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Heat reduction of concentrator photovoltaic module using high radiation coating

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ABSTRACT

A thermal radiation layer was coated on the aluminum chassis of a concentrator photovoltaic (CPV) module. The temperature of the solar cell in the CPV module with the thermal radiation coating was approximately 10 °C lower than that of the module without the thermal radiation coating. The uniformity of the temperature distribution in the CPV module was considerably improved. The thermal radiation coating acted not only as a thermal radiation layer but also as a thermal conduction layer. The open-circuit voltage of the CPV module with thermal radiation coating was 0.5 V higher than that of the module without the coating during the period evaluated. The conversion efficiency of the CPV module with thermal radiation coating was 0.5% higher than that of the module without the coating.

1. Introduction

Multijunction solar cells have been attracting increasing attention for application in concentrator photovoltaic (CPV) systems owing to their high conversion efficiency [1–3]. Multijunction solar cells consisting of InGaP, InGaAs, and Ge diodes are recognized as super-high-efficiency solar cells and are used for space applications. A metamorphic $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As/Ge$ triple-junction solar cell has delivered a conversion efficiency of 41.1% at 454 suns (454 kW/m^2, AM1.5D) [4]. Light concentration is one of the important issues for the development of an advanced photovoltaic (PV) system using high-efficiency solar cells. High-efficiency multijunction cells under high light concentration have also been investigated for terrestrial applications [5–8].

It is considered that the temperature of solar cells considerably increases under light-concentrating operations, and the conversion efficiency of solar cells decreases with increasing temperature [9–11]. It is therefore very important to reduce the cell temperature in CPV modules.

In this study, a thermal radiation layer was coated on the aluminum chassis of a CPV module and the effect was evaluated.

2. Experimental procedure

Fig. 1 shows a schematic diagram of the CPV module (area: 1005 mm × 1005 mm). The CPV module consisted of 25 pairs of Fresnel lenses (200 mm × 200 mm), a InGaP/InGaAs/Ge triple-junction solar cell (7 mm × 7 mm), and an aluminum chassis. The concentration ratio of the CPV module was 820 times. A thermal radiation layer [Pelcool (R), PELNOX Ltd.] was coated on the aluminum chassis of a CPV 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 CPV module. The thermal emissivity of the layer coated on aluminum is 0.95, whereas that of aluminum is approximately 0.02–0.1. The triple-junction solar cells were arrayed on the aluminum chassis. Fig. 2 shows a cross-sectional diagram depicting the arrangement from the solar cell to the aluminum chassis. The solar cell was connected to a copper ribbon electrode using a high-thermal-conductivity solder. In order to retain the insulation quality, an aluminum alloy was adopted, and the copper ribbon was applied on it with an insulation layer. In order to detect the temperature of the solar cell in the CPV module, temperature sensors (Pt100) were embedded just below the solar cell. A CPV module was fabricated by connecting 25 lens–cell pairs in series. The current–voltage (I–V) characteristics were measured using an I–V curve tracer (EKO, MP-160). The modules with and without a thermal radiation coating were evaluated at the University of Miyazaki (Miyazaki, Japan). The evaluation was carried out from 13:00 to 17:00 h on September 23, 2011.

3. Results and discussion

Fig. 3(a) shows the direct normal irradiance (DNI). The weather during the experiment period was clear. Fig. 3(b) shows the ambient temperature and wind speed. The wind speed was low and there were no significant changes. During the evaluation, the meteorological conditions were stable.

Fig. 4 shows the temperature of the solar cell at the center of the CPV module. The cell temperature of the CPV module with the thermal radiation coating was approximately 10 °C lower than that in the CPV module without the thermal radiation coating. The cell temperature

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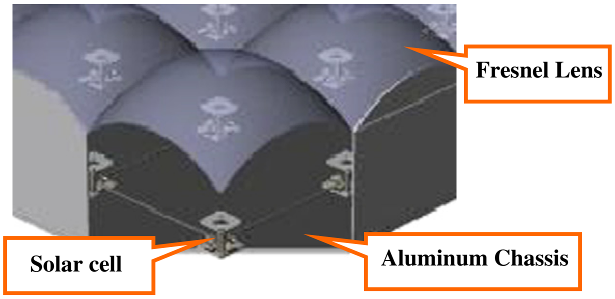

Fig. 1. Schematic diagram of a CPV module. The CPV module consisted of 25 pairs of Fresnel lens (200 mm×200 mm) and a InGaP/InGaAs/Ge triple-junction solar cell (7 mm×7 mm).

for the CPV module without the coating reached 93.1 °C at 13:16 h. On the other hand, that for the CPV module with the coating decreased to 82.6 °C. The effect of the high-radiation layer was remarkable.

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

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

where σ, T_1, and T_2 are the Stefan–Boltzmann constant (5.67 $\times 10^{-8}$ W/$m^2 \cdot K^4$), the absolute temperature (K) of the chassis, 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 chassis to the environment.

