Accelerated Aging Tests of High Concentration Multijunction Solar Cells

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Abstract

High concentration multi-junction solar cells are starting to be commercialized. However, few studies about their reliability have been carried out. In this paper, we present the results of accelerated aging tests performed on Sanan high concentration solar cells. It is found that the relative power degradations of tested samples are within 10%. For comparison, commercial cells from Emcore are also tested under similar conditions, and the results are similar with that from Sanan. The tested electrical insulations of these cells before and after thermal cycling test also meet requirements from IEC 62108.

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1. Introduction

In recent years, multi-junction solar cells have attracted increasing attention for their very high conversion efficiencies as a way of producing cost-competitive photovoltaic electricity at terrestrial application. Some high-efficiency solar cells have also been reported, such as lattice-matched GaInP/GaInAs/Ge triple-junction solar cell with an efficiency of 41.6% at 364 suns, metamorphic In₀.₆₅Ga₀.₃₅P/In₀.₁₇Ga₀.₈₃As/Ge solar cell with an efficiency of 41.1% at 450 suns, AM1.5D, and inverted metamorphic In₀.₄₉Ga₀.₅₁P/In₀.₀₄Ga₀.₉₆As /In₀.₃₇Ga₀.₆₃As solar cell with an efficiency of 40.8% at 326 suns, AM1.5G [1-3]. These satisfactory results have crystallized into the current commercial ventures of concentration photovoltaic (CPV) systems based on III–V high efficiency solar cells. However, under high concentration of several hundreds or even thousands suns, multi-junction solar cells will suffer high temperature and high current density, which are challenging the reliability of these devices [4]. To obtain the approval from CPV customers, it is necessary to demonstrate the reliability of multi-junction solar cells operated under high concentration.
A new qualification standard, namely the IEC62108, has been developed in which the procedure for qualifying CPV systems and assemblies is described [5]. The IEC62108 is currently the only one international standard on assessment of high concentration solar receivers and modules, which specifies the minimum requirements for the design qualification and type approval of concentrator solar cells, and the corresponding test procedures for each test sample, such as outdoor exposure test, electrical performance measurement, electrical test, irradiation test, and mechanical load test. Passing the IEC62108 certification, both the modules and assemblies can be suitable for long-term (25 years) operation in general open-air climates.

In real operating conditions, solar cells are encapsulated into receivers, which can protect the solar cells and dissipate the heat energy. With the aim of enhancing the reliability of solar cells and receivers and ensuring that the operation of these devices is safe, reliable and stable in the CPV systems, this paper presents the accelerated aging tests and the quantitative analysis of test samples performance evolution.

2. Tests and Results

The purpose of the thermal cycling test is to determine the ability of the receivers to withstand thermal mismatch, fatigue, and other stresses caused by rapid, non-uniform or repeated changes of temperature. This test is vital to the reliability of concentrator solar cells, since generally these devices have to operate at high concentration of more than 500 suns, high working current density of more than 5A/cm², high working temperature of more than 60 °C and big temperature difference between day and night.

In order to simulate the real operating conditions, IEC 62108 requires that during the process of thermal cycling test for concentrator solar cells carried out in the oven, a current should be flowing through the chips. Table 1 shows the three optional conditions. In Fig. 1, the schematic illustrations of temperature and current profile during thermal cycling test for concentrator solar cells are presented.

In principle, the temperature and the current injection time of cells are required to be exactly monitored during thermal cycling test. However, as shown in figure 2, it is very difficult to monitor the real temperature of cells in real operating conditions, because a high electric current passes through the cells can lead to difference in temperature between the cells, the heat sink and oven. Figure 3 shows the temperature profiles of the oven, the heat sink and the cell with a cell size of 10×10 mm², according to NREL’s researchers. We can see that the difference between the temperatures of cell and oven is about 20 °C when there is a current of 7A flowing through the cell, which is about 1.25 times higher than the short-circuit current of a cell at 500 suns.

Using the thermal cycling test condition of TCA-1 from table I, and the cell temperature is controlled between -40 °C and 85 °C. A dwell time of 10 min of the high and low temperatures is required. The cycling period and frequency are 120 minutes and 12 cycles per day, respectively. In one thermal cycle as shown in figure 1, a specific current level of 7A is periodically on and off for 10 cycles, when the cell temperature is above 25 °C. In order to illustrate the changes of electrical performance of test samples, control samples are chosen and measured under similar test condition. By this method, test condition variables are self-correcting, and the complex translation procedures can be eliminated. Finally, the relative power \( P_r \) and relative power degradation \( P_{rd} \) are defined as follows:

\[
P_r = \frac{P_m}{P_{mc}} \times 100\% \tag{1}
\]

\[
P_{rd} = \frac{P_{ri} - P_{rf}}{P_{ri}} \times 100\% \tag{2}
\]
Where $P_m$ is the test sample’s maximum power, $P_{nc}$ is the control sample’s maximum power measured at the similar condition as $P_m$, and $P_{rf}$ and $P_r$ are the relative powers measured after and before the given test, respectively.

For comparison, eight Sanan cells and eight Emcore cells were tested together. Table II and Fig. 4 show the relative power degradation of Sanan receiver samples, when that of Emcore receiver samples are listed in Table III and Fig. 5 after different numbers of thermal cycles, respectively. The output powers gradually decrease with increasing the thermal cycles due to the samples’ degradation. It is found that the relative power degradations of tested samples are within 10%. The degradation is believed to be responsible for the perimeter degradation as discussed in references [4] and [8].

According to reference [4], the arbitrary definition of device failure is a 10% of power loss, so the majority of test samples do not have failure, except the Emcore receiver #56, the relative power degradation of which is from 12.85% after 560 thermal cycles to 14.89% after 1000 thermal cycles. Besides, from visual inspection on these samples, the DBCs soldered on alumina substrates are not peeled off after the 1000 thermal cycles, which indicates that it is suitable for long-term (~25 years) operation in general open-air climates.

