OPTIMIZED MODULE PACKAGING FOR SILICON HETEROJUNCTION SOLAR CELLS AND INCREASED PID RESISTANCE

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ABSTRACT: Recent studies showed that silicon heterojunction (SHJ) solar cells can be prone to potential induced degradation (PID) when encapsulated with a low volume resistivity ethylene vinyl acetate (EVA). We perform PID test in humid conditions (85°C/85% RH) on glass/glass one-cell modules with and without an edge sealant, to ensure an uniformly applied potential all over the module surface. We also analyze the effect of moisture ingress by using these module structures. We demonstrate that with the proper module packaging (i.e. a glass/glass structure with edge sealant), EVA can be used as an encapsulant material for SHJ solar cells. PID can be completely prevented even when subjected to extended tests (e.g. eight times the 96 h of test duration foreseen in the IEC Technical Specification for c-Si modules). On the other hand, SHJ modules packaged in a glass/glass structure using EVA (and no edge seal) start exhibiting a degradation in performance after 192 h of PID test (i.e. twice the test duration foreseen by IEC TS 62804-1). The degradation becomes considerable after 800 h of test, driven by a reduction in short-circuit current (J_{SC}), fill factor (FF) and open-circuit voltage (V_{OC}).

1 INTRODUCTION

Potential induced degradation (PID) is a frequently reported degradation mode for solar photovoltaic (PV) modules. The degradation mechanism depends, among other factors, on the cell technology [1].

Whereas extensive research exists for solar modules with conventional crystalline silicon cells (Al-BSF), not many works on the same subject are available for silicon heterojunction (SHJ) cells. In general, compared to more conventional cell architectures, the presence of a transparent conductive oxide (TCO) layer that avoids the accumulation of charges is believed to prevent the occurrence of PID. However, the encapsulant materials used in these studies were not specified, so that the good performance might have been guaranteed by the use of encapsulants with a high electrical resistivity rather than by the cell technology itself. In 2018, Yamaguchi and coauthors reported about PID occurring in SHJ solar cells when using an ethylene vinyl acetate (EVA) with a low-volume resistivity [2]. These tests were performed on glass/foil modules at 85°C in nearly dry conditions (<2% RH), with a bias of -1000 V applied to the cell.

However, this is not representative of the environment solar modules are exposed to when installed in the field. During their outdoor operation, PV modules are exposed to humidity and the diffusion of moisture into the encapsulant enhances the PID by reducing the encapsulant resistivity [3].

Our aim in this work is to investigate the PID mechanism in SHJ solar cells under more realistic environmental conditions.

In another contribution to this conference (4AV1.8), we demonstrate that in SHJ glass/glass (G/G) mini-modules PID is completely suppressed when using encapsulants with high volume resistivity (such as ionomer, POE and TPO), and that EVA is the most sensitive encapsulant. In the present work, we demonstrate that in SHJ cells/modules PID can be easily prevented by using the proper packaging scheme, even when using EVA as an encapsulant.

2 EXPERIMENTAL WORK

We investigate the impact of moisture by performing PID accelerated tests in humid conditions (85°C/85% RH) and employing encapsulation schemes with different permeability properties (see Table I). We approach this by encapsulating one-cell mini-modules with G/G and G/G with edge sealant (G/G-ES) encapsulation designs, the last one representing a configuration impermeable to water. As encapsulant material, we employed a 0.5 mm thick EVA with a relatively high electrical resistivity ($\rho \sim 1 \cdot 10^{15}\ \Omega \cdot$cm). An aluminum tape was placed at the four edges of the mini-module to simulate the presence of a metallic frame. Voltage biases of -1000 V and +1000 V were applied to the short-circuited module leads with respect to the grounded frame to analyze the effect of voltage polarization. At each testing condition, a couple of samples were kept unbiased as reference.

Table I. Testing conditions on the one-cell mini-modules using commercial SHJ cells and glass/glass module design.

Temperature/ RH	Module design	Voltage
85°C/85%	G/G	-1000 V (2x)
		0 V (2x)
		+1000 V (2x)
	G/G – ES	-1000 V (2x)
		0 V (2x)
		+1000 V (2x)

The mini-modules were characterized during the PID testing by one-sun and dark current-voltage (IV) curves, electroluminescence (EL) and external quantum efficiency (EQE) measurements.

