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Investigating Non-Uniformities in Mono-Crystalline Solar Cells Using Out-put Response Signal of LBIC/LBIV of Unknown of Probe Profile

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ABSTRACT

Solar devices majorly include the mono-crystalline, multi-crystalline and thin film cells. Different inherent non-uniformities reduce the efficiency of these cells. The study of these defects and non-uniformities has been done using different techniques but in this article the Light Beam Induced Current (LBIC)/Light Beam Induced Voltage (LBIV) technique is employed since it is a non destructive technique that performed localized characterization on a mono-crystalline solar cell using a light beam as a probe. The aim of this paper is to investigate the out-put response from a mono-crystalline solar cell using an LBIC/LBIV system of a laser beam of an unknown profile. Thus determine places of defects and contact fingers examining their shape, size and depth and how they impact on the out-put electrical characteristics. The samples were prepared by cutting solar cells from a well working mono-crystalline solar module, and then dissolved in ethyl vinyl acetate to delaminate it. Solar cells obtained were scanned using the LBIC/LBIV apparatus at University of Eldoret producing the output response signals. Electrical characterization was done by determining the local photo-response of the scanned solar cell which enabled the determination of electrical parameters from which spatial distribution of defects was inferred.

KEY WORDS: LBIC/LBIV, response signal, defects, mono-crystalline

1. INTRODUCTION

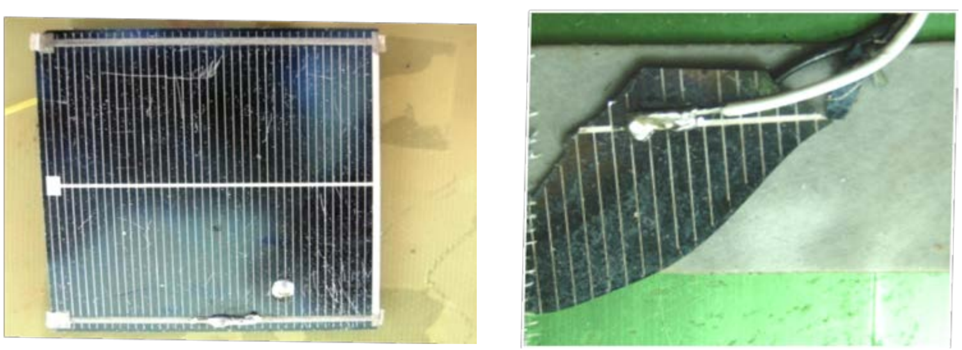
The ever increasing demand of energy raises concerns and thus need to venture in energy research production measures. Solar energy is the most convenient form of energy. PV systems have proven themselves in demonstration in developing world to be largely reliable and durable under extreme conditions. For large scale energy production solar cells produced from crystalline silicon is currently the dominant technique at the moment, [5]. Solar cells experience high cell temperatures and non-uniform illumination and they become less efficient as temperatures increase, [3][6]. In silicon based solar cells most of photons with energies greater than 1.1eV which is the band gap energy for silicon are converted into electricity. Photons with energy less than 1.1eV have been shown only to increase the temperature of the cell [3][6]. Increasing the power output of the cell by concentrating sunlight uniformly increases unwanted heating. When the module temperature and global irradiance are at their highest levels, the module efficiency is at its lowest. PV modules have been the main source of solar energy production and thus the need to upgrade their production and working. In photovoltaic industry, like in other industrial process, it is necessary to check incoming materials and find product faults/ defects. In the attempt to characterize solar cells in terms of their general efficiency, in an effort to come up with a low cost PV module, results have shown that there are defects which lower the efficiency of the modules. [8]

The measurements by LBIC/LBIV method provide a direct link between the spatial non-uniformities inherent in solar cells, and the overall performance of these cells. [3] This is uniquely used to produce quantitative maps of local quantum efficiency with relative ease [4]. LBIC/LBIV analysis is widely used as universal method for detecting local defects in the solar cell structure [3]. Examples of such defects include those related to edges, grids, or scrabs, spatial variations in alloying, locally decreased diffusion length, strong local shunt or high local series resistances and local changes due to high-temperature stress and many others. [2]

