

# The Impact of Acetic Acid Corrosion on the Front-side Contacts and the Finger Electrodes of c-Si PV Cells

Nikoleta Kyranaki\*, Jiang Zhu, Thomas R. Betts, Ralph Gottschalg  
Centre for Renewable Energy Systems Technology (CREST), Wolfson School, Loughborough  
University, United Kingdom, \*[N.Kyranaki@lboro.ac.uk](mailto:N.Kyranaki@lboro.ac.uk),  
+44 (0)1509 227161

## Abstract

Damp-heat stresses typically lead to corrosion related degradation for Ethylene-vinyl acetate (EVA) encapsulated PV modules. The degraded module appears as bright areas along the busbars in electroluminescence (EL) images. The most likely mechanism that causes these bright areas is corrosion at the silver contacts and the finger electrodes at the front surface of the cell, due to acetic acid accumulation. In this work, these mechanisms are investigated by immersion of half encapsulated cells into acetic acid solutions with different concentrations. Dark and light I-V curve measurements and electroluminescence images were conducted during the course of ageing to investigate the power degradation. The chemical changes in materials are identified by optical microscopy images and SEM-EDX analysis.

## 1. Introduction

The PV modules that use Ethylene-vinyl acetate (EVA) as a pottant, usually show degradation after Damp-Heat aging (3000-5000 hrs) [1]. This type of degradation is visible in electroluminescence images as dark areas on the margins of the cells, which spread to the centre, and bright areas close to the busbars [2]. The purpose of this work is to analyse the chemical reactions that occur and cause the brightening of the areas close to the busbars and to investigate their influence on the power output of a c-Si PV cell.

## 2. Experimental Setup

The experiment concerns immersion of commercially available c-Si PV cells into acetic acid solutions of three different concentrations (10%, 30% and 50% v/v, two cells for each concentration) at room temperature. The cells

remain in the bath until the contacts and/or the ribbons fully lose their adhesion. A commercial standard flux, and a standard 2-mm-wide Sn-Pb-Cu ribbon are used for the soldering procedure. For the achievement of better mechanical stability and, to avoid the introduction of degradation due to handling stress, the cells are half encapsulated in a glass-EVA-cell structure (Fig. 1). The acidity and the temperature of the solution are monitored by a pH meter and kept at pH 1.7 $\pm$ 0.1, 1.9 $\pm$ 0.1, and 2.5 $\pm$ 0.1, for 50%, 30% and 10% v/v concentration of acetic acid solution, respectively. The temperature of the solutions is 19 $\pm$ 1°C.

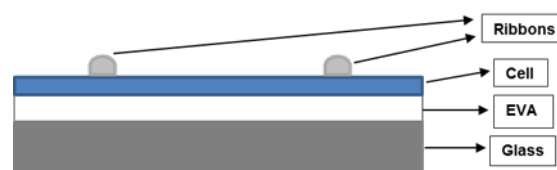


Figure 1 The structure of the half-encapsulated PV cells that are used for the experiment.

## 3. Characterisation Methods

### 3.1. I – V Curve measurements

Dark I-V curve measurements are conducted in-situ by Keithley 2460 every 5 minutes while the cells are immersed in the solution, without introducing handling stress by removing the cells from the solution frequently. Light I-V curve measurements are received every 2 days. Testing samples were removed from box and measured at STC with Pasan IIIb solar (flash) simulator.

### 3.2. Electroluminescence

For the observation of the degradation of the busbars and the ribbons (increased series resistance, shunting), Electroluminescence images are received every 2 days.

### 3.3. Material/Chemical Analysis (SEM-EDX, Optical Microscopy)

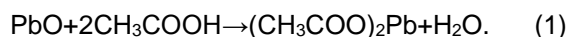
Optical microscopy is used during the experiment for the observation of the alterations on the surface of the busbars, the metallisation and the ribbons, due to acetic acid exposure. SEM-EDX analysis is used at the ribbon/silver front contact and front contact/cell interfaces and at the surfaces separately, for the final material characterisation and the identification of the products that are generated due to reaction of acetic acid with different compounds contained in ribbon and contact materials.

## 4. Theory of Possible Reactions

This section summarises the reactions that are reported in literature and are related to acetic acid corrosion of the ribbons, the metallisation and the contacts of PV cells.

### 4.1. Silver Contact and Metallisation Corrosion

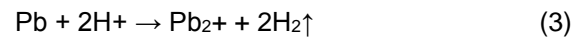
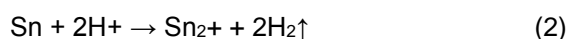
For the construction of the contacts and the metallisation of a PV cell, usually, a silver paste is applied by screen printing. The silver paste contains glass frits. The main material of the glass frits is lead oxide which reacts with acetic acid, following the reaction below:



The product of the reaction above is lead acetate which is highly soluble in water (221 g/100g at 50 °C). The reaction of lead oxide with acetic acid seems to be accelerated under electric field [3]. The dissolution of the glass frit gradually degrades the adhesion between the silver contacts or the metallisation and the solar cell, leading to an increased series resistance ( $R_s$ ) and a decreased short circuit current ( $I_{sc}$ ) [4].

