Analysis of homogeneity in thin film photovoltaic modules using large area light beam induced current (LA-LBIC) measurements

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Abstract. In this study a large-area light beam induced current (LA-LBIC) measurement system is used to analyse homogeneity in photo-current in thin film PV modules. A laser light source mounted onto a motorized x-y scanning stage is used to raster scan while illuminating a PV module point-by-point. The measured PV module current output is mapped and presented as an LBIC image. As a consequence of the large area deposition process and the laser scribing to form individual cells in thin film PV modules, the module may be prone to inhomogeneities that can cause a reduction in performance. The accurate interpretation of the LBIC data depends on knowledge of the operating bias voltage of each cell. In this work the module is scanned at various constant bias voltages. The experimental setup used is presented and LA-LBIC results discussed. Electroluminescence imaging of the scanned modules is also used to verify the results of the LA-LBIC mapping. In addition, the limitations of the LA-LBIC technique are highlighted and possible solution to obtain meaningful results from the LA-LBIC technique is presented.

Key words: LA-LBIC, Thin film, PV Modules, Homogeneity

1. Introduction

Film thickness of the semiconductor absorbing layer in thin film Photovoltaic (PV) module cells is one of the key parameters that influence the module electrical performance. The effects of the absorbing layer thickness on the performance of solar cells have been reported [1-4]. The production method for thin film Photovoltaic (PV) modules, where a thin layer of semiconductor material is deposited over a large area makes it difficult to maintain material thickness uniformity over the entire area. When series connected module cells have varying film thicknesses, their electrical properties may become inhomogeneous affecting the module current output. Inhomogeneity in electrical performance may also arise from the presence of defects in the active layers [5].

Different techniques such as solar LBIC, electroluminescence (EL) and thermoreflectance imaging have been reported as some of the techniques to investigate the nature of defects and their localization in solar cells and modules [6-8]. Structural, point defects or impurities in the solar cell may introduce localized intermediate energy levels in the band gap of semiconductor materials. These levels act as deep level traps for charge carriers. Material defects in thin film modules may result from the laser scribing process during module manufacture [9]. In this work, the use of large area light beam induced current (LA-LBIC) technique is used to investigate the homogeneity in photo-current in PV modules.

Further the correlation between the changes in the photo-current with the nature and type of defects is explored.

2. Experimental

2.1. Equipment

The LA-LBIC measurement system used for the non-destructive investigation of PV module performance is shown in Figure 1. The system allows for investigation of a module area up to 1.3 m x 1.3 m. The system consists of a motorized x-y scanning stage with a mounted light beam source, a source measure unit (SMU) and a control computer. The entire system is controlled by a custom-built labview program.

The amorphous silicon (a-Si) and copper indium diselenide (CIS) PV module used in this study are the ones manufactured by monolithic integration. The CIS module is manufactured by Siemens while the manufacturer of the a-Si module is not indicated.
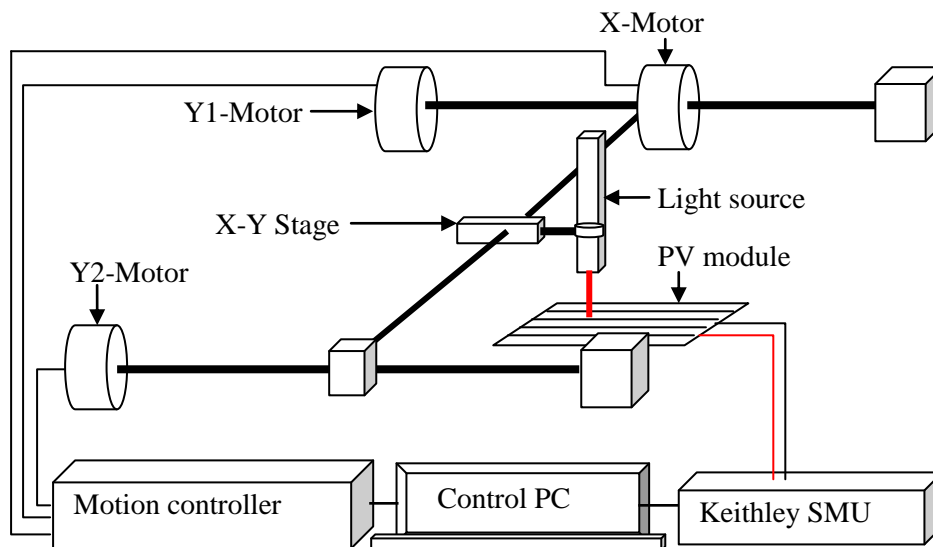