In the LBIC/LBIV a LASER beam is chosen to be used for detecting defects in the solar cell structure because the technique is a non-destructive technique. It focuses light onto a solar cell device thus creating a photo-generated current that is measured as function of its position on the cell surface. Also the spot size can be made very small, in the order of microns, and very precise measurements can be made. [4] In this paper, there is determination of the local photo-response of the solar cell which enabled characterization of the spatial distribution of defects and electrical parameters by scanning the beam probe across a solar cell while measuring the voltage-position characteristics at each point, a map of cell parameters like quantum efficiency (voltage) of the solar cell was extracted.

2. METHODOLOGY

Silicon solar cells are obtained from a well working mono-crystalline PV panel. The mono-crystalline silicon solar cells are then scanned using the LBIC/LBIV system. Several parameters were put into consideration in the design stage including tuning the LBIC/LBIV system for data access periodic time, LASER power and amplifier frequency together with the SMC Pollux driver velocity. Using a well operating silicon module, samples are obtained by cutting single cells from the module. A glass cutter is used to cut the single cells from the module. A suitable solvent is selected to delaminate the solar cells from an encapsulant called EVA (Ethylene Vinyl Acetate). The cut solar cell is soaked for a period one week and all the EVA dissolves. The delaminated solar cell is then welded on the top and bottom sides to some conductor then connected to the LBIC apparatus. Figure 1 (a) shows a delaminated solar cell and figure 1 (b) shows a section of the cell after welding and connected to LBIC/LBIV system.



(a) (b)

Fig. 1 (a) The delaminated solar cell from a crystalline module (b) A section of the delaminated cell cut and connected to the LBIC/LBIV

A typical scan is done on a solar cell of approximately 1 cm^2 .To perform an LBIC scan using a LASER, the LASER wavelength is chosen to generate current within the material of interest. The LASER used is of wavelength of 635 nm, which can be used to penetrate different depths into the silicon substrate. The LASER beam from the coherent LASER cube 635nm, 25mW; passes through a chopper and then through a glass convex focusing lens, and onto the cell. A chopper is used to minimize the noise in the measurement from other light sources. A beam splitter splits the beam into two; one half perpendicularly focused onto the sample mounted on translation stages and the other half transmitted straight and is absorbed by an integrating sphere (see figure 3). The focusing lens allows the spot size to be focused to approximately 8 microns in diameter. The cell is placed on a gold plated vacuum chuck (heat sink), which is mounted on top of an x-y-z axis stage. This allows precise movement of the mounted cell under the LASER in the x-y directions using stepper motors, while the z direction is used to focus the LASER spot size. A two-dimensional scan of the photo-active surface, measuring the photo response is generated point to point in a raster manner.

During the measurement, the current signal is fed through a trans-impedance Bentham 225 Lock- in amplifier. This converts the current signal to an AC voltage signal. The AC signal is then passed via a BNC cable to a lock-in amplifier. The output of the lock-in amplifier is passed via a GPIB cable to a computer. The control software for the system is a custom made Lab-VIEW program. The light bias is turned on and the filter wheel combination then adjusted for the specific junction to be tested. The LASER is then turned on. Some fine tuning adjustments are made to the LASER power level and the light bias intensity to assure the light bias induced current is greater than that of the LASER induced current. Once the setup is complete, the cell scan is started. The scan is conducted starting from the top right of the scan area input in the setup process. The direction of the scan was horizontal, starting from the top to bottom rows. The scan was also conducted from left to right, and the LASER returns from left to right side of the scan area and the process continues. During a specific data point measurement, the x-y stage was moved into position, and there was a 100 ms settling time before a reading of that location is taken. Then the data was saved to file and the x-y stage is moved again to the next location. Figure 2 is an illustration of the raster response for data collection.

