The role of EVA encapsulation in the degradation of wafer based PV modules

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Abstract

This paper investigates the effects of ethylene vinyl acetate (EVA) encapsulation on PV module ageing and how crosslinking degree of encapsulation influences module durability under damp-heat (DH) and thermal cycle (TC) stresses. Results show that the high crosslinking samples favoured TC stresses, while the low crosslinking samples performed better under DH stresses. The primary mechanism of DH-induced degradation is series resistance (R_S) increase and parallel resistance (R_P) decrease due to moisture ingress and grid/contact corrosion. Comparison analysis of the result indicates that the lower cross-linked EVA appeared to be able to accommodate a smaller amount of the generated acetic acid and thus resulted in a lower corrosion rate. The primary effect of TC is to impose thermal expansion/compression on device. The EVA with lower crosslinking degree is less compact and the freedom of motion of EVA macromolecules is higher, which appeared to be less resistant to the effect of expansion/compression.

Introduction

PV modules rely on packaging materials to provide them durability/reliability during operation, which plays a significant role in the success of photovoltaics. The encapsulant which encapsulates the solar cells and adheres to the module front/back sheet is the crucial component that needs to ensure good resistance against environmental stresses, low water permeability, good mechanical strength and electrical isolation. Typical wafer based PV module uses EVA as the encapsulant material due to its high quality to cost ratio. EVA is a copolymer of ethylene and vinyl acetate (VA) with VA groups randomly distributed along the backbone. The most important parameters influencing the properties of EVA are the content of the VA groups. With increasing VA content, the crystallinity, melting point and stiffness decreases while the transparency and softness increases. Another important issue is that the virgin type of EVA is not stable and different kinds of additives are needed to ensure stability. Lots of research has been carried out on investigating the degradation properties of different types of EVA at the material level and how they respond to environments. This work, however, uses the acquired knowledge of EVA properties as a basis and further investigates the effects of EVA encapsulation on module current-voltage degradation during environmental stress tests. The objective is to reveal the role of EVA encapsulation in terms of long-term durability for PV modules.

The IEC standard [1] defines the stress tests which are widely used as an approach to identify manufacturing or material flaws of PV modules though they are not able to provide any information on module lifetime performance or longevity. Typical stress tests for PV modules include the damp-heat (DH) test and thermal cycling (TC) test, which may lead modules to different degradation mechanisms.

The encapsulation process is performed during PV module lamination and several lamination factors, such as curing temperature, evacuation time, dwell time and cooling method, will influence the quality of encapsulation. Crosslinking is one of the useful indicators of encapsulation quality.

In this work, 32 mini-modules fabricated in the laboratory under different lamination conditions were used for DH and TC tests. Electrical degradations over ageing time are analysed in dependence of the sample’s crosslinking degree in order to investigate the role of EVA encapsulation in module power degradation.

Experimental Setup

The PV mini-modules used in this test were laminated in the laboratory at CREST. Its size is 12.5cm by 20cm with a glass /EVA /single solar cell /EVA /backsheet structure. No frames or sealants are used. All the materials are commercially available. The glass front layer is 2.9mm thick float un-tempered glass. Standard 460µm fast cure EVA is used as encapsulant. The backsheet is a tri-layer insulating polymer consisting PET /PET /primer layer. The solar cells are 1.8W multi c-Si cells.

In order to test the effect of EVA of different crosslinking degrees on the durability of module power performance, a total of 32 mini-modules were fabricated under different lamination temperatures at 125ºC, 135ºC, 145ºC and 150ºC with a constant curing time of 10 minutes (8 samples at each temperature and in the following they are referred to as L125, L135, L145 and L150). Various levels of crosslinking degree between 50% and 85% for EVA were achieved in dependence of lamination temperature as shown in Figure 1. EVA samples with lamination temperature lower than 134°C could not be measured accurately using the Soxhlet Extractor method [2] as the remaining EVA could come out of the thimbles. This also means that a gel content of 60% is the threshold for this type of EVA.

The 32 laminated mini-modules were subjected to DH and TC tests as summarised in Table I. The I-V curves were measured at the Standard Testing Condition before and after the tests for ageing analysis. Each condition has 4 samples and good repeatability in ageing was achieved too.

