ENCAPSULANT SELECTION FOR PID RESISTANT MODULES MADE WITH SILICON HETEROJUNCTION SOLAR CELLS

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ABSTRACT: Recent studies showed that SHJ solar cells can be prone to PID when encapsulated with a low volume resistivity encapsulant, such as ethylene vinyl acetate (EVA). These studies also demonstrated that their degradation mechanism is different from Al-BSF modules. It is well known that PID in Al-BSF cells can be prevented by a high volume resistivity encapsulant. In this work we perform PID tests in humid conditions (85°C/85% RH) on one-cell SHJ glass/glass modules with and without edge sealant. Seven different encapsulants are used: ionomer, three elastomer polyolefin (POEs), thermoplastic polyolefin (TPO), polyvinyl butyral (PVB) and EVA. Moreover, the effect of water ingress and the voltage polarization are also considered. The results indicate that PID can be prevented with the proper selection of encapsulants. Ionomer, POEs and TPO show beneficial effects on preventing degradation, both with and without edge sealant. Modules encapsulated with EVA do not suffer from PID when encapsulated with an edge seal configuration, even after extended tests (e.g. five times the 96 h of test duration foreseen in the IEC Technical Specification for c-Si modules).

1 INTRODUCTION

Potential-induced degradation (PID) is a frequently found mechanism in conventional crystalline silicon solar cells (i.e. Al-BSF) [1]. Silicon heterojunction (SHJ) are thought to be less prone to PID because of the presence of a transparent conductive (TCO) layer. In fact, silicon nitride (SiN_x) layers with increased conductivity are used in conventional Al-BSF cells to prevent or delay the occurrence of PID. It is well known that PID in Al-BSF cells can be prevented by a high volume resistivity encapsulant.

Recent studies showed that SHJ solar cells can be prone to PID when encapsulated with a low volume resistivity encapsulant, such as ethylene vinyl acetate (EVA) [2]. These studies also demonstrated that their degradation mechanism is different from Al-BSF modules. The PID tests performed by Yamaguchi et al. were done at very low relative humidity (<2% RH) and 85°C with a bias of -1000 V applied to the cell, with respect to a grounded Al plate over the mini-module glass surface. The observed degradation mode is different from what has been commonly observed in conventional crystalline Si solar cells

During their outdoor operation, however, PV modules are exposed to humidity and the diffusion of moisture into the encapsulant enhances the PID by reducing the encapsulant resistivity [3].

Here, we complement the previous studies by investigating the PID mechanism in SHJ solar cells under more realistic environmental conditions and analyzing the effect of seven encapsulants with different volume resistivities. Moreover, we study the impact of water ingress from the edges of the modules as well as the effect of the voltage polarization with respect to the grounded frame.

In the present work, we demonstrate that PID in SHJ glass/glass (G/G) mini-modules can be completely suppressed using the adequate encapsulants with high volume resistivity (i.e. ionomer, elastomer polyolefin (POE) and thermoplastic polyolefin (TPO)). We also observe that the EVA is the most sensitive encapsulant. In another contribution to this conference (4BO12.2), we demonstrate that in SHJ G/G mini-modules PID can be easily prevented by using an edge sealant (ES), even when using EVA as an encapsulant material.

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. 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 seven different encapsulants with a variety of volume resistivities: ionomer, three polyolefin elastomers (POEs), thermoplastic polyolefin (TPO), polyvinyl butyral (PVB) and EVA. Hence, we analyze the effect of each one of the encapsulants with respect to PID. 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.

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

Fig. 1 summarizes the relative variation of the electrical parameters at the end of the extended PID test (500 h) of G/G mini-modules for all seven encapsulants. Modules with a voltage bias of -

1000 V with respect to the grounded frame and no voltage (acting as reference) are considered here. The different degradation rates to the PID tests are evident among them. Ionomer, three POEs and TPO do not show any kind of degradation even after 500 hours of test, regardless of the voltage applied. Conversely, PVB and EVA degrade, although at different rates; the modules encapsulated with EVA degrade more than those encapsulated with PVB. The diagram also demonstrates that the degradation is due to the voltage applied, since the mini-modules with no voltage applied do not degrade.

