CHAPTER 3

OVERVIEW OF LIGHT BEAM INDUCED CURRENT TECHNIQUES

3.1. Introduction

The variations of the induced photocurrent generated by a narrowly focused light beam that is scanned over the surface of multicrystaline solar cells have been used to create spatially resolved defect maps in the µm range since the late 1970's. The use of laser light has surpassed the use of white light and monochromators as a light source due to the highly collimated and coherent nature of laser light. Light Beam Induced Current (LBIC) based investigations have matured over the years to a standard characterization technique for process development of solar cells. One of the main objectives for LBIC investigations is the identification of spatially resolved defects and features in solar cells. Although some techniques are still partly under development at the research laboratory level, others have found widespread application as standard techniques for the characterization of spatially distributed defects in solar cells.

In this chapter, a brief overview of the status of some of the LBIC scanning techniques will be given. Together with other measurement techniques that produce spatially resolved data, the set of LBIC techniques that are available today form part of a range of techniques that can produce a wide variety of

spatially resolved data that are used for modelling and detection of failure mechanisms.

3.2. Basic LBIC Measurement System

3.2.1. Measurement Principles

The LBIC technique involves scanning a light beam in the absorbing plane of the solar cell surface. The LBIC signal is normally very small, sometimes in the picoampere range. Before the use of modern high precision current pre-amplifiers become prevalent, a beam chopper or modulator in combination with a lock-in amplifier was generally used to distinguish the LBIC signal from noise. A fundamental aspect of any LBIC measurement that must be borne in mind is that the electrical measurements are done at the external contacts of the cell and not at the beam position. The LBIC signal is therefore representative of the whole cell's response to being spot illuminated in a particular way.

The light beam probe may either be fixed while the cell is being moved or the beam is scanned across a fixed cell. Two types of movements are possible: Stepwise measurements allows the measurements to be taken while the beam is in a stationary position relative to the cell surface or dynamic continuous scanning while the beam probe is effectively in motion. The beam may be scanned by moving the light source or using a set of beam steering mirrors. The resulting induced cell current or voltage is measured, under a wide variety of specialized conditions, as a function of beam position and is used to produce topographical images of various cell parameters.

3.2.2. Characteristics of the Beam Probe

Traditionally the spectral composition of the beam probe may be controlled using monochromators, filters, or multiple laser beams. The spectral composition and intensity of the beam determines the generation profile (including depth) and in the case of near infrared beams, the generation of carriers with energies in the region of the bandgap of the semiconductor material. Although the intensity of the beam is normally limited to intensities low enough to avoid saturating minority carriers, LBIC measurements have been performed at higher laser intensities [1, 2].

The intensity of the beam probe may be varied either sinusoidally or pulsed (square waveform), depending on the application.

3.2.3. Light and External Voltage Biasing

The cell as a whole may typically be biased by an external light source or current injection via the cell contacts. The light bias intensity and externally applied voltage may change while the beam probe is stationary. In all applications it is important that the external bias light intensity must be absolutely uniform over the scanned solar cell. A solar cell's contact grid helps to apply the external bias as uniformly as possible across the solar cell's junction. Performing LBIC measurements on ungridded cell material will, however, complicate comparisons of LBIC signals between lateral positions on the cell surface.

3.3. Selection of LBIC Techniques and Corresponding Mapped Cell Features

The induced current signal that results from scanning a beam of narrowly focused light across the absorbing surface of a solar cell gives a good indication of spatial variations in the illuminated photovoltaic (PV) response from the cell. The variations originate from defects and variations in either the optical or electrical cell features. Optical defects and features include any kind of beam impediment such as dust particles, cracks, scratches and changes in reflection or refraction coefficients. Cell features that are electrical in nature include defects that cause non-uniformities in either the generation or the collection of minority carriers. The PV response of a solar cell due to an incident LBIC beam is summarized in the quantum efficiency (QE) at a specific wavelength or photon energy and is discussed in chapter 4. The external QE exclude external reflection losses while the internal QE compensates for reflection losses.

Initially the LBIC technique was used purely as a way to locate defects and features on solar cells and to form topographical images of the induced photogenerated current or QE. New tools had to be developed in order to identify the observed LBIC features. In the development process new innovative techniques evolved that could image previously undetected features and defects. Novel semiconductor cell materials and device structures also posed additional challenges that required fresh ideas. Brief descriptions of some LBIC techniques that are currently available or that are in the development stage are given in the following paragraphs.

3.3.1. LBIC Scanning while Pulsing or Modulating the Beam probe Intensity

In many techniques, modulating the light beam and using a lock-in amplifier serves as a way to reduce signal noise. The use of modern current pre-amplifiers that have advanced signal-processing functions has made the lock-in technique obsolete.

By pulsing the incident laser beam probe and measuring the point-by point decay of the LBIC signal, information about the carrier lifetimes can be obtained. The photocurrent decay (PCD) method uses an argon-ion pumped titanium:sapphire laser with wavelengths of λ = 700 - 1100 nm to determine a solar cell's back surface recombination velocity and average minority carrier diffusion length, as well as the depth dependence of the diffusion length in polycrystalline material [3].

3.3.2. LBIC Scanning while Biasing the Cell with an External Voltage

By applying a sufficiently small reverse bias to the cell while performing LBIC scans, series resistance effects that show up on the topographical image of ungridded cadmium sulphide cells may be minimized [4]. To help in the identification of some defects and features the cell can be biased in either the forward or reverse direction [5]. By varying the temperature of a laser diode, the emission wavelength of the beam probe may be changed by a small amount, corresponding to the bandgap of the scanned sample. Various layers within the cell will be activated, thus aiding the identification of defects and features [6, 1].

