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The influence of laminate design on cell degradation

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Abstract

In this study, the influence of the PV laminate design on the silicon cell degradation was investigated. Laminates consisting of two different kinds of encapsulation (EVA and PVB) and three different back-sheet materials (TAPT, PA and a TPT foils) were manufactured. Standard cells with a two and three bus bar design were used as well as MWT cells. The laminates were subjected to a UV, heat and damp-heat aging tests. The degradation of the cell metallization was investigated by means of electroluminescence imaging, the degree of polymeric aging was determined by Raman spectroscopy. Special attention was paid to the spatial distribution of corrosion effects on the cell. A severe influence of the solar cell type, i.e. the metallization paste, could be shown. Furthermore, a strong dependence of the degree of metallization degradation on the type of back-sheet material was found. An extensive UV aging for up to 180 kWh appeared to have no influence on the metallization corrosion.

Keywords: degradatiopn; metallization; damp-heat; electroluminescence

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1. Motivation

The influence of the permeation of atmospheric gases on the metallization corrosion has not been fully understood yet. Depending on the relative position of the polymer to the cell, degradation can be accelerated or reversed. An inhomogeneous aging is induced by water vapor and oxygen diffusion processes. The ingress of such gases is governed by the permeation properties of the polymeric back-sheets or encapsulation materials as well as by the ambient climate because of the strong temperature dependence of diffusion processes as described by Fick’s law. Some materials, like PA back-sheet foils, exhibit a very strong temperature-dependence of the WVTR compared to TPT foils [5].

After the damp-heat test, a shaded outer area of each cell in the electroluminescence images (fig.1) is a frequently observed phenomenon. This damp-heat-induced-degradation effect (DHID) is typically accompanied by serious losses in module performance. But the root cause of this effect is not yet investigated. Possible causes for the DHID are a degradation of the cell, i.e. the SiN_x coating, due to water

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vapor ingress and resulting degradation reactions, or the corrosion of the Ag grid. The Ag grid is usually applied by screen printing of an Ag paste. The applied paste contains Ag particles of an average size of 1 μm (80-90%), glass frits (0-5%) an organic solvent (3-15%), a cellulose resin (3-15%) and inorganic additives and surfactants (1-2%) [6, 7]. The most common additives are oxides of Pb, Bi, Zn, Sn, B, Al, Mn, Th, Gd and Ni which are supposed to lower the temperature and minimize the shrinkage mismatch with the dielectric during the co-firing process and increase mechanical strength. The glass frits help dissolving the AR layer since SiN_x:H does not react with Ag [7].

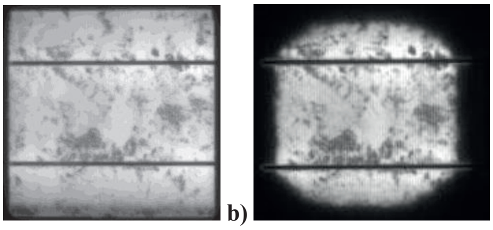


Fig.1. Electroluminescence picture of one laminated cell before (a) and after 2500 h of damp heat (b) aging showing a shaded, inactive outer cell area and a light, active center

The interaction between the cell, including the grid material and the solder bonds, humidity and EVA at high temperatures was investigated. EVA aging may accelerate metallization corrosion in different ways. As a degradation by-product, acetic acid is released [8] which may lead to a corrosion of the solder bonds, visible as green Cu acetate patterns. Furthermore, delamination of EVA from the cell facilitates water ingress and therefore grid corrosion. The polymeric aging was investigated by Raman Spectroscopy.

The influence of altered diffusion pathways around the solder bonds was probed by different laminate set-ups with a double EVA layer in front of the cell, double solder bonds on top of each other and a general set-up of one to three solder bonds per cell.