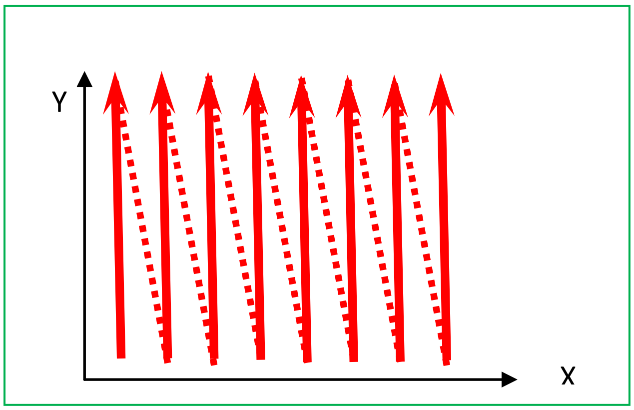


Fig. 2 Raster scan pattern used through the motion control.

The scan rate is approximately 25000 data points per minute. Typically scans of high resolution for a cell that is 1 cm^2 take approximately 14 hours to complete, whereas scans of lesser resolution take approximately 3 hours to complete. The data collected is fed in data programes that generated the graphs and surface maps.

The solar cell under investigation is studied using the LBIC/LBIV configuration below. Various system components are put together to form our system design. The full description of the system design and construction is shown in figure 3.

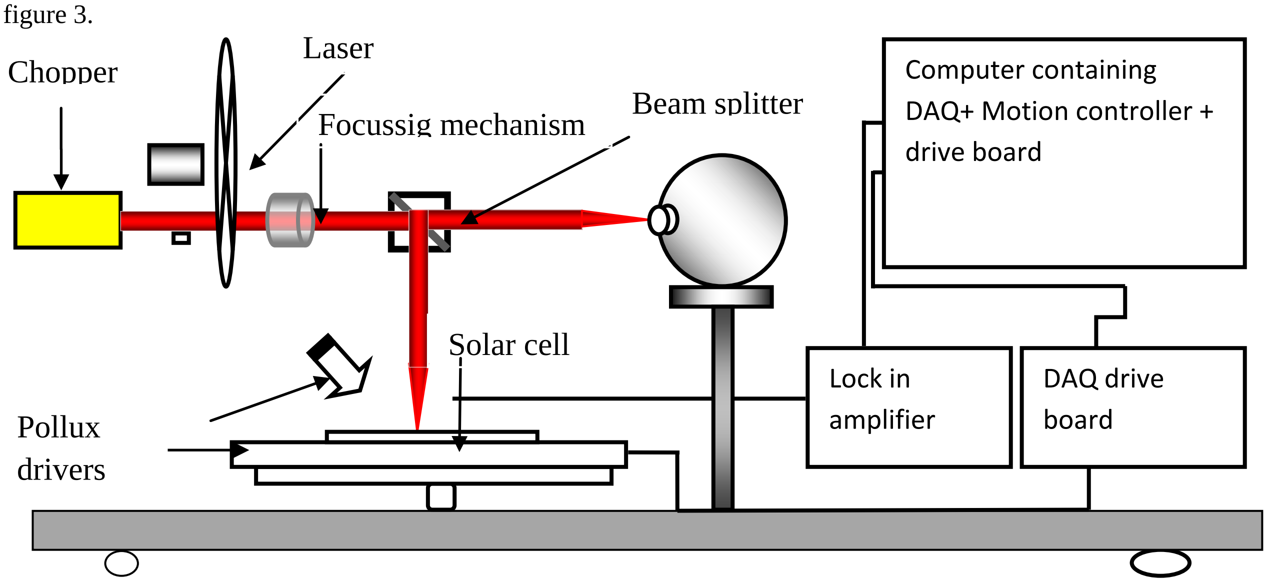


Fig. 3 The LBIC system design and construction with a laser beam falling on the surface of the solar cell [6]

3. RESULTS AND DISCUSSION

3.1 2-D Voltage response maps from a mono-crystalline solar cell

The scan of the mono-crystalline solar cell shows that the voltage of the solar cell is maximum when the beam hits at the cell substrate (region at positions 9.7 to 10). However, when beam hits at the metal contact the voltage is minimum (position 9.55) as seen from figure 4.

