Application of Electroluminescence and Thermal Imaging in Defect Identification in Photovoltaic Modules

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Abstract.
In order for solar energy to become an alternative to traditional fossil fuel energy it is important that defects in photovoltaic (PV) modules can be easily identified. Typically a module is characterised by measuring the current-voltage (I-V) characteristics under standard test conditions. In addition to this, electroluminescence (EL) can be used to indentify defects in the module. A cooled Si CCD camera is used to detect the EL signal. Infrared imaging can be used to identify irregular heating patterns which are indicative of defective cells or contacts. In this study both techniques were used in conjunction to assess the defects present in an Edge-defined film-fed (EFG) silicon module and a single crystalline silicon module. Both modules had visible signs of degradation. These techniques identified several defects in the modules. Cells which have cracks due to mechanical damage were quickly identified. The cracked areas appeared dark in the EL image due to the lack of electrical contact to these areas. The damaged cells are visible as a hot spot in the infrared image indicating that these cells are low current producing cells.

1. Introduction

Solar energy is an alternative energy source that has great potential to solve the energy problems in South Africa. However, defects present in photovoltaic (PV) modules can greatly reduce the performance of the module. Characterisation techniques such as current-voltage curves provide information about the short circuit current (Isc), open circuit voltage (Voc) and maximum power (Pmax). However, one is unable to identify the cause of reduced performance from I-V curves. Electroluminescence (EL) is a non-destructive characterisation technique that can evaluate the extent of the degradation while also identifying damaged areas which are not optically visible.

When a silicon solar cell is forward biased carriers are generated in the junction, when these carriers recombine energy is emitted in the form of electroluminescence. The intensity of the EL is proportional to the recombination rate and the minority carrier lifetime and diffusion length. [1] The minority carrier lifetime is the measure of how long a carrier exists before recombination occurs. The minority carrier diffusion length is a measure of how far the carrier can move before it recombines. [2] Both depend on the type and magnitude of recombine processes and relate to the collection efficiency of the cell material. Defects in the cell material that result in a decrease in the recombination rate or collection efficiency can be identified in the EL image. The EL signal intensity is detected using a cooled CCD camera which provides a greyscale spatial representation of defects in the cell.

Thermal imaging is used in conjunction to differentiate between intrinsic material defects such as grain boundaries and extrinsic defects such as manufacturing faults, broken contact fingers or cracks. Variations in the module temperature (hot-spots) indicate poorly performing cells. A hot-spot occurs when that cell is performing worse than the other cells in the series string. It becomes reverse biased and starts to dissipate power and heat up.

2. Experimental

In this study two modules with different visible degradation were examined. The Edge-defined film-fed (EFG) module has 36 cells connected in series. The module is configured with two strings of 18 cells. There is visible delamination around the edges of the module. Previous studies on this module have shown that the encapsulant delaminated and moisture ingress has occurred. [3] The Single crystalline silicon module consists of 44 cells connected in series. The module is configured into two strings of 18 cells. The module is visibly damaged over the majority of the cells. These white speckled variations in the cells may be attributed to degradation in the cell material or the anti-reflective coating.

Electroluminescence was used to non-destructively evaluate the extent of the degradation in these two modules. The modules under investigation were forward biased to a current greater than the short circuit current of the module. The emitted luminescence of a silicon sample has a peak at about 1150 nm and a portion of this peak can be detected by the coolSamBa HR-830 Si CCD camera which has a range of 300-1000 nm. [1] The CCD camera is cooled to -50 °C and has a resolution of 3300 x 2500 pixels. The data acquisition time is in the range of 1.5 to 2.5 seconds. The experimental set-up is illustrated in figure 1. The DC power supply forward biases the module by 30 V and 5 A. In order for the electroluminescence to be detected the setup must be placed in a dark room as any other light source will affect the results. The CCD camera is connected to the computer where the Sensovation image processing software, which is supplied with the camera, is used to capture and analyse the images.

