INFRARED THERMOGRAPHY AS A CHARACTERISATION TOOL OF SILICON SOLAR CELLS

Y. SAYAD

Département de Sciences de la Matière, Faculté des Sciences et Technologie, Université Mohamed Chérif Messaâdia, Souk-Ahras, 41000. Email : sayad.yassine@gmail.com

Abstract:

Recently, independent research groups have developed camera based techniques to evaluate local silicon solar cells parameters. Among these techniques, Dark Lock-In Thermography DLIT is, conventionally, used to evaluate shunts and minority carrier lifetime, but, since few years DLIT is becoming a versatile technique capable to do full solar cell characterisation.

Here, we apply a DLIT based method to evaluate solar cell local dark parameters. The method is completed by external evaluation of local series resistance from two electroluminescence images taken under different conditions.

Keywords: IR Thermography, electroluminescence, solar cell, local parameters.

Introduction

The widely accepted model of silicon solar cells is the so-called two-diode model, eq.1. In this model the first diode represents diffusion current with a saturation current J_{01} and unity ideality factor, and a second diode representing recombination current with a saturation current J_{02} and an ideality factor n (after [1] it equals to 2 in ideal conditions). In dark, these two terms have to be summed up to give the total current

$$J(V) = J_{01}\, exp\left(\frac{eV}{kT}\right) + J_{02}\, exp\left(\frac{eV}{nkT}\right) = J_{diff} + J_{rec} \qquad \text{eq.1}$$

Where V is the applied voltage, and when we take into account voltage drop at series resistanceR_s, and current loss in parallel resistance $R_p$as a third current path, total current became

$$J(V) = J_{01}\, exp\left(\frac{e(V-R_s.J)}{kT}\right) + J_{02}\, exp\left(\frac{e(V-R_s.J)}{nkT}\right) + \frac{V-R_s.J}{R_p} = J_{diff} + J_{rec} + J_G$$
eq.2

In general, the model parameters $\left(J_{01}, J_{02}, R_s \text{ and } R_p\right)$ are measured globally from current-voltage curves, but since silicon cells as large area devices, these parameters varies significantly from one position to another. Recently, several imaging techniques allowing local evaluation of these parameters has been developed, like Dark Lock-In Thermography DLIT [2], luminescence techniques [3], Light Beam Induced Current LBIC [4].

In this work, we apply a recently developed method [5] to determine local $J_{01}(x,y), J_{02}(x,y)$and $R_p(x,y)$ $\left(\text{or } G_p(x,y) = \frac{1}{R_p(x,y)}\right)$ parameters from IR thermography measurements in dark. We will, also, compare two different methods for local series resistance calculation $R_s(x,y)$ [6,7].

Calculation

The used method for calculation of two-diode model parameters is based on Dark Lock-In Thermography DLIT measurements [5]. In this method three temperature distribution images of the silicon solar cell have to be taken under three direct biases ($V_1 = 0.50$, $V_2 = 0.55$ and $V_3 = 0.60V$) and one image under reverse bias($V_r = -1V$), see Fig.1. These DLIT images are, first, converted to local dissipated power $p(x, y)$ images, then, knowing local series resistance $R_s(x, y)$, one calculates local voltage $V(x, y)$ and local current $J(x, y)$ for each local diode voltage $V(x, y)$as following,

$$J(x, y) = p(x, y)/V(x, y) \qquad \text{eq.3}$$

$$V(x, y) = V_a - R_s(x, y).J(x, y) \qquad \text{eq.4}$$

In this work, we have applied two different methods to evaluate local series resistance $R_s(x, y)$. In first method, called RESI [7], the local series resistance is calculated using one DLIT image and a local diode voltage image V(x,y), which is obtained by evaluating two electroluminescence EL images, from which one is taken under the same conditions, whereas, in the second method [6] one uses two electroluminescence images taken under two different direct biases.