Figure 1: Schematic diagram of LA-LBIC measurement system

2.2. LBIC principle

In a PV module, the cells are connected in series. As a result, the current generated by the laser beam that is incident at a point on a cell has to pass through all the other series connected cells. Figure 2 illustrate the flow of induced current from one cell in a module made of three series connected cells. The LBIC signal depends on the laser induced current at a point on a particular cell as well as the combined constant series and shunt resistance of all the remaining series connected cells in the module. The dark leakage current through the pn junction of the dark cells can be considered negligible. The variation in LBIC signal during the scanning process thus originates from the cell being scanned and not from the rest of the module cells that are essentially in the dark.
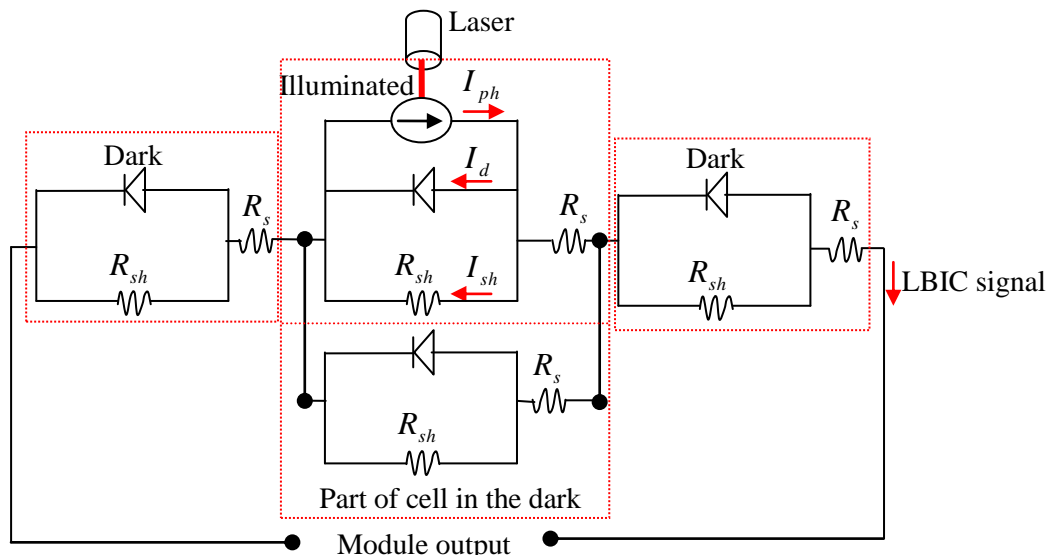
I_{ph} is the photo-generated current, I_d is the dark current, R_{sh} is the shunt resistance and R_s is the series

Figure 2: Shows the current flowing through R_{sh} and R_s of the dark cells.

2.3. Measurements

A laser light source (633 nm, 5 mW) mounted on an x-y stage is used to spot illuminate the module point-by-point. A source measure unit was used to keep the module at a fixed bias voltage while measuring the module current output. Measurements are performed on the module in the dark.

