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Signal Processing of LBIC/LBIV System Using the Fourier Convolution Technique

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ABSTRACT

Photovoltaic solar cells are large area devices that are used to convert sunlight into electrical energy. There are different types of solar cells which majorly include the mono-crystalline, multi-crystalline and thin film cells. Different effects including defects and 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 was 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 profile of the probe signal from the LBIC/LBIV system is not known. The main objective of this article is to determine the profile of this probe signal. Fourier convolution is done on four input signals of Gaussian with moderately narrow tip, one of Gaussian of an elongated tip and the other comprising of two narrow Gaussians with non-homogeneous intensities combined together (inter-twined profile). The results obtained from the theoretical output-responses are then compared with the experimental output results. The profile of the assumed input signal arising from the resulting theoretical signal that agreed with experimental was a Gaussian of a narrow tip that is elongated. Experimental techniques with a pre-determined probe signal suitable to map the spatial distribution of local parameters can provide valuable information, and thus help to improve the technology for production of efficient and reproducible solar cells.
KEY WORDS: Probe, signal, Profile, Convolution, LBIC/ LBIV, solar

1. INTRODUCTION

PV modules have been the main source of solar energy production and thus the need to upgrade their production and working. Results have shown that there are defects which lower the efficiency of the modules when characterizing solar cells in terms of their general efficiency [2]. The LBIC/LBIV apparatus is one of methods whose measurements provide a direct link between the spatial non-uniformities inherent in solar cells, and the overall performance of these cells and is uniquely used to produce quantitative maps of local quantum efficiency with relative ease.

From the experiments done so far, no information regarding the profile of the probe signal is known. [5] The aim of this work was to determine the profile of the probe signal through Fourier convolution. The main objective of this article is to process the LBIC/LBIV input signal probing a mono-crystalline solar cell using Fourier convolution technique. Primarily the article is to profile the laser beam for an LBIC/LBIV to give quality scan that will show inherent properties of a solar cell.

In the LBIC method focused light beam scans the surface of examined specimen point by point, causing the arising of different signals as shown in figure 1.

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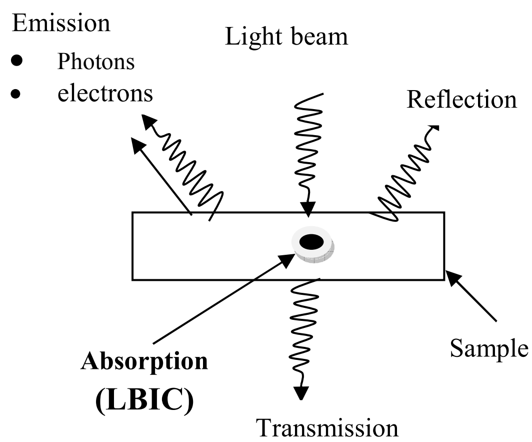


Figure 1Types of signals and phenomena occurring when light beam incidences on the sample in LBIC method

LASER beams have unique irradiance profile that gives them very significant profile. The significance of the beam profile is that the energy density, the concentration, and the collimation of the light are all affected by it.

METHODS

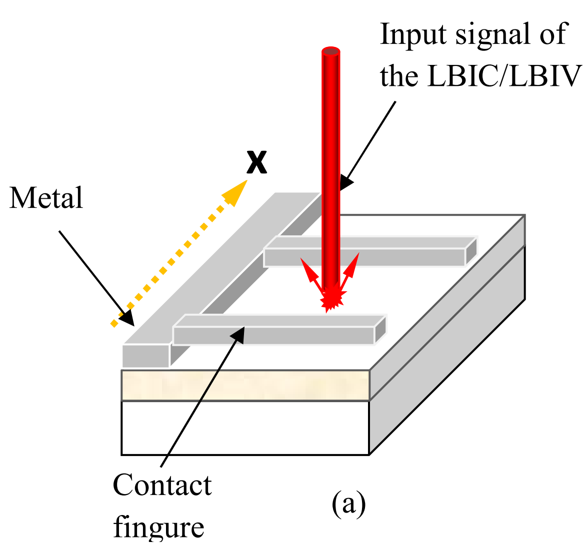
If the probe surface was point the assumption is that the surface details are much finer. An ideal solar cell (one which does not contain any defects or non-uniformities) was assumed to produce the impulse signal. The signal of the ideal solar cell was modeled as rectangular shape by the function

$$\begin{aligned} F(x) &= 1\, for 0 < x < b \\ &= 0, 0 < x < b \end{aligned} \qquad 1.0$$

