ANALYSIS OF ELECTRICAL PROPERTIES OF SEMICONDUCTOR SOLAR CELLS

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1. Introduction

Photovoltaic solar energy is one of the main constituents for solving the future energy problems. Silicon photovoltaic modules play a central role in providing the electricity in the world together with several other important forms of renewable energy. In our work projects we study problems connected with the improvement of the solar cell (SC) performance – forming the SC structure, passivation of defects, optimization of the light trapping and similar. In this paper the study the SC performance is based on the two diode model of a solar cellI-V function [1-7].We construct optimized theoretical model of experimental I-V data based on the two diode approach. From this model we extract the SC parameters and study their development during the technological treatment of the SC structure.

The two diode equivalent circuit model of the SC is shown in Fig. 1 and its mathematical description is given by Eq.(1). The terminal current I of the cell is modelled as a superposition of several terms: the photogenerated current I_{ph}, the diffusion-diode current $I_{d1}\left(e^{\frac{q(V+R_sI)}{n_1kT}}-1\right)$,the recombination-diode current $I_{d2}\left(e^{\frac{q(V+R_sI)}{n_2kT}}-1\right)$ andthe current $I_{sh}=\frac{V+R_sI}{R_{sh}}$ through the shunt resistance R_{sh}. I_{d1} is the reverse saturation current and n_1 is the ideality factor of the diffusion diode. I_{d2} is the reverse saturation current and n_2 is the ideality factor of the recombination diode, k is Boltzmann constant, q is the elementary charge and T is the p-n junction temperature.

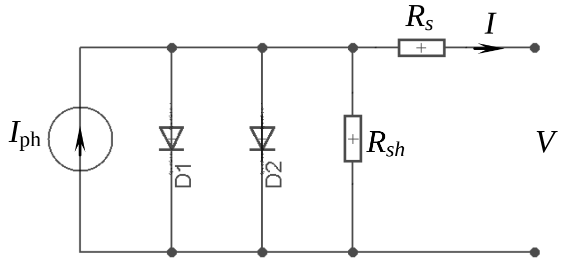

Fig. 1. *Equivalent circuit model.*

Series resistance R_s of the SC is influenced by the movement of charges in the structure of SC and by the contact resistance. Shunt resistance is influenced by the technological steps in the SC forming andits values are critical at low light levels due to the low light-generated current.

Both resistive effects reduce the SC efficiency due to the dissipation of power (reduce the fill factor).

The parameters in the two-diode model depend onthe irradiance and SC temperature. We constructed computer controlled measuring system for the determination of the I-V curves of the solar cells and implemented software solution for theoretical modelling of the SC properties based on the experimental data and the two diode model.

$$I(V) = I_{ph} - I_{d1}\left(e^{\frac{q(V+R_s I)}{n_1 kT}} - 1\right) - I_{d2}\left(e^{\frac{q(V+R_s I)}{n_2 kT}} - 1\right) - \frac{V + R_s I}{R_{sh}} \quad (1)$$

The efficiency of the SC η is determined by Eq.(2).

$$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}}, \quad (2)$$

where the fill factor FF is defined by [1]

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}}. \quad (3)$$

and P_{in} is the input power. In Eq.(3) V_m and I_m correspond to the maximal power P_m of the SC, V_{oc} is open circuit voltage and I_{sc} is short-circuit current. These parameters are determined from optimized theoretical model of I-V curve (see Fig. 4).

2. Experimental

Measuring system for the determination of the I-V curves of the SC consists of the light source with defined spectral and power characteristics Oriel Sol3A Solar Simulator (Newport, USA) and the measure unit Keithley 2400 Source meter. The K2400 source meter is configured by a sequence of SCPI commands via GPIB/USB interface. Experimental I-V data are analysed in two steps. In the first step parameters of Eq.(1) are visually modified in a graphical user interface in order to reach good initial estimation of the I-V theoretical model. In the following step the I-V estimation is refined by the genetic algorithm (VIMSO method [8]. In this optimization procedure parameters of Eq.(1) are coded into chromosomes of genetic algorithm and their fitness is computed by comparing theoretical I-V curve with the experimental data.

3. Results and discussion

The influence of serial and parallel resistance in the I-V curve of SC is shown in Fig. 2. Values of the simulation parameters used in Fig. 2 and Fig. 3 are in Table 1. With increasing values of the series resistance R_s the shape of the SC I-V curve decrease, the power is dissipated, fill factor decreases and degrade the SC efficiency (Fig. 2a). In Fig. 2b) the simulation of I-V curve of the SC by the modification of the G_{sh} value is shown. With increasing G_{sh} the solar cell performance degrades and the efficiency decreases too.

In Fig. 3 the simulated two diode model development with changes of the reverse saturation current I_{d1} and the ideality factor n_1 of the diffusion diode D1 is illustrated. With increasing value of the I_{d1} current the V_{oc} decreases significantly and degrades of the SC efficiency.

Tab. 1.*Values of the simulated parameters of I-V curves in Fig.2 and Fig.3.*

	series				
	a	b	c	d	e
R_s	0.022	0.027	0.032	0.037	0.042
G_{sh}	0.0123	0.0323	0.0523	0.0723	0.0923
I_{d1}	0.8889	0.9819	1.0749	1.1679	1.2609
n_1	1.634	1.639	1.644	1.649	1.654

The ideality factor of a diode is a measure of how closely the real diode models the ideal diode equation. Ideal diode model is based on the band-to-band recombination or recombination by trap states in the bulk area of the SC.