An Infrared (IR) camera was used in conjunction with EL images to detect hot spots in the module. The IR camera can measure temperature in a range from 0 to 280°C with approximately 2° uncertainty.

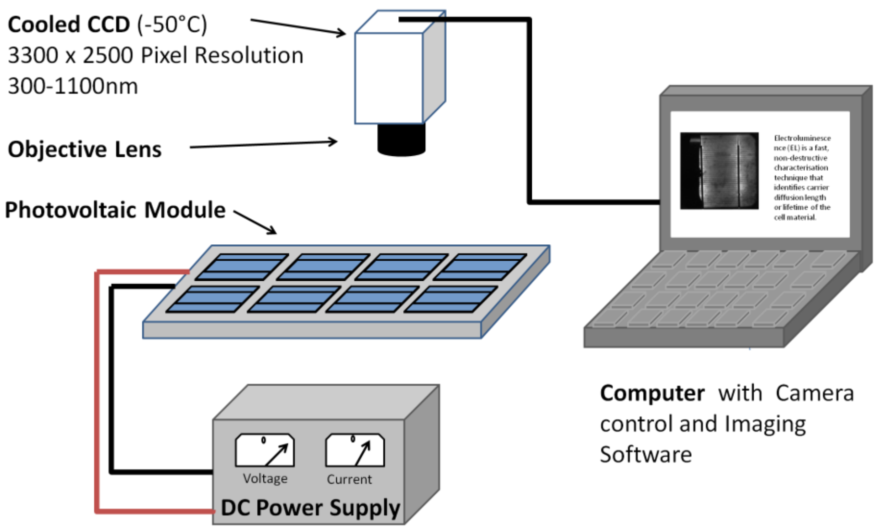

Figure 1. Schematic outline of EL experimental setup.

3. Results and Discussion

3.1. EFG Module.

The EFG module has delaminated allowing air and moisture to infiltrate between the encapsulant around the sides of the module. Figure 2(a) shows the optical image of the EFG module with cells C5 and C9 indicated. Figure 2(b) and 2(c) show the EL images of the C5 and C9 respectively.

Despite there being no optically visible damage to cell C5, the EL image shows that the cell has cracked. This crack decreases the electrical contact to a portion of the cell and thus lowers the intensity of the EL signal. The nature of the EFG growth process results in non-parallel variations in the cell material which are visible in the EL image. The eight back contacts that are present in each EFG cell are visible are areas of lower EL signal intensity. This is due to the high collection efficiency in these areas due to the back contact.

Cell C9 is severely affected by delamination which has spread along the busbar and affects about half of the cell. The EL image shows very low signal intensity over the areas of the cell affected by delamination meaning that the exposure to moisture has degraded the cell material and what little luminescence that is produced is blocked by the encapsulant discolouration.

Figure 3 shows the infrared image of the bottom-right corner of the EFG module under short circuit conditions. A hot spot is visible over cell C9. This suggests that cell C9 is a poor current producing cell. This supports what is seen in the optical and EL images.

