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Dark and under illumination electric PV parameters of modified solar cells

The paper presents and compares the top electrode topology influence of PV poly-Si samples on parasitic elements described by simple one-diode model. The results of solar cell samples measured at the dark and under illumination conditions were acquired. The measurements at the dark conditions were focused to calculation of the series resistance and its behavior at temperature range from 25°C to 75°C. The output parameters were calculated from I-V characteristics measured under AM1,5G illumination and compared.

Keywords: PV cells, poly-Si, top electrode, grain boundaries

I. INTRODUCTION

Polycrystalline semiconductors consist of small monocrystalline areas. It is caused by cooling process and conditions (mainly the rate of cooling) which are crucial for the dimensions and orientation of areas called grains. The grains are randomly oriented to each other and connected by boundary between two or more neighbor grains [1].

The boundaries between grains may have different properties. If they consist of amount of defects, then boundaries represent places with considerably disturbed lattice. This circumstance can lead to the change of its character of conductivity (e.g. from donor to acceptor if the grains are the N-type) and also the impurities may precipitate to the grain boundaries during crystallization process of bulk. Furthermore, grain boundaries may behave as areas of similar type but with different resistance or as areas of different types or even may be insulating [2, 3].

The presence of active defects and discontinuous bonds contribute to the recombination of minority carriers at grain boundaries which tend to behave as a potential barrier. The PV devices based on poly-Si materials as well as other semiconductor devices markedly depend on the properties of the grain boundaries whereby its behavior has great influence on life time and diffusion length [3]. Lower conversion efficiency of poly-Si compared to the mono-Si PV cells is ascribed to the presence of these boundaries between grains. Whole PV cell is so separated to the sub-cells with a resulting dispersion of characterized parameters [4].

Technology of commercial available PV cells uses a classical topology of top electrode, so called “H-pattern” (Fig.3a). Within the design of top electrode is necessary to take into account the maximal collection of electrons with appropriate arrangement of conductive wires nevertheless with considering minimal shading of cell´s emitter (commonly about 5% of whole plane). Standard distance between two conductive wires connected to the bus is about 3 mm with 150-200 μm of width.

In this paper the main focus is devoted to the poly-Si samples with alternative pattern of top electrode which to a great extent follows the grain boundaries and its influence on parasitic elements in comparison with the classic pattern.

II. ELECTRIC MEASUREMENT OF PHOTOVOLTAIC STRUCTURE

The DC electric measurements are commonly used for the purpose of characterization the behavior of solar cells and their properties in the dark and under illumination. The circuit equivalent elements are obtained with finite accuracy by investigation of I-V curve. The results can provide the information about components like series and parallel resistance or diode currents. Also measurement at illumination finally leads to the output determination of PV cell or module [5].

STATIC (DC) MEASUREMENT

An ideal diode is described by Shockley relation thus without presence of parasitic elements. But parameters of real diode are influenced just by the parasitic elements. I-V curve of PV cell in the dark (under illumination too) is influenced by series resistance R_S and parallel (shunt) resistance R_P (1). Parallel resistance R_P dominates in low voltage area of I-V characteristic (and in the reverse area). The R_S dominates in the high voltage area which is represented as deviation from linear part of I-V curve dominated by diffusion process if the curve is plotted in logarithmic scale [5].

$$I = I_D + I_P = I_S[\exp\left(\frac{q(V+IR_S)}{nk_BT} - 1\right)] + \frac{V+IR_S}{R_P} \qquad (1)$$

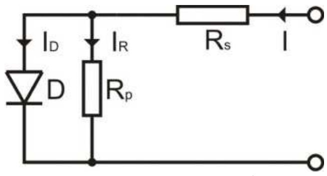


Figure 1. One-diode model of PV cell.