Nomenclature

DH	Damp-heat
DHID	Damp-heat induced degradation
EL	Electroluminescence
EVA	Ethylene vinyl acetate
IQE	Internal quantum efficiency
MWT	Metal wrap through
PVB	Polyvinyl butyral
TAPT	Tedlar® – Aluminum - Polyethylene terephthalate – Tedlar®
TPT	Tedlar® – Polyethylene terephthalate – Tedlar®
WVTR	Water vapour transmission rate

2. Materials and methods

2.1. Laminate designs

Laminates were made from low iron solar glass with STR 15420 P/UF EVA as encapsulation material and a TPT back-sheet. Lamination was performed in a Meier vacuum laminator at 150°C for 10 minutes. A polycrystalline Si-solar cell with Cu-Sn-Pb tabbing and an Ag-based grid were incorporated. Cells with two bus bars were supplied by manufacturer 1 and three bus bar cells by manufacturer 2. An overview of the different laminate set-ups is given in tab.2. At each bus bar of laminates #52, #53 and #52, two solder bonds were soldered on top of each other. Laminates #57 - #58 and #87 - #88 were manufactured with two layers of EVA in front of the cell. On laminates #92, #93 and #97, only one of the three bus bars was soldered. Altered back-sheets were used for laminates #32, #33, #34 ("TAPT") and #42, #43, #44 ("PA").

2.2. Aging tests

Samples of each laminate type were aged in a Horstmann climatic cabinet (HS 200K 46L) under conditions similar to the standard damp heat test (IEC61215) at 80°C and 90°C with 80% r.h., respectively, up to 2500 h (tab.1).

Table 1. Accelerated aging test conditions

Aging test	Abbreviation	Aging conditions
No aging	ref	-
UV	UV	60°C, <5% r.h., 180 kWh
Heat	H90	90°C, <5% r.h., 1500 h
Damp heat – 80°C	DH80	80°C, 85% r.h., 2000 h
Damp heat – 90°C	DH90	90°C, 85% r.h., 2000 h

2.3. Analytics

In order to investigate the degree and spatial distribution of cell and metallization degradation, electroluminescence imaging (EL) was carried out with a Greateyes GE 1024 256 NIR. The voltage was adapted for each laminate in order to induce a current of 7 A.

Raman Spectroscopic measurements were carried out with a WiTec Alpha 500 Raman Microscope with a remote Raman probe attachment to gain information about the extent of polymeric degradation. The 532 nm line of a frequency doubled Nd:YAG laser with an excitation power of 16,6 mW was used as excitation source. All spectra were normalization on the EVA CH stretching vibration at 2832 cm^{-1}.