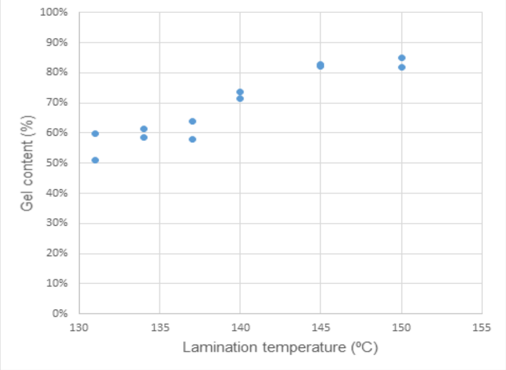


Fig. 1: Gel content of EVA laminated under different temperature.

Table I: Summary of testing samples.

Lamination Temperature (°C)	Gel content (%)	Number of samples	
		DH	TC
125	<60	4	4
135	60-65	4	4
145	82-83	4	4
150	82-85	4	4

Initial performance

Figure 2 plots the initial maximum power (P_{MPP}), short circuit current (I_{SC}), open circuit voltage (V_{OC}) and fill factor (FF) of the 32 tested samples in dependence of lamination temperature. 145°C is the manufacturer's recommended lamination temperature, where the highest averaged

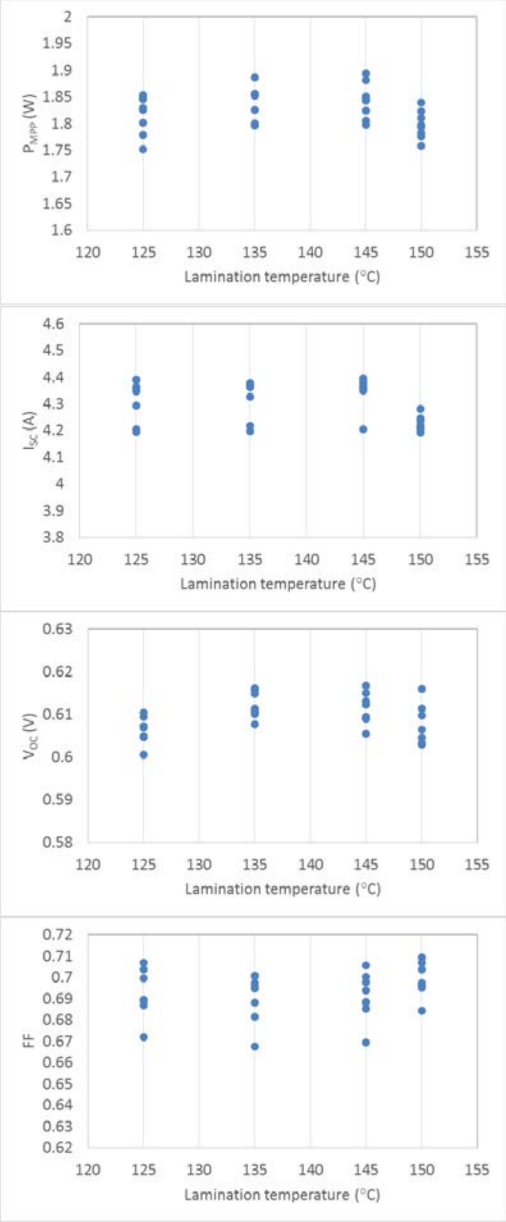


Fig. 2: Initial P_{MPP}, I_{SC}, V_{OC} and FF in dependence of lamination temperature.

P_{MPP} was achieved. Although L150 samples had good encapsulation in terms of high gel content, their P_{MPP} was relatively low due to the losses in I_{SC}. There were minor differences in V_{OC} and FF and the potential reasons causing these differences were not clear yet.