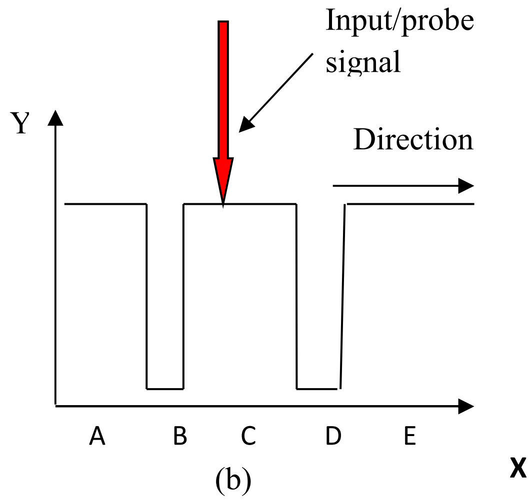
Where *F(x)* is a Fourier transform and *b* is the width of the rectangle. The matrix of the solar cell profile generated by Matlab is as given below;

u= [0 0 0 1 1 1 1 0 0 0 1 1 1 1 0 0 0 1 1 1 1 0 0 0];

Where u is the vector matrix of the solar cell (Impulse signal). The designed model is as shown in figure 2(b). The maximum denotes the substrate part and the minimum (seen as a rectangular hole) was the contact fingure. Figure 2 (a) demonstrates the scan process of the cell. The LBIC probe signal scanned the cell in x-direction and when it crosses the contact fingure it was assumed that there existed a hole at that point in the shape (the output response signal was minimum) as the one observed at B and D in figure 2 (b).



(a)



(b)

Figure 2 (a) Drawing showing motion in x direction scan of the solar cell and (b) shows the model of a perceived solar cell profile, Y is the height of the cell and X the length of the cell in millimeters.

The spot of the probe signal is designed to be a Gaussian in shape by using the Gaussian equation 2.0.

$$f(x) = e^{-ax^2/2} \qquad 2.0$$

Where *f(x)* is the assumed input signal and *a* is the width of the Gaussian profile. The scanning of the probe signal on the solar cell profile is theoretically the convolution of the assumed input signal with the impulse signal (solar cell profile) by convolution as shown below

g(x)=[0 0 0 1 1 1 1 0 0 0 1 1 1 1 0 0 0 1 1 1 1 0 0 0];
t=10:10;
f(x)=exp(-t);
C(x)=conv(u,v);
plot(*C(x)*);

where *g(x)* is the periodic solar cell impulse signal profile, *f(x)* is the assumed input (probe) signal and *C(x)* is the convolved output response. Note that $t = ax^2/2$.

The modeled input signal was theoretically scanned across the solar cell in figure 2. The Gaussian spot is assumed to run across the perceived solar cell profile and the response of voltage obtained. The output response matrix is used to develop voltage versus position spreadsheets. This procedure is repeated for the other LBIC/LBIV inputs signals that are developed. Further models including one of Gaussian with a moderately narrow width, the Gaussian of an elongated tip and one comprising of two narrow Gaussians with non-homogeneous intensities combined together (inter-twined profile)by varying *a* and *x*. Since $t=ax^2/2$, the value of *t* in equation 2.0 is varied to vary the width of the beam and to skew *t*, the values of *a* are unevenly balanced. To obtain the intertwined beam, two Gaussian signals are made to scan the solar surface. When doing this, the fine result depends on probability of varying *t*. The laser beam profile underscores the width of the incident LBIC/LBIV LASER beam on the surface of a solar cell. The theoretical results that give output voltage versus position responses that agree with the results obtained in the experimental results is chosen to be the probe signal of the LBIC/LBIV apparatus.

RESULTS AND DISCUSSION

We start by looking at experimental results obtained when an LBIC/LBIV probe scans a solar cell. The experimental results gives the output signal obtained from the LBIC/LBIV measurements and is given in figure 3.