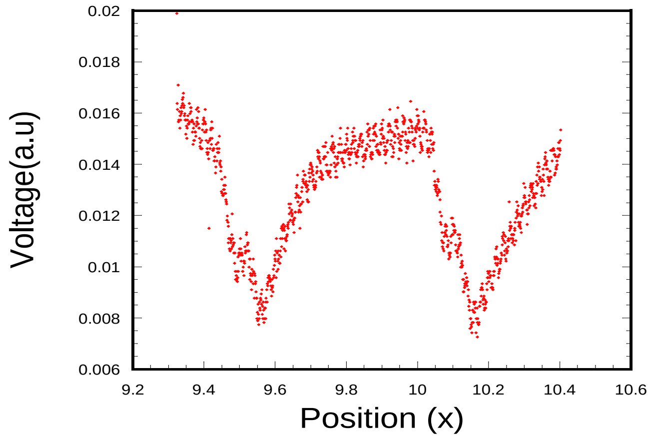


Fig. 4 The graph of voltage against displacement for a solar cell scans at a period time of 100 ms

The points of low voltage signify the metal fingers of the solar cell. There are some areas of distortion on the graph which indicate that the incident spot on the cell is not a uniform spot, but has varied intensities or there exists a defect at that point on the solar cell. Figure 5 shows the results of the LBIC/LBIV scan on a mono-crystalline solar cell but at a different position from the one of figure 4.

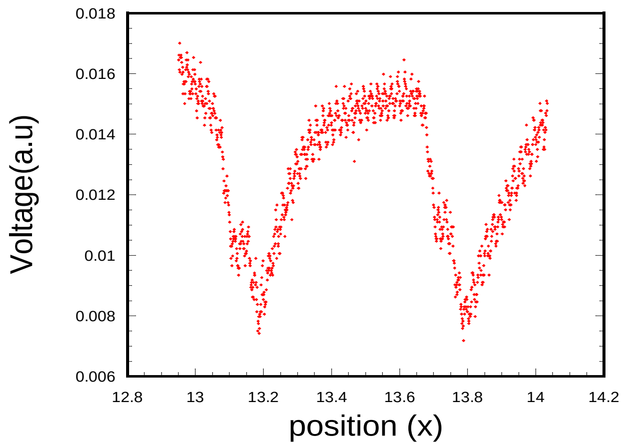


Fig. 5 The graph of voltage against displacement for a solar cell scan at a period time of 100 ms at a different section of the solar cell

The results obtained in figure 4 and 5 show that scans for two regions of the cell are same. The shape of the output signal that is obtained, gave a correlation between the input signal and the surface of the cell that is irradiated.
The scaled output signals of voltage were found by scaling the voltage by a factor of 1000. This is because the maximum voltage that could be measured by the meters was 2 V. The voltages obtained were too small thus scaled as shown in figure 6.

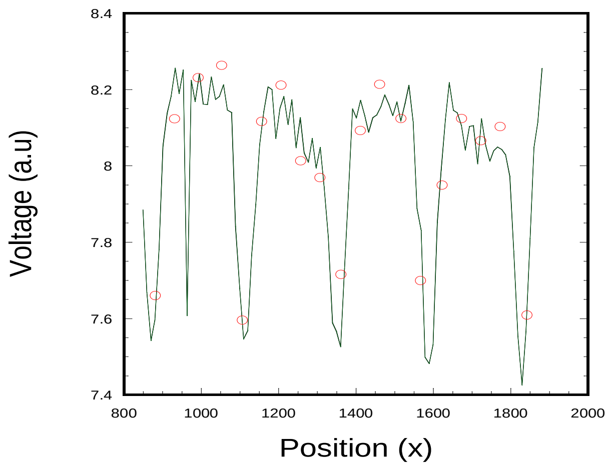


Fig. 6 The scaled signal of plotted with voltage against position when a solar cell is scanned