3. Results

3.1. Electroluminescence imaging

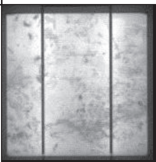
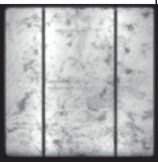
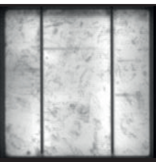
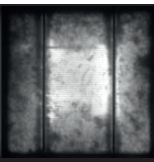
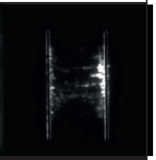
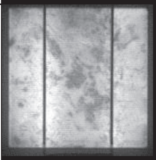
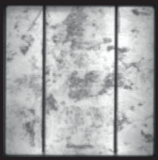
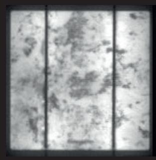
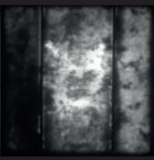
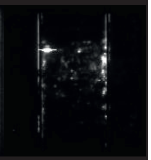
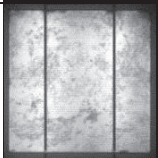
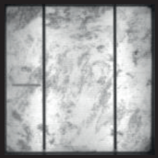
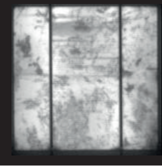
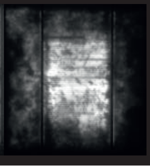
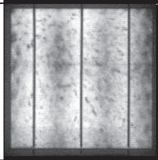
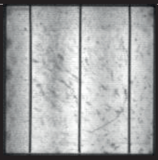
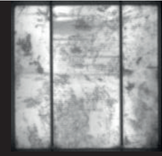
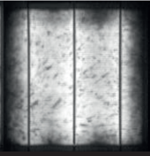
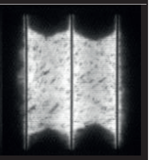
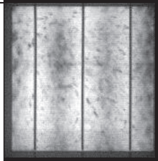
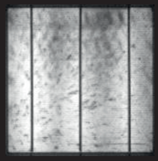
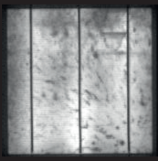
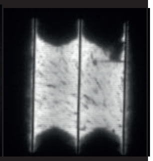
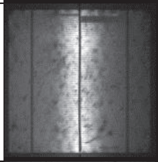
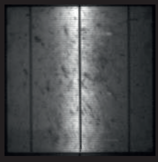
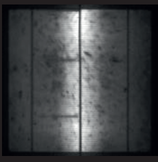
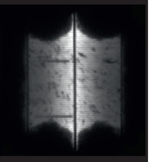
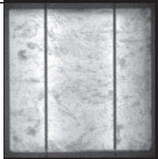
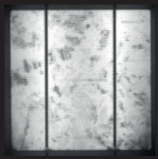
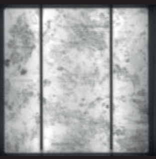
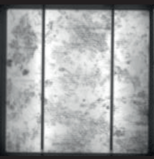
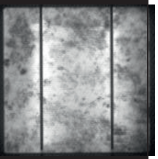
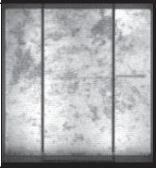
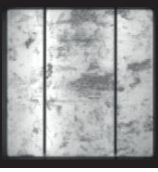
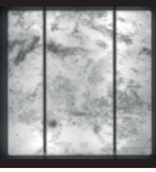
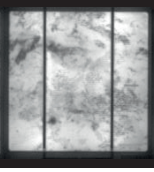
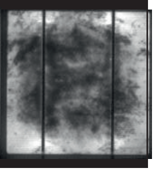
Tab. 2 shows the sample set-ups and the EL images after 180 kWh of UV aging, 1500 h of heat aging at 90°C and after 1500 h, 2000 h and 2500 h of DH90. In case of UV and heat aging, no degradation could be observed at any laminate. The reference sample #12, built comparable to commercial PV modules, which was assigned to DH90, showed the typical failure mode of the damp-heat test (DHID) after 2000 h of testing and exhibited an almost full area degradation after 2500 h, due to the acceleration by temperature.

Earlier results, indicating a degradation starting from the edge of the cell, raised the question whether the cross section between the solder bond and glass might have an influence on the DHID. Therefore, samples #51 and #52 were manufactured with two solder bonds on top of each other. In case of an existing influence of the geometry, for #51 and #52 the degradation should be slowed down compared to samples #11 and #12 due to the reduced cross section between solder bond and glass. Since the two layers of EVA in front of the cell form a larger cross section in samples #56 and #57, the opposite was expected to happen in these samples. As Tab. 2 shows, no influence of the sample set-up was observed for samples #12, #52 and #57. Due to no significant differences in the EL results, sample #57 was taken out of the test after 2000h DH90 and assigned to an EDX measurement (see 3.3).

Additional laminates had three bus bars in order to find out whether there is a different blocking effect by an altered distance between the solder bonds. The EL images showed a blocking of the shading at the solder bonds. But again, the size of the cross section had no influence. The difference between the set-ups of sample # 82, #87 and #92 is that #82 has one solder bond per bus bar, #87 is built with two layers of EVA and again one solder bond per bus bar and #97 has only one solder bond on the bus bar in the middle of the cell. But despite these different sample set-ups, the degradation appeared to be identical for each sample. Therefore, no influence of the geometry on the degradation and no barrier effect inhibiting vapor diffusion could be found. Rather than the sample geometry, the specific cell type and thus the pastes and processes showed a significant influence on DHID. All laminates with a two-solder-bond set-up as well as all three-solder-bond laminates showed a similar extend of degradation, respectively.

Besides geometry variation, the back-sheet materials were varied. Laminate #32 with the low permeation back-sheet TAPT showed only slight signs of the DHID after the 2500 h of DH90. Sample #42 with a PA back-sheet showed a different appearance of the DHID, this sample degraded from the middle of the cell.

Table.2. Electroluminescence images of selected laminate types after UV, heat and d.h. exposure.