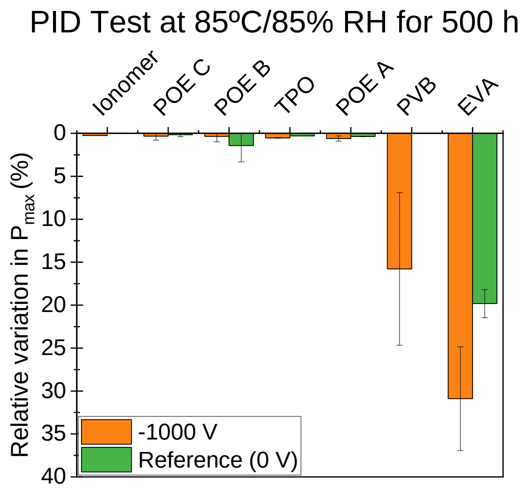

Figure 1. Relative variation of the maximum power (P_{max}) of SHJ cells encapsulated in a G/G structure with seven different encapsulants, after 500 h of test at 85°C/85% RH and -1000 V and 0 V (as reference) conditions. Values are the averages of each type of samples.

The diagram in Fig. 2 (a) clearly shows that the module designs with an ES do not suffer from PID. This diagram demonstrates that the suppression of PID is possible with the right module configuration, even with an encapsulant like EVA, which is susceptible to it. We thus conclude that humidity has an impact on PID in SHJ cells and cannot be neglected in a PID testing procedure. We can also state that ionomer, POEs and TPO are completely immune to PID in any of the two configurations (G/G and G/G-ES) and thus, would be ideal for a high PID resistant module configuration.

On the other hand, no degradation is observed for the positively polarized (+1000 V with respect to the grounded frame) for both G/G (Figure 2 2 (b)) and G/G-ES module designs (the results of unbiased samples and samples biased at +1000 V will be part of a later contribution). Therefore, PID degradation in SHJ solar cells is only triggered by the application of a negative bias.

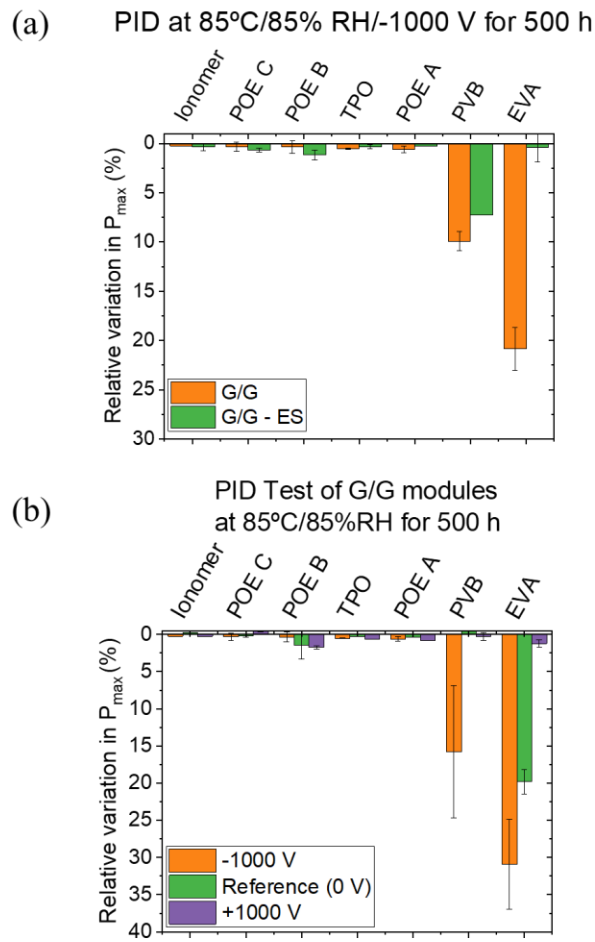

Figure 2. Relative variation of the maximum power (P_{max}) of SHJ cells with seven different encapsulants after 500 h of PID test at 85°C/85% RH. (a) Comparison between G/G and G/G-ES mini-module schemes and an applied voltage of -1000 V with respect to the frame, to analyze the effect of the module configuration design concerning water permeability. (b) Comparison between applied voltages of -1000 V, 0 V (as reference) and +1000 V with respect to the frame and packaged in a in G/G mini-module structure, to study the effect of voltage polarization in the degradation rate. Values are the averages of two samples.

The illuminated and dark IV curves of two different G/G mini-modules are shown in Fig. 3, corresponding to those encapsulated with POE C and EVA (Fig. 3 (a) and (b), respectively). The IV curves from the mini—module with POE C clearly shows that it does not degrade at all, also in the dark, even after 500 h (i.e. 5 times the standard 96 h foreseen in IEC TS 62804-1:2015 [4]). Regarding the module with EVA, and in accordance to what we observed in the previous diagrams, it is degraded after 500 h. However, the degradation rate needs to be considered: the module does not degrade for the 96 h of PID test, nor when extended to twice the aforementioned IEC TS. The degradation starts once we push the module for a 500 h test duration. This PID mechanism is driven by a loss in short-circuit current (J_{SC}) and open-circuit voltage (V_{OC}). Therefore, the cause could be a combination of optical and passivation issues; this is further demonstrated by the dark IV curves, where there is also a degradation in the curve.

