`CELLO` - LBIC MEASUREMENT TECHNIQUE

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ABSTRACT

LBIC measurement for solar cell local characterization, called `CELLO` has been developed and tested on mono- and multi-crystalline Si solar cells. A solar cell is illuminated with near to 1.5 AM light intensity and additionally subjected toan intensity modulated and scanning local illumination by a focused IR-laser. The linear response (current or potential) of the solar cell is measured for various fixed global conditions (different preset voltage or current values) 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 theoretical approach to this technique will be discussed and the applicability of this new solar cells characterization tool will be demonstrated.

1 INTRODUCTION

I studied an advanced LBIC measurement technique `CELLO` on the theoretical base and I would like to design the whole device next year.

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 PVScan 5000 by NREL [1] can be used to map defects and grain boundaries using reflectivity data, and special surface etching, and minority carriers 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 [2,3].

2 ANALYSE

The aim of this paper is to describe a new advanced LBIC measurement technique, called ‘CELLO’, which is, to the best of our knowledge, the first tool that 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 materialand process-induced, efficiency relevant defects. In principle, the data obtained could also be used to simulate the behavior of the complete solar cell for any set of technology parameters.

3 THE MEASUREMENT TECHNIQUE

A simplified schematic diagram of CELLO is depicted in Fig. 1.

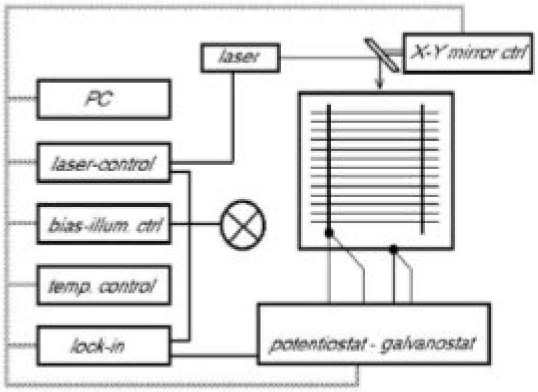

Fig. 1: *The `CELLO` system*

The solar cell is illuminated homogeneously by a set of halogen lamps with near to 1.5 AM intensity. Additionally, a sinusoidally modulated infrared laser beam is focused onto the sample through a piezo-controlled mirror and provides a X-Y-scanned local perturbation. A potentiostat/galvanostat is used to pre-set the voltage (potentiostatic control) or the current (galvanostatic control) of the solar cell. A lock-in amplifier, synchronized to the laser beam modulation signal, is used to measure the solar cell response to the laser beam perturbation – a.c. current or voltage, respectively. The `CELLO` technique essentially measures the global response of a solar cell to local perturbations for several pre-set working points of the cell as shown in Fig. 2. `CELLO` works in the linear regime by analyzing the small signal response of the solar cell. Several sets of data for $dI(V_{cell},x,y)$ and $dV(I_{cell},x,y)$ are measured for pre-set constant values of V_{cell} or I_{cell}, according to Fig. 2.

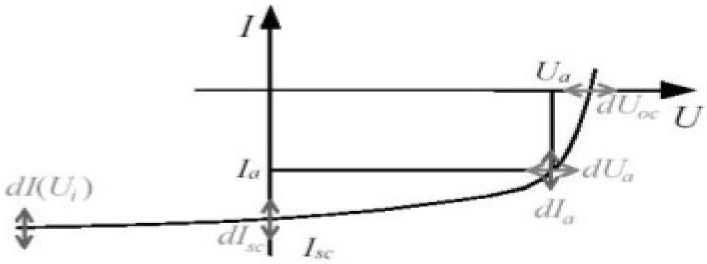

Fig. 2: *Linear response of the current (potentiostatic control) or of the voltage (galvanostatic control) to an additional local illumination.*

The amplitude of the modulated laser beam can be expressed as a current *dIph* (the photo current signal on the solar cell for infinite diffusion length and neglectable recombination at the back surface) and the ratios dI/dI_{ph} (V_{cell},x,y) and dV/dI_{ph} (I_{cell},x,y) represent local transfer functions. The data obtained are fitted to a complete (and partially novel) model of the solar cell which allows:

- to draw solar cell surface maps of the measured data.
- to calculate maps of the local series- and shunt resistances, diffusion length and back-surface field.
- to construct the complete local IV-curve for each point of the solar cell.

4 MODELINGS AND CALCULATIONS

Assuming that sufficient data sets have been obtained experimentally, the raw data must be converted into local parameters of the solar cell. This is done with the help of the equivalent circuit diagram as shown in Fig. 3.

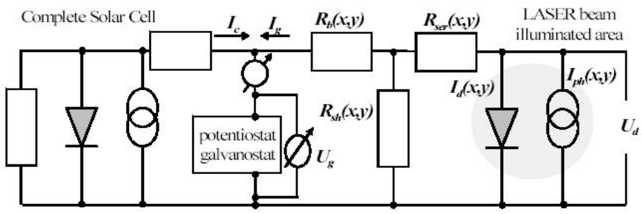

Fig. 3: *Equivalent circuit for the interpretation and evaluation of the `CELLO` measurements.*

The solar cell is divided in a global part (denoted "complete solar cell" on the left) and a local part (on the right) which are distinguished by different sets of parameters for their respective elements. Since we are looking locally at a very small part of the solar cell (the laser beam spot), the global part can be described by a constant set of parameters and is known by measuring the IV curve.

