*J. Basic. Appl. Sci. Res.*, 1(3)215-221, 2011

ISSN 2090-424X
Journal of Basic and Applied Scientific Research
*www.textroad.com*

# LBIC Measurements Scan as a Diagnostic Tool for Silicon Solar Cell

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**ABSTRACT**

Light Beam Induced Current (LBIC) measurements for solar cell local characterization has been developed and tested on mono-crystalline Si solar cells. A solar cell is illuminated with an intensity modulated and scanning by local illumination of a focused ***He-Ne*** laser ($<1mW$ & $\lambda = 633nm$). The linear response (current and potential) of the solar cell is measured during scanning. A large number of independent data with high spatial resolution are obtained. Applying an advanced fitting procedure on these data yields a set of local parameters for each point on the solar cell which give information on the spatial distribution of the photo current, the series and shunt resistance, the lateral diffusion of minority carriers, the quality of the back surface field and even allows the calculation of local IV-curves. The applicability of this solar cells characterization tool will be demonstrated.

**KEY WORDS:** LBIC, LBIV, diagnostic tools, reliability, silicon solar cell.

## INTRODUCTION

Photovoltaics is the field of technology and research related to the practical application of photovoltaic cells in producing electricity from light, though it is often used specifically to refer to the generation of electricity from sunlight.

Since the late 1970's, scanned laser beams have been used to measure photocurrent variations in multicrystalline silicon cells (Zook, *et al.,* 1980; Hari Rao, *et al.,* 1976; Belouet, *et al.,* 1978). In the 1980's, the two-dimensional laser scanner, which used oscillating mirrors to produce a rastered response map, was developed and used to map defects in thin-film solar cells (Phillips, *et al.,* 1982). Improvements to the two-mirror scanner reduced the laser spot size to 2 µm (Damaskinos, 1989) and introduced modern computer techniques to capture and store the data (Matson, *et al.,* 1994). The two-mirror scanner, however, is not well suited to quantitative studies of small areas, since it is difficult to align and to maintain a highly focused spot over a significant area.

A solar cell is a large area device, thus its global IV-characteristic and efficiency strongly depend on local properties. The existence of local defects, such as locally decreased diffusion length, strong local shunt- or high local series resistances, may adversely influence the solar cell global properties. Experimental techniques suitable to map the spatial distribution of such local parameters can provide valuable information, and thus help to improve the technology for production of efficient and reproducible solar cells. The LBIC (Light Beam Induced Current) is a well known technique for mapping of the spatial distribution of the photo current of a solar cell. LBIC is usually employed under short-circuit current conditions and allows the calculation of the local diffusion length of the solar cell material from local photo current data. The mapping analyzer PV Scan 5000 by NREL (NREL – Technology brief (NREL, 8/96) can be used to map defects and grain boundaries using reflectivity data, and special surface etching, and minority carrier's diffusion length using LBIC measurement with correction for surface reflectivity. Localized shunts can be mapped by sensitive infrared CCD-cameras or nematic liquid crystal thermography (King, and Langenkamp, *et al.,* 2000).

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In this paper a simple LBIC measurement technique, which is, used to allows the determination of all local parameters on large area silicon solar cells, especially the local series- and shunt resistance, $R_s(x,y)$ and $R_{sh}(x,y)$, and thus to identify all material and process-induced, efficiency relevant defects is introduced. In principle, the data obtained could also be used to simulate the behavior of the complete solar cell for any set of technological parameters.

## 2- THE MEASUREMENT TECHNIQUE

As the solar cell market is one of the most quickly developing one between the renewable sources of energy, the demands on quantity and quality of these cells grows rapidly. For diagnostics of cell homogeneity, LBIC and LBIV methods are widely used. This paper deals with comparing two solar cell diagnostic methods via both the qualitative and quantitative analyses. A simplified schematic diagram of the LBIC technique is depicted in Fig.1.