The scaled signal shown by plotted dots show that the voltage obtained by the LBIC/LBIV signal is not even but has points of low voltage in the cell substrate itself apart from the metal fingers areas where the voltage is low. On the peaks of the voltage there are also uneven voltage produced which is seen by the irregular shape of the graph in figure 6. This response maps tend to tilt on one side since the beam that scans the solar cell is a moderately narrow point source that is an elongated Gaussian shape. In addition the peaks tilt in an alternating manner (for instance the peak between position 1100 to 1300 tilts to the right, the peak between 13500 to 15500 tilts to the left and that between 1600 to 1800 tilts to the right) since the beam probing the solar cell ’spins’ in energy, meaning the beam has varrying energy points. So, the tilts in the maps do not imply existance of a non-uniformity. The data points were reduced to investigate detailed shapes and depths of the inherent non-uniformities of the cell as shown in figure 7.

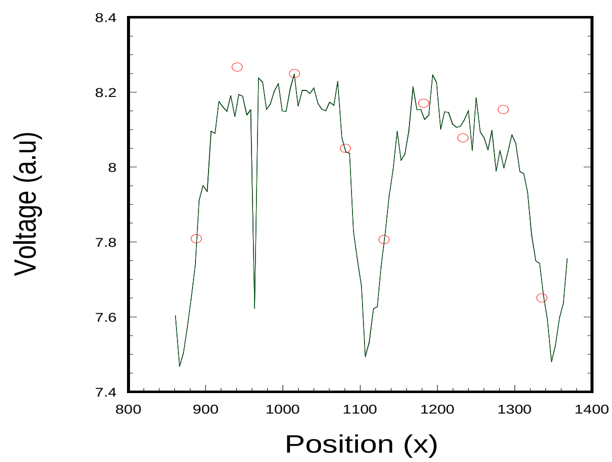
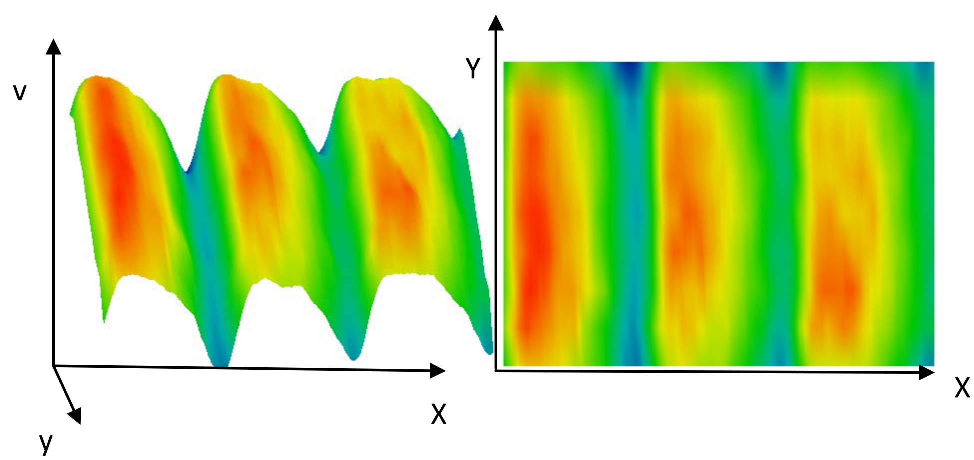


Fig. 7 The scaled signal of plotted with voltage against position when a solar cell is scanned with reduced data points