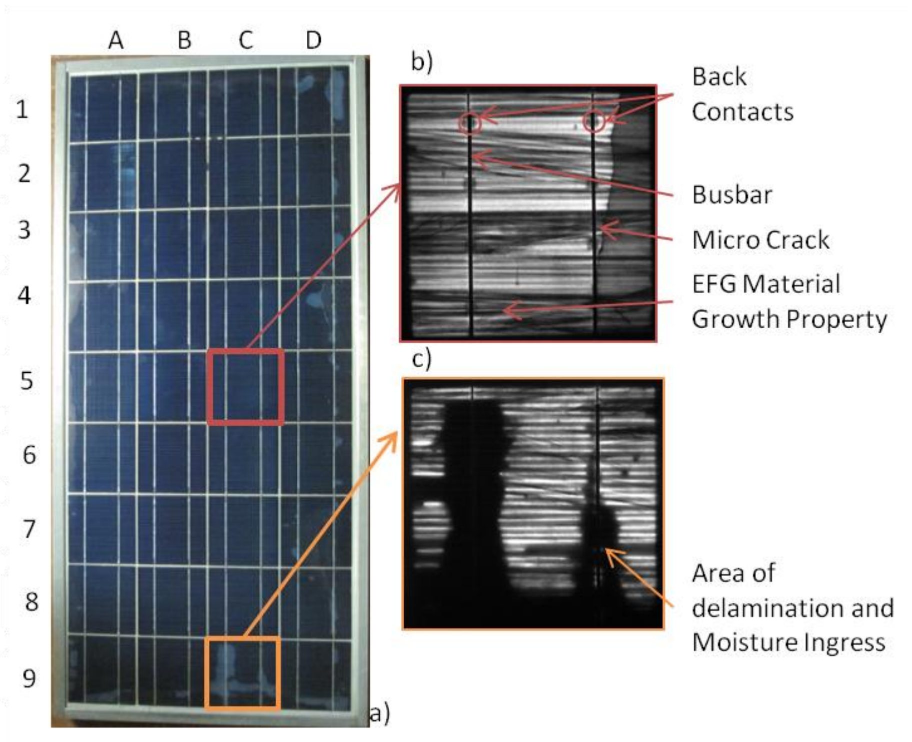

Figure 2. (a) Optical image of EFG module with cells indicated. (b) EL image of cell C5 with defects highlighted, (c) EL image of cell C9 showing the effect of delamination.

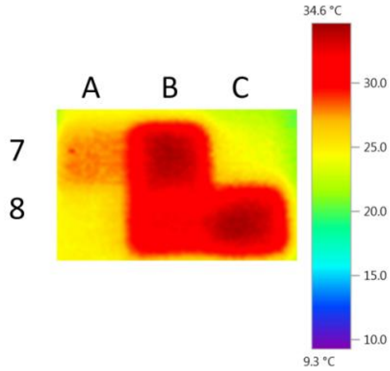

Figure 3. Infrared image of a portion of the EFG module.

3.2. Single Crystalline Module

Figure 4(a) shows an optical of the single crystalline module with the damaged cells highlighted. The infrared image of the single crystalline silicon module under illumination and in short circuit connection is shown in figure 4(a). The EL image of the damaged cells is shown in figure 4(b). The hot-spot indicates poorly performing cells which are reverse biased and heat up. The cells identified as poorly performing cells are A7, B7, B8 and C8. The El images of these cells indicate that they appear to have cracked. Figure 5(a) shows an optical image of these cells with defects highlighted. Figure 5(b) shows scratches on the back of the module. Figure 5(c) shows a magnified image of damage on cell C8. Scratches on the back of the module correspond with features observed in the EL image. These cracks most likely occurred due to some mechanical damage. Scratches on the back of the module suggest that the module might have been dropped or hit with some force. The cracks remove portions of the cell from electrical contact and thus the carriers are not injected into this region and thus no luminescence occurs in these areas. These four damaged cells probably contribute greatly to the decreased performance of the module but would not have been easily detected without using EL.

The silver grey discolouration present in this module is most likely due to degradation in the silver nitride anti-reflective coating. The areas of discolouration have a varying effect on the EL signal intensity. Degradation in the anti-reflective coating may not affect the performance of the cell material in that area but rather block the luminescence so that it is not detected from that area. The areas affected by the reflective coating degradation thus affect the photoresponse of the cell material.