Fig. 5 shows the difference between the cell temperature at the center (T_{center}) and that at the corner (T_{corner}). The cell temperature at the center is highest because the central cell is enclosed by other cells. In the CPV module, the solar cell that receives high energy light behaves as a heat source. A large value of the difference ($T_{center} - T_{corner}$) means that the temperature distribution in the CPV module is not uniform. When the temperature distribution is not uniform, the chassis of the CPV module will become distorted owing to the local elevation in temperature. A partial misalignment between the optical system and the solar cell occurs, and the output characteristics of the CPV module decrease. The value of $T_{center} - T_{corner}$ for the CPV module without the coating reached 14.5 °C at time 13:25 h. On the other hand, that for the CPV module with the coating was reduced to 5.1 °C, which shows that the uniformity in the temperature distribution for the CPV module was considerably improved. It is considered that the coating acted not only as a thermal radiation layer but also as a thermal conduction layer.

Fig. 6 shows the open-circuit voltage (V_{oc}) of the CPV module with and without the thermal radiation coating. V_{oc} of the CPV module

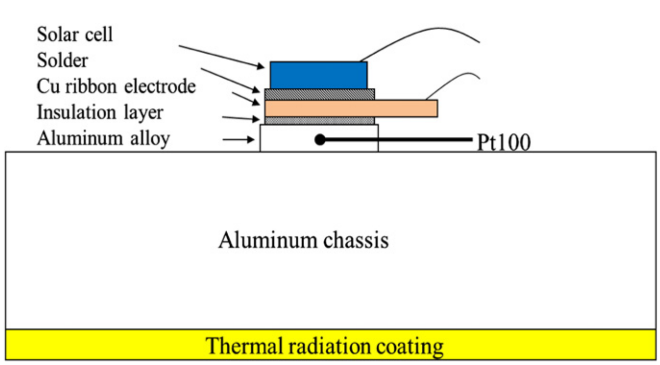

Fig. 2. Cross-sectional diagram showing the arrangement from the solar cell to aluminum chassis.

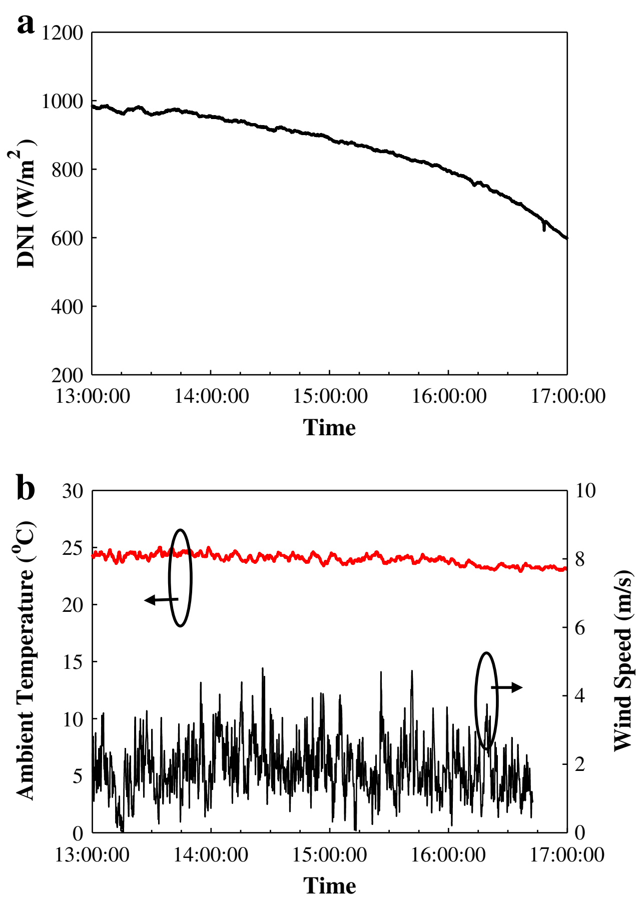

Fig. 3. Meteorological conditions during measurement; (a) direct normal irradiance, (b) ambient temperature and wind speed. The arrows in the figure show the corresponding vertical axis.

with the thermal radiation coating was approximately 0.5 V higher than that of the module without the coating during the test period.

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

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

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].

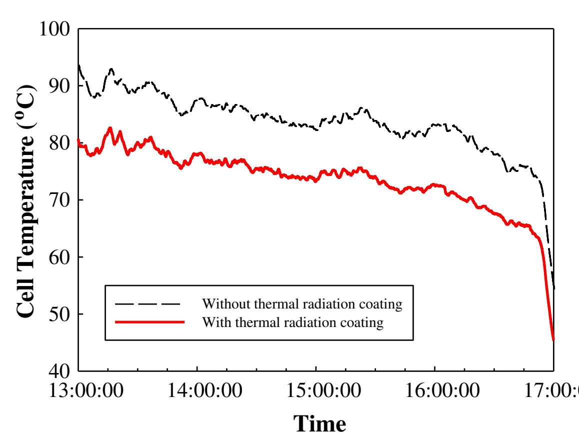

Fig. 4. Temperature of solar cell at the center of the CPV module.