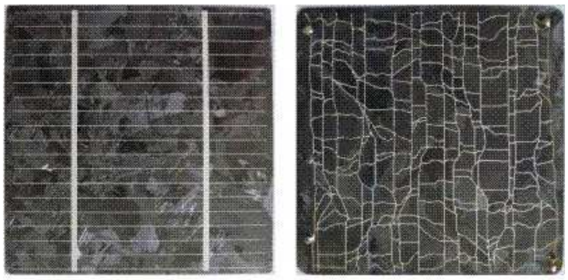
The fit of a linear function (diffusion linear area) is required for the calculation of R_S. The voltage value assignment to the linear function (V_d) and the voltage value read from I-V curve (V) at the same current introduces the “decrease” due to R_S, which defines as follows [3]:

$$\Delta V_S = V_d(I) - V(I) = IR_S \qquad (2)$$

III. EXPERIMENT

Measurements were focused on investigation of samples with the non-standard pattern of top electrode to avoid the influences between grains which are shown in fig.2 b).

The *Keithley 5A Source Meter*, Model 2440 was used to measure I-V characteristics at defined temperature in the dark and under illumination. We would like to remark that the polycrystalline PV samples are without anti-reflection layer, because they were prepared only for investigative purpose. The lack of anti-reflection coating significantly decreases the output PV parameters. The dimensions of all samples are 100 x 100 mm.



a) b)

Figure 2. Top electrode topologies: a) standard b) with wires which follows the grain boundaries.

IV. RESULTS AND DISCUSIONS

For evaluation of DC parameters the I-V curves in the dark were carried out at the temperature range from 25°C to 75°C. Fig.4 shows the I-V curves of poly-Si samples at low voltages which are influenced by the recombination currents in boundaries. One can see the influence of recombination processes at samples with non-standard top electrode which occurs around the grain boundaries. The consequence is reduced conversion quantum efficiency.

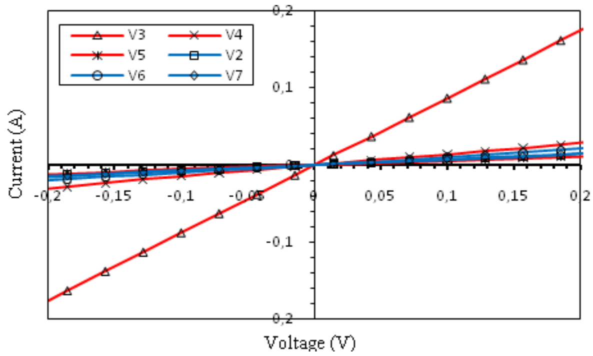


Figure 3. The comparison of I-V characteristics of investigated samples with standard (blue line) and non-standard pattern (red line) at the room temperature (25°C).

The characterization of series resistance R_S and its temperature dependence were carried out by relation (2). In Fig.4 the increasing R_S with rising temperature is shown. The dispersion of R_S by rising temperature is clearly visible in case of non-standard samples. For samples with strandard pattern are the values of R_S higher by larger plane of top electrode which is contributing to shading the emitter. The R_S may also be lower probably by reduced current paths along the grain boundaries.

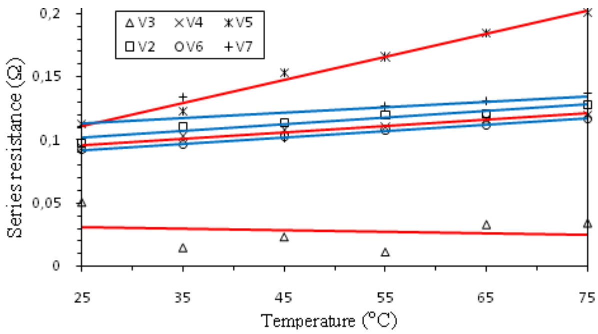


Figure 4. The series resistance dependence of temperature in the range from 25°C to 75°C.

The R_S, as the dynamic quantity, depends from rate of current of PV cell as one can see from DC measurement results presented in Fig. 4.

Fig. 5 shows the dependence where the difference between both investigated types of sample is visible. The R_S influence of non-standard samples is visibly smaller at lower current values compared to the standard ones. But with increasing current the R_S tend to has adrupt logarithmic increase with reaching the higher values.