To a sufficiently good approximation, any local part (with a locally changing set of parameters) can be added without changing the global values. In a conventional equivalent circuit diagram both parts would be connected via one resistor; but this proved not to be sufficient for the present task. There are two important modifications in the equivalent circuit shown in Fig. 3 with respect to conventional diagrams:

- the two parts of the cell are connected via two resistors as shown,
- the combination of the local diode and the local current source (modeling the photo current induced by the laser) is not described by the usual equations, but couples the diode current, I_d, and the photo-currents I_{ph} and $I_{ph,0}$.

Here $I_{ph,0}$ and I_{ph} are the generated and the collected photo currents for a given point of the solar cell surface, respectively. $C_{rec}I_d^3$ represents the current due to local recombination losses with C_{rec} as a fit parameter. This equation essentially describes the lateral diffusion and recombination of minority carriers and expresses a sensitivity of the solar cell to gradients of the diffusion length.

5 RESULTS

The `CELLO` equipment and its control program were repeatedly tested with various silicon *pn*-junction solar cells and are currently extensively used to test solar cells from different producer. The operation of `CELLO` will be illustrated here by the series of maps which can be obtained from one measurement on a solar cell, made on multicrystalline silicon wafer. Maps of the linear current responses dI_1, dI_2, and dI_3 at $U = -250\ mV,\ 0\ mV\ a\ 300\ mV$ are illustrated on the Figure 4, 5, and 6. Maps of the voltage responses dU_1 a dU_2 measured galvanostatically at fixed cell currents $I = 100\ mA$ and $300\ mA$ are illustrated on the Figure 7 and 8.

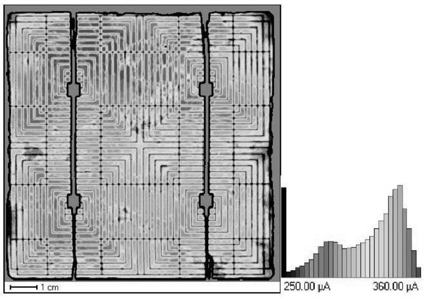

Fig. 4: *Map of the linear current response dI_1 obtained at $U = -250mV$*

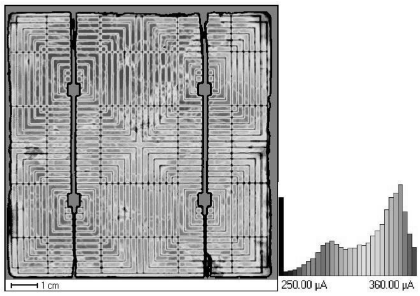

Fig. 5: *Map of the linear current response dI_2 obtained at$U = 0mV$*

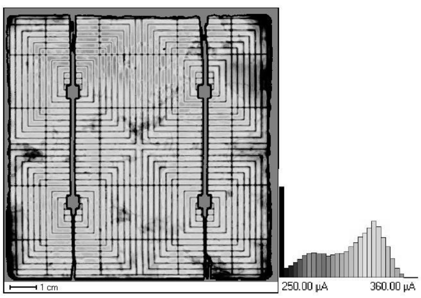

Fig. 6: *Map of the linear current response dI_3 obtained at $U = 300mV$*

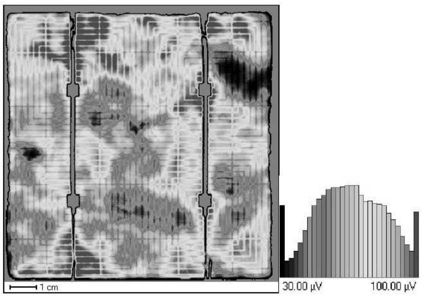

Fig. 7: *Map of the voltage response dU_1 measured at $I = 100mA$*

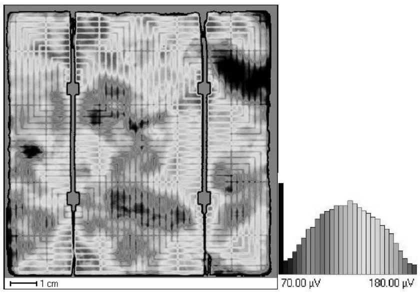

Fig. 8: *Map of the voltage response dU_2 measured at $I = 300mA$*

6 CONCLUSIONS

These first results demonstrate that `CELLO` is a universal method for detecting and characterizing local defects in all solar cells since it is not restricted to silicon or crystalline materials. Including `CELLO` results into a detailed simulation program for solar cells, should provide a powerful tool for improving the efficiency of solar cells since this would allow to systematically optimize the technology for particular materials and processes.

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