CORROSION RESISTANCE TEST BASED ON ELECTROCHEMICAL NOISE - LIMITING THE NUMBER OF LONG-LASTING AND COSTLY CLIMATE CHAMBER TESTS

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ABSTRACT: Damp-heat testing of PV modules is a time-consuming process, taking months. The electrochemical noise (EcN) set-up is a fast, direct corrosion measurement of solar cells, whereby results can be obtained within one hour. EcN measurements are presented for several solar cell concepts and different environments. It correlates with damp-heat degradation involving corrosion, which is rather common in EVA-encapsulated crystalline Si modules. Furthermore, the EcN test can be done as an evaluation tool when probing alternative brands, formulations or processing for metallisation pastes and as a screening test for new batches of metallisation paste.
Keywords: climate testing, corrosion, experimental set-up, photovoltaic cells, silicon

1 INTRODUCTION

Acetic acid release by the most commonly applied encapsulant EVA, in combination with heat and humidity, leads to degradation of the metallisation on crystalline Si solar cells, see for an overview [1]. However, damp-heat testing is a time-consuming process as a full IEC cycle requires 1000 hours (6 weeks). We present an alternative, fast method for the corrosion sensitivity of metal/wafer combinations. Whereas the damp-heat experiments take 6 to 15 weeks, EcN measurements can be as short as ten minutes to an hour.

EcN measurements are a standard tool in the metal industry to evaluate the corrosion rates and corrosion resistances of steel and aluminium alloys. The noise consists of potential and/or current fluctuations generated by spontaneous corrosion reactions. The EcN measurement is sensitive to initiation and propagation of corrosion. Although the theoretical basis is not completely developed, the EcN measurements can be related to the corrosion rate. In particular, the electrochemical resistance noise has a good inverse correlation with the corrosion sensitivity. The electrochemical current noise is also rather consistent with the corrosion susceptibility activity and the loss of metal [2].

In standard corrosion experiments, the material surface under investigation is exposed to corrosive agents from the outside, e.g. rain water or corrosive gases. In contrast, in our EcN set-up, the electrolyte can be chosen to simulate the conditions that a solar cell is exposed to inside a module: e.g., an acetic acid solution to mimic degraded EVA.

EcN measurements are presented for several situations. For testing variations in MWT cell technology, we varied both the metallisation pastes used and the area of the overlap region between Ag and Al in dedicated test structures. It was found that the larger the Ag/Al overlap area, the larger the EcN signal is. Also, when we use metallisation pastes that show little degradation in damp-heat testing, the current noise is small and vice versa.

We have also tested the corrosion rate of the front side and back side metallisation of n-type monocrystalline solar cells [3]. The current noise shows a clear bias towards corrosion occurring on the front side.

These measurements can be seen as a filter for combinations of materials (metallisation and encapsulants) that are viable candidates for the long-lasting and costly damp-heat test. These can then be done for material combinations which have proven to be stable in the EcN test.

2 EXPERIMENTAL SET-UP

The set-up exists of two pieces of sample material. These are placed on either side of a tube which is filled with an electrolyte. The two pieces are connected to the electronics unit, recording the potential and the current flow between the samples. The two samples can be placed as a conventional galvanic cell, with a working electrode and a counter electrode. The observed electrochemical current between the two electrodes could give information on the corrosion rate.

Alternatively, for noise measurements, we actually place two identical samples with the same composition towards the electrolyte. In this way, there should be no electrochemical potential or current. However, depending on the combination of samples and environment, corrosion can still occur. Every corrosion event on either of the electrodes will lead to a small, short current peak. The sign of the peak is determined by the reaction and electrode. These current peaks are observed as electrochemical noise.

Historically, this noise on the current and potential data was regarded as a nuisance, but nowadays it is well-known that the noise contains valuable information. The current noise is most sensitive to the corrosion rate. To extract this information, first the DC trend in the current noise is removed. Sometimes the raw current noise data is already enough to determine differences in corrosion resistance. If a qualitative ranking of the electrochemical behaviour is required, the noise data, i.e. the current peaks in the time domain, are transformed to the frequency domain, i.e. the number of times each current peak value occurs.

