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Potential-Induced Degradation for Thin-Film Si Photovoltaic Modules

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Abstract

Potential-induced degradation (PID) was investigated for thin-film Si photovoltaic (PV) modules. PID phenomena for thin-film Si PV modules are much different from those for crystalline Si PV modules. Not only performance loss but also delamination were observed. Recovery from PID was also observed by positive voltage application. However, rapid progress in PID was found after the second negative voltage application after recovery from PID.

1. Introduction

Potential-induced degradation (PID) has attracted much attention since severe power loss due to PID was reported in mega-watt scale photovoltaic (PV) plant. PID may occur during relatively short period, for example, several months or a few years. Many reports on PID were presented for p-type crystalline Si PV modules [1,2] and relationship between PID and Na diffusion or leakage current was discussed. Recently, PID for high-efficiency n-type crystalline Si PV modules has been intensively studied [3,4]. However, PID phenomena were much different between p- and n-type crystalline Si PV modules. PID phenomena for $Cu(In_{1-x}Ga_x)Se_2$ (CIGS) PV modules were also different from those for crystalline Si PV modules [5]. It is supposed that PID phenomena strongly depend on the type of PV modules. Recently, thin-film Si PV modules were installed in many PV plants in the world. In this study PID phenomena for thin-film Si PV modules were systematically examined. Both recovery process from PID and delamination phenomena were also observed.

2. Experimental

Superstrate-type thin-film Si cell composed of hydrogenated amorphous Si (a-Si:H) top cell and hydrogenated microcrystalline Si (μc-Si:H) bottom cell tandem structure was formed on glass substrate and integrated. Thin-film Si PV modules were fabricated by lamination of thin-film Si cell, ethylene-vinyl acetate (EVA) encapsulant and polyvinyl fluoride (PVF)/polyethylene terephthalate (PET)/PVF triple layer backsheet. Size of the module was 18 cm × 18 cm or 18 cm × 9 cm.

PID test was carried out by Al-plate method in the climate chamber. In this method, Al plate was put on the glass substrate for thin-film Si PV modules through conductive rubber sheet. Interconnector ribbons for positive and negative electrodes for thin-film Si PV modules were shorted and voltage was applied from grounded Al plate to the shorted interconnector ribbons. Typical applied voltage was -1000 V. During PID test temperature and relative humidity were 85℃ and below 2%, respectively. In some cases, positive voltage of +1000 V was applied for observing the recovery process from PID.

3. Results and Discussion

Figure 1 shows the normalized short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), fill factor (FF) and maximum power (P_{max}) as a function of PID test time. All parameters before PID test were normalized to 1. I_{sc} and FF decrease in the initial stage of the PID test; however, the decrease seems to be saturated. On the other hand, V_{oc} decreases after PID test over 150 h and no saturation tendency is observed until 300 h. On the other hand, no decrease in shunt resistance was also confirmed by dark current-voltage characteristics. Delamination is also observed after PID test over 150 h, as shown in Fig. 2. Such delamination was also observed for thin-film Si PV modules exposed outside for a few years. The delamination may occur at transparent conductive oxide (TCO) layer between glass substrate and a-Si:H top cell [6]. Dark area in the electroluminescence images was also observed after delamination occurred.

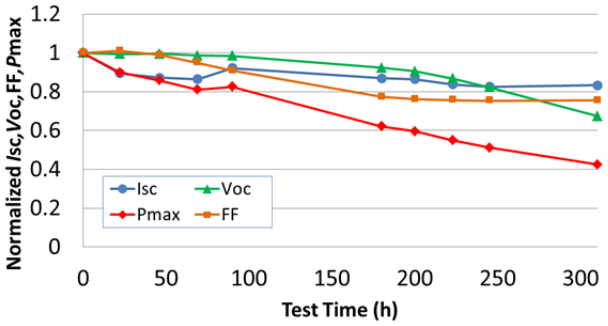

Fig. 1 Normalized I_{sc}, V_{oc}, FF and P_{max} as a function of PID test time.

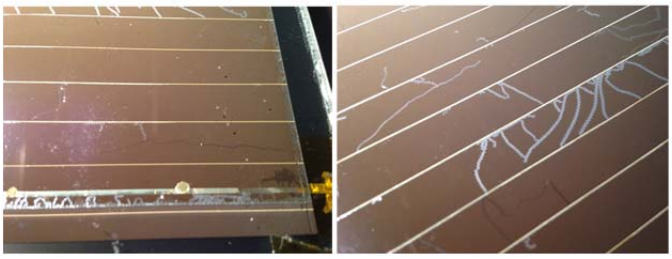

Fig. 2 Photographs of the examples of the delamination observed after PID test over 150 h.