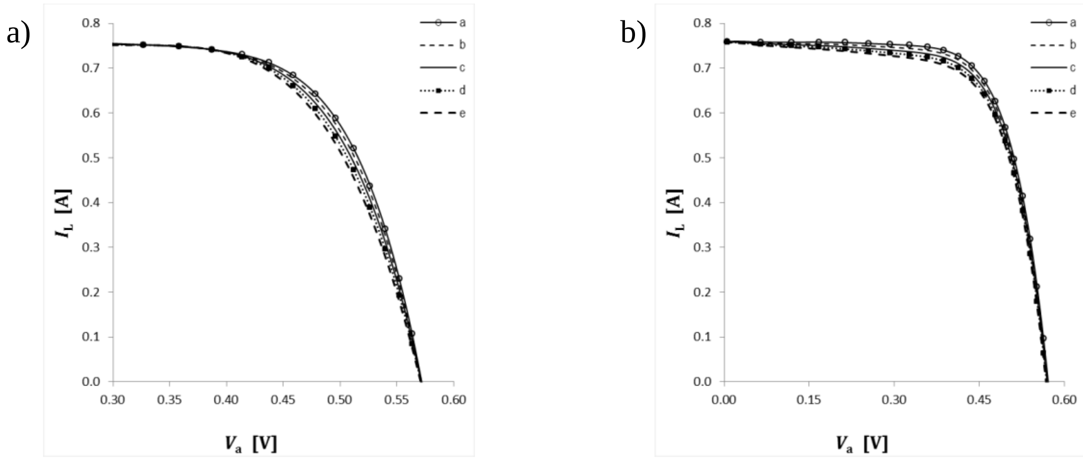

Fig. 2. *Influence of* R_s(a) *and* $G_{sh} = 1/R_{sh}$ (b) *on the shape of I-V curve of solar cell.*

However the recombination process is not so simple and another recombination processes and the diffusion processes introduce changes in the ideality factors. In Fig. 3b) the influence of the ideality factor n_1 is shown. By modelling of the n_1 value we can study the properties of diffusionprocesses in given structure of SC. Changes of the I-V curve with the modification of the I_{d2} and n_2 for the recombination diode are similar and not shown here.

By the modelling of the SC two diode model parameters we can study the influence of the technological treatment operations on the solar cell properties and its behaviour under various external conditions (irradiance, temperature and similar.)

a) b)

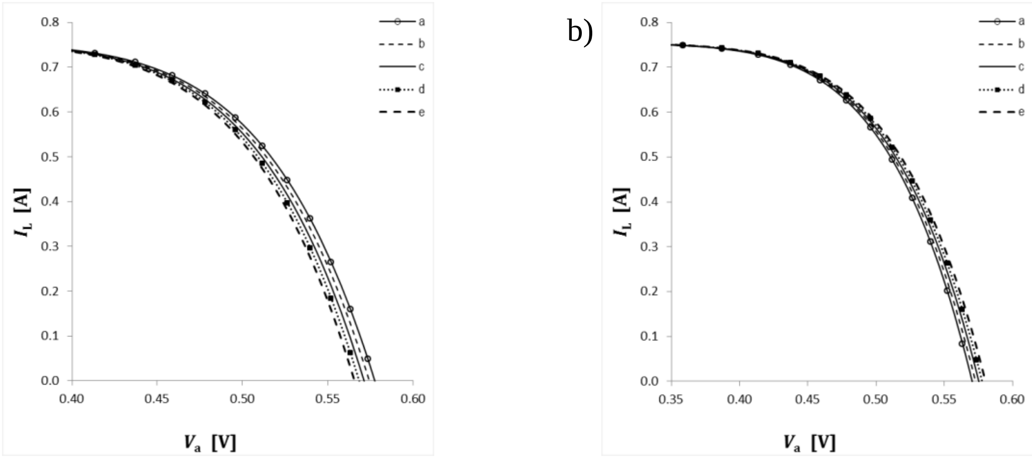

Fig. 3. *Influence of* I_{d1} (a) *and* n_1 (b) *on the shape of I-V curve of solar cell.*

In Fig. 4 optimized theoretical model of the I-V curve is shown. From this model we can compute power $P(V)$, determine V_m, I_m, V_{oc} and I_{SC} characteristics needed for the solar cell efficiency estimation from Eq.(2).

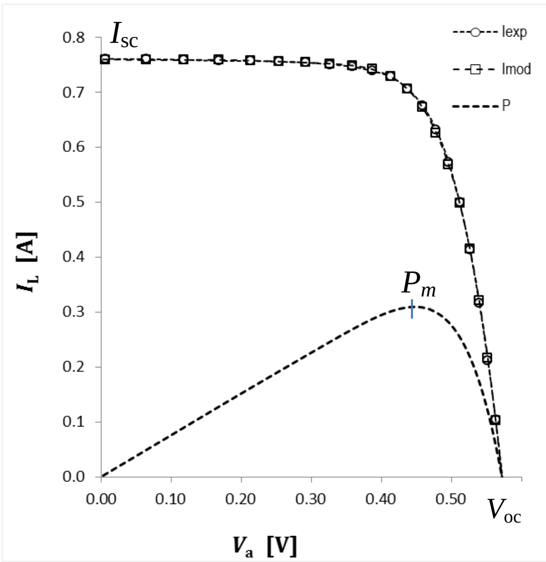

Fig. 4. *Optimized theoretical model based on the two diode I-V curve equation.*

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