Performance after Degradation

A) P_{MPP}

The 2000 hours DH test and 200 cycles of TC are typically used testing protocols. Figure 3 plots the averaged degradation rate of P_{MPP} for L125, L135, 145 and L150 samples after DH and TC ageing. The L125 samples had the lowest degradation due to DH stresses but the highest degradation due to TC stresses. The mechanism of DH-induced degradation is explained elsewhere [3]. A key accelerator in the process is the EVA degradation by-product acetic acid. According to the result, the amount of generated acetic acid depends on the crosslinking degree of the EVA. The lower cross-linked EVA appeared to result in less generation of acetic acid. The TC-induced degradation is mainly due to the thermal expansion/compression on the device and material vibration. A stronger dependency of power degradation on EVA crosslinking degree is observed. L145 and L150 samples of high gel content had more rigid encapsulation and thus better resistance to thermal vibration.

B) DH-induced degradation

The 2000 hours DH test does not incur enough degradation to discriminate the effect due to different crosslinking degree of EVA. Figure 4 plots the degradation of P_{MPP}, I_{SC}, V_{OC} and FF after 5000 hours of DH test. Clearly, those samples with gel content greater than 60%, i.e. L135, L145 and L150, degraded much faster than the L125 samples which did not have measureable gel content.

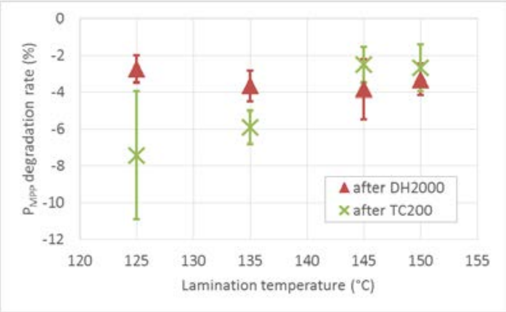
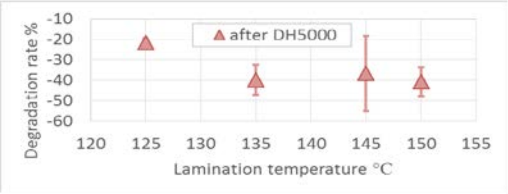
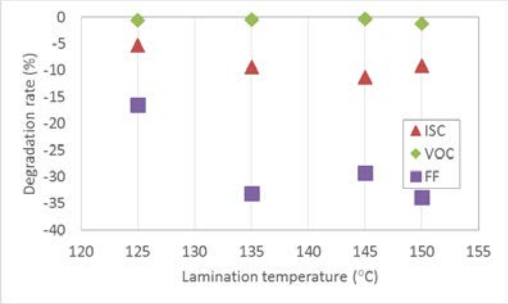


Fig. 3: P_{MPP} degradation after 2000 hours DH and 200 cycles TC tests.

The I_{SC}, V_{OC} and FF degradation result shows that the FF appears to be the primary degradation indicator for DH-induced degradation. This can be further confirmed by the I-V measurements for one L125 and one L150 samples as

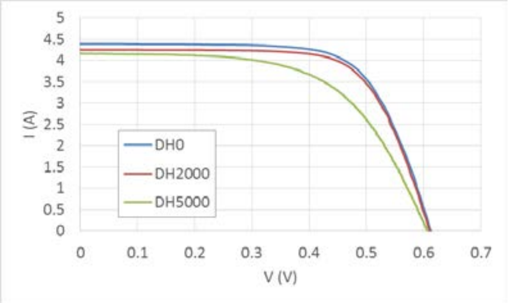


(a): P_{MPP}

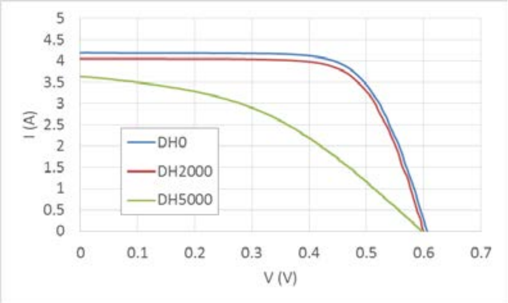


(b): I_{SC}, V_{OC} and FF

Fig. 4: DH induced degradation rate of I_{SC}, V_{OC} and FF after 5000 hours.