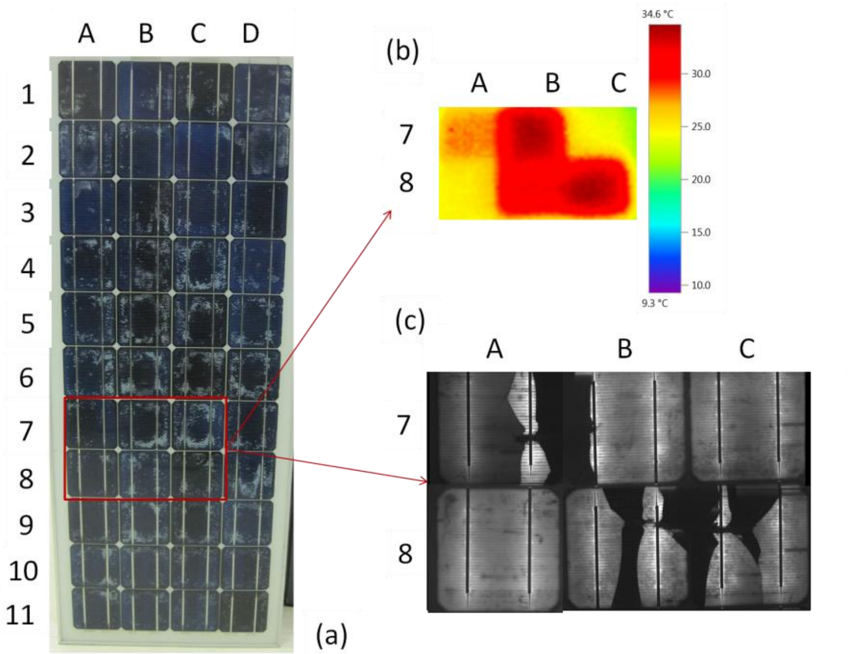

Figure 4. (a) Optical image of the single crystalline silicon module with damaged cells highlighted. (b) Thermal image of portion of module under illuminated, short-circuited conditions. (c) EL image of damaged portion of module

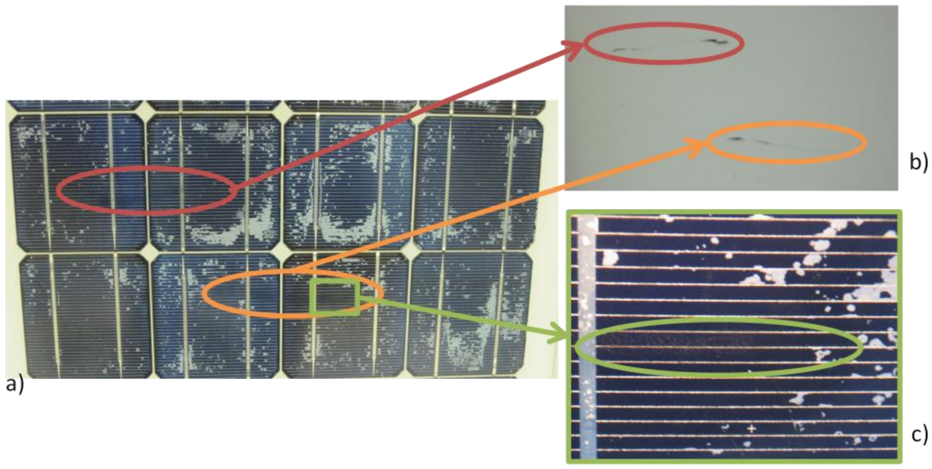

Figure 5. a)Optical image of damaged cells with defects indicated. b) Optical image of back of modules with scratches, c) close-up image of damaged area of cell with visible damage to cell material

4. Conclusions

Electroluminescence and thermal imaging are informative, non-destructive characterisation techniques that allow defects in assembled modules to be detected and quantified. When used together they provide a better idea of the defects present. Extrinsic defects such as cracks and broken fingers are difficult to identify from visual inspection but can be quickly identified in EL images and by hotspots in thermal images. Degradation of the anti-reflective coating in a PV module results is a decrease in the module performance and the effects can be seen in the lower EL signal in these regions. The effects of delamination are visible in the EL image of a module indicating that there is a drop in photoresponse of the affected cell material.

References

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[3] Van Dyk E E, Chamel J B and Gxasheka A 2005 *Sol. Energ. Mat. Sol C.* **88** 403-411