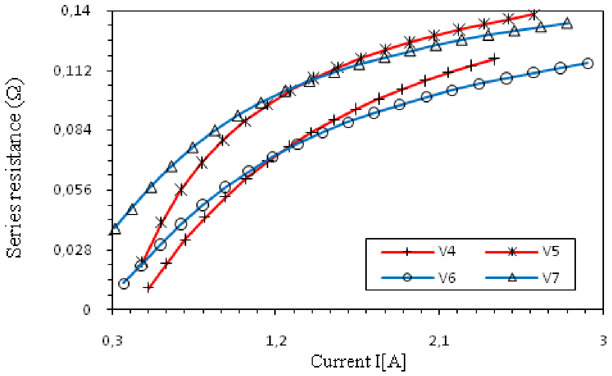


Figure 5. The dependence of R_S from current in the dark at room temperature.

In fig. 6, I-V curves illuminated by Air mass 1.5, global radiation (AM 1.5G) using solar simulator Oriel (Xe 1000 W, 250-1100 nm), class AAA, are shown. Five basic output parameters like open circuit voltage (U_{OC}), short current (I_{SC}), fill factor (FF), maximal output power (P_m) and conversion efficiency (η) were obtained. The influence of R_p and R_s on the shape of I-V curve, both those in the dark and under illumination is commonly known. Both effects lead to decrease of fill factor. R_P is caused by recombination currents and its contribution to the overall diode current (low voltages area) while R_s results mainly due to pure conductivity of conductive paths (electrode fingers, busbars, interconnections and others).

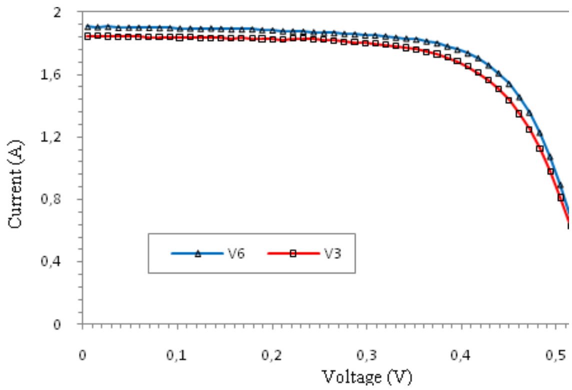


Figure 6. I-V curves of each sample at illuminated by AM1.5G.

The influence of series resistance R_S causes an decreaes of output current due to voltage drop on R_S resistor. In high voltage area finally contribute to the overall diode current too (high voltages area).

TABLE I
Output parameters

	U_{oc}[V]	I_{sc} [I]	P_{max}[W]	FF	η[%]
V3	0,5425	1,8464	0,6733	0,6721	6,732605
V4	0,5425	1,89185	0,6216	0,6057	6,216074
V5	0,5425	1,86625	0,6474	0,6394	6,473513
V2	0,5425	1,9547	0,693008	0,6535	6,9301
V6	0,5425	1,908	0,712589	0,6884	7,1259
V7	0,5425	1,8963	0,707997	0,6882	7,0800

The comparable disspersion of I_{SC} values of samples with non-standard top electrode compared to standard ones is visible. Table 1 shows all mentioned investigated parameters and maximal values are marked, as shown [V2 (I_{SC}=1,95 A); V6 (FF=0,6884; P_m=0,713 W/dm^2; η=7,126 %)].

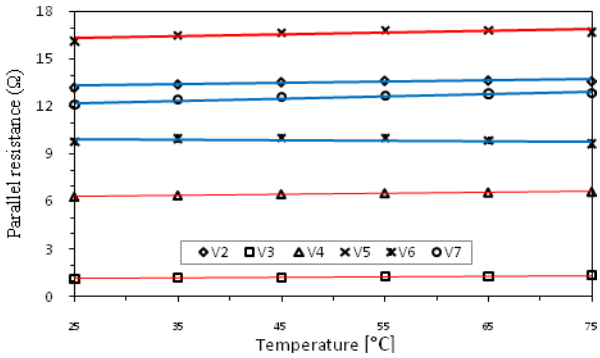


Figure 7. Temperature dependence in the dark of parallel (shunt) resistance R_P in the temperature range from 25°C to 75°C.

In the case of parallel resistor R_P calculation is possible to determine it by ratio of voltage (ΔU) and current (ΔI) alteