Do we really understand the failure mechanism of a PERC cell?

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Abstract

Because it leads to higher efficiencies than aluminium back-surface field (Al-BSF) cells, passivated emitter and rear cell (PERC) technology is attracting more and more attention in the industry and gaining market share. However, PERC technology brings new challenges with regard to the phenomenon of degradation: some monofacial/bifacial PERC cell modules were found to demonstrate much higher power degradation than Al-BSF cell modules after damp-heat (DH: 85°C and 85% relative humidity RH, 1000h) and potential-induced degradation (PID: 85°C and 85% RH, –1,500V, 96h) tests, which will be the focus of this paper. The power degradation of PERC cell modules after DH and PID tests was also determined to be mainly caused by a decrease in short-circuit current. For bifacial glass–glass modules, PID failure can occur under either negative or positive bias voltage, but the power degradation can be recovered after conditioning the modules in a dry-heat climate chamber at 75°C for 48h and injecting forward I_{sc} current. This result indicates that such a failure does not happen outdoors, because the conditions of high heat and absence of current do not occur in the field. Consequently, the deviations of standard IEC conditions from real field conditions might lead to drawing the wrong conclusions from lab test results.

Introduction

Passivated emitter and rear cell (PERC) modules, because they demonstrate higher efficiency than aluminium back-surface field (Al-BSF) cell modules, are attracting more and more attention in the industry and starting to become a more promising candidate for reducing the levelized cost of electricity (LCOE). Furthermore, bifacial PERC modules fabricated using a glass–glass or glass–white backsheet configuration, which can lead to a higher power gain than that of monofacial PERC cell modules in the field, have increased their market share. Nevertheless, along the pathway of PERC cell technology development, the reliability problem has recently grabbed considerable attention from researchers, manufacturers and investors.

It has been found that the rear side of a bifacial glass–glass module is more sensitive to potential induced degradation (PID) than the front side, since the rear side of a PERC cell is not equipped with a full-area rear-side metallization [1,2]. The degradation on the rear side of a bifacial cell module has been shown to be fully or partially recoverable under illumination [1–3]. According to the research conducted by Sporleder et al. [1], the electrochemical formation of SiO_2 and the interfacial Na, K and Ca contaminations under cathodic conditions appear to play a major role in the degradation mechanism of the rear side. However, for modules incorporating PERC technology, except for the PID failure of bifacial PERC cells, other failure phenomena – such as continuous degradation in the dark at room temperature of bifacial PERC cell modules, and substantive degradation after damp-heat (DH) and PID tests of monofacial PERC cell modules – have not been explored yet.

> **"The rear side of a bifacial glass–glass module is more sensitive to PID than the front side."**

This paper reports not only the results of PID tests on bifacial PERC cell modules fabricated using glass, transparent backsheet and white backsheet as the backboard, but also the results of DH and PID tests on monofacial PERC cell modules. The focus is on the recovery behaviour and how to reduce the degradation. The recovery test is conducted by conditioning the modules in a dry-heat climate chamber at 75°C and injecting a forward I_{sc} current, which mimics the conditions of light and elevated temperature-induced degradation (LeTID) regeneration.

It is found that the power degradation of a bifacial cell module can be restored after the recovery test. The degradation of a monofacial PERC cell module after DH and PID test is also shown to be partially recoverable by injecting a forward I_{sc} current. A bifacial PERC cell module fabricated with a glass–glass layout is more sensitive to PID than one with a glass–transparent backsheet layout. In addition, it is possible for PID failure to occur on a bifacial glass–glass PERC module under either negative or positive bias voltage. The PID degradation of a bifacial PERC cell module with a glass–white backsheet layout can be reduced by using white ethylene-vinyl acetate (EVA) instead of transparent EVA as an encapsulation material on the rear side.

Experimental

Monofacial PERC cell module test

Commercial monofacial PERC solar cells from four different manufacturers were used, abbreviated as cell type A, B, C and D. Types A and B were made from boron-doped monocrystalline silicon wafers, while types C and D were made from gallium-doped monocrystalline silicon wafers. All the modules

Module no.	Cell type	Encapsulation material	Stressed	PID recovery	Forward I_{sc} current injected	DH	High temperature
1	A	EVA	–1,000V	--	1 cycle (48h)	–	–
2	B	EVA	–1,000V	--	1 cycle (48h)	–	–
3	C	EVA	–1,000V	--	1 cycle (48h)	–	–
4	D	EVA	–1,000V	96h	1 cycle (48h)	–	–
5	D	EVA	–	–	1 cycle (48h, after DH test)	1000h	–
6	D	EVA	–	–	–	–	200h

Table 1. Test items for modules 1–6.

Module no.	Cell	Fabrication type	Encapsulation	Stressed material	Dark storage	Forward I_{sc} current injected	Light
7	E	Glass–glass	POE	–1,500V	536 days	4 cycles (each cycle 48h)	–
8	E	Glass–glass	POE	+1,500V	536 days	4 cycles (each cycle 48h)	–
9	E	Glass–glass	POE	–1,500V	6 days	–	530 days
10	E	Glass–glass	POE	+1,500V	6 days	–	530 days
11	F	Glass–glass	POE	–1,500V	536 days	1 cycle	–
12	F	Glass–glass	POE	+1,500V	536 days	1 cycle	–
13	E	Glass–transparent backsheet	POE	–1,500V	–	–	–
14	E	Glass–transparent backsheet	POE	–1,500V	–	–	–
15	E	Glass–glass	POE	–1,500V	–	–	–
16	E	Glass–glass	POE	–1,500V	–	–	–

Table 2. Test items for modules 7–16.

