A simple solar cell series resistance measurement method

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Résumé. — On décrit une technique nouvelle et simple pour mesurer la résistance série d'une Cellule Solaire. Ce procédé ne demande que des mesures $I(V)$ à l'obscurité et un dispositif expérimental simple, comprenant une résistance standard étalonnée. On discute aussi cette méthode par rapport à d'autres utilisées couramment.

Abstract. — A new and simple technique to evaluate the series resistance of a solar cell is described. This procedure only needs dark $I(V)$ measurements and a simple experimental-arrangement including a calibrated standard resistor. Comparison with other commonly used methods is also discussed.

The series resistance of a solar cell is a parameter of special interest because of its influence in the maximum available power and fill factor. It is also a parameter that indicates in some way the quality of the device and can be used as production test.

There exists a number of methods to evaluate the series resistance of the cells based on $I(V)$ characteristics, most of them using more than one $I(V)$ curve (Refs. 1, 2).

The new method is based on the dark $I(V)$ characteristics model that can be written with the help of figure 1, where R_s is the series resistance, R_{sh} is the shunt resistance and D1 and D2 — are the two diodes accounting for Shockley diffusion term (D1), and Space Charge Region recombination term (D2).
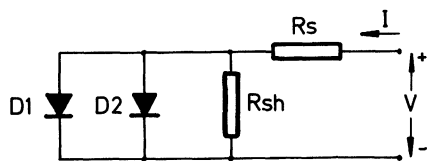

Fig. 1. — Circuital model of a solar cell corresponding to equation 1.

The equation relating I with V in figure 1 can be written as follows

$$I = \sum_{i=1}^{2} I_{0i} \left[\exp\left[\frac{q(V - IR_s)}{n_i\,kT} \right] - 1 \right] + \frac{V - IR_s}{R_{sh}} \quad (1)$$

where the first term, $i = 1$, is the current flowing

through D1 and the second, $i = 2$, is the current that flows through D2. The last term takes into account the shunt current which can be an important effect for low bias levels.

Our method is based in the experimental arrangement shown in figure 2 where only the addition of an external calibrated resistor R_{ext} is needed. Obviously, the model given in equation 1 is still valid and only R_s must-be replaced by $(R_s + R_{ext})$. Series resistance effects appears for the higher voltage values where the term given by $i = 2$ and the last one can be neglected in front of the diffusion term modified by the series resistance effect.
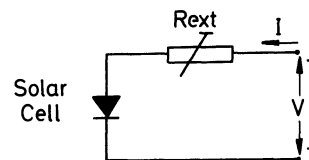
Fig. 2. — Experimental-arrangement proposed.

Equation 1 can now be written as follows :

$$\frac{I}{I_{01}} = \exp\left[\frac{q[V - I(R_s + R_{ext})]}{KT} \right]. \quad (2)$$

For several given values of the external resistor R_{ext}, a set of $I(V)$ curves is obtained being R_{ext} the parameter. Figure 3 shows a set of experimentally obtained $I(V)$ curves in dark conditions.

In order to obtain the series resistance R_s, two

strategies are possible, giving origin to two methods : A (constant voltage) and B (constant current).

Method A : Let us consider two $I(V)$ characteristics of figure 3, corresponding to R_{ext1} and R_{ext2} ; We can easily determine the current values I_1 and I_2 of each characteristic corresponding to the same voltage value V_A.

With the help of equation 2 it can be written that

$$R_s = \frac{\dfrac{KT}{q}\ln\left[\dfrac{I_2}{I_1}\right] + I_2 R_{ext2} - I_1 R_{ext1}}{I_1 - I_2}. \qquad (3)$$

Equation 3 gives R_s for a given value of I_1, I_2, R_{ext1} and R_{ext2}. This method needs only two experimental dark measurements for constant voltage. Obviously, one resistor can be null ($R_{ext1} = 0$, for example).
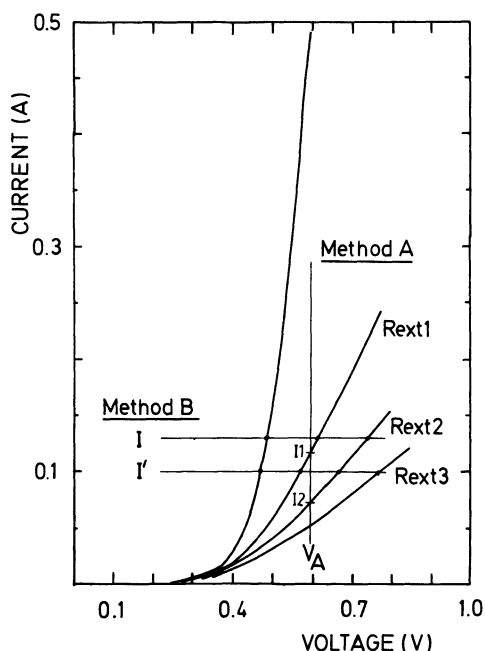

Fig. 3. — Set of experimental $I(V)$ curves in dark conditions. R_{ext} is the parameter.

Method B : Conversely the shape of the curves of figure 3 suggest that R_s could be also measured taking the voltage values corresponding to different $I(V)$ curves for the same current-value. In such conditions equation 2 can be written as follows

$$R_{ext} + R_s = \frac{1}{I}\left[V + \frac{KT}{q}\ln\left[\frac{I_{01}}{I}\right]\right] \qquad (4)$$

for several values of R_{ext}, the function R_{ext} vs. V is a straight line with slope $1/I$. If, further, we take two current values, two sets of points are obtained that can be plotted as it is shown in figure 4. There are two
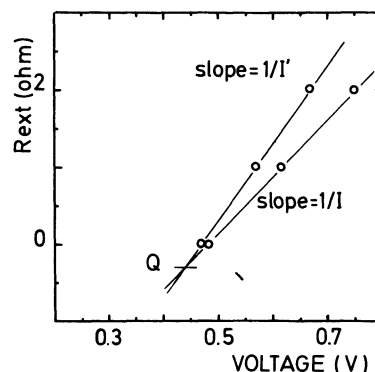

Fig. 4. — Implementation of method B.

straight lines of slopes $1/I$ and $1/I'$ intersecting at point Q. The ordinate of this point is

$$R' = -R_s + \frac{KT}{q(I' - I)}\ln(I/I') \qquad (5)$$

R' can be easily and accurately calculated using a simple interpolation technique, then R_s value can be obtained from equation 5.

Table I shows the results obtained with methods A and B, on a commercially available cell indicating in each case the values of the parameters R_{ext1}, R_{ext2}, V_A, I, I' involved.

The same cell has been analysed using the Wolf and Handy methods (Ref. 1.2) and a numerical method

Table I. — *Results on a commercial cell.*

Method A	Constant voltage V_A (V)		R_{ext1} (Ω)	R_{ext2} (Ω)	R_s (Ω)
	0'8		0	1	0'356
	0'8		2	3	0'374
	0'9		1	2	0'378
	0'925		1	2	0'385
Method B	I (A)	I' (A)	R_s (Ω)	Method	R_s (Ω)
	0'1375	0'1	0'34	Wolf	0'388
	0'275	0'1375	0'364	Handy	0'381
	0'275	0'25	0'404	Numerical	0'373

based on optimization algorithms (Ref. 3). Table I, also, includes these results.

We have checked the methods A and B with a terrestrial silicon solar cell. In such a device, series resistance values of the order of $0'01\ \Omega$ are expected.

This fact makes very inaccurate the results obtained with the Wolf and Handy methods. The results are shown in table II.

Table II. — *Results on a terrestrial solar cell.*

Method	Series resistance (Ω)
Method A $V_A = 0'575$ V $R_{ext1} = 0\ \Omega$ $R_{ext2} = 1\ \Omega$	$0'0407$
Method B $I = 0'175$ A $I' = 0'15$ A	$0'0452$
Numerical (Ref. 3)	$0'0392$

The results shown in tables I and II suggest some comments :

a) The experimental measurement procedure uses a calibrated resistor decade (Danbridge CDR4/BCDE) with $\pm$ 2 % tolerance in the range in which we have worked.

The precision of the current and voltage measurements is $\pm$ $0'5$ % in the range of measurement. Those precisions and tolerances allow to say that a $\pm$ 3 % accuracy is predicted for method A around the values given in the tables I and II.

The evaluation of the accuracy of the method B is not as simple than that of method A because the calculation procedure uses a numerical routine. Nevertheless the experimental arrangement uses the same equipments and the results obtained with method B are inside the tolerance of the values obtained with method A.

b) The values of R_s obtained by the two methods present a certain dispersion that can not be atributed to measurement innaccuracies. It is well known (Ref. 4) that the series resistance depends on the value of the current used in the measurement, more precisely, R_s increases when the current increases. This behaviour can be seen in our results of table I.

Conclusions.

We can conclude that the use of the two proposed methods is simple and the experimental complexity is lower than the other methods commonly used. The limitations of our methods are mainly two. First, these methods are not applicable when the series resistance is influenced by the photoconductivity of the upper solar cell layer. On the other hand, the methods applies only to the solar cells with $I(V)$ characteristics that can be represented by equation 1 with the diode factor of the diffusion term equal to the unity.

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