From local voltage $V(x, y)$ and local current $J(x, y)$ images, taken under -1V, one determine local parallel conductance $Gp(x, y)$,

$$Gp(x, y) = \frac{J_r(x,y)}{V_r(x,y)} \qquad \text{eq.5}$$

Then, one can calculate ohmic current at each applied voltage using

$$J_G(x, y, V_a) = G_p(x, y).V(x, y, V_a) \qquad \text{eq.6}$$

Then, using an iterative procedure [6], one determine (x, y) , $J_{01}(x, y)$ and $J_{02}(x, y)$ local parameters from the remaining images,

$$n^m(x, y) = \frac{\frac{e}{kT}\left(V_2(x,y) - V_1(x,y)\right)}{ln\left(\frac{J_2(x,y) - J_{diff}^{m-1}(x,y,V_2) - J_G(x,y,V_2)}{J_1(x,y) - J_{diff}^{m-1}(x,y,V_1) - J_G(x,y,V_1)}\right)} \qquad \text{eq.7}$$

$$J_{02}{}^m(x, y) = \frac{J_2(x,y) - J_{diff}^{m-1}(x,y,V_2) - J_G(x,y,V_2)}{exp\left(\frac{eV_2(x,y)}{kT}\right)} \qquad \text{eq.8}$$

$$J_{01}{}^m(x, y) = \frac{J_3(x,y) - J_{rec}^{m-1}(x,y,V_3) - J_G(x,y,V_3)}{exp\left(\frac{eV_3(x,y)}{kT}\right)} \qquad \text{eq.9}$$

Results and Discussion

In our experiment, we have used a standard industrial p-type multi-crystalline solar cell, of size$15.6\ cm \times 15.6\ cm$, with three bus-bars on front and full aluminium at rear surface. Infrared thermography images were made using high sensitivity thermocamera [8] at room temperature under 0.50V, 0.55, 0.60 and -1.0 V biases, the resulted Fig.1.

Local resistance $R_s(x, y)$ were calculated from two electroluminescence images taken under 0.55 and 0.60 V biases by applying Breitenstein method [6] using an adjusted Fuyuki factor [9] $f = 4.2\ 10^{-19}$ to find a mean series resistance value, of $0.47\Omega.cm^2$, that equals the global one. The resulted local series resistance image scaled to $1.5\ \Omega.cm^2$is shown in Fig.2, were one can see a high values at edges and at some placed in the middle. We note that one obtains a similar image by using RESI method [7].

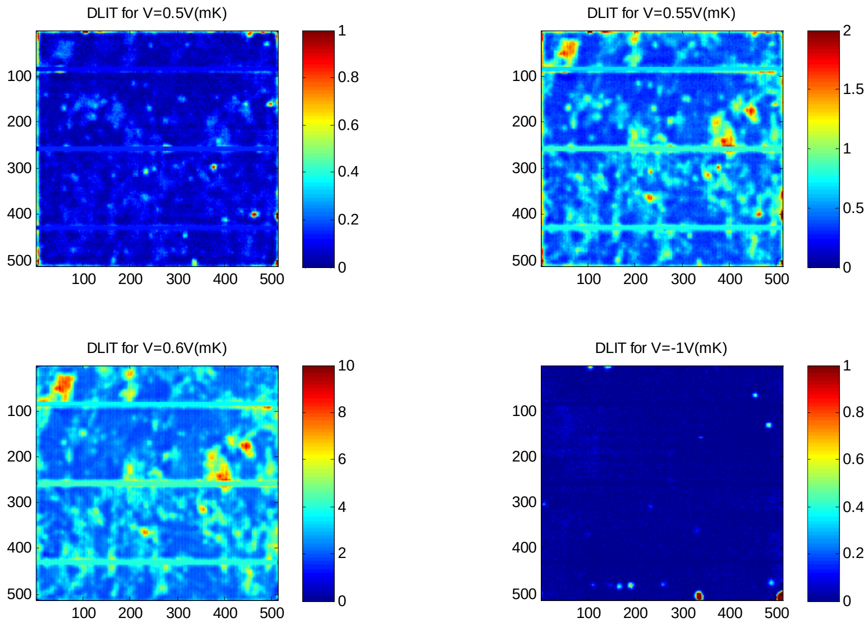

Fig. 1. Measured DLIT images under 500, 550, 600 and -1000mV polarisation voltages.

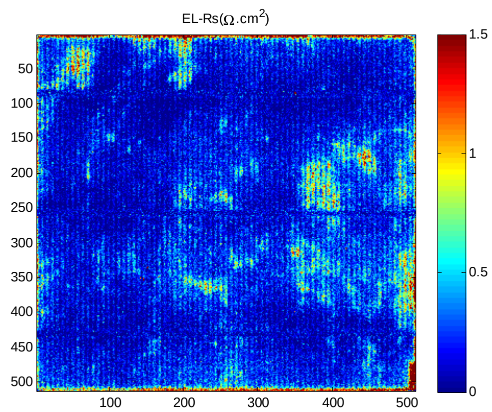

Fig.2. Local series resistance calculated from two electroluminescence images.

Next, local series resistance and DLIT images are used to calculate local conductance $G_p(x,y)$, local ideality factor $n(x,y)$, saturation diffusion and recombination currents $J_{01}(x,y)$, $J_{02}(x,y)$ using equations 3-9. The obtained images are shown in Fig.3.

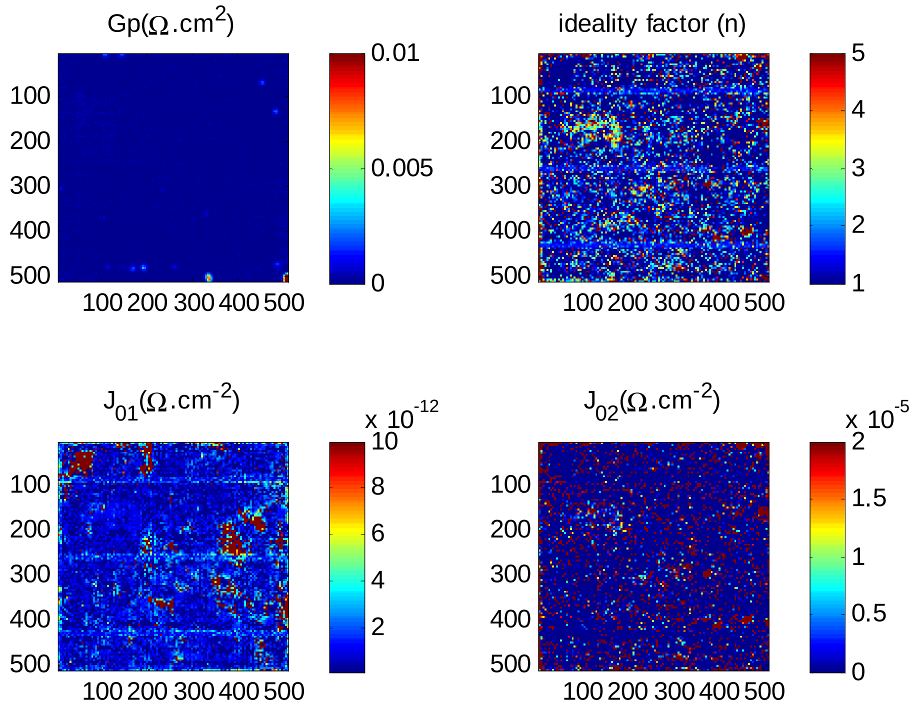

Fig. 3. Local conductance, ideality factor, diffusion current and recombination current images calculated from DLIT images under 0.5, 0.55, 0.60 and -1V biases.

Conclusion

Thanks to infrared thermography, fast and reliable evaluation of local parameters in silicon solar cells is becoming a reality. In this technique, we just need to process four temperature distribution images to extract dark parameters, which make this technique very suitable for in-line characterisation of industrial solar cells.

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