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Characterisation of a LBIC System by Scanning of Silicon Solar Cells and Modules

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Abstract

A laser beam induced current (LBIC) system has been used as a non-destructive characterisation tool for photovoltaic (PV) devices. It provides a detailed two-dimensional map of the current signal. Each data point in the map is generated by the laser beam scanning over the devices. The signal strength depends on the response of that particular area on which the laser beam is incident, thereby reflecting the absorption and collection characteristics of that local PV area.

However, the magnitude of the measured signal, induced by modulated laser, is very small. Adjustment of set parameters, measurement variables and environmental influences may affect the measurement result and thus could lead to misinterpretation. The LBIC system at the Centre for Renewable Energy Systems Technology (CREST) is analysed for reliability and optimised. It is evident that with appropriate settings under controlled environmental conditions, the system can provide a highly repeatable measurement result.

Introduction

The LBIC system has been developed for application to large area, multi-cell photovoltaic modules at CREST. Unlike most other characterisation apparatus, it allows a localised analysis of fully encapsulated devices. It is a spatially resolved measurement process and is capable of identifying localised defects which otherwise would not be identifiable, such as deposition inhomogeneity and performance variation of series connected cells in the module.

There are only two terminals available for connection to external circuits in an encapsulated commercial module, which makes characterisation extremely difficult. However, localised measurements are crucial for optimising thin-film technologies, as there is no possibility of cell sorting prior to module assembly. The inability to access each cell will require to measure cells essentially in mismatched conditions, where the signal being picked up is essentially the mismatched signal. This unavoidably limits the current induced by the modulated laser beam to a very small magnitude, of the order of micro-Amperes.

Therefore, the measurement is carried out using a lock-in technique. With this method signals as small as nano-Amperes can still be recovered even in high noise environments. There are a number of factors that affect the signal including optical and electrical properties of the laser beam, lock-in amplifier (LIA) settings and the ambient measurement conditions. These variables need to be correctly set and adjusted in order to obtain an accurate measurement result that gives a meaningful interpretation and is able to be use for comparison purposes.

In this work, the measurement is designed to investigate and optimise several parameters of the laser beam characteristic, resolution, and the measurement conditions. Initially, the measurement is configured according to typical settings based on the lock-in amplifier and the characteristic of PV samples. Then, several environments have been set up to identify possible sources of uncertainties.

Both single line and area scans have been carried out on a number of samples including a 5.8x5.8 mm active area silicon photodiode, a 2x2 cm mono-crystalline silicon cell, a 4.75x4.75 cm and a 29.5x90 cm amorphous silicon module. Every measurement was at the same place throughout the investigation, to avoid any hypothetical changes in signal.

LBIC System

The LBIC system uses a laser scanner to map the photocurrent signal of the PV cell or module. It is currently installed with Helium-Neon laser with a power of 5 mW and a wavelength of 632.8 nm. The laser beam is modulated by a chopper wheel with specific frequency. It is then guided by a Scanlab varioSCAN20 and SCANgine14 focussing unit and controllable mirror guide in order to control and adjust the focal length corresponding to the x-y position on the measurement plane. The system is also equipped with an array of halogen lamps working as background illumination to provide a measurement with different illuminated conditions. The measurement is controlled by PC via custom-made software implemented in LabVIEW. More detail on the system structure and a schematic diagram of the LBIC system can be found in [1, 2].

The signal generated from PV devices is shunted by a resistor, currently 0.01 ohm, and then amplified by pre-amplifier (100x or 500x) preparing the signal for the signal recovery stage by LIA. The LIA uses a phase sensitive detection technique to detect and extract the required signal that matches with the reference frequency.

Laser Characteristics

The laser characteristics play a key role in the LBIC measurement. As it is directly proportional to the output signal, it needs to be as constant and precise as possible in order to obtain high precision measurements: with only a small deviation, the output signal could change dramatically [3].