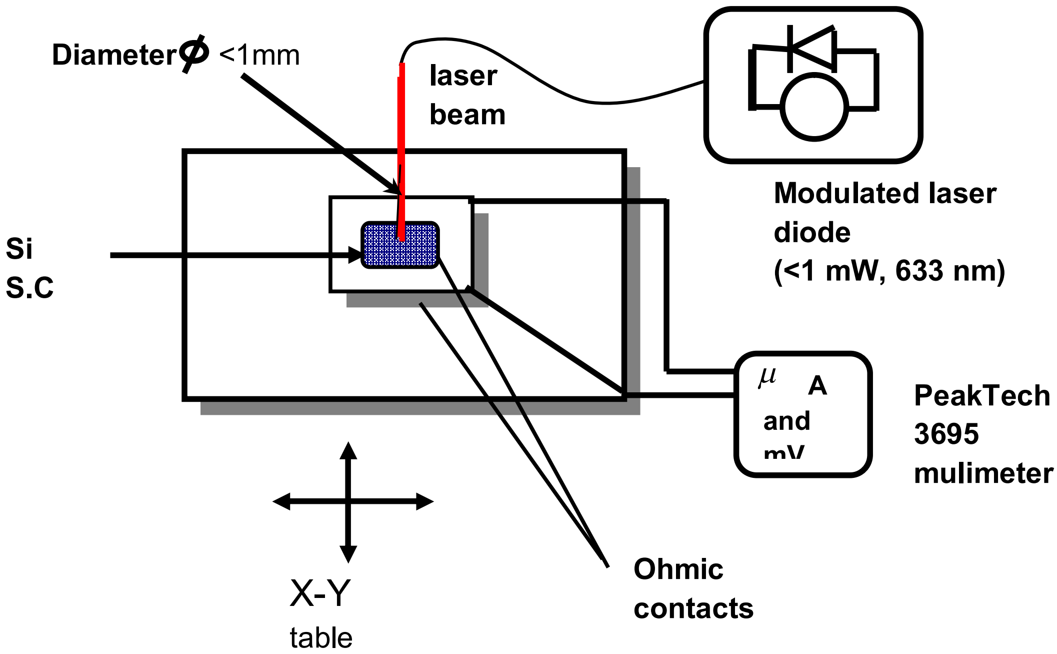


Fig.1: schematic diagram of LBIC and LBIV techniques.

## 3- Data analysis

Both LBIV and LBIC methods are based on measuring either short circuit current ISC or open circuit voltage VOC under conditions of local illumination by monochromatic light of a proper wavelength (usually realized by laser or LED diodes). Assuming the characteristic of a solar cell with series resistance $R_s$ and parallel resistance $R_p$ (Goetzberger, *et al.,* 1998) under conditions of illuminated spot of area A, it is possible to find out for short circuit current (V = 0). From the equation:-

$$I_{SC} = AJ_{FV} - I_{01}\left[\exp\left(\frac{eR_sI}{kT}\right) - 1\right] - I_{02}\left[\exp\left(\frac{eR_sI}{2kT}\right) - 1\right] - \frac{R_sI}{R_p} \tag{1}$$

And for open circuit voltage it can be derived (supposing a high parallel resistance Rp), while:-

$$V_{oc} = \frac{2kT}{e}\ln\left(\frac{-I_{02} + \sqrt{I_{02}^2 + 4I_{01}\left(I_{02} + I_{01} + AJ_{FV}\right)}}{2I_{01}}\right) \tag{2}$$

I01 represents the diffusion component of the p-n junction reverse current, and I02 is the generation-recombination component of the p-n junction reverse current. JFV is the density of current generated within the cell structure of thickness H by incident light. Non-uniformity in either the generation or the recombination rate over the area of the solar cell results in a nonuniform distribution of JFV and consequently, in non-uniform distribution of both VOC and ISC under conditions of local illumination (Kress, et al., 2000). The use of different wavelengths of incident light allows obtaining different types of important information about non-uniformity in recombination rate in different depth below the solar cell surface (Benda, 2005).
The silicon solar cell under investigation is shown in Fig.2.

Fig. 2:Photo for silicon solar cell under test.

Where the laser beam (wavelength $\lambda = 633$ nm & maximum power less than 1mW) is directly incident on each trace of the cell.
Figs.3 & 4 illustrate the short circuit current Isc variation on each trace of the cell by using the LBIC technique. It is clear that, the results of Isc are not constant but there is a variation from a point to another. Also, it seems that the solar cell is divided into 2 sections. One has an average value of Isc of about $I_{sc\ ave}$.= 85 $\mu$ A and the other half has an $I_{sc.ave}$.= 64.5 $\mu$ A.
There is a difference of nearly 20 $\mu$ A, this means that there is a non homogeneity of the doping material of silicon solar cell. Also, this leads to local hot spots on the surface of the solar cell in the case of using the cell in outdoor conditions. The darker colors indicate less of a current response, while the lighter colors indicate a stronger current response under the same laser intensity. This contrast scheme was used for all of the LBIC plots; however, the difference between the specific colors may vary in each plot. In each specific LBIC scan, the maximum current is recorded and then normalized, making the maximum current reading the “100%” level, and no current response the “0%” level.
One area of interest in the scan is the edge of the active area of the cell. There is a reduced current response in the edges of the cell, nearly on half of the four sides of the silicon solar cell. The right edge of the cell, which does not have interconnects attached to the metallization, shows a good response. This could indicate that the process used in attaching the interconnects to the sides of the cell is damaging the edges of the cell, possibly with heat or pressure when soldering. Several small defects can also be seen in this top junction at various points. Note there is a small strip of active cell area outside of the metallization region that responds to and appears on each LBIC scan.

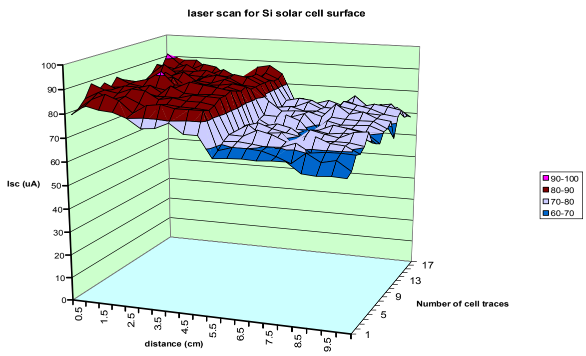


Fig.3: LBIC map for silicon solar cell under room temperature.

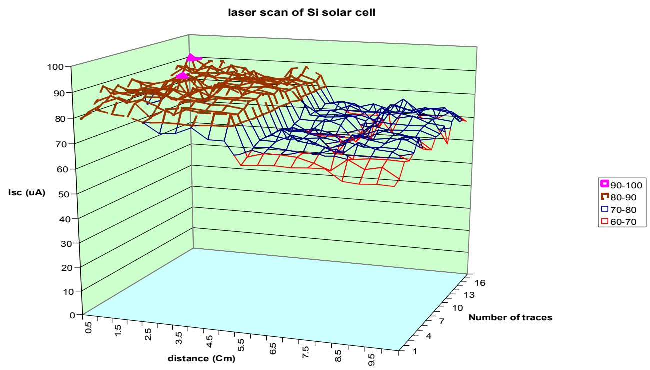


Fig.4: LBIC map for silicon solar cell under room temperature.