Nº	***Laminate Set up***	**UV**	**H90**	**DH90**		
		180 kWh	***1500 h***	***1500 h***	***2000 h***	***2500 h***
#14 #13 #12	Glass | EVA | 2 SB cell | EVA | TPT 					
#54 #53 #52	Glass | EVA | 2 SB^2 cell | EVA | TPT 					
#59 #58 #57	Glass | 2x EVA | 2 SB cell | EVA | TPT 					used for EDX
#84 #83 #82	Glass | EVA | 3 SB cell | EVA | TPT 					
#89 #88 #87	Glass | 2xEVA | 3 SB cell | EVA |TPT 					
#94 #93 #92	Glass | EVA | 1 SB cell | EVA | TPT 					
#34 #33 #32	Glass | EVA | 2 SB cell | EVA | TAPT 					
#44 #43 #42	Glass | EVA | 2 SB cell | EVA | PA 					

3.2. IQE measurements

The degradation of the anti-reflection coating of the cells has been suspected to be the cause for the DHID, the internal quantum efficiency (IQE) shown in figure 2 disproved this assumption. The IQE of the un-aged and DH-exposed samples showed no variation, demonstrating intact AR-coatings.

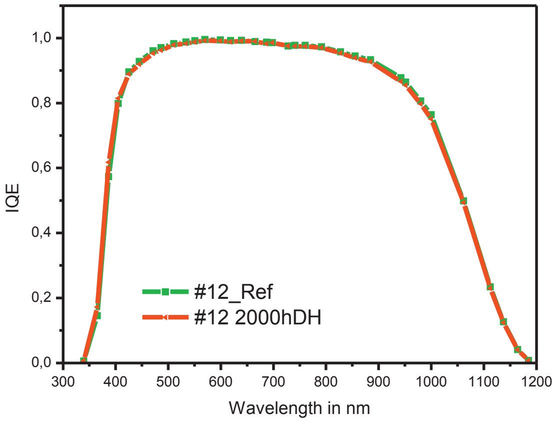


Fig. 2. Internal quantum efficiency (IQE) of laminate with TPT back-sheet and low iron solar glass.

3.3. Raman spectroscopy

Figure 3 shows the Raman spectroscopic measurements of the UV-exposed and the damp-heat aged laminates with a standard material composition, measured across the whole cell. In contrary to the EL measurements, these results suggest a chemical degradation of the UV-aged laminate, which is reflected in the fluorescence intensity. Therefore, the polymer degradation is in this case not correlated to the metallisation degradation, as in the DH-exposed laminates. The spectra at the outer edges of the cell showed less fluorescence than in the center of the cell, suggesting diffusion induced bleaching reactions.

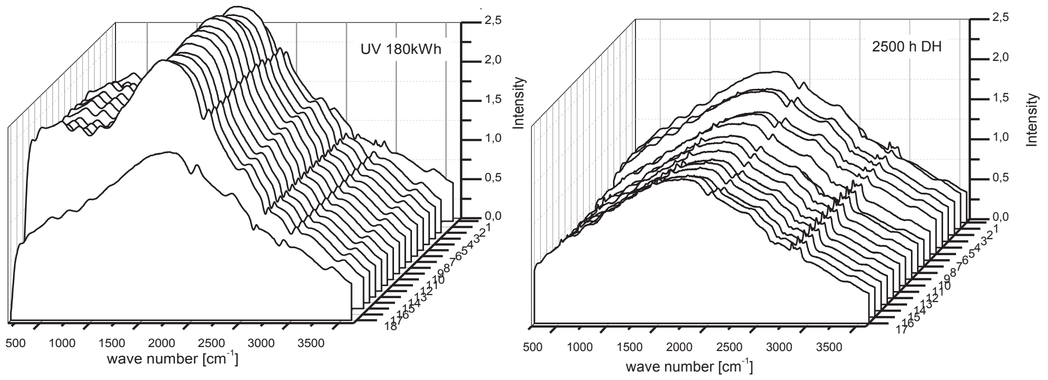


Fig. 3. Internal quantum efficiency (IQE) of laminate with TPT back-sheet and low iron solar glass

4. Conclusion

It was found that the laminate design in terms of the composition of different materials has a high impact on cell degradation. The different back-sheets as well as the metallization paste materials revealed a strong influence on the degradation effects, which is described in detail in [2]. The laminate design, i.e. the laminate construction (number and height of bus bars etc.), showed no significant impact on cell degradation.

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