3 RESULTS

3.1 MWT cells in artificial rain water

Climate chamber tests at 85% humidity and 85ºC are standard tests to qualify the reliability of modules. The IEC criterion is that a module should have no more than

5% power loss after 1000 hours damp-heat exposure. Moreover, module manufacturers expect modules to survive exposure for at least twice as long and still have less than 5% power loss. However, 2000 hours of damp-heat testing takes 12 weeks, without breaks for intermediate measurements. We have fabricated MWT modules with different metallisation pastes A and B. After 500 hours exposure, there is no difference between the two series of modules in power loss. After 1000 hours, that is 6 weeks exposure, modules B fail with 25% and more power loss. In contrast modules with paste A have only 2- 3% power loss after 2500 hours, but this is only apparent after more than 3 months of exposure. We measured the electrochemical noise of these cell types as described above.

Figure 1 shows the current noise of the MWT solar cells, described above, exposed to artificial rain water – a common corrosion promoting agent – in the electrochemical noise set-up. Cell type A shows hardly any noise signal during the 25 minutes of this test. Cell type B shows a more interesting behaviour. Initially there is hardly any noise signal too, up to 2 minutes. Then we see a sudden increase in noise signal with peaks of about 0.3 μA. The much lower noise signal for the first few minutes indicates a low initiation rate for corrosion. However, after 5 minutes the noise increases sharply in intensity, displaying strong peaks of up to 3 μA. This regime continues for about 10 minutes. Then the noise signal fades to the lower values again, but still higher than in cell type A.

We have shown that modules with cell type A show hardly any damp-heat degradation and cell type A shows a very low noise signal. In stark contrast, cell type B shows a much larger noise signal and modules with cell type B fail the 5% power loss criterion after 1000 hours damp-heat exposure. The damp-heat experiments take 6 to 15 weeks, whereas the EcN measurement takes only half an hour.

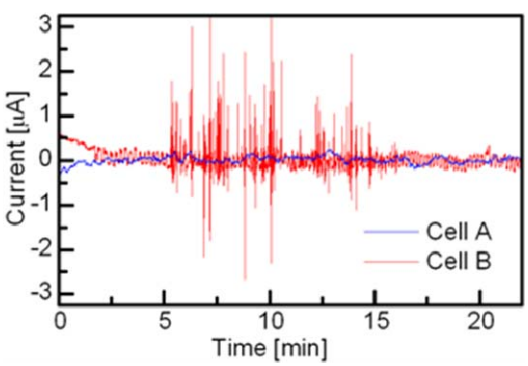

Figure 1: Electrochemical current noise as a function of time for two MWT cells with different base contacts. The DC trends in the current noise signals have been removed

3.2 Silver/aluminium overlap regions

Corrosion can occur when two metals are in contact. This situation occurs, for instance, at the rear side of p-type solar cells, where the Al BSF is contacted with Ag paste for interconnection purposes. In most cases, not only the metal/metal/electrolyte combination determines the corrosion activity but also the geometry. We have fabricated dedicated test structures to test the influence of the metallisation paste formulation (not shown) and of the amount of Ag/Al overlap area. The three samples have been exposed to 0.01 M acetic acid solution to simulate degraded EVA and the electrochemical noise has been recorded for a period of about an hour.

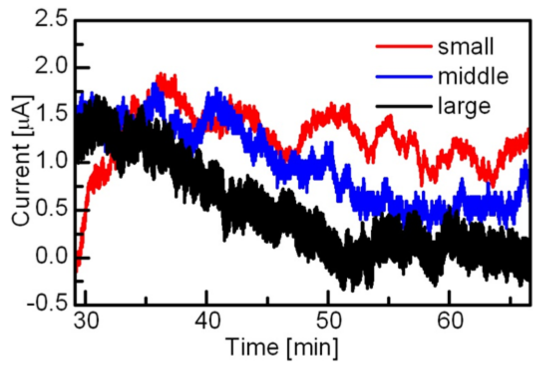

Figure 2: Electrochemical current noise against time for the three Ag/Al overlap samples. The DC trends in the current noise signals have not been removed to be able to see all three curves

Figure 2 shows the current noise transients for the three samples with small, middle and large overlap areas. DC trends in the current signals have not been removed; the electrochemical noise scales with the short timescale current variations. Clearly, the noise level increases with overlap area. The samples have been inspected visually after the EcN measurement. Samples with low noise signal, like the "small overlap" sample shown in Figure 2 (red), appear similar to non-exposed samples. In contrast, the sample with the same metal paste but large overlap area, shown in black in Figure 3, looks strongly degraded with uneven surfaces and blurred edges. This suggests that the larger signal for "large" overlap area is not only due to the larger area but also that the corrosion has advanced further.