Module no.	Cell type	Encapsulation material	Stressed	Forward I_{sc} current injected	EDS
17	E	Front side: transparent EVA Rear side: white EVA	–1,000V	–	Y
18	E	Front side: transparent EVA Rear side: transparent EVA	–1,000V	–	Y
19	F	Front side: transparent EVA Rear side: white EVA	–1,000V	2 cycles (96h)	–
20	F	Front side: transparent EVA Rear side: transparent EVA	–1,000V	–	–

Table 3. Test items for modules 17–20.

were fabricated with a glass–white backsheet and transparent EVA as the encapsulation material. Table 1 lists all the test specifications for the modules.

In the first part of the experiments, the degradation due to the PID test, as well as the recovery behaviour afterwards, was investigated for modules 1 to 4. The PID test was performed by using a high voltage of –1,000V applied to the frame at a module temperature of 85°C and a relative humidity (RH) of 85%. For the recovery test, stressed modules were injected with a forward I_{sc} current for 48h at 75°C. In the case of cell type D, module 4 was stressed by the PID test and followed by the PID recovery procedure (a high voltage of +1,000V applied to the frame at a module temperature of 85°C and RH of 85% for 96h). The recovery behaviour was subsequently investigated.

In the second part of the experiments, the degradation due to high temperature and high humidity, as well as the recovery behaviour afterwards, was investigated for modules 5 and 6.

Bifacial glass–glass / glass–transparent backsheet module test

Commercial bifacial PERC solar cells made from boron-doped monocrystalline silicon wafers from two different manufacturers were used, abbreviated as cell types E and F. All the modules were fabricated with a glass–glass or glass–transparent backsheet and polyolefin elastomer (POE) as the encapsulation material. Table 2 lists all the test specifications for the modules.

The degradation due to the PID test, as well as

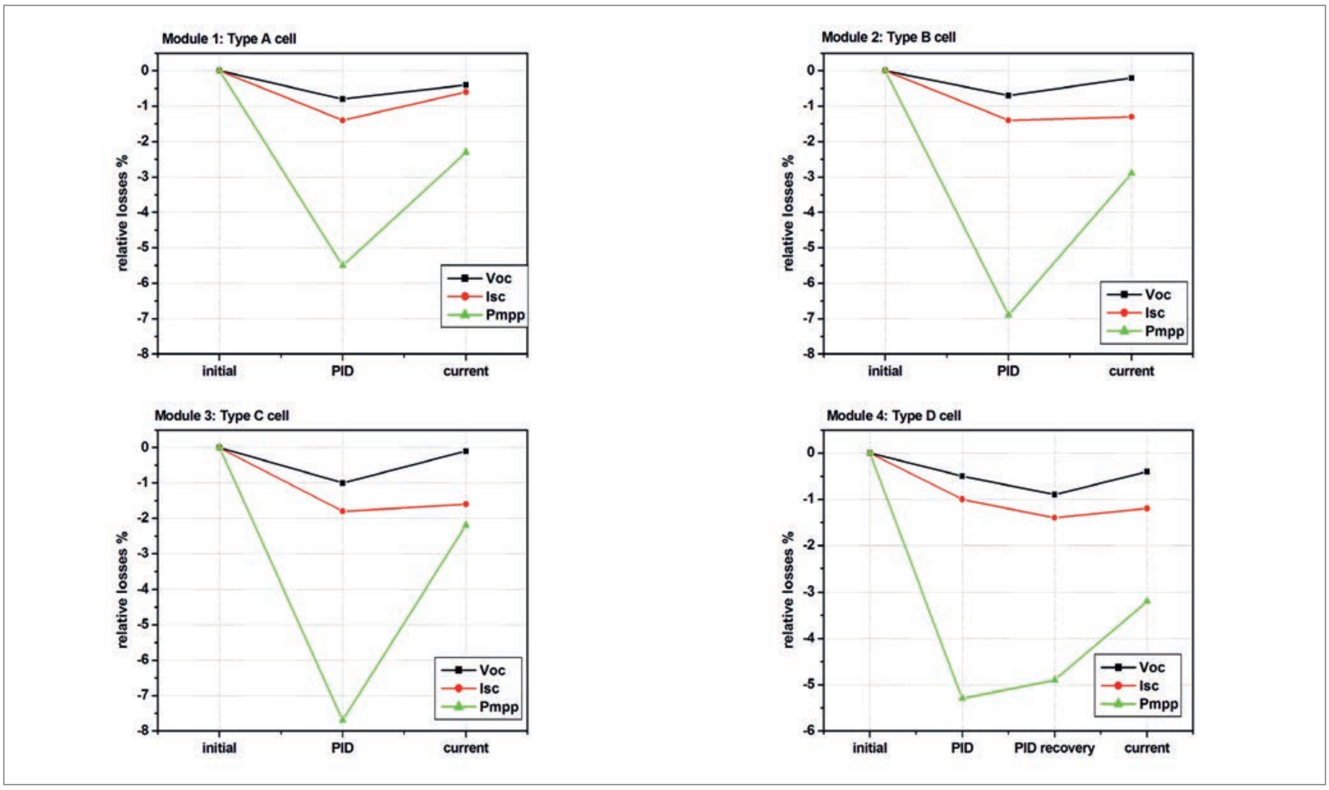


Figure 1. Relative losses in short-current I_{sc}, open-circuit V_{oc} and maximum power output P_{mpp} of the modules under testing.

the recovery behaviour afterwards, was investigated for modules 7–16. The PID test was performed by using a high voltage of –1,000V applied to the frame at a module temperature of 85°C and RH of 85% for 96h. For the recovery test, two methods were used. In method A, stressed modules were stored in the dark at room temperature for a period of 536 days and subsequently injected with a forward I_{sc} current at 75°C until the power stabilized. In method B, stressed modules were stored in the dark at room temperature for a period of 6 days and then illuminated in the field for 530 days.