Table 1 The options of thermal cycling test from IEC 62108

| Option | Maximum cell temperature | Total cycles | Applied current |
|--------|--------------------------|--------------|-----------------|
| TCA-1  | 85 °C                    | 1000         | Apply 1.25×$I_{oc}$ when $T > 25^\circ C$, cycle speed is 10 electrical/thermal |
| TCA-2  | 110 °C                   | 500          | Apply 1.25×$I_{oc}$ when $T > 25^\circ C$, cycle speed is 10 electrical/thermal |
| TCA-3  | 65 °C                    | 2000         | Apply 1.25×$I_{oc}$ when $T > 25^\circ C$, cycle speed is 10 electrical/thermal |

Figure 1 Temperature and current profile of thermal cycle test.

Figure 2 Schematic illustration of thermal cycling test setup.
Figure 3 Temperatures with different forward bias current of the oven, the heat sink and the cell with a cell size of 10×10mm².

Table 2  Relative power degradation of Sanan receiver samples after different numbers of thermal cycles

| Serial sample | 0 cycle | 360 cycles | 560 cycles | 760 cycles | 1000 cycles |
|---------------|---------|------------|------------|------------|-------------|
| #182B5        | 0.00%   | -2.47%     | -4.00%     | -5.56%     | -8.02%      |
| #183D1        | 0.00%   | -0.14%     | -3.19%     | -3.88%     | -5.44%      |
| #182D5        | 0.00%   | -3.66%     | -4.78%     | -5.82%     | -8.21%      |
| #183B1        | 0.00%   | -2.48%     | -4.83%     | -6.33%     | -8.25%      |
| #182D1        | 0.00%   | -4.62%     | -5.38%     | -6.21%     | -7.95%      |
| #183B6        | 0.00%   | -5.85%     | -6.08%     | -5.84%     | -7.09%      |
| #183A4        | 0.00%   | -5.02%     | -5.70%     | -6.97%     | -7.96%      |
| #183D5        | 0.00%   | -5.47%     | -5.83%     | -6.06%     | -7.37%      |

Figure 4  The relative power degradation of Sanan receiver samples with different numbers of thermal cycles.
Table 3 Relative power degradation of Emocore receiver samples with different numbers of thermal cycles.

| Serial sample | 0 cycle | 360 cycles | 560 cycles | 760 cycles | 1000 cycles |
|---------------|---------|------------|------------|------------|-------------|
| #112          | 0.00%   | -5.93%     | -6.83%     | -6.84%     | -7.72%      |
| #44           | 0.00%   | -4.10%     | -5.60%     | -6.12%     | -8.11%      |
| #56           | 0.00%   | -8.02%     | -12.85%    | -13.05%    | -14.89%     |
| #94           | 0.00%   | -2.76%     | -4.94%     | -5.19%     | -6.78%      |
| #78           | 0.00%   | -5.17%     | -6.39%     | -6.76%     | -7.36%      |
| #90           | 0.00%   | -7.14%     | -7.75%     | -8.17%     | -8.32%      |
| #97           | 0.00%   | -3.19%     | -3.38%     | -4.38%     | -7.42%      |
| #136          | 0.00%   | -6.30%     | -6.69%     | -7.05%     | -9.34%      |

In addition, to determine whether the receiver samples are sufficiently well-insulated during the whole thermal cycling test period, the insulation tests under the dry and wet operating conditions were carried out. The dry- and wet-insulation resistances are listed for Sanan samples in table IV. It is shown that after the 1000 thermal cycles, the insulation performances of all test samples can meet the requirements from IEC 62108, where the insulation resistances are required to be the order of million ohm ($\text{M}\Omega$).

3. Conclusion

High concentration multijunction solar cells are still at an early stage of technological development, and thus it is necessary to demonstrate the reliability of these solar cells before their industrialization. Accelerated aging test is a necessary tool to demonstrate the reliability of concentration photovoltaic solar cells, which is expected to be working for no less than 25 years. According to the requirements from IEC 62108, this paper presents the reliability results derived from thermal cycling test performed on Sanan high concentration solar cells. We find that the light emitting intensity and the relative power degradation of Sanan receivers are are similar with that of commercial cells from Emcore. According to the dry and wet insulation tests, the insulation performances of all test samples can meet the requirements from IEC 62108. This is the first report on successful fabricating of high concentration multijunction solar cells in China.
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Table 4 The dry- and wet-insulation tests of Sanan receivers before and after one thousand thermal cycles

| Serial sample | Before thermal cycles | Wet insulation test | After one thousand thermal cycles | Wet insulation test |
|---------------|-----------------------|---------------------|-----------------------------------|---------------------|
|               | Procedure 1 | Procedure 2 | Procedure 1 | Procedure 2 | Procedure 1 | Procedure 2 |
| #182B5       | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, 14.94 GΩ | 2.2KV, 0 μA | 500V, 45.83 GΩ | 500V, 13.93 GΩ |
| #183D1       | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, 41.15 GΩ | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, >50 GΩ |
| #182D5       | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, 16.74 GΩ | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, >50 GΩ |
| #183B1       | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, 12.62 GΩ | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, >50 GΩ |
| #182D1       | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, 16.18 GΩ | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, >50 GΩ |
| #183B6       | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, 24.95 GΩ | 2.2KV, 0 μA | 500V, 45.44 GΩ | 500V, 7.858 GΩ |
| #183A4       | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, 24.95 GΩ | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, >50 GΩ |
| #183D5       | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, 9.873 GΩ | 2.2KV, 0 μA | 500V, >50 GΩ | 500V, >50 GΩ |