By using the different emission wavelengths of a narrowly focussed krypton laser beam source and comparing the LBIC signal with modelled data, a first attempt was made to calculate the diffusion length inside the grain boundary and recombination velocity of carriers in the grain boundary of polycrystalline material [7]. The beam probe's wavelength could also be changed by using a white light source and a monochromator. By applying a best fit for several values of the beam probe's wavelength to the measured QE, the minority carrier diffusion length, L_n, may be calculated [8].

3.3.3. LBIC Scanning while Biasing the Cell with an External Voltage and Applying Bias Lighting

When a uniform bias light is applied across a sample while performing an LBIC scan, the area surrounding the illuminated beam spot also generates minority carriers thus reducing the voltage drop to the surrounding areas. The lateral flow of the beam induced current would thus be reduced. Further discrimination between collection loss mechanisms can be achieved by applying fixed voltage biases and uniform light biases across the cell at the different excitation wavelengths [5].

By measuring the LBIC response at constant cell voltage (potentiostatic mode) or constant current (galvanostatic mode) after applying an additional beam intensity over the cell's bias light, the sheet resistance, local potential and shunt resistance could be analysed [9]. In a further development called the CELLO technique, a sinusoidally modulated infrared laser beam is used to cause small local perturbations in the current (galvanostatic control) or voltage (potentiostatic control) of a light biased cell. The laser beam is continuously

(dynamically) scanned using a set of beam steering mirrors. Several sets of data at pre-set current and voltage values are used to calculate maps of the local series and shunt resistance, diffusion length and back surface field [10]. The authors of the CELLO technique also claim to be able to construct local *I-V* curves for each point on the cell.

A technique known as Spectrally Resolved LBIC (SR-LBIC) developed at Fraunhofer ISE (Institute for Solar Energy), makes use of high-speed simultaneous LBIC measurements at a series of diode laser wavelengths. To distinguish the LBIC signals from each other the continuously scanned laser beams are modulated and digitally demodulated. The local perturbations caused by the modulated laser beams are used to obtain topographies of the effective diffusion length of multicrystalline Si solar cells [11].

LBIC techniques that can image strong and weak shunts have been used in conjunction with the Dark Lock-in Thermography (DLT) technique to correlate and improve identification techniques [12]. The light biasing used in LBIC techniques also opens up the possibility of using the Illuminated Lock-in Thermography (ILT) technique to correlate LBIC shunt topographies.

When modulating the beam intensity while performing LBIC scans, the phase shift between the excess carrier density obtained from the LBIC signal and the beam intensity can also be measured and imaged. This Modulated Free Carrier Absorption (MFCA) method developed at the Fraunhofer ISE, has been used to image carrier lifetimes in multicrystalline Si material [13]. In a similar technique

under development by Pernau et al [14], four sinusoidally modulated laser beams with different wavelengths are used.

3.3.4. Standard LBIC Scanning

The main aim of many standard LBIC scanning techniques is to reduce the size of the beam probe to near diffraction limits. This is done especially when very high resolution is needed to image defects in polycrystalline material that has a very fine crystalline and defect structure [1, 7, 6]

3.4. Summary

The list of publications listed in the references only represents a small subset of the activities of LBIC investigations over the years. Going through the list of publications, it is clear that the original standard LBIC techniques have found widespread application, and far-reaching and important developments of the technique have taken place over the years. This was driven by natural progression as well as the availability of newly developed advanced measurement equipment. Several techniques such as Lock-in Thermography and the use of infrared cameras have developed as complimentary techniques to advanced LBIC techniques. Development of new LBIC techniques is ongoing. One of the main challenges for this application is for its use in an industrial solar cell production line. To achieve this, the overall measurement speed must be improved. As an accurate contactless evaluation tool that is able to image spatially distributed defects in cell material, this method remains promising.

3.5. References

1. J.F. Hiltner, J.R. Sites, Proceedings of the 16th European Photovoltaic Solar Energy Conference, 630-633 (2000)
2. F.J. Vorster, E.E. van Dyk, Review of Scientific Instruments, accepted for publication in 2007.
3. L.A. Verhoef et al, Proceedings of the 21st IEEE Photovoltaic Specialist Conference, 793-799 (1990)
4. P.G. Lasswell and B.C. Plunkett, Proceedings of the 15th IEEE Photovoltaic Specialist Conference, 1021-1024 (1981)
5. S. Damaskinos, Solar Cells, 26, 151 -158
6. J.R. Sites, T.J. Hiltner, Proceedings of the 31th IEEE Photovoltaic Specialist Conference, 199-204 (2005)
7. J. Marek, “Quantitative Evaluation of LBIC Signals at Grain Boundaries” Proceedings of the 17th IEEE Photovoltaic Specialist Conference, 1207-1212 (1984)
8. M. Stemmer, S. Martinuzzi, “Minority Carrier Diffusion Length Mapping of Extended Crystallographic Defects in Semiconductor Silicon” Inst Phys. Conf. Ser 135, 239 (1993)
9. S. Litvineko et al, Materials Science and Engineering, B71, 238-243, (2000)
10. J. Carstensen et al, Solar Energy Materials and Solar Cells, 76, (2003)
11. W. Warta et al, Proceedings of the 2nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion, 1650-1653 (1998)
12. A. Kaminski et al, Journal of Physics: Condensed Matter **16**, S9–S18 (2004)

13. WWW-Link:

http://www.ise.fraunhofer.de/english/fields/field2/mb7/tool/mfca/mfca.html

14. Th. Pernau, P. Fath, E Bucher, Proceedings of the 29th IEEE Photovoltaic Specialist Conference, 442-445 (2002)