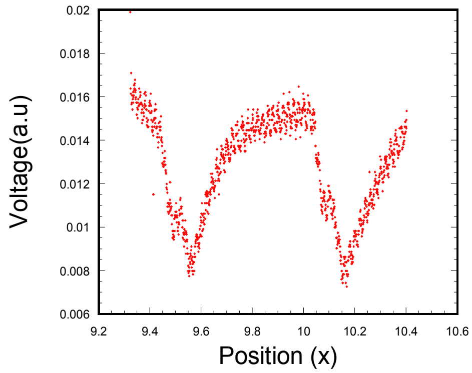


Figure 3 The graph of voltage against displacement for a solar cell scan at a period time of 100 ms

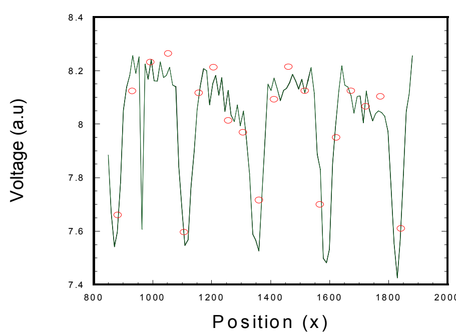
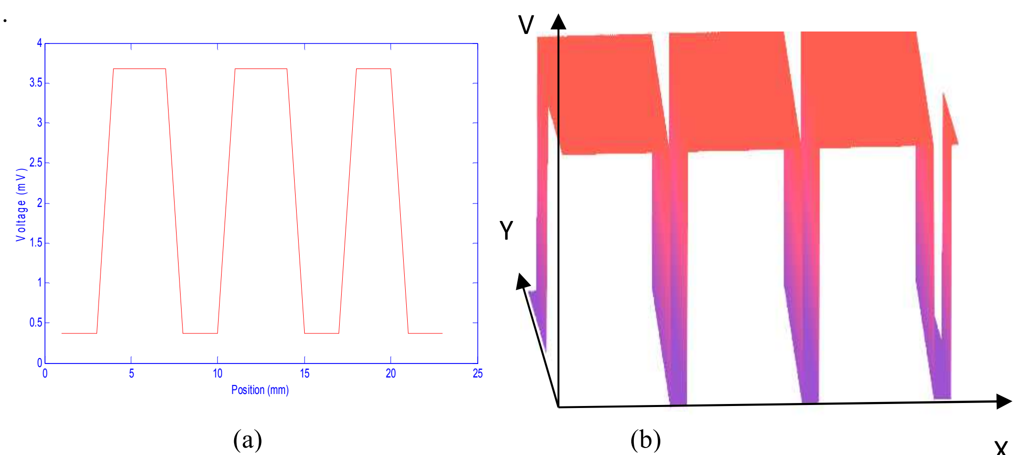


Figure 4 The scaled signal of voltage plotted against time when a solar cell is scanned

When characterizing solar cells using the LBIC/LBIV, these types of maps in figure 3 and figure 4 are obtained. The maps show some minimums in voltage as the probe scan the cell. At the maximum voltages on the maps, there are also non-uniformities as in figure 4 which give a reason to study the type of the profile the probe which scans the cell has. In addition the voltage-position response maps obtained show some tilt on one side. For instance on the left side of figure 3 and at the maximum after the first minimum there is a tilt, and in figure 4 not only do we see the tilts but the tilts tend to alternative in the left and right manner.

The theoretical models give finer details of the LBIC/LBIV results as compared to the experimental results. If the probe signal of an LBIC/LBIV apparatus is scanned on a solar cell surface, then the output signals obtained are as shown in figure 5.



(a) (b)

Figure 5 (a) 2D Theoretical model LBIV/LBIC for an ideal solar cell and (b) the model in 3D

If an ideal solar cell existed, it would have no defects and if the input is a circular tip of a very sharp point spot then it would give LBIC/LBIV map in 2D and 3D as shown in figure 5. This result of the output has never been obtained in any experiment [1,2,5,6]. When the input signal of the LBIC / LBIV is taken to be a Gaussian beam of moderately narrow width, the spread sheets in 2D and 3D LBIC/LBIV image are as shown in figure 6 (a) and (b) respectively .

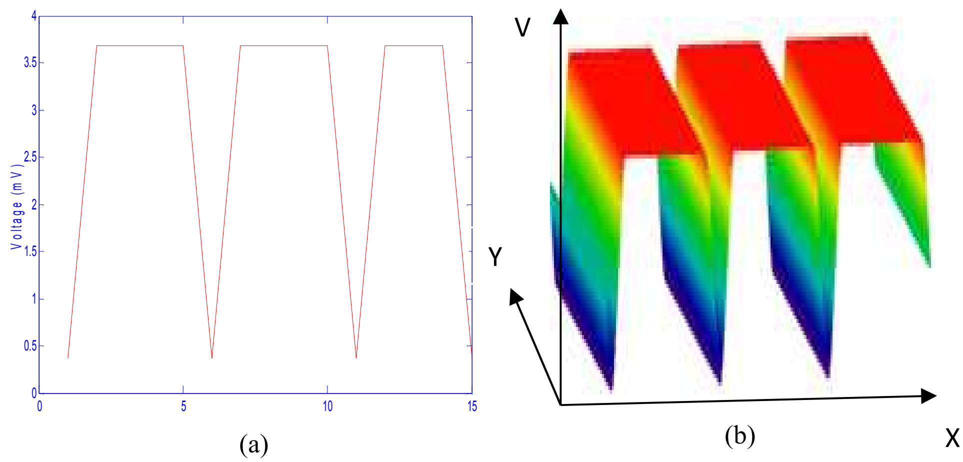


Figure 6 (a) 2D line scan voltage response for a moderately narrow Gaussian spot after convolution and (b) 3D theoretical LBIV for a Gaussian spot.