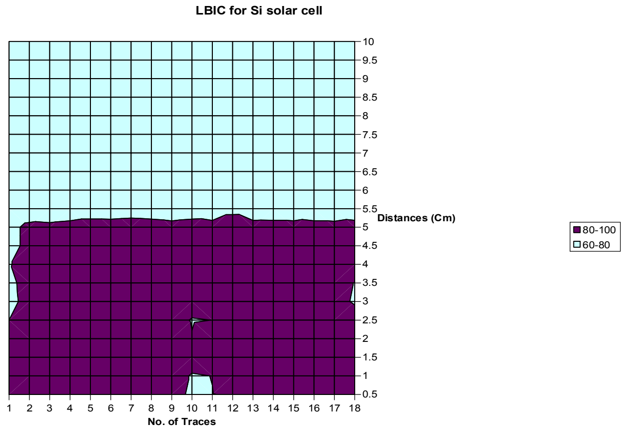


Fig. 4. The Isc map on the solar cell surface by using the LBIC technique.

The Isc map of the silicon solar cell under test is shown in Fig.4. Where there is a variation of the Isc values during the cell surface, this will leads to local hot spots during the cell surface. On the other hand, figs. 5&6 give information for Isc for selected distances and selected traces for the Si solar cell, respectively. LBIC scans are detailed and clearly show defects, grain boundaries (both external and internal), and problems in the metallization. Also, it shows the homogeneity or non homogeneity of the doping material of the solar cell.

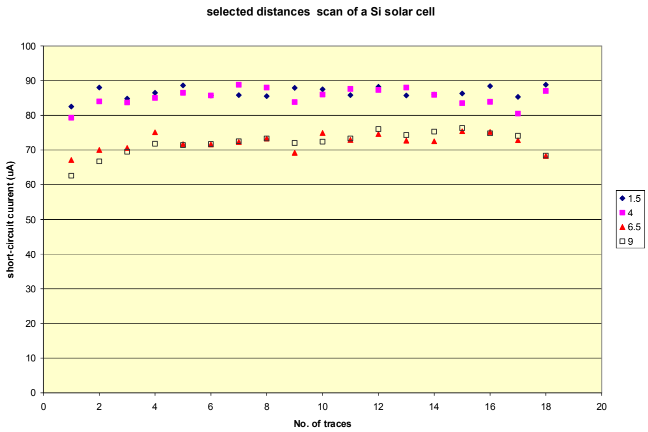


Fig. 5: Short circuit current for selected distances of the cell solar cell versus number of traces.

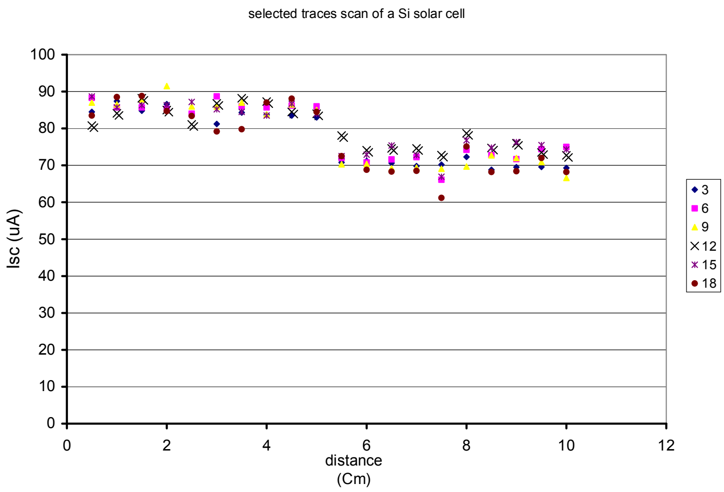


Fig. 6: Short circuit current for selected traces of the cell solar cell versus distances.

Matching the maps obtained by the LBIV method with those obtained by the LBIC method is subject of this paper. Even the LBIC method is relatively simple; its results are not always easy to interpret. The main reason arises from the position of measuring point on the I-V curve that can differ from short circuit conditions due to non-zero internal resistance of measuring device. As follows form Eq. (2), the short circuit current is very sensitive to the series resistance value that may depend on the distance between the light spot and the contact grid. On the other hand, this method can be used for detecting microscopic ruptures in the material, because these ruptures act as short circuit (reducing the shunt resistance value ~ 0), thus influencing the measured value of the short circuit current radically. From the equivalent circuit model of the solar cell follows, that the method LBIV operates in a well defined point of I-V characteristic, but it is insensitive to changes in shunt resistance value.

Figs.7&8 illustrate the LBIV for the silicon solar cell under test at room temperature. It is clear that, the variation in Photovoltage map is much less and cannot give accurate information about the construction the cell under investigation.

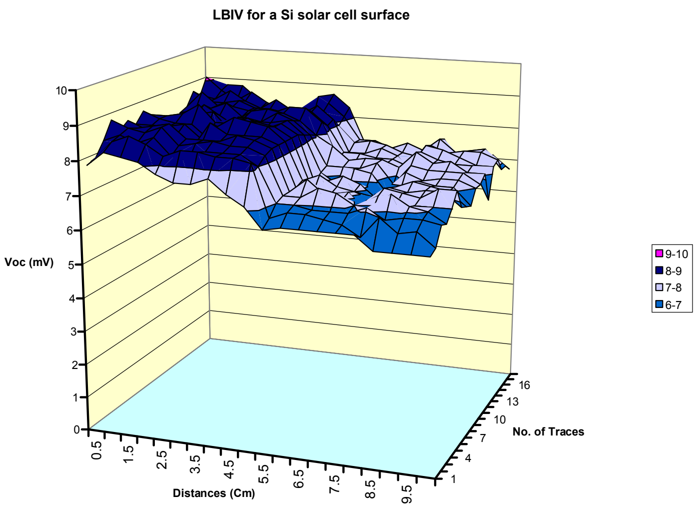


Fig. 7: LBIV for the Silicon solar cell under investigation at room temperature

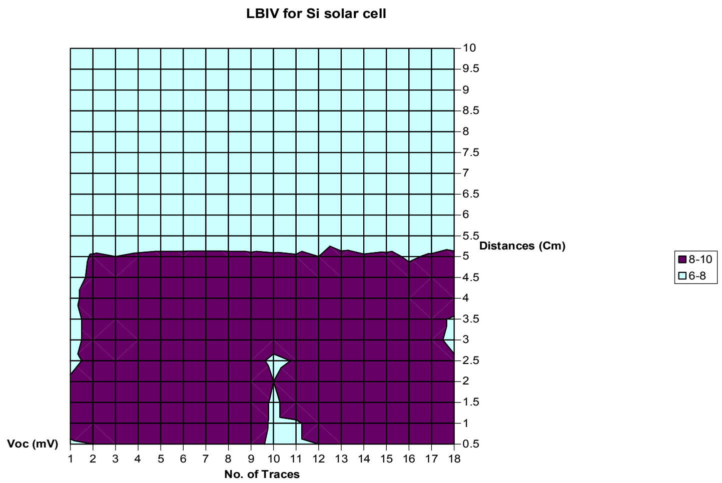


Fig. 8: Photovoltage map for the solar cell under test.

**Conclusion**

The ability to accurately characterize each junction in a monocrystalline solar cell using the LBIC technique. This technique allows multi-junction solar cell designers and manufacturers to perform in-depth diagnostics on each junction. This technique can diagnose non-uniform cell response, microcracking, metallization defects, and other material or growth-driven imperfections which reduce power output that are not easily identified using existing diagnostics. In addition, the spectral response measurement allows the specific junctions in a multi-junction cell to be characterized as an absolute measurement. These two testing capabilities will allow multi-junction cell manufacturers to optimize their manufacturing process and produce cells with greater efficiencies as a result. Where:-

i. LBIC is a reliable tool for investigating a wide variety of solar-cell non-uniformities.
ii. LBIC has become much more practical with improvements in translation stages, laser diodes, and data-handling techniques.
iii. LBIC is particularly valuable to explain differences due to processing variations or changes induced by elevated temperature stress.
iv. LBIC can be reliably combined with other investigation techniques to study the same cell area at different labs.

Poorer performing cells almost always show larger LBIC variations indicative of poorer uniformity.

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