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Effect of Damp Heat on the Performance Degradation of Flexible CIGS Photovoltaic Modules

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Abstract

The performance degradation of flexible CIGS photovoltaic modules was studied under damp heat stress condition. For the fabrication of modules, two different types of modules were fabricated using different number of lamination sheet; one on top of back sheet; the other underneath of front sheet. The effects of heat and moisture stresses on the flexible CIGS photovoltaic modules were systematically investigated in non-destructive fashion using electroluminescence and insulation resistance. It was found that the moisture attack on the cell was the major factor lowering the Pmax with exposure time during the damp heat tests, which was confirmed by the decrease in the resistance with the insulation resistance tests as well as the increase in the damaged area of cells with the electroluminescence tests.

Keywords: CIGS; PV module; Damp heat; Degradation; Electroluminescence

Introduction

CIGS is attracting a great deal of attention and expanding its market share in recent years due to its ease of fabrication and less cost for production compared to widely spread crystalline silicon photovoltaic (PV) modules [1]. In addition, CIGS PVs have potential advantages such that they can be the most appropriate candidate as thin film photovoltaic devices due to high absorption coefficient, appropriate band gap and outstanding electro-optical properties [2-4]. Recent research and development devoted to flexible thin film solar cells have focused on substituting the rigid glass substrates with flexible polymer substrates [5,6]. Flexible PVs are advantageous in various ways such that they exhibit a high potential in reducing fabrication costs and they can be easily applied to building components, consumer products related to leisure, national defence materials, and etc. For the success in those markets, flexible CIGS photovoltaic modules require excellent performance such as high efficiency, low cost and long and predictable lifetime, and etc. when they were actually applied in the real fields. One of the most important properties they have to attain is the long-term stability [7]. In fact, long-term stability of photovoltaic (PV) modules is still a crucial topic in the realm of PVs. Thin-film PV modules are especially subject to discussion about their stability over long outdoor periods due to their rather recent appearance on the market. On the other hand, it is challenging to assess 25 and even 30 years stability of thin-film modules in the absence of sufficient long-term outdoor experience [8]. Furthermore, performance predictions are largely affected by the location where the modules are installed.

Granting of a voluntary efficiency guarantee from the manufacturers of solar modules is normally a common practice in the market and so it is often the case such that 90% of the initial power output is guaranteed for the first 10 years or 80% of the initial power output can be acceptable for the first 20 years. Therefore, it is of pivotal importance for the manufacturers to assure and obtain the long-term stability information of their products. To ascertain the long-term stability without actual filed data, several types of accelerated degradation tests have been performed. One way to investigate the long-term stability is to apply repeated or prolonged accelerated degradation tests on the module, and this method is widely used due to its cost-effectiveness and less time-consuming. According to the IEC 61646 standard, thin film modules should pass the damp heat (DH) test (1000 h at 85℃ and 85% RH), thermal cycling (TC) test (200 cycles at -40℃ to 85℃), and a preconditioning procedure based on light soaking (LS), among other requirements. Especially, the damp heat test is considered as the most harsh environment test condition. Therefore, the effect of the damp heat test on the performance degradation of CIGS photovoltaic modules was studied by non-destructively analysing the lowering of power with electroluminescence and insulation resistance.

Experimental Procedures

Two types of flexible CIGS modules were obtained from Solar Flex Co., Ltd. briefly; type 1 has one lamination sheet on top of back sheet. On the other hand, type 2 has two lamination sheets; one on top of back sheet; the other underneath of front sheet. The CIGS modules were subject to the damp heat exposure with different time intervals, and the IV, electroluminescence (EL), and insulation resistance characteristics were measured at each time intervals in order to observe the effect of the heat/moisture stresses on the performance of modules.

Damp heat tests were conducted following the procedures shown below, in accordance with IEC 61646.

- Test temperature : (85 ± 2) °C
- Relative humidity : (85 ± 5) %
- Test duration : (1000 -0 / +48) h

After a recovery time of 2 to 4 hrs at (23 ± 5) °C, the modules were characterized by measuring the maximum power, insulation resistance, and EL at a relative humidity of less than 75% under open-circuit conditions (Table 1).

For the determination of maximum power, the I-V characteristics of the modules were measured with a solar simulator at 1 sun condition, following the procedures illustrated in IEC60904.

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	Pmax	Eff.	Voc	Isc	FF
Type 1	6.682	6.36	3.195	5.974	35.01
Type 2	7.970	7.59	3.230	6.122	40.30

Table 1: I-V characteristics of flexible CIGS photovoltaic modules.

For the non-destructive characterization of PV modules after the damp heat test, electroluminescence (EL) and insulation resistance were performed for monitoring the heat and moisture attack inside the CIGS modules. The modules were kept in the dark overnight at room temperature prior to the transient measurements. EL images were taken every 5s starting immediately after the application of constant voltage or current bias.

Results and Discussion

The photo images of flexible CIGS modules are presented in Figure 1. For each module, a total of 5 sub-cells (210 × 110 mm) were connected in series to form a 25 × 55 cm² module.

The initial performance of power generation of flexible CIGS photovoltaic modules were measured as shown in Figure 2 and the I-V characteristics of 2 sample modules were summarized in Table 2. Before damp heat tests, a maximum power of 6.682 and 7.970 W were obtained for each module samples.