### 4.2. Ribbon Corrosion

The solder of the ribbons that are attached on the silver contacts of a solar cell, usually contains  $\text{Sn}_{37}\text{Pb}$ . The Sn and the Pb possibly react with acetic acid according to the following reaction:

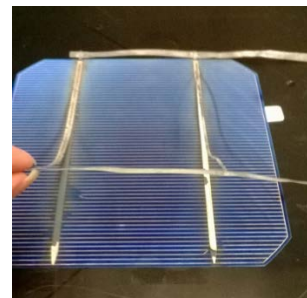


As Sn and Pb dissolves, a gap is generated and extended between Ag and  $\text{Sn}_{37}\text{Pb}$ , resulting in separation of the Ag contact from the ribbon [5].

## 5. Results-Discussion

### 5.1. Visual Inspection

Figure 2 represents a PV cell after acetic acid exposure. Delamination at both interfaces of solar cell/silver contact and silver contact/ribbon is shown to occur.



*Figure 2 Loss of adhesion of ribbon/silver contact and silver contact/cell interfaces because of acetic acid exposure*

### 5.2. Light I-V and Dark I-V Curves

Figure 3 and figure 4 demonstrate the variation of the performance parameters extracted from the light I-V curves and the dark I-V curves of solar cells immersed into acetic acid solutions with concentrations 50%, 30% and 10% v/v.  $V_{oc}$  stays unchanged for all samples. Power degradation is mainly due to FF and  $I_{sc}$  losses, except for samples in 10% concentration of acetic acid solution, the FF did not degrade. More specifically, the degradation of  $P_{max}$  for 50% and 30% of acetic acid solution is 6-7.5%, and for 10% of acetic solution, the degradation of  $P_{max}$  is 4% and mainly driven by  $I_{sc}$  degradation. By comparing the results from the light and dark I-V curves of the PV cells immersed in different concentration of acetic acid solution, it is summarised that the cells immersed in 50% and 30% v/v of acetic acid show similar degradation. The cell that is immersed in 10% v/v concentration of acetic acid solution appears to degrade slower than the other cells. On the dark I-V curves, the change of the inclination of the curves close to  $V_{oc}$  for 50% and 30% of acetic acid solution

indicates an increase of  $R_s$ , but the inclination for 10% of acetic acid doesn't change, indicating that the  $R_s$  remains constant.

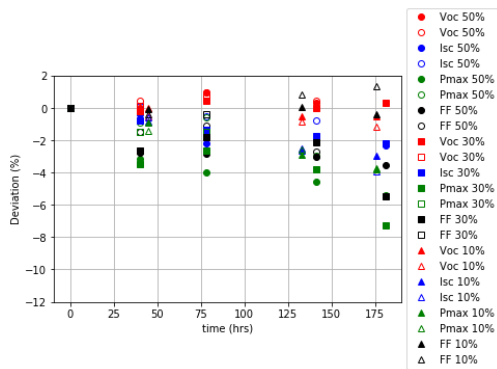


Figure 3 Variation of the diode parameters extracted from the light I-V curves of solar cells immersed into acetic acid solutions with concentrations 50%, 30% and 10% v/v.

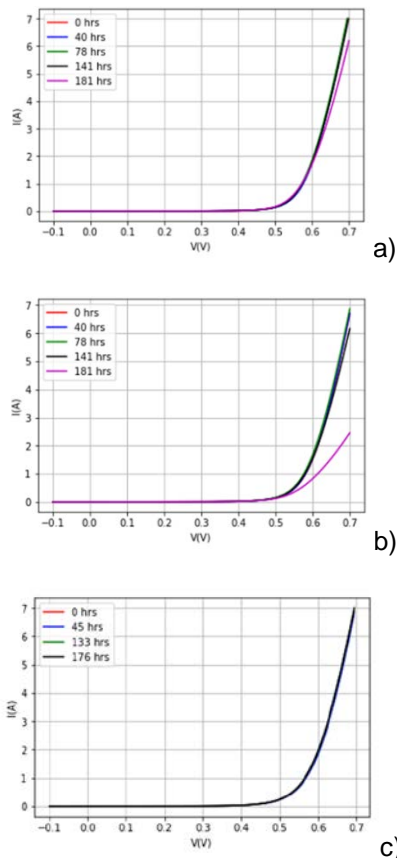


Figure 4 Dark I-V curves of solar cells immersed into acetic acid solutions with concentrations a) 50%, b) 30% and c) 10% v/v.

### 5.3. Electroluminescence

In Figure 5 EL images of an unaged and an aged PV cell are shown. The bright patterns

close to the busbars of the aged PV cell are likely due to an increased series resistance [2].

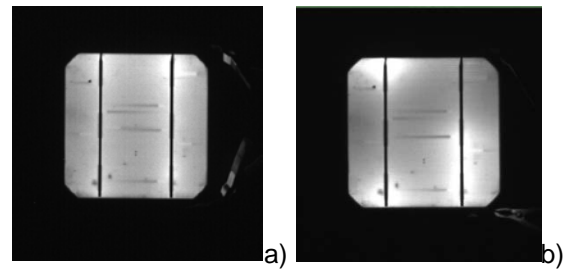


Figure 5 EL images of a) an unaged and b) an aged PV cell.