Bifacial glass–white backsheet module test

Glass–white backsheet modules with cell types E and F were fabricated with white EVA or transparent EVA as the encapsulation material on the rear side. Table 3 shows all the specifications for the modules.

In the first part of the experiments, the degradation due to the PID test, as well as the recovery behaviour afterwards, was investigated in modules 17–20. The PID test was performed by using a high voltage of –1,500V applied to the frame at a module temperature of 85°C and RH of 85%. For the recovery test, stressed modules were injected with a forward I_{sc} current for 96h at 75°C.

In the second part of the experiments, energy-dispersive spectroscopy (EDS) (ZEISS X-Max^{N}20 (51-XMX1121)) was employed to investigate the elemental changes of white EVA and transparent EVA before and after the PID test.

"It is thought that LeTID may play a role during the PID test."

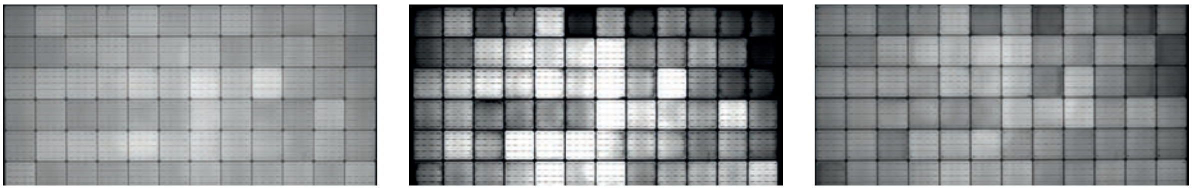
Results

Characterization of monofacial PERC cell module degradation and recovery behaviour after PID and DH tests

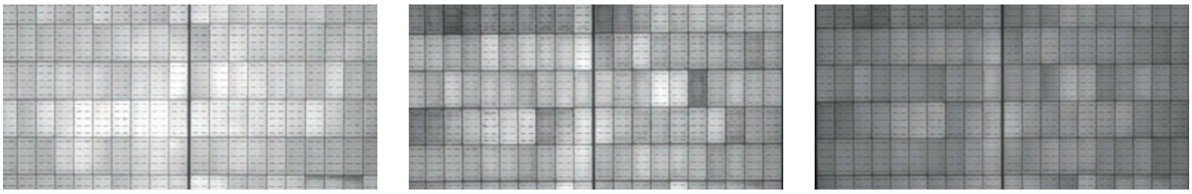
After PID tests

Fig. 1 shows that all tested modules are prone to PID. The power losses of modules 1, 2, 3 and 4 are –5.5%, –6.9%, –7.7% and –5.3%, respectively, where the corresponding I_{sc} losses of the same testing groups are –1.4%, –1.4%, –1.8% and –1.0%, and the V_{oc} losses are –0.8%, –0.7%, –1.0% and –0.5%. It is clear that the I_{sc} loss is the dominating loss factor here, which is different from the well-known shunting type PID (PID-s) of Al-BSF solar cell module, in which the V_{oc} loss is the dominating loss factor.

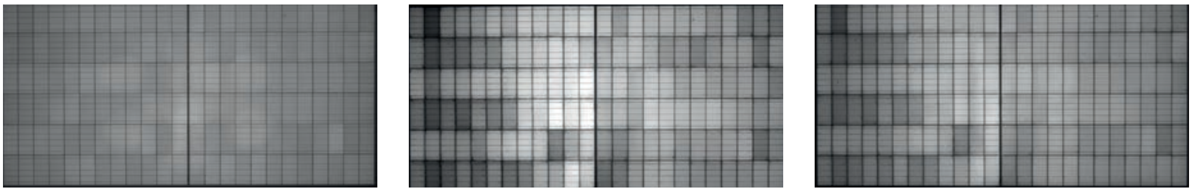
Following the PID test, modules 1, 2 and 3 received the recovery test by injecting a forward I_{sc} current. The results show that P_{mpp} and I_{sc} of all the modules recovers partially, whereas V_{oc} shows almost a full recovery. For module 4, the PID recovery test was applied after the PID test, and the subsequent current recovery behaviour was studied. The relative power loss recovers from –5.3% after the PID test to –4.9% after the PID recovery test. In contrast to the power recovery behaviour, I_{sc} and V_{oc} show continuous losses. However, the relative power loss recovers significantly from –4.9% after the PID recovery to –3.2% after the forward I_{sc}



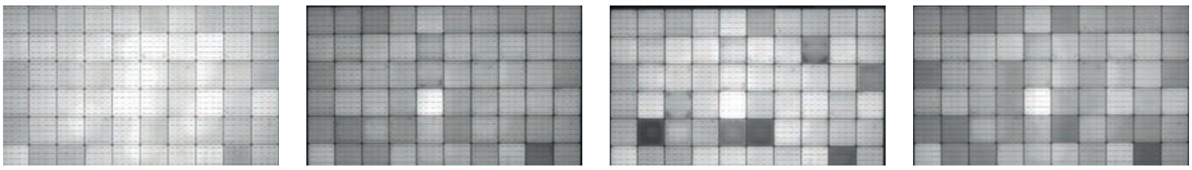
Module 1: cell type A (left: initial; centre: PID test; right: current injection)



Module 2: cell type B (left: initial; centre: PID test; right: current injection)



Module 3: cell type C (left: initial; centre: PID test; right: current injection)