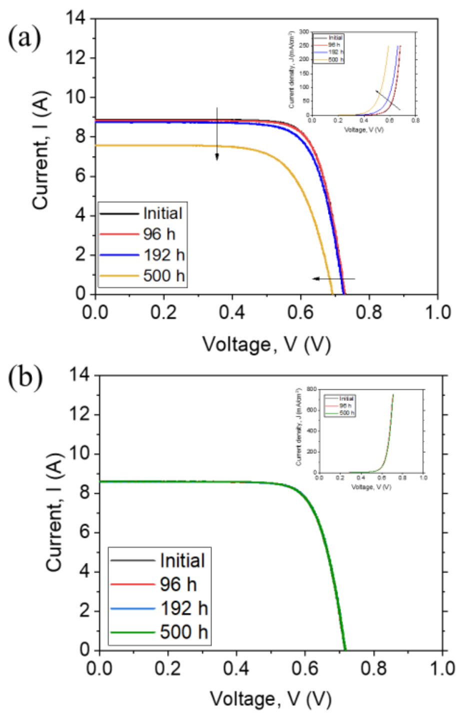

Figure 3. One-sun and dark IV curves of G/G mini-modules encapsulated with (a) POE C and (b) EVA and tested at 85°C/85% RH/-1000 V for up to 500 h. We observe that both the one-sun and dark I-V curves remain stable in the case of the mini-module encapsulated with POE, whereas there is a gradual degradation for the mini-modules encapsulated with EVA.

In this work, we also aimed to understand the reasons behind this difference in degradation among the different encapsulants that where tested at the same conditions. The first approach was to measure the volume resistivity of each of the encapsulants, since it is shown to have a big effect on the PID mechanism. Previous studies have demonstrated that the dependence of encapsulants is shown to be highly related to the temperature and humidity of the environment they are in. Consequently, all seven encapsulants were laminated and tested in lab ambient (23°C/50% RH) and in damp heat (85°C/85% RH) conditions (see Fig. 4). We observe that Ionomer, TPO, POE A, POE B and EVA are more or less in the same range of magnitudes in lab ambient conditions. The results prove that the resistivity decreases when both the temperature and relative humidity increase, especially for EVA. However, even in damp heat, the resistivity of EVA is similar to some POEs, but the mini-modules with POEs do not degrade under any condition, unlike the ones with EVA. This means that the volume resistivity is not the sole reason of these different degradation rates. One possible explanation could be the water diffusion through the encapsulant, which is known to be slower for ionomer and POEs. Further experiments are being peformed to prove this supposition.

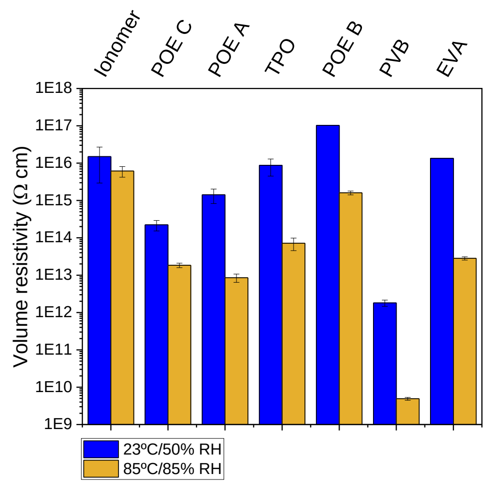

Figure 4. Volume resistivity values measured for all the seven encapsulants (after the lamination process) at two different environmental conditions: lab environment (23°C/50% RH) in blue and damp heat (85°C/85% RH) in yellow. All values are averages of five different samples.

4 CONCLUSIONS

In another contribution to this conference (4BO12.2) we demonstrate that the occurrence of PID can be suppressed using the G/G modules with edge sealant, even with a low volume resistivity encapsulant, such as EVA. Here, our extended PID tests showed that this degradation can be prevented by using an appropriate encapsulant material and module configuration design. We observed that the mini-modules encapsulated with ionomer, POEs and TPO do not suffer from PID, even after an extended test of 500 h (i.e. five times the test duration of 96 h foreseen in the IEC TS 62804-1), regardless of the module configuration and voltage polarization. The situation is a bit different regarding the other two encapsulants, EVA and PVB.

Further tests are necessary to confirm these results and understand the origin of the degradation. The results from EVA demonstrate that degradation can be prevented by encapsulating the cells in a G/G-ES scheme, even after 500 h of PID test. For the samples laminated with PVB, mini-modules with a G/G-ES structure exhibit degradation too;

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