(a): L125



(b): L150

Fig. 5: I-V curves of low crosslinking and high crosslinking samples after 0h, and 5000h of DH test 2000h.

shown in Figure 5. It is observed that both the R_S increase and the R_P decrease caused the FF reduction.

C) TC-induced degradation

Figure 6 plots the degradation of I_{SC}, V_{OC} and FF after 700 cycles of TC test. The FF, which is the major degradation driven factor, appears to depend on the crosslinking of EVA. The FF reduction due to TC stresses, however, is a different mechanism compared to FF reduction due to DH stresses. The I-V measurements for one L125 and one L150 samples are plotted in Figure 7. The increase of R_S led to the decrease in FF of L125, while the R_P remained unchanged.

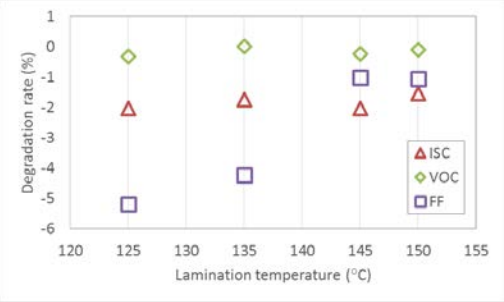
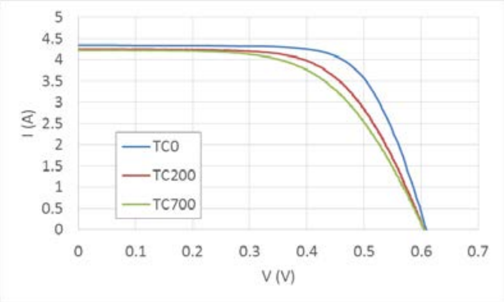
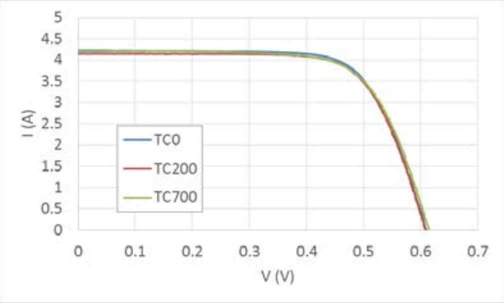


Fig. 6: TC induced degradation rate of I_{SC}, V_{OC} and FF after 200 cycles.



(a): L125



(b): L150

Fig. 7: I-V curves of low crosslinking and high crosslinking samples after 0, 200 and 700 cycles of TC test.

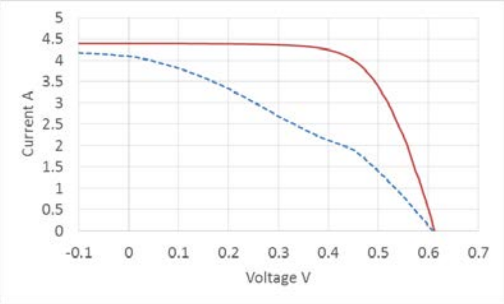


Fig. 8: I-V curves of a sample due to TC-induced degradation.

Another type of degradation was observed for a number of samples under TC stresses as shown in Figure 8. Apart from the R_S increase, the I-V curve is skewed around the maximum power point. This might be due to the micro cracks generated on the solar cells which caused inhomogeneous degradation and shunting. Further investigation is needed to identify the primary causes.

Conclusions

Mini-modules with EVA of various degrees of crosslinking were degraded due to DH and TC stresses. The EVA encapsulation plays a crucial role in degradations of module power performance. Results show that the samples of high cross-linked EVA favoured TC stresses, while the samples of low cross-linked EVA performed better under DH stresses. It is also observed that the level of power degradation depends on the degree of EVA crosslinking.

References

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[2] F. Soxhlet, Die gewichtsanalytische Bestimmung des Milchfettes, *Dingler's Polytechnisches Journal*, 1879, 232, 461-465.

[3] C. Peikea, S. Hoffmanna, P. Hülsmanna, B. Thaidigsmanna, K.A. Weiβa, M. Koehla, P. Bentz, Origin of damp-heat induced cell degradation, *Solar Energy Materials and Solar Cells*, 2013, 116, 49-54.