This spot gives sharp tips (wedge shaped minimum) at the metal contact unlike for a narrow circular spot that is flat. This is because the spot overlaps the metal contact to some extent hence reducing the width of the minimum voltage. If the spot is a narrow spot, the beam hits the metal fingure as shown in figure 7 by beam A and the expected output voltage is zero. However, a beam whose profile is moderately narrow Gaussian, when it crosses the contact finger as shown in figure 7 by spot of beam B, a section of it reaches the cell substrate; hence some little voltage is registered.

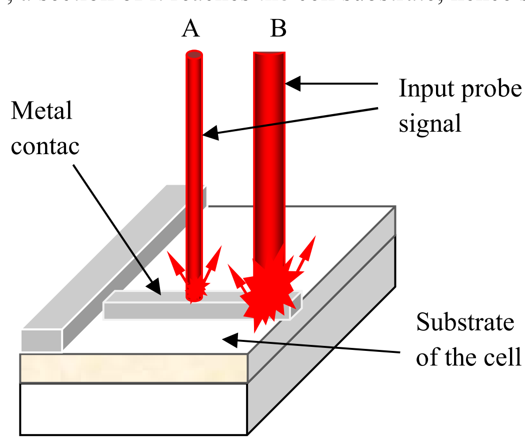
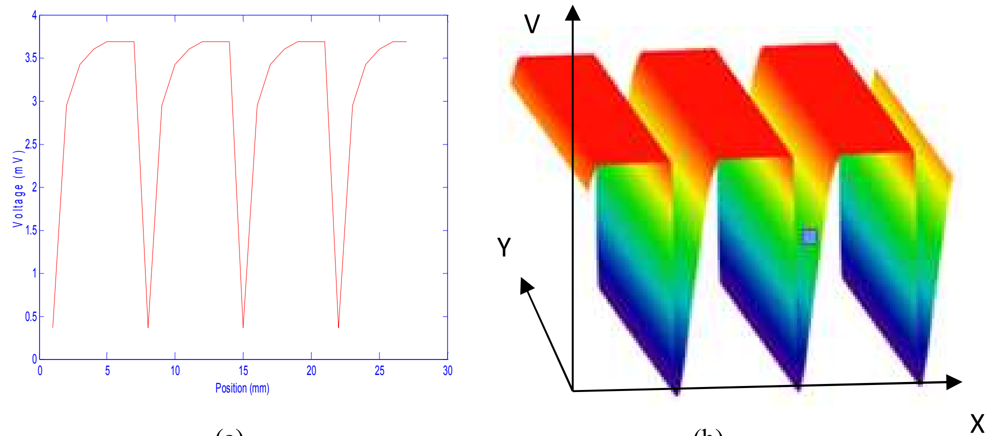


Figure 7: A is a narrow circular beam and B a moderately narrow spot scanning across a metal contact

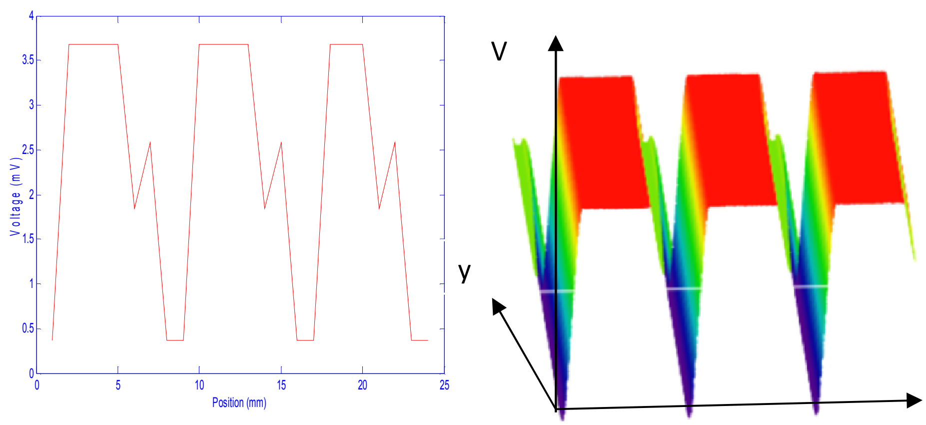
The input probe signal when modeled to be an elongated (skewed) spot signal, the theoretical model for Gaussian of an elongated tip is shown in figure 8 (a) for the 2D line scan while the figure 8 (b) shows the 3D theoretical model for the same spot.