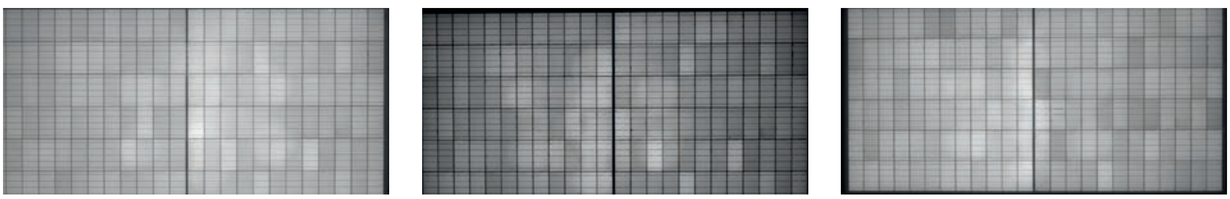


Module 4: cell type D (left: initial; centre left: PID test; centre right: PID recovery; right: current injection)

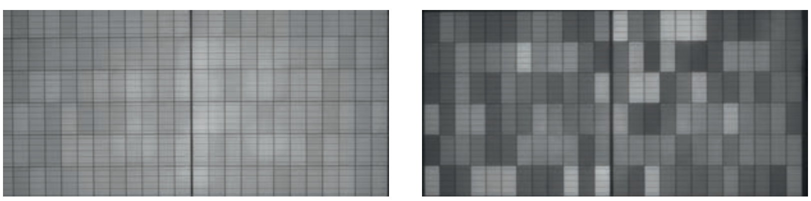
Figure 2. EL images of the modules under testing (modules 1–4).

Module no.	State	V_{oc}	I_{sc}	P_{mpp}	V_{oc} loss [%]	I_{sc} loss [%]	P_{mpp} loss [%]
5	DH test	49.26	9.76	382.75	−0.5	−4.6	−5.4
	Forward current injected	49.44	9.88	390.51	−0.1	−3.4	−3.5
6	Initial	49.03	10.08	395.19			
	High-temperature test	48.28	9.89	375.76	−1.5	−1.8	−4.9

Table 4. Electrical characterization of degradation and recovery behaviour.



Module 5 (left: initial; centre: DH test; right: current injection)



Module 6 (left: initial; right: high-temperature test)

Figure 3. EL images of the modules under testing (modules 5 and 6).

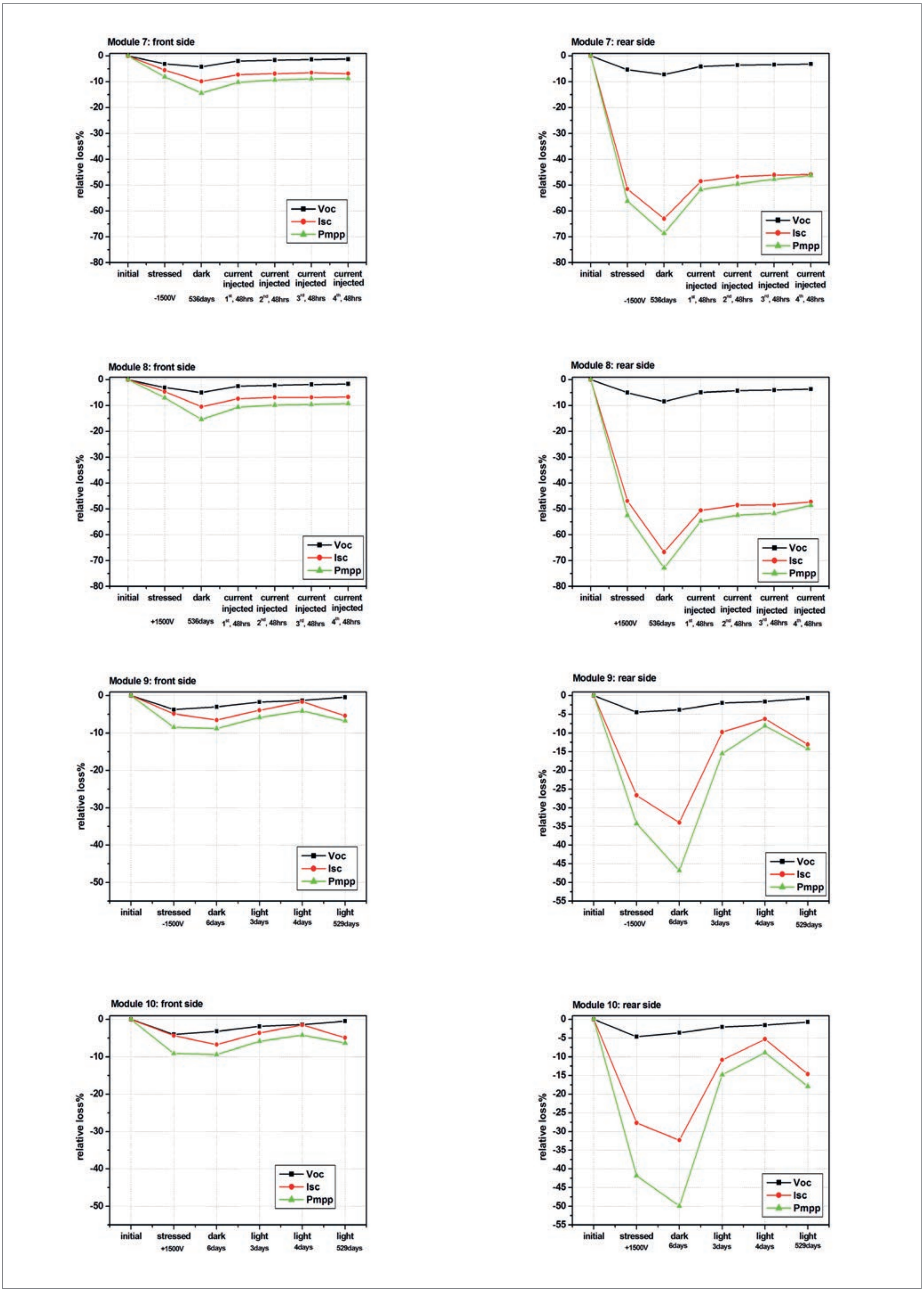
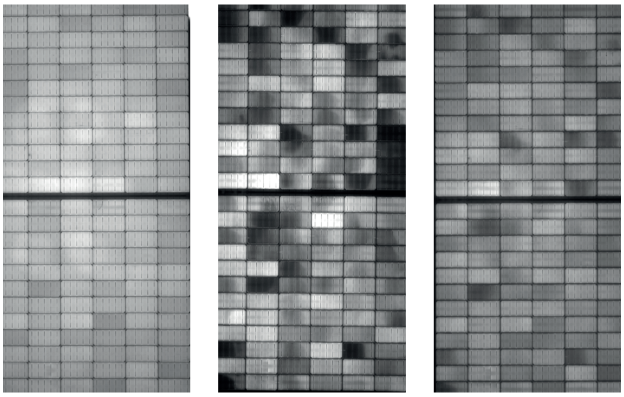
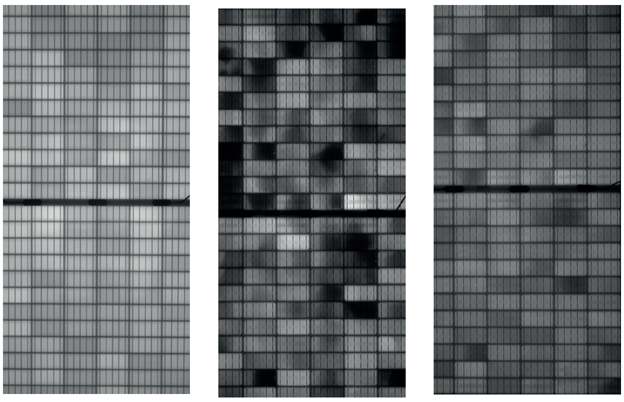