3 RESULTS

In this contribution, we present the results on the mini-modules subjected to PID under a bias of -1000 V (the results of unbiased samples and samples biased at +1000 V will be part of a later contribution). Fig. 1 summarizes the relative variation of the electrical parameters at the end of the extended PID test (800 h) for both G/G and G/G-ES mini-modules with EVA. This diagram clearly shows that the module designs with an ES do not suffer from PID. It demonstrates that the suppression of PID is possible with the right module configuration, even with an encapsulant like EVA, which may be susceptible (depending on the volume resistivity) to PID. The results indicate that, even in a G/G structure and using EVA encapsulant material, moisture ingress has an impact on PID in SHJ cells.

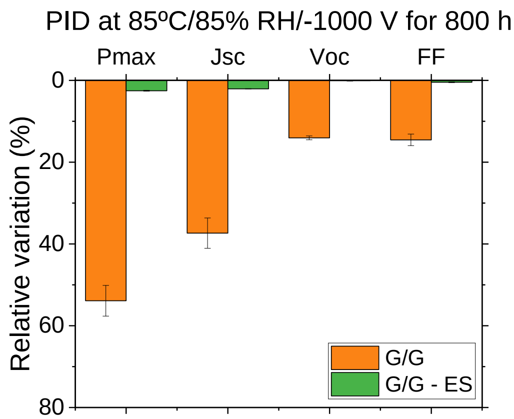

Figure 1. Relative variation of the electrical parameters of SHJ 1-cell mini-modules in G/G and G/G-ES schemes, after an extended 800 h of test at 85°C/85% RH and -1000 V conditions. The test conditions foreseen in IEC TS 62804-1 (i.e. 60°C/85% RH for 96h), have increased in terms of relative humidity (85% RH) and test duration (8 times the standard). The values plotted in the chart are the averages of each type of sample. With a negative voltage bias applied, the P_{max} loss is dominated by a reduction in J_{SC}. The losses in V_{OC} and FF are less pronounced.

We find that the occurrence of PID is due to the negative bias, since no degradation is observed for the positively polarized (+1000 V with respect to the grounded frame) and un-biased (reference) samples in the G/G module design.

The PID mechanism is driven by a loss in short-circuit current (J_{SC}), although the open-circuit voltage (V_{OC}) and fill factor (FF) are also affected. In the following sections we describe more in detail the results of these tests.

The illuminated IV curves (see Fig. 2) demonstrate that these modules tested at 85°C/85% RH/-1000 V do not degrade if we follow the standard test duration (i.e. 96 h) foreseen in IEC TS 62804-1:2015 [4]. In this set of experiments, however, we pushed these tests for even longer, up to 800 h (i.e. 8 times the IEC TS).

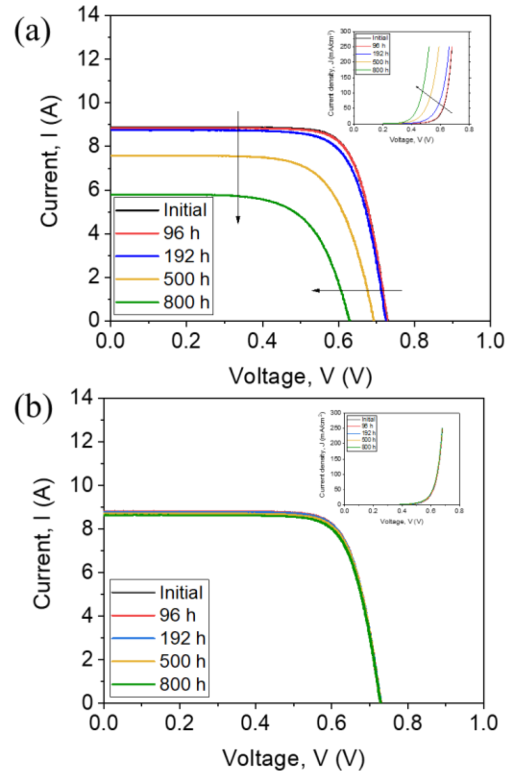

Figure 2. One-sun IV curves of (a) G/G and (b) G/G – ES mini-modules with EVA subjected to PID test at 85°C/85% RH/-1000 V for up to 800 h. Dark IV curves of the same sample are shown in the inset due to space constraints. We observe that both the one-sun and dark I-V curves remain stable in the case of the G/G – ES mini-module, whereas there is a gradual degradation for the mini-modules without an edge seal.

If we consider this extended test, it shows that, for these G/G mini-modules, one-sun IV curves degrade mostly in the J_{SC}, while there is a less pronounced degradation the V_{OC} of the cell. Therefore, it would seem that if degraded, it is driven both by optical and passivation issues.

For these G/G mini-modules, also the dark IV curves are gradually affected (see the inset in Fig. 2). This indicates that the PID mechanism concerns the diode itself.

The G/G – ES mini-modules show no degradation at all, in neither the one-sun nor the dark I-V curves, even after 800 h of test. Therefore, the edge seal prevents the degradation from happening.