Firstly, the beam intensity is measured as a function of time after turn-on of the laser and secondly, the beam diameter at the measurement plane is calculated. The output signal generated by the PV devices and measured by the lock-in amplifier is directly proportional to the incident beam intensity. Thus, in order to examine the stabilisation time of the laser after turn-on, the experiment is executed by running a single line scan over the photodiode and measuring at regular intervals i.e. every 4 minutes after turn-on, which is shown in Figure 1. The measured signal on the y-axis

represents the current signal generated by the photodiode, which is proportional to the beam intensity. The experiment shows that the laser beam intensity takes approximately 24 minutes to reach its stable condition. The result quantifies the considerable warming up time required by the He-Ne laser. After this warming up, however, the measurements are virtually identically each time the line scan is carried out.
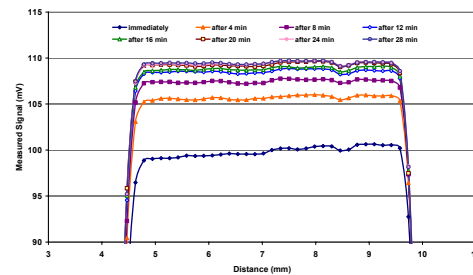

Figure 1 shows variation of the laser beam intensity immediately after turning on the laser for nearly half an hour by applying a single line scan to the photodiode. The first measurement starts immediately after turning on the laser and about every 4 minutes thereafter.

It can be seen from Figure 1 that after reaching its steady state the laser beam intensity is considered to be constant. The difference in measured signal between 24 and 28 min at the active area of photo diode is not more than 0.16% of it average.

The laser beam diameter determines the possible resolution of the scanning. Before the laser beam terminates at the tested module, the beam passes through the optical instrument to adjust the focus and then undergoes reflection by the mirror to the required x-y coordinate on the measurement plane. The laser beam diameter has been measured at the plane where the PV module is placed by running the single line scans over the sharp edge of the photodiode with known length. Several measurement batches with different resolutions were performed. The beam diameter is obtained from the distance when the signal suddenly changes at the edge of photodiode active area. At the measurement plane, the average beam diameter appears to be approximately 0.95 mm with uncertainty in measurement of ± 5%. One of

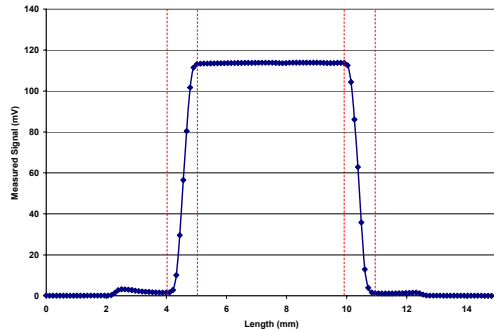the measurements is shown in Figure 2 with 0.114 mm laser step movement.

Figure 2 displays a single line scan over the 5.8x5.8 mm photodiode. The resolution of this scan is 0.144 mm per laser step. The broken line is drawn for visual aid in the area where the signal changes suddenly at the edge of the photodiode.

In addition, from the above measurement it is also possible to calculate the calibration factor. The calibration factor represents the ratio of a unit (bits) used in the measurement control to actual distance. Initially, the system was designed with a calibration factor of 25 µm/bit while that calculated from the experiment is approximately 23±1 µm/bit which is in good agreement with typically settings. However, the difference could be attributed to the movement of reflecting mirrors and the effect of temperature. Later in this paper, the experimentally determined value is used.

Scanning Resolution

The resolution setting is an optimisation of scanning time and detail of the scan. Acquisition time can range from a few seconds for a single line scan to tens of hours for a high resolution large area scan, albeit one should keep in mind that the CREST system is a research system and has not been optimised for scanning time. In general, the single line scan over the module is sufficient for cell to cell comparison. However, the area scan is needed for suspect modules in order to locate or pinpoint the possible cause of low performance, e.g. detected by solar simulator measurements.

Figure 3 shows area scans of a 2x2 cm crystalline silicon cell with different

resolutions, from top left clockwise, laser steps of approximately 0.92, 0.46, 0.23 and 0.114 mm are used. It is clear from Figure 3 that all of them show a similar pattern of signal strength (the white patterns). However, with higher resolution, i.e. 0.23 mm, it is possible to clearly identify the alignment of the collection grid.
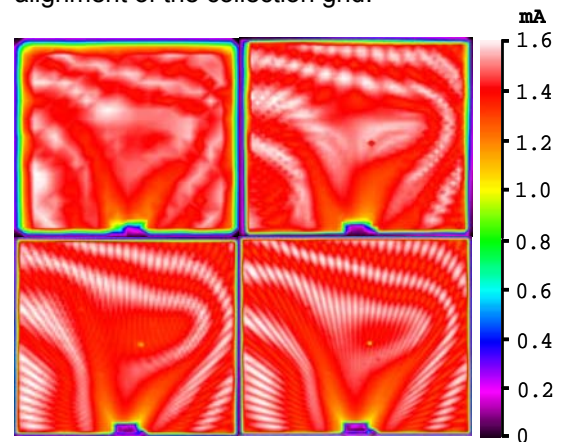

Figure 3 shows area scans of a 2x2 cm crystalline cell with different resolutions, ranging from each laser movement of 0.92 mm (top left), 0.46 mm (top right), 0.23 mm (bottom left) and 0.114 mm (bottom right). The colour represents the strength of measured signal.