Figure 4. Relative losses in short-circuit current I_{sc}, open-circuit voltage V_{oc} and maximum power output P_{mpp} of the modules using cell type E under testing. For modules 7 and 9, a negative 1,500V voltage was applied during the stress test, while for modules 8 and 10, a positive 1,500V voltage was applied during the test.



Module 10: front side (left: initial; centre: PID test; right: illumination)



Module 10: rear side (left: initial; centre: PID test; right: illumination)

Figure 5. EL images of the module under testing (module 10).

current injection, and I_{sc} also partially recovers, whereas V_{oc} shows almost a full recovery.

Electroluminescence (EL) tests were carried out at each test stage (see Fig. 2). In the stressed state, dark cells can be observed, and the dark cells in modules 1, 2 and 3 can be recovered by injecting a forward I_{sc} current. For module 4, even more dark cells can be observed after PID recovery, although they can also be recovered by injecting a forward I_{sc} current. The changes in the EL images correspond to the changes in electrical characterization. It is therefore thought that LeTID may play a role during the PID test.

After DH tests

DH (85°C and 85% RH, 1000h) and high-temperature tests (105°C, 200hrs) were conducted on two modules using cell type D and the same encapsulation materials; these underwent the current recovery test afterwards. From the results in Table 4 it can be seen that the tested modules are sensitive to high temperature and that this degradation can be recovered after the current recovery test. The P_{mpp} and I_{sc} of module 5 show partial recovery by injecting forward I_{sc} current, while V_{oc} shows almost a full recovery. An EL test was carried out at each test stage (see Fig. 3). The changes in the EL images correspond to the changes in electrical characterization. It is therefore thought that LeTID may also play a role during high-temperature and high-humidity tests.