3.3 n-type Pasha front and rear side

In n-type H-pattern solar cells, the front side metallisation has to make contact with the p-type emitter through the passivation layer, typically SiNx. The rear side metallisation contacts the n^{++}-BSF surface. To ensure a well conducting contact with the front side, some Al is added to the Ag paste. The back side metallisation has only Ag as metallic component. In a typical module the n-type cells are encapsulated with EVA. It is well known that under damp-heat conditions the EVA can degrade and form acetic acid.

We have placed the front and back side of such a solar cell in contact with an electrolyte, consisting of a 0.01 M acetic acid solution to mimic the corrosive behaviour of degraded EVA. The current data is plotted against time in Figure 3. Initially we observe a current of several μA, indicating a relatively large difference in electrochemical potential. After time, the current falls off to ~200 nA. In the magnified inset, we can clearly observe that the "negative" noise signal is much larger than the noise peaks in the positive direction.

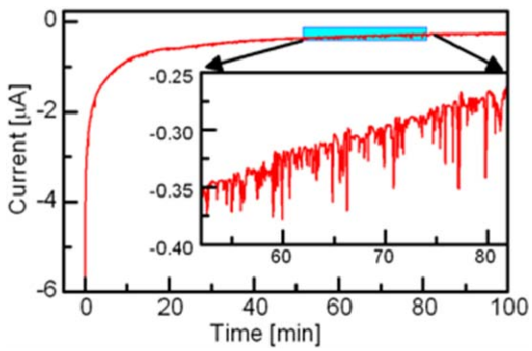

Figure 3: Electrochemical current for a conventional galvanic cell-type measurement of an n-type H pattern wafer. The inset shows a magnification of a part of the noise signal

Figure 4 shows the EcN measurements for the front and back of this solar cell in the "noise signal set-up". Clearly, the back side data shows a much lower noise than the front side, in agreement with the observations in the "galvanic cell set-up". Post-mortem analysis of damp-heat exposed laminates with EVA and these solar cells also show corrosion damage on the front. In contrast, on the rear and in laminates with non-EVA encapsulant no corrosion and also no degradation in fill factor is observed after 2000 hours of damp-heat testing

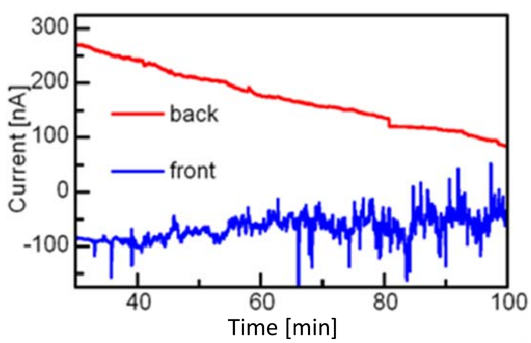

Figure 4: Electrochemical current noise for two front side grids (blue) and two back side grids (red).

In conclusion, the current noise shows a clear bias towards corrosion occurring on the front side. Post-mortem analyses of damp-heat exposed n-type laminates with EVA also show corrosion damage on the front. In contrast, in laminates with non-EVA encapsulant no corrosion and no degradation in fill factor is observed after 2000 hours of damp-heat testing.

4 CONCLUSIONS

We have presented corrosion tests of solar cells using electrochemical noise measurements (EcN). EcN is a fast and direct corrosion measurement technique, whereby results can be obtained within one hour. We have compared modules in damp-heat climate chamber tests and with the EcN method. The EcN corrosion rate correlates with DH-degradation mechanisms involving corrosion, which is rather common in EVA-encapsulated crystalline Si modules. Finally, the EcN test can be done as an evaluation tool when probing alternative brands, formulations or processing for metallisation paste and as a screening test for new batches of metallisation paste

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