Temperature Coefficients of FLATCON® Modules

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Abstract: A method for the derivation of the temperature coefficient of Fresnel lens based CPV modules is presented. The method is applied on FLATCON® modules. Their temperature coefficients are presented and discussed.

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INTRODUCTION

The temperature coefficient of CPV modules has remained relatively uninvestigated until now. This is due to the fact that sun simulators for CPV modules became available only recently [1-3]. A sun simulator permits a temperature variation of a photovoltaic device independently of other influences. Especially flash light simulators are suitable for an investigation of the temperature dependence of photovoltaic modules, since the module shows almost no change in temperature during the short time (~ 10 – 100 ms) of illumination.

We present a method for varying the temperature of Fresnel lens based CPV modules at a sun simulator. The method is applied on FLATCON® and their temperature coefficients are derived.

EXPERIMENTAL

For the experiments the sun simulator for CPV modules at the Fraunhofer ISE was used [3]. This sun simulator uses a flash bulb in the focus of a parabolic mirror. In addition to this set-up, infrared (IR) bulbs were applied in order to heat the CPV modules. The IR bulbs are located behind the modules and illuminate their rear-side. In order to increase the absorption of the IR light, the module rear-sides were covered with black tape. Due to the absorption of IR light, the modules are heated up. Depending on the distance between the IR bulbs and the modules, the equilibrium temperature of the modules varies. Higher module temperatures were achieved for relatively close distances (~ 0.5 m). This experimental set-up permits measurement of the I-V curve of the CPV modules at different temperatures, whereas the irradiation intensity and the spectrum are constant. A sketch of the experimental set-up is shown in FIGURE 1.

The following measurement procedure is applied:

1. The rear-side of the CPV module is covered with black tape.
2. The CPV module is mounted and aligned.
3. A fist measurement of the module’s I-V curve is taken at an irradiation intensity of 850 W/m². The module’s temperature corresponds to the laboratory temperature (~ 22.5°C).
4. The rear-side of the module is illuminated/heated with IR light. After about 30 minutes the surface temperature is constant (thermal equilibrium).
5. The surface temperature of the rear-side is measured with a thermocouple at several locations. (32 measurements for module#1 and 6 measurements for module#2). The mean of the temperature measurements is

FIGURE 1. A sketch of the experimental set-up is shown.
calculated (average bottom plate temperature).
6. The I-V curve of the CPV module is measured at an elevated temperature and at an irradiation intensity of 850 W/m².
7. The distance between the IR bulbs and the CPV module is changed to variation of module temperature. The points 4 to 6 are repeated for the changed temperature.

Within this paper two FLATCON® modules are investigated. The modules are equipped with Ga0.50In0.50P/Ga0.99In0.01As/Ge triple-junction solar cells [4, 5]. The cells are designed to be current matched under the AM0 spectrum [6]. Module#1 has no secondary optics, whereas module#2 is equipped with reflective secondary optical elements [7]. The geometrical concentration ratio is 385X for both modules. The modules differ in properties are listed in TABLE 1.

TABLE 1. Some properties of the investigated FLATCON® modules are listed.

<table>
<thead>
<tr>
<th>Module #</th>
<th>Optical area</th>
<th># of cells</th>
<th>secondary optics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module#1</td>
<td>2400 cm²</td>
<td>150</td>
<td>None</td>
</tr>
<tr>
<td>Module#2</td>
<td>96 cm²</td>
<td>6</td>
<td>Reflective</td>
</tr>
</tbody>
</table>

RESULTS

FIGURE 2 shows the I-V curves of module#1 modules at different average bottom plate temperatures. The same is shown for module#2 in FIGURE 3.

Obviously, the open circuit voltage of all modules decreases when the temperature is increased, which is a consequence of the temperature dependence of the intrinsic carrier concentration and the temperature dependence of the band-gap. For a more detailed analysis, the electrical cell parameters are plotted versus the module temperature. The short circuit current (I_{SC}), the open circuit voltage (V_{OC}) and the fill factor (FF) are shown relative to the corresponding values at laboratory temperature, see FIGURE 4 and FIGURE 5.
FIGURE 5. The relative temperature dependence of the electrical parameters of module#1 is shown versus its average bottom plate temperature. The electrical parameters refer relative to the values at laboratory temperature (~22.5°C).

A linear regression is performed for the relative electrical parameters. The slope of the linear regression is the relative temperature coefficient for the corresponding electrical parameter (reference temperature ~ 22.5°C).

**DISCUSSION**

The $V_{\text{OC}}$ temperature coefficients are found to be equal (-0.16 %/K) for both investigated modules. This is close to the literature value of Ga$_{0.50}$In$_{0.50}$P/Ga$_{0.99}$In$_{0.01}$As/Ge triple-junction solar cells [8]. There a $V_{\text{OC}}$ temperature coefficient of about -0.15 %/K is given for a concentration ratio similar to that of the investigated modules.

The FF temperature coefficient is -0.08 %/K for module#1 and -0.07 %/K for module#2. Thus, the decrease in FF with increasing temperature is slightly larger for module#1. The found values are not directly comparable to literature values, since the FF of multi-junction solar cells depends also on the spectrum. However, the FF temperature coefficients are found to be negative for most solar cells [9].

The $I_{\text{SC}}$ of module#2 increases by 0.07 % per K of temperature increase. In literature the $I_{\text{SC}}$ temperature coefficient of these cells is also found to be positive [10]. The result on the $I_{\text{SC}}$ temperature coefficient for module#1 is remarkable. The $I_{\text{SC}}$ of this module is not affected by changes in the average bottom plate temperature. Since both investigated modules use the same type of solar cell, the difference in the temperature coefficients must have other reasons. The most obvious difference between the two investigated modules is the total area and the secondary optical elements. Further investigations are required to determine the reason for can explain the difference observed in temperature behavior more precisely.

**CONCLUSIONS**

An experimental set-up and a measurement procedure are presented which permit the derivation of temperature coefficients for Fresnel lens based CPV modules. The presented method is applied on two FLATCON® modules and their temperature coefficients at an irradiation of 850 W/m$^2$ are determined. Their open circuit voltage and their fill factor are found to decrease when their temperature is decreased. In particular the open circuit voltage temperature coefficient is found to be equal for both modules and similar to the values given in literature for triple-junction solar cells. In contrast the short circuit current temperature coefficient is different for the two investigated modules. Since both modules use cells of the same type, the difference in temperature behavior must be related to other differences between the modules. Most obvious is the difference in area – one module is 25 times larger than the other. Furthermore, the optics of the CPV modules are different. Both modules use the same type of Fresnel lens; however, only one is equipped with secondary optical elements. In further investigations the temperature influence on the module area and the optics must be analyzed.

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**REFERENCES**