EQE measurements were performed both at the center and at the edge of the samples, which experience different degradation dynamics (see Fig. 3). The degradation at the edge is more prominent for short wavelengths, whereas all wavelengths are affected at the center of the modules. This further demonstrates that the degradation in G/G modules can be caused by water ingress. Along with the large decrease in J_{SC} in the one-sun IV curves, it indicates that there is recombination at the front surface of the solar cell.

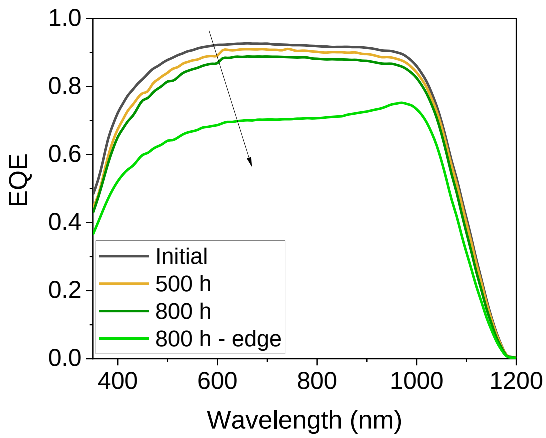

Figure 3. EQE measurements of a G/G mini-module subjected to PID test at 85°C/85% RH/-1000 V for up to 800h. Measurements were performed at the center and edges of the mini-module. The degradation at short wavelengths of the edges is more pronounced than at the centers.

EL images at several PID test duration times for G/G and G/G – ES modules are presented in Fig. 4. The top row shows the contribution and progression of water ingress from the edges for test times higher than 500 h. We observe that after 800 h, the current is injected mostly at the busbars and the center of the cell for the G/G mini-module, whereas there is no apparent degradation to the G/G-ES mini-module.

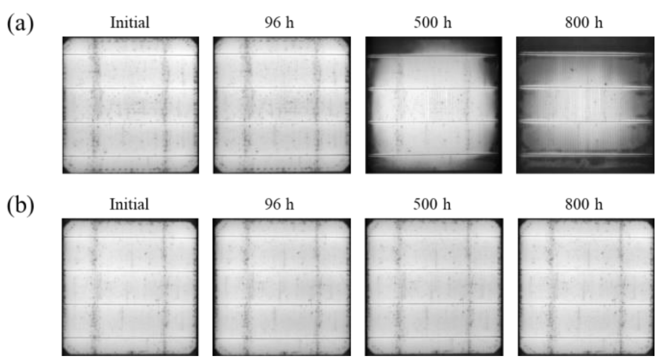

Figure 4. EL images of (a) G/G and (b) G/G – ES mini-module before and after 1000 h of PID test at 85°C/85% RH/-1000 V. For the G/G mini-modules degradation starts at the edges of the module after 500 h of test, gradually expanding the inactive area. On the other hand, G/G – ES module configuration prevents degradation by PID even when EVA is used.

4 CONCLUSIONS

In another contribution to this conference (4AV1.8), we demonstrate that in SHJ G/G mini-modules PID is completely suppressed when using encapsulants with high volume resistivity (such as ionomer, POE and TPO) and that EVA is the most sensitive encapsulant. In this work, our extended PID tests showed that PID can be prevented by using either the right PV system polarity or an appropriate module configuration design, even using EVA as an encapsulant material. In fact, we observe that glass/glass mini-modules manufactured using EVA in combination with an edge seal show an excellent resistance to PID even after 800 h of test (at 85°C/85% RH/-1000 V test conditions). The same samples (with no edge seal) do not exhibit sign of degradation if we stick to the 96 h of test duration, but start degrading slowly after 192 h of test duration, and show sign of strong degradation after 500 h. Therefore, by using an edge seal it is possible to obtain a very good resistance, not only to damp heat, but also to PID stress by preventing the ingress of water.

We further studied the degradation mechanism for the G/G mini-modules degraded after 800 h. The electrical characterization measurements show that the degradation is driven by a reduction in J_{SC}, FF and V_{OC}. The gradual degradation of the dark IV curves indicate a passivation loss. On the other hand, the reduced absorption in short wavelengths of the EQE spectra at the edges of the module indicate that the loss in performance can as well be ascribed to increased recombination at the front surface of the cell. EL images further illustrate that the degradation originates at the edges and spreads all over the cell as the stress duration increases. This directly relates the degradation mechanism to the effect of water ingress.

Ongoing experiments on cell-level analysis (electronic microscopy) will provide a deeper understanding on the underlying degradation mechanism.

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