Figure 3 shows normalized I_{sc}, V_{oc}, FF and P_{max} as a function of PID test time. In this case, voltage of -1000 V and +1000 V were alternately applied. It was found that decrease in I_{sc} by -1000 V application is completely recovered by +1000 V application. Some PV parameters are over 1 during +1000 V application due to annealing effect at test temperature of 85℃. However, such recovery did not occur after severe PID with delamination. Surprisingly, all of the PV parameters drastically decrease in very short period during the second -1000 V application. Normalized P_{max} after the second -1000 V application is smaller than normalized P_{max} by only application of -1000 V for 250 h. Some spots like particles also appear after the second -1000 V application as shown in Fig. 4. Figure 5 shows normalized P_{max} as a function of test time. In this case +1000 V is applied from the start of the test. During the first +1000 V application P_{max} somewhat increases due to the annealing effect. Drastic decrease in P_{max} is observed by the next -1000 V application. P_{max} again increases by the second +1000 V application. During the second +1000 V application the above-mentioned spots also disappeared. Rapid decrease in P_{max} by negative voltage application and complete recovery of P_{max} by positive voltage application are alternately observed as shown in Fig. 5. It was also confirmed by cross-sectional scanning electron microscopy that the origin of the spots are not particles or precipitates but delamination at TCO layer.

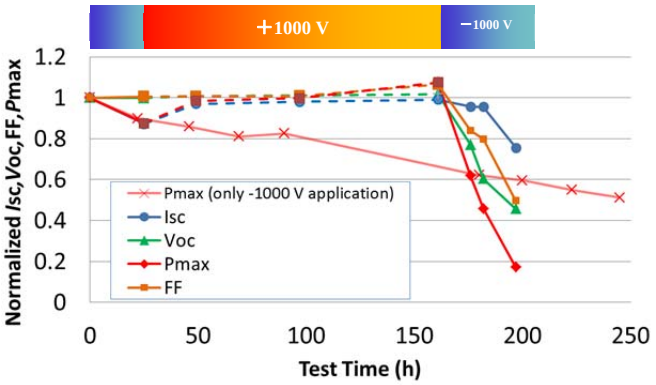

Fig. 3 Normalized I_{sc}, V_{oc}, FF and P_{max} as a function of test time. Blue and red bars show -1000 V and +1000 V applications, respectively.

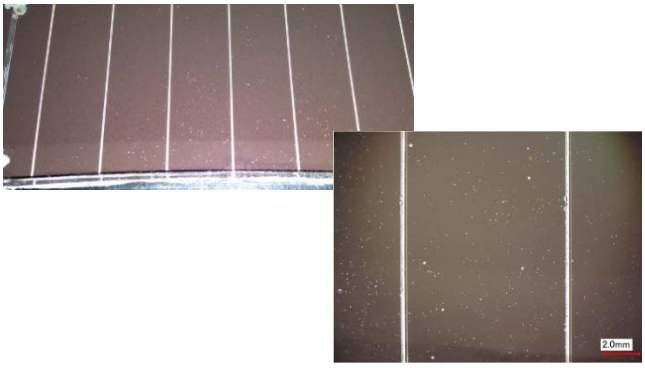

Fig. 4 Photographs of the examples of the spots appearing after the second -1000 V application.

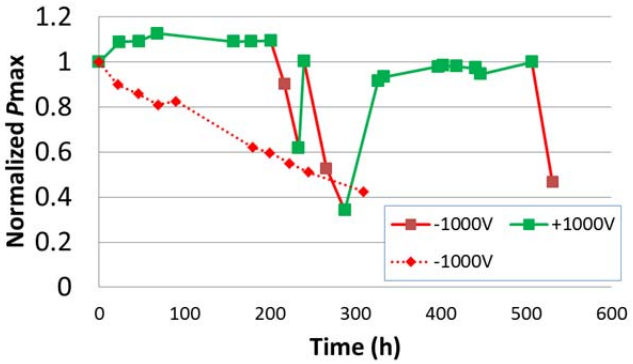

Fig. 5 Normalized P_{max} as a function of time for alternate test of +1000 V and -1000 V applications. Normalized P_{max} as a function of time for test of only -1000 V application is shown for comparison.

4. Conclusions

PID phenomena for thin-film Si PV modules were studied in detail. PID phenomena for thin-film Si PV modules show decrease in the all PV parameters including I_{sc}, V_{oc}, FF and P_{max} together with delamination at TCO. Positive voltage application completely recovers all the PV parameters. However, negative voltage application after such positive voltage application induces very rapid decrease in PV parameters with generation of spots due to delamination. These PID phenomena with delamination seem similar to the degradation phenome with delamination observed for thin-film Si PV modules exposed outside.

Acknowledgements

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