acrylate resin and inorganic fillers. The fillers were selected to radiate the heat, particularly in the temperature range from 40 to 100°C, which is the main range of operating temperature for the PV module. The thermal emissivity of the layer is 0.95. In order to detect the temperature of the PV module (T_{mod}), temperature sensors (Pt100) were set on the back surface of the PV modules. The temperature of the PV module with the thermal radiation coating was lower than that of the PV module without the thermal radiation coating. V_{oc} of the PV module with the thermal radiation coating was 0.1 V higher than that of the module without the coating during the test period. The operating temperature range of the PV module with the thermal radiation coating was decreased by 2–3°C. By adopting the thermal radiation coating, the module efficiency was easily improved. A new simple coating technology for handling heat radiation was developed. By adopting the thermal radiation coating for the PV module fabrication, the module efficiency was easily improved.

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