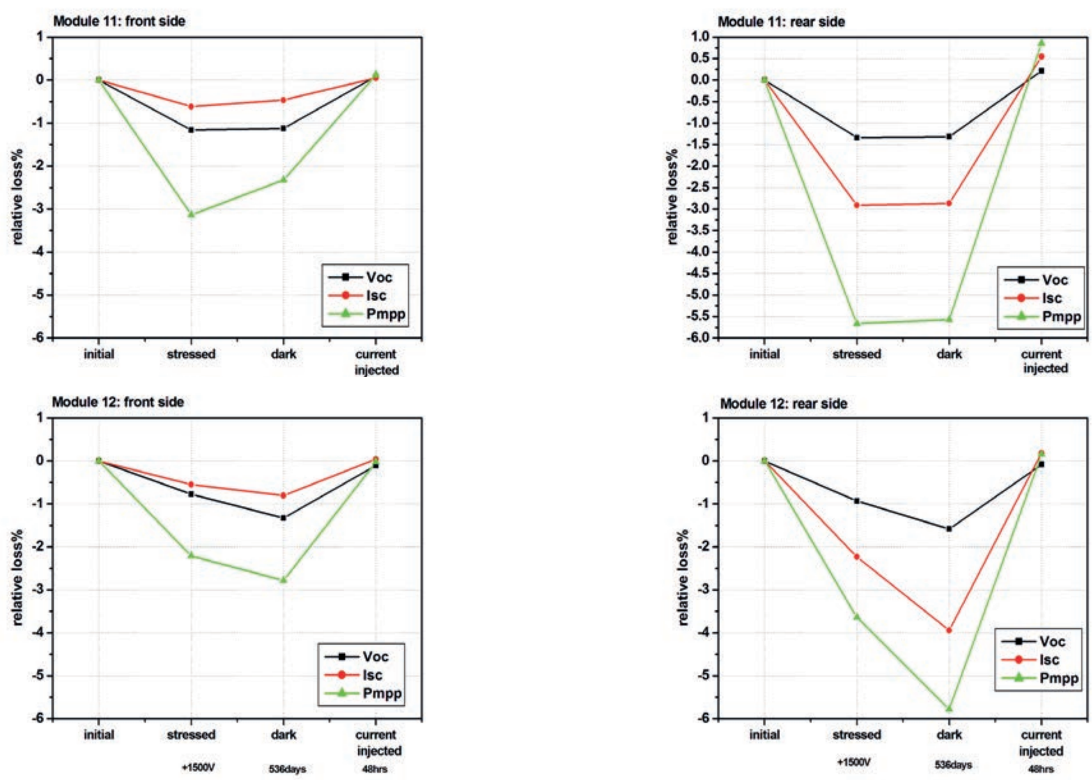


Figure 6. Relative losses in short-circuit current I_{sc}, open-circuit voltage V_{oc} and maximum power output P_{mpp} of the modules using cell type F under testing. For module 11, a negative 1,500V voltage was applied during the stress test, while for module 12, a positive 1,500V voltage was applied during the stress test.

Characterization of bifacial glass–glass / glass–transparent backsheet module degradation and recovery behaviour

The rear side of the modules using cell type E (modules 7–10) was found to be more sensitive to PID than the front side; this phenomenon could be observed under either negative or positive voltage (see Fig. 4). The relative P_{mpp} loss is mainly caused by the loss in I_{sc}. After the PID test, the modules were stored in the dark at room temperature. Further losses could be observed on the front and rear sides of all tested modules.

Subsequently, modules 7 and 8 exhibited a recovery behaviour after forward I_{sc} current injection, whereas modules 9 and 10 showed illumination recovery behaviour (illumination of the rear side). The P_{mpp} and I_{sc} of these modules only recover partially, whereas V_{oc} shows almost a full recovery after applying the two different recovery methods. Furthermore, the recovery behaviour by illumination on the rear side is more pronounced than that achieved by forward I_{sc} current injection.

Fig. 5 shows the EL images of module 10 for each test stage. The changes in the EL images correspond to the changes in electrical characterization.

In contrast, for the modules using cell type F, a full recovery can be observed after forward I_{sc} current injection (see Fig. 6).

The same difference in PID sensitivity mentioned earlier was observed for the bifacial modules from different manufacturers: the rear side was more sensitive to PID than the front side. However, it was found that the loss on the rear side can be reduced when using a transparent backsheet instead of glass, probably because of the fact that the backsheet has a higher insulation resistance than that of glass (see Figs. 7 and 8).

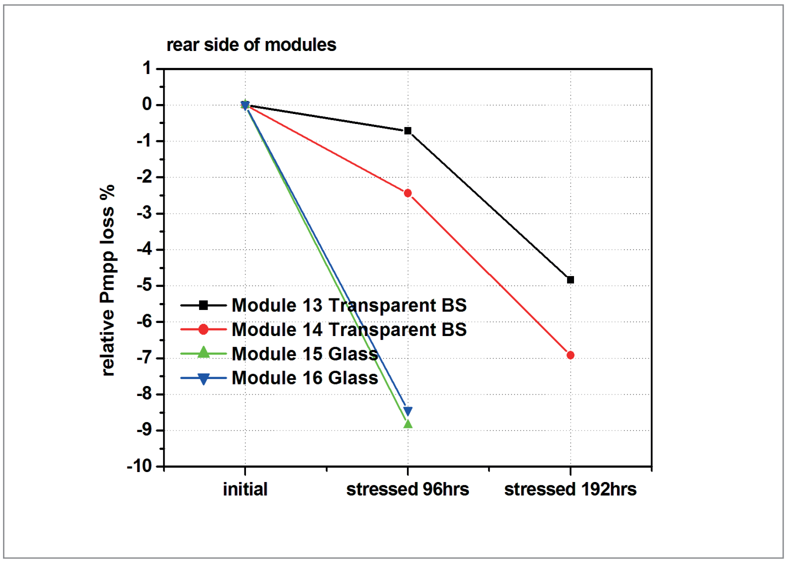


Figure 7. Relative losses in maximum power output P_{mpp} for modules using a transparent backsheet and glass as the backboard.

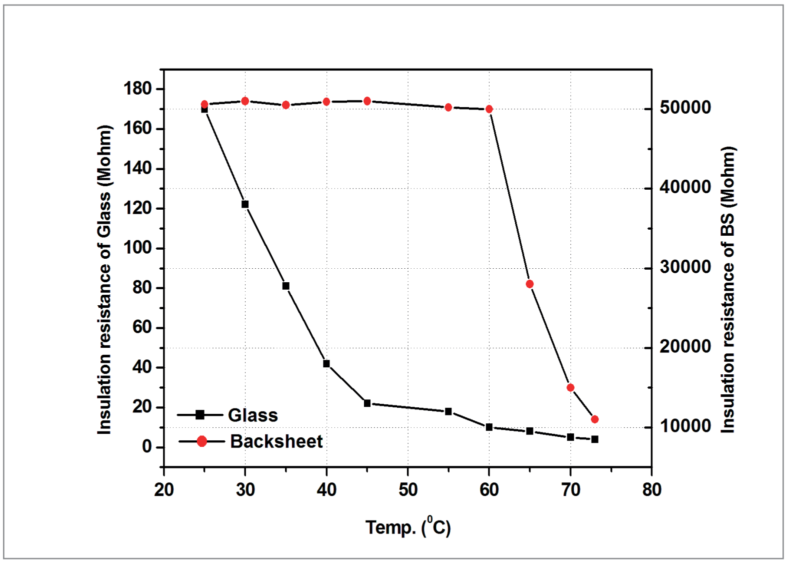


Figure 8. Insulation resistance of glass and backsheet at different temperatures.