(a) (b)

Figure 8 (a) Theoretical LBIV 2D line scan voltage response for Gaussian of an elongated spot after convolution and (b) 3D for elongated spot after convolution.

This signal gives outputs that tilt on one side. An elongated spot is a Gaussian shape beam that is skewed on one side. If a Gaussian skewed shape moves over a rectangular obstacle for instance, the flat side produces a flat trajectory while the elongated side produces a curved trajectory. This is the basic idea that explains the tilting of the response outputs. In case there is surface reflection and two spots come close together, such an artifact will interfere with the LBIC/ LBIV map and may give false result on the existence of a defect at the point where the two spots join up together. A theoretical model on 2 spots intertwined together gave us the results shown in figure 9 (a) and (b) for 2D and 3D respectively.



(a) (b)

Figure 9 (a) theoretical LBIV for 2D line scan for 2 spots intertwined after convolution and (b) the 3D for 2 spots after convolution.

In this work, correlation is used to develop the input signal of the LBIC/LBIV system, where the modeled input (probe) signal that gives an output response after convolution that resembles the experimental data is chosen to be the probe profile for the LBIC/LBIV apparatus. Using the theoretical data obtained from the methods section, the type of a surface map of a solar cell obtained from the LBIC/LBIV measurements depends on the beam profile, shape and size. Using the theoretical result as shown in figure 6, it shows that the probe signal of the LBIC/LBIV is a Gaussian signal of a moderately narrow tip. This is because this result is similar to the experimental results shown in figure 3 and 4 and other experimental results from previous researches. [1,3,5,6] The probe signal is also elongated from the theoretical result given by figure 7 is similar to that obtained in experimental result of figure 3 since the minimum voltages have a wedge shape which is similar to other results[2,5,6]. The comparison of figure 8 and figure 3 shows the spreadsheets tilted on one side. From this we deduce the elongated nature of the probe signal profile. At some points the spots of the probe intertwine producing a double scan since it is seen by both experimental and theoretical results in figure 3 and 9 respectively. From these many findings thus develop a comprehensive profile of the LBIC/LBIV apparatus. Therefore the beam profile is a Gaussian shaped beam of an elongated spot with a narrow tip head. The input probe signal has also varying intensities at the tip (due to spinning of the beam in energy) which at times cause double scan shown by the intertwined spots. This gave a processed LBIC/LBIV input signal, and can be deduced as shown in figure 8.

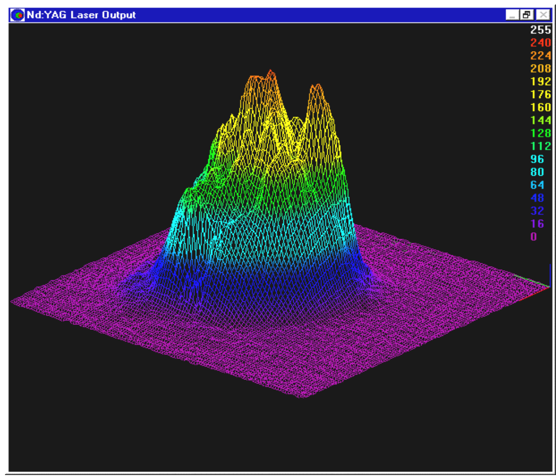


Figure 8 A Gaussian beam of a narrow tip, elongated and structured [4].

The probe beam profile is Gaussian in shape but highly structured (has packets of energy of varying intensity which makes it highly structured) thus has varying energy tips. The varying energy tip is the reason that makes the beam to 'spin'. The beam does not rotate (spin) but the energy intensities vary at the tip.

CONCLUSION

This work involved the designing of the probe signal of LBIC/LBIV. The profile of probe signal is a composite beam of Gaussian shaped beam of an elongated spot with a moderately narrow tip head. The input probe signal was also with varying intensities at the tip (due to spinning of the beam) which at times cause double scan shown by the intertwined spots. This gave a process LBIC/LBIV processed input signal.

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