When the data points are reduced to obtain few data points, the scaled plots are seen as given in figure 7. This reduction in data points shows very clearly the shape of the plots. For figure 7, at position 1100 the voltage is minimum, this shows the area of metal contact. The voltage though is not zero, which implies that the input signal from the LBIC/LBIV is not a point source but it is an elongated spot such that it overlaps the metal contact so that some minimum voltage is produced. The minimum voltage obtained at position 980 may not necessarily imply a metal contact, but this may have resulted from a defect inherent in the cell (example is shown in figure 1 (a)) thus giving the minimum voltage. The defect gap is small hence this shows that defect is small thats why it shows a small gap as compared to that of the metal fingure. The peaks are not smooth which gives an insight about the subtrate fabrication. The uneven peaks on the voltage plots result from the minor defects resulting from device fabrication and this reduces the general performance of the solar module. In addition, the probe signal being of varrying intensities results to these even peaks.

3.1 2-D Voltage response maps from a mono-crystalline solar cell

The 3D graphs in figures 8 and 9 give the surface maps of the solar cell which gives finer details of the response signals. The blue regions show points of contact fingers giving low current. The voltage increases as shown by the green regions and the orange areas give points of maximum current. The 3D surface representations of the signals are as given in figure 8 (a) & (b) and figure 9 (a) & (b).



(a) (b)

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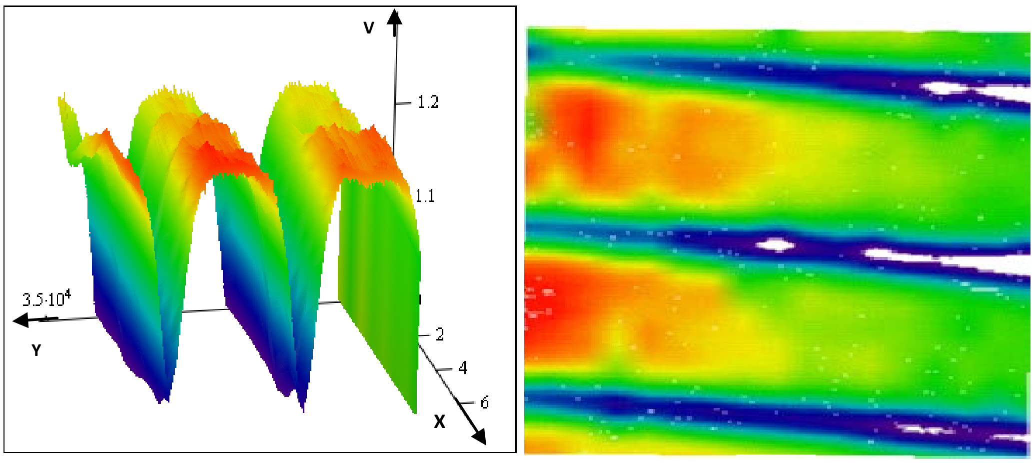
Fig. 8 (a) 3-D LBIV map for a mono-crystalline silicon solar cell voltage plot and (b) a rotated at different angle



(a) (b)

Fig. 9 a) 3-D surface plot of voltage generated against displacement as scanning is done in x and y direction (b) LBIV map as solar cell is scanned in x and y direction

The results obtained in this work are similar to those from previous researches [3][2][6], where points of non-uniformities are observed. Using these results we deduce the existence of non-uniformities in a mono-crystalline solar cell. Points where the non-uniformities exist the voltage response signal gives low values. Thus the existence of non-uniformity reduces the efficiency of the solar modules. When the LBIC/LBIV apparatus are used to scan these modules we discover that at the points of non-uniformities there is no output obtained and if any is due to the non-uniformity (either a defect or a contact figure) being overlapped by the probe signal and the non-uniformities existing are of different shapes, size and depth.

4. CONCLUSION

The article was necessarily done to produce solar cell output signals that are obtained from a mono-crystalline solar cell when scanned with an LBIC/LBIV probe of unknown profile. The study of the solar cell is very important since solar energy has become an important form of energy in the world given that it is clean, readily available and generally cheap. Further research can use this information to design new materials that can be used to improve the efficiency of solar cells.

5. ACKNOWLEDGEMENT

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