Characterization of bifacial glass–white backsheet module degradation and recovery behaviour

A bifacial PERC cell module with a glass–white backsheet layout can achieve higher power gains than a monofacial PERC cell module, and is therefore normally considered to be an alternative choice for a high-power module. Nevertheless, the PID phenomenon on the rear side still influences the power output of the module, although the power on the rear cannot be measured because of the use of a white backsheet. However, it was found that the degradation on the rear side of a bifacial PERC module can be reduced when using white EVA instead of transparent EVA as the rear-side encapsulation material (see Fig. 9). The difference between white EVA and transparent EVA is the inclusion of titanium dioxide (TiO_2), which can enhance the reflection of light on white EVA and therefore increase the power output.

The recovery test by the injection of a forward I_{sc} current after the PID test was conducted on module 20 and followed by a PID recovery test. It was found that the module recovered partially after injecting forward I_{sc} current: the relative P_{mpp} loss decreased from −7.57% after the PID test to −1.66% after forward I_{sc} current injection (Fig. 10). On the other hand, the module showed further power loss after the PID recovery test: the relative P_{mpp} loss increased from −1.66% after forward I_{sc} current injection to −2.83% after the PID recovery test.

EDS was carried out on modules 17 and 18 to analyse the difference between white EVA and transparent EVA after a 288h stress test. The result shows that Na, K and Cl can be found in white EVA after the PID test, compared with the initial state (see Fig. 11). No change in transparent EVA can be observed before and after the PID test. It is believed that the TiO_2 in white EVA can influence the movement of Na and K coming from the cell.

"The loss on the rear side can be reduced when using a transparent backsheet instead of glass."

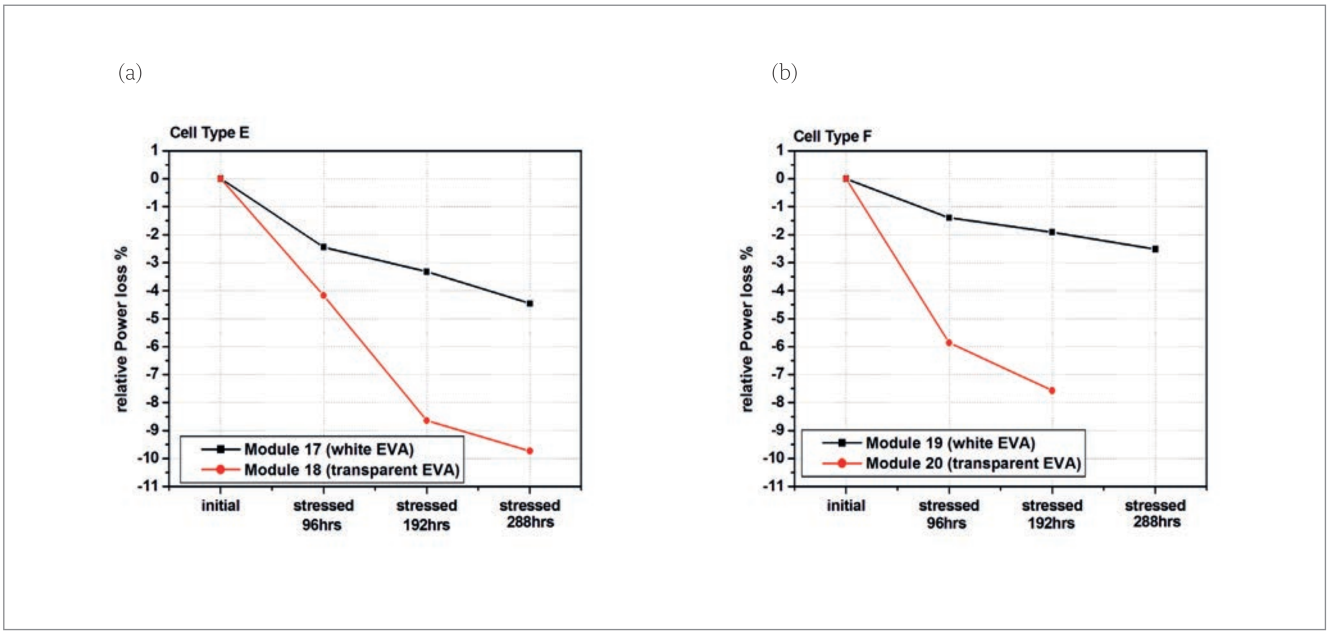


Figure 9. Relative losses in maximum power output P_{mpp} of a module using transparent EVA and white EVA as the encapsulation material: (a) module with cell type E; (b) module with cell type F.