Since the performance of the individual cells in a module is likely to vary, cell mismatch in modules become very probable. When a module with mismatched cells is illuminated, the operating points of individual cells get shifted along the module's current-voltage (I-V) curve in order to ensure equal laser beam induced current to flow in the series connected string. Figure 3 illustrate the shift in the operating points of the module cells during scanning. When a point on a cell is illuminated, the illuminated cell is forced into forward bias which subsequently reverse bias the non-illuminated cells. The changing laser beam induced current causes the operating point of individual cells to change during the scanning process while the sum of the individual cell voltages remains constant, equal to pre-selected module bias set by the SMU. The operating points of individual scanned cells therefore depend on the selected module bias and on the sum of the reverse bias voltages of remaining cells in the dark. The operating point range of individual cells may therefore be vastly different, making it difficult to compare LBIC signals between cells of a module. LBIC signals within an individual cell can however be compared due to the fact that the influence from neighbouring cells in the dark is considered constant. By changing the pre-set module bias voltage between scans and comparing the LBIC signals between cells, valuable insight may be gained on the operating point of scanned cells as well as the origin of LBIC features.
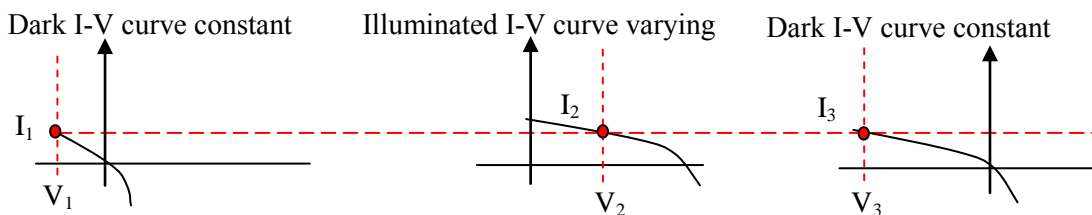

Figure 3: Shifts in operating points on the I-V curves of three module cells during scanning.

3. Results and Discussion

The LA-LBIC measurement results for small areas of a-Si and CIS module are presented. The complete a-Si module has an area of 45 cm x 30 cm and is made up of 29 series connected cells while the CIS has an area of 36 cm x 28 cm, of 50 series connected cells. Figure 4 shows photographs of the scanned areas of the modules.
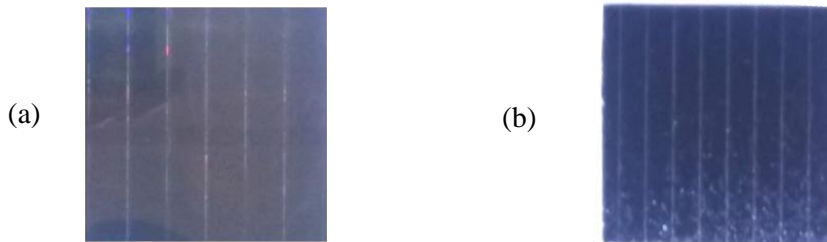

Figure 4: Photograph of part of (a) a-Si module of area 6 cm x 6 cm (b) CIS module of area 5 cm x 5 cm