Figure 3 shows the changes in the maximum power of flexible CIGS modules as a function of damp heat exposure time. It was observed that the maximum power of flexible CIGS modules gradually decreased as a function of the exposure time under damp heat condition. The degradation of Pmax of each module was summarized in Table 2. After exposure to DH for 500 hours, the maximum power was reduced to 47% and 61% of the initial power, for type 1 and type 2 modules, respectively. In particular, it was more severe after the 1,000 hr. exposure to damp heat, only 14% and 41% of Pmax were maintained compared to the initial Pmax, for type 1 and type 2 modules, respectively. For manufacturers, it is of utmost importance to maintain the Pmax within 10% of initial Pmax after 1,000 hrs. of exposure to damp heat in order to satisfy the requirements of IEC 61646.

It is interesting to note that the Pmax was maintained over 500 hrs of exposure to damp heat for type 2 modules while it further decreased with exposure time for type 1 module. It could be due to the structures of the each module; only 1 lamination sheet for type 1 module whereas 2 lamination sheets for type 2 module, which could lead to a better moisture insulation performance.

The electrical degradation behaviors of the modules after damp heat test were analysed first with EL images as shown in Figure 4.

The EL images indicated that the modules gradually became damaged or out-of-function with damp heat stress, i.e., heat and moisture, which is verified with the dark area in the modules. In general, the degradation of modules is largely affected by the moisture penetration. The EL images indicated that the cells of type 1 module were affected by the heat and moisture stresses, gradually from the edge of the modules, and it became dark in the entire area of the module after 1,000 hrs. of DH stress. On the other hand, type 2 module maintained the bright image even after 1,000 hrs. of DH stress, which is well consistent with the I-V results. This could be due to the better moisture insulation for type 2 module. In order to further analyse the damp heat effect on the modules, the insulation resistance was measured as shown in Table 3.

Figure 1: I-V characteristics of flexible CIGS photovoltaic modules.

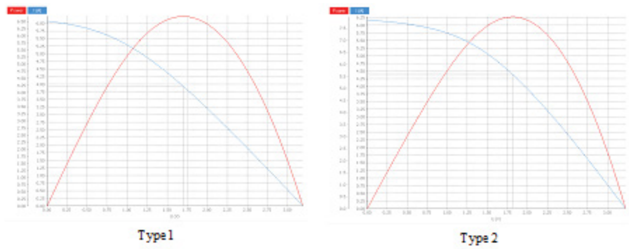

Figure 2: I-V Curves of flexible CIGS photovoltaic modules.

Damp heat exposure time	200 h	500 h	1,000 h
Type 1	75%	47%	14%
Type 2	87%	61%	41%

Table 2: Pmax at each damp heat exposure time in relevance to the initial Pmax.

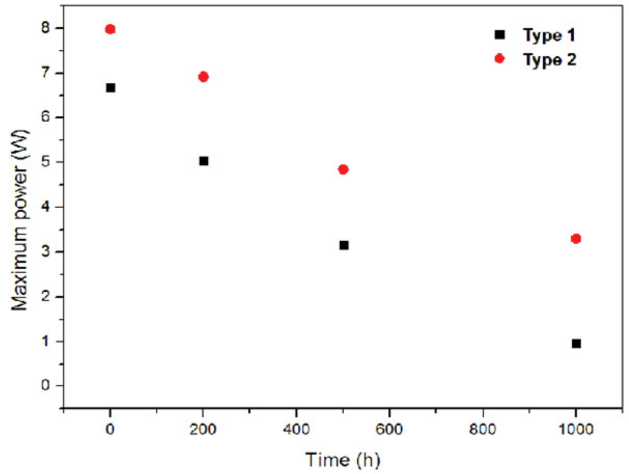

Figure 3: Degradation of I-V characteristics as a function of damp heat exposure time.

Damp heat exposure time	0 h	200 h	500 h	1,000 h
Type 1	13.2	6.67	3.76	1.52
Type 2	35.7	7.36	4.55	2.01

Table 3: Insulation resistance at each damp heat exposure time (unit: GΩ).

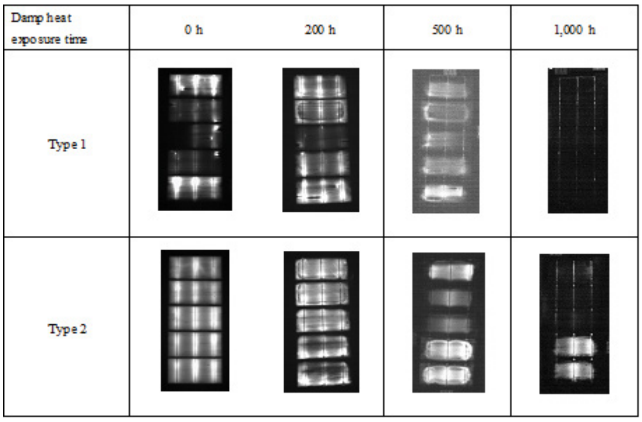

Figure 4: Electroluminescence (EL) images of flexible CIGS modules.

Conclusion

The effect of damp heat on the performance degradation of flexible CIGS photovoltaic modules was studied. It was found that the moisture attack inside the module was the major factor lowering the Pmax with exposure time during the damp heat tests, which was confirmed by the decrease in the insulation resistance during the insulation tests as well as the increase in the damaged area of cells during the electroluminescence tests. It was also found that the number of lamination sheets is becoming more important in order to maintain the performance of the modules for longer exposure time to damp heat since the resistance to the moisture penetration is more facilitated as the number of lamination sheets increases.

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