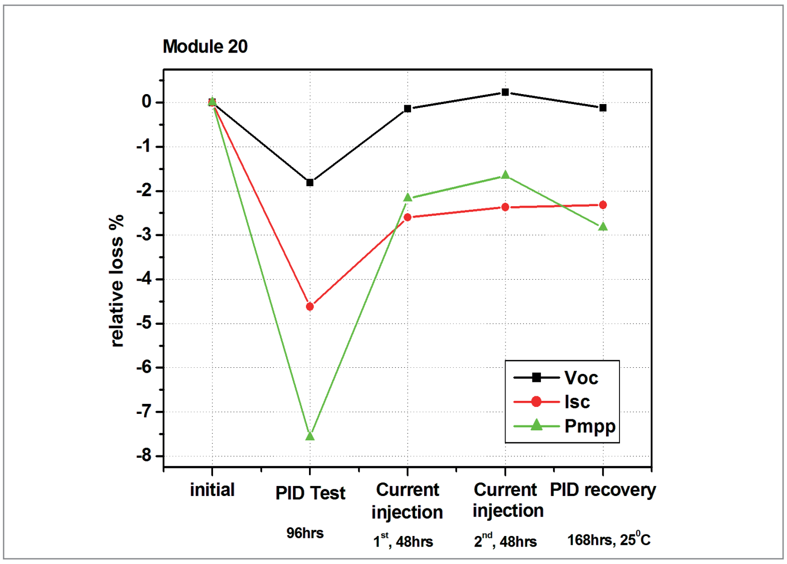


Figure 10. Relative losses in maximum power output P_{mpp} of module 20 after the forward I_{sc} current injection recovery test and the PID recovery test.

"The degradation on the rear side of a bifacial PERC module can be reduced when using white EVA instead of transparent EVA as the rear-side encapsulation material."

Conclusions

Modules using monofacial PERC cells from four different manufacturers (cell types A, B, C and D) were found to be prone to PID. For modules using cell type D, high power loss was also observed after DH and high-temperature tests. The relative P_{mpp} loss in all tested modules recovered partially by injecting forward I_{sc} current at 75°C.

For bifacial glass–glass modules, PID failure can occur under either negative or positive voltage. The modules using cell type E or cell type F were found to be prone to PID on the rear side, which is in good agreement with the findings in the literature [1–3]. The relative P_{mpp} loss can be recovered by injecting forward I_{sc} current at 75°C or by subjecting to illumination. Different recovery behaviours were observed in cells from different manufacturers: the relative P_{mpp} loss in modules using cell type E partially recovered, whereas modules using cell type F fully recovered.

In the case of bifacial PERC cell modules fabricated with a glass–white backsheet, the PID failure on the rear side can be reduced when using white EVA instead of transparent EVA as the encapsulation material. An EDS analysis showed that Na and K can be found in white EVA after the PID test, compared with the initial state.

The failure of PERC cells under PID and DH tests can be recovered by applying the LeTID regeneration method, where forward I_{sc} current is injected at 75°C. It is therefore believed that LeTID may play a key role during PID and high-temperature tests.

References

[1] Sporleder, K. et al. 2019, "Root cause analysis on corrosive potential-induce degradation effects at the rear side of bifacial silicon PERC solar cells", *Sol. Energy Mater. Sol. Cells*, Vol. 201, p. 110062.
[2] Luo, W. et al. 2018, "Elucidating potential-induced degradation in bifacial PERC silicon photovoltaic modules", *Prog. Photovolt: Res. Appl.*, Vol. 26, No. 10, pp. 859–867.
[3] Luo, W. et al. 2018, "Investigation of the impact of illumination on the polarization-type potential-induced degradation of crystalline silicon photovoltaic modules", *IEEE J. Photovolt.*, Vol. 8, No. 5, pp. 1168–1173.

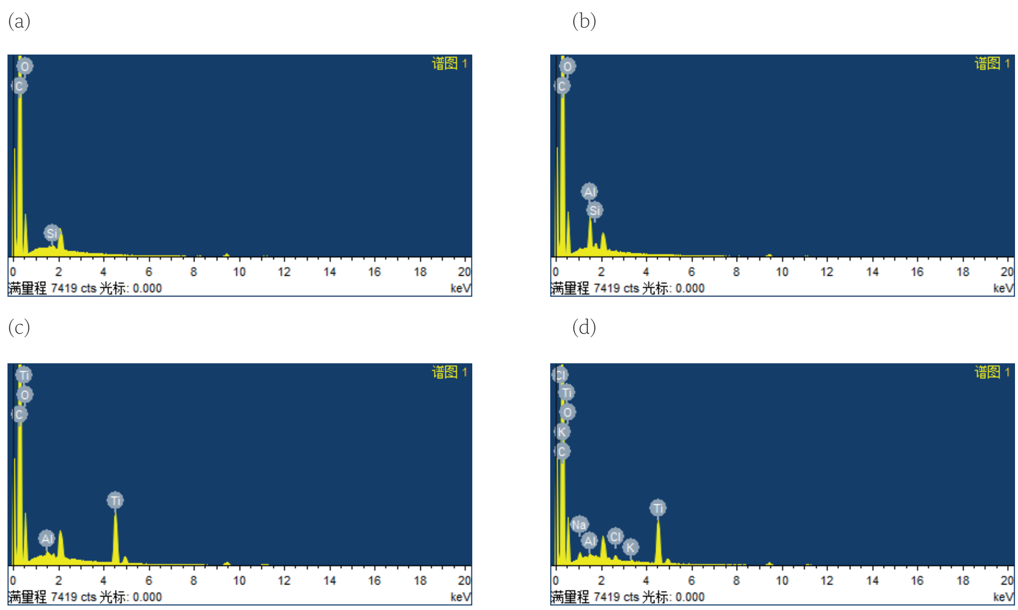


Figure 11. EDS characterization of white EVA and transparent EVA: (a) transparent EVA in the initial state; (b) transparent EVA after the PID test; (c) white EVA in the initial state; (d) white EVA after the PID test.

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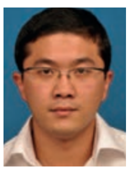

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