### 5.4. Optical Microscopy

Figure 6 represent the variation of the optical microscopy images of the silver contact of a PV cell immersed into acetic acid solution of 50% concentration for 0 and 181 hours. As the PV cells are immersed in the acetic acid solution the migration of particles from the silver contacts to the cells is visible. In addition, the ribbons appear darker. In Figures 7 a and b the optical microscopy images of an unaged PV cell and the same PV cell immersed into acetic acid solution of concentration 10% v/v for 133 hours are shown. By comparing the pictures for both concentrations, for the cell that is immersed in acetic acid solution of concentration 10% v/v, the migration of the particles from the silver contact is observed to be more limited.

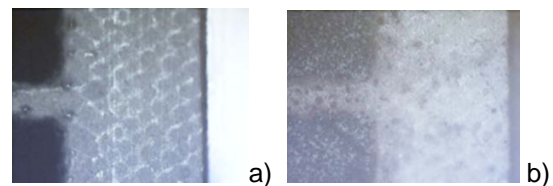


Figure 6 Optical microscopy images of the silver contact of a PV cell immersed into acetic acid solution of 50% concentration for a) 0 and b) 181 hours.

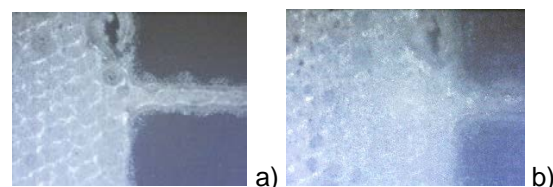


Figure 7 Optical microscopy images of the silver contact of a PV cell immersed into acetic acid solution of 10% concentration for a) 0 and b) 176 hours.

## 5.4. SEM-EDX Analysis

In Figure 8 the SEM image and the EDX analysis of the metallisation and the surface of an aged silicon solar cell are represented. On the metallisation, the Sn is detected that is suspected to have migrated from the ribbons. On the surface of the silicon solar cell Pb is present, which is possible to have been dissolved from the ribbons and the silver contacts.

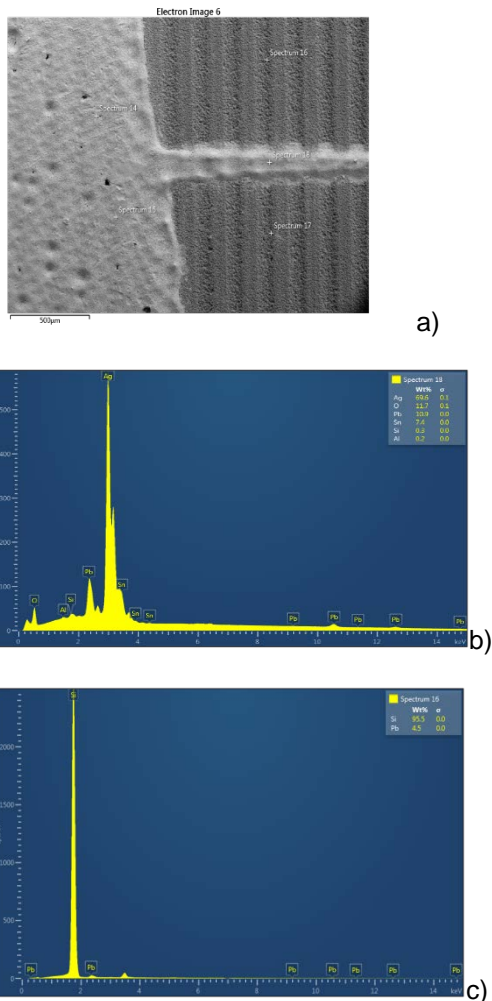


Figure 8 a) SEM image and EDX analysis of b) the metallisation and c) the surface of an aged silicon solar cell

## 6. Conclusions

This work aims to understand and quantify the impact of acetic acid corrosion of the front-side contacts and fingers electrodes of c-Si solar cells. The first steps of work towards this aim are presented in this paper. The experiment includes immersion of half encapsulated c-Si

PV cells into acetic acid solutions of concentrations 50%, 30% and 10% v/v at room temperature. From the dark and light I-V curve measurements it is concluded that the cells immersed in 50% and 30% v/v of acetic acid show a similar FF,  $P_{max}$  and  $I_{sc}$  deviation, as their pH are similar, and the cell immersed in 10% v/v of acetic acid shows a smaller FF and  $P_{max}$  deviation. From the optical microscopy images it is confirmed that a bigger concentration of acetic acid increases the dissolution of the particles that are contained in the silver paste of the silver contact. SEM-EDX analysis of an aged PV cell indicates the dissolution of Pb and Sn from the silver contacts and the ribbons, reactions that are proposed in theory. More chemical analysis needs to be done for the verification of the reactions that occur.

## 7. Acknowledgements

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## 8. References

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