For thin film technology in particular, one may need slightly higher resolution to be able to distinguish the separation between each cell and in this detailed resolution, unexpected defects can become apparent on the laser scribed area between cells, shown in Figure 5.
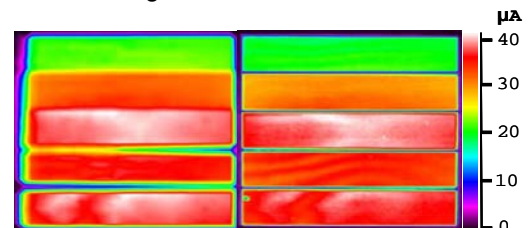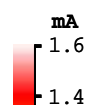

Figure 4 The measurement of an 4.75x4.75 cm amorphous silicon module with two different resolutions. Image on the left, the laser step is 1.14 mm while on the right is 0.46 mm.

Figure 4 illustrates the comparison between two different resolution measurements on an amorphous mini module consisting of 5 cells

connected in series. With a laser step of 1.14 mm, the picture on the left has no clear boundary between cells. On the other hand, with 0.46 laser step, the scan on the right shows clear boundary and a small defect at the bottom left corner.

To further illustrate the importance of resolution, the detail scans are shown for large area amorphous silicon module. As can be seen in Figure 5, each image is part of the scan covering a scan area of 15 cm^2. They show the micro-short-circuits in the interconnection area of two adjacent cells. This introduces a short circuit between two cells which could affect the performance of module to a certain extent. This type of defect most probably occurs during the cell separation process, laser scribing, after the semiconductor deposition.
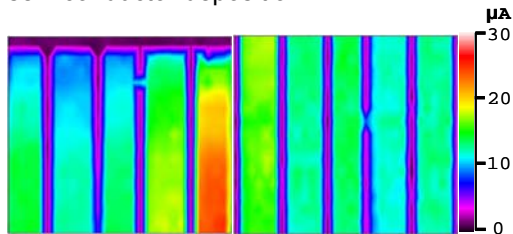

Figure 5 shows two scan areas, approximately 15 cm^2 each, obtaining from the measurement of 29.5x90 cm single junction amorphous silicon module. Both illustrate the defects in the interconnection area between two adjacent cells.

Temperature Effect
The ambient temperature is suspected to have a significant effect on LBIC measurements, if not controlled tightly. To investigate this effect, the single line scans were performed on the photodiode. The settings are identical except that inside LBIC the temperature was increased by approximately 10ºC for one scan.

Figure 6 shows that the signal increases with increasing temperature. This can be considered to be a combination effect from the changing of laser beam intensity and the photodiode itself. Moreover, the changing temperature also has an effect on the movement of the guide mirror. As shown in Figure 6 it is clear that at higher temperature, the signal is shifted towards the right with approximately 0.16 mm off.

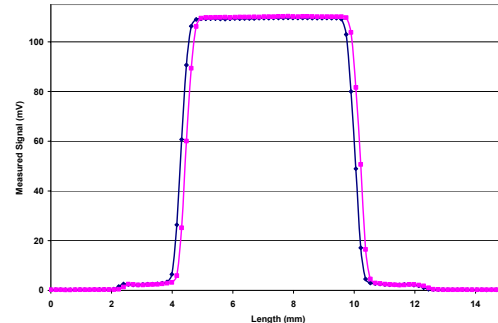This is most likely due to the effect of temperature on the motor that drives the mirror.

Figure 6 shows the average of single line scan measurement signal on the photodiode where both settings are identical except the temperature inside LBIC is about 10ºC different.

Conclusions
Under controlled conditions with appropriate measurement parameter setting, the CREST LBIC system can give a repeatable measurement. More importantly, this accuracy and repeatability will ensure that the investigation and analysis of scanning results allows the correct interpretation of performance variation and defect detection leading to significant improvement of production processes, material quality and thus performance of photovoltaic devices.

Acknowledgement

References
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