The modules were scanned at various constant module bias voltage levels using a laser with a 633 nm wavelength, a power of 5 mW and an illumination spot diameter of approximately 1 mm. Figure 5 shows the photo-response maps of the a-Si module at different module bias voltages. Apart from cell 3 and 4 from the left, the rest of the cells show a reduction in photo-response with increase in forward biasing, which is typical of the diode electrical behaviour along the I-V curve. Cell 3 and 4 however show an increase in photo-response with increase in forward bias indicating an unexpected non-linear response. Since the power of the laser beam and the temperature of the module are assumed to remain constant, the I-V curves of all cells should remain constant while the laser beam illuminates a particular spot on cell 3. The slight overall increase in LBIC signal (module current) can thus only result from a drop in the bias voltage of the (current producing) cell 3 while the sum of the dark cell's bias increases. This non-linear behaviour is contradictory and is the subject of further investigations. The response of this cell to forward biasing is similar to the defect stretching from the left and covering five cells of the module shown in Figure 5. This defect could result from a variation in deposition layer thickness. Little variation in current is observed within cells and indicates a relative uniformity of the deposited material properties over the cell surface. The large variation in current between cells are due to differences in individual cell biases and can be ascribed to large differences in series and shunt resistances between cells.
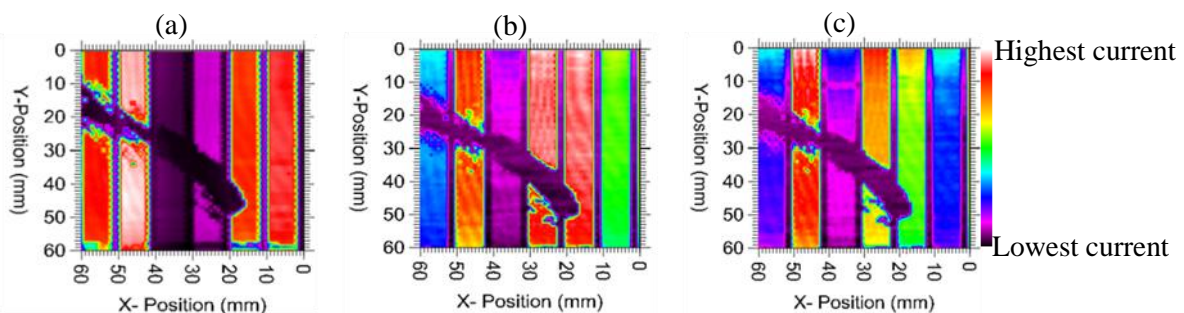

Figure 5: Photo-response map of a-Si module at module bias of (a) 0 V (b) 3 V (c) 5 V

The LBIC scan of the CIS module shown in Figure 6(a), shows a line of electrical disconnection across the cells. A line scan extracted from the LBIC map in Figure 6(a) at position x = 15 mm is shown in Figure 6(c), indicating a drop in current from 3.61 µA to 0.26 µA as a result of the disconnection. This electrical disconnection is verified by the electroluminescence (EL) image in

Figure 6(b) and is indicated by arrows. EL measurement is performed by forward biasing the module using a d.c power supply and taking its image by use of a CCD camera. When a module is forward biased, radiative recombination of carriers results, leading to emission of light. Significant variations in performance both between and within individual cells are observed in this particular module. Large variations in performance within individual PV cells are usually uncommon, and for this particular case, it is a result of the disconnecting feature.
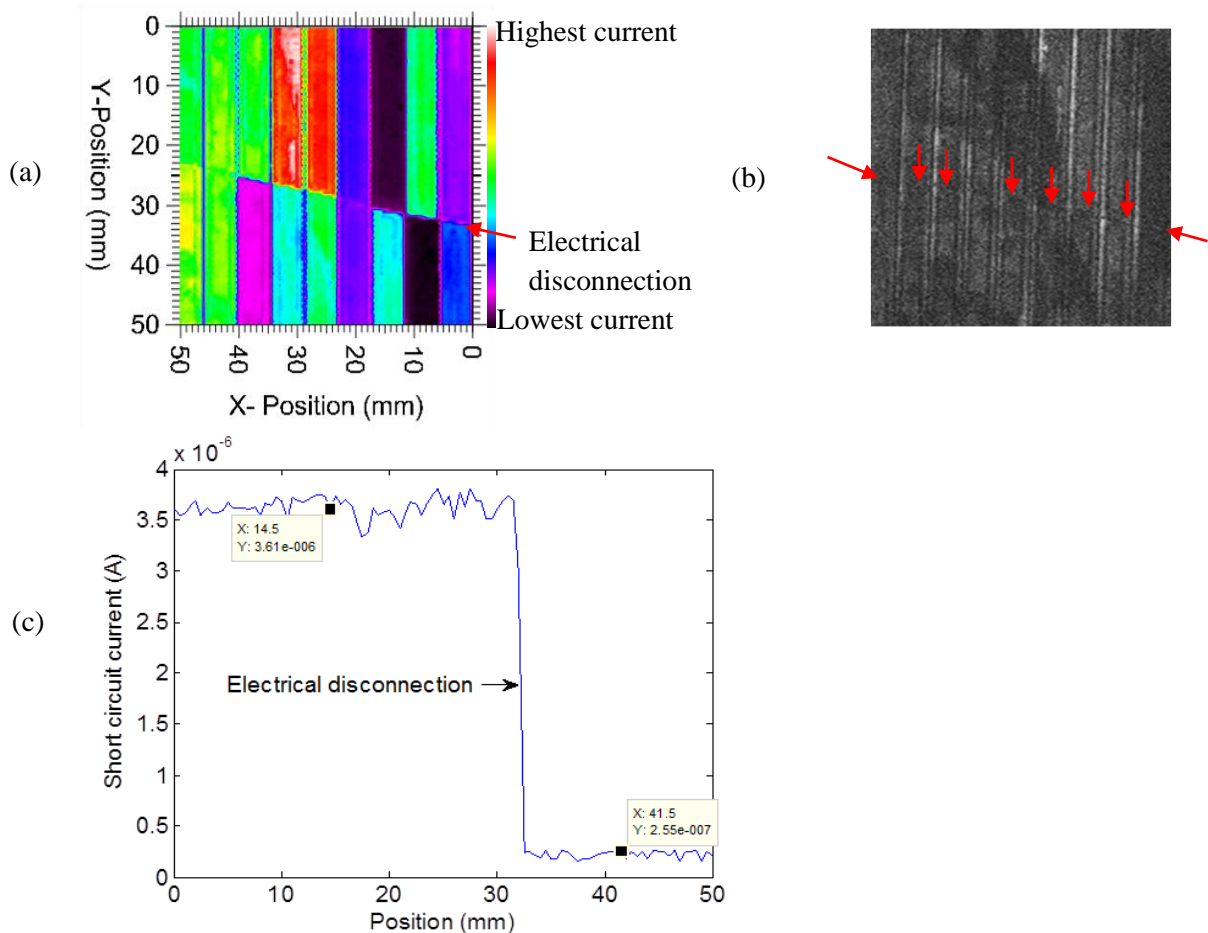

Figure 6: (a) LBIC map of CIS module (b) EL image (c) Line scan at position x = 15 mm in (a)

4. Challenges of LA-LBIC and possible solution

The variations in individual dark cell voltages due to the differences in cell resistances complicate the interpretation of LBIC data since the conditions are bound to vary from cell to cell during scanning.

To minimise this effect, the use of background light biasing is proposed. This method has been reported previously [10] and entails placing the scanned cell under a limiting condition. To achieve this, background illumination is applied to the whole module while the cell being scanned is covered with a bandpass filter that allows the scanning laser beam's light to pass through. This is expected to yield more reliable results as the cell being scanned is the weakest cell and hence determines the module current output and LBIC signal.

5. Conclusion

Homogeneity in photo-current within, and between cells as well as defects in a-Si and CIS thin film photovoltaic modules were investigated using a LA-LBIC measurement system. As a consequence of variations in I-V operating points between series connected cells, small material differences between cells are greatly amplified. Within a cell, the scanned points are essentially parallel connected and variations are less dramatic, since the whole cell's bias remains constant. The uniformity of the LBIC signal within cells gives an indication of the homogeneity of the deposited thin film material whereas the dramatic differences between cells points to big differences in the contact formation between cells. The electroluminescence technique was found to complement the LA-LBIC measurement technique in module defect investigations. The complications involving interpretation of results obtained by scanning the modules in the dark at a fixed module voltage were discussed and possible solution presented. Performing LA-LBIC scans on a cell placed under a complete limiting condition was proposed to be the most viable solution to acquire reliable signals from modules while scanning at a fixed module voltage. Variation in photo-current between cells and defects are regarded as the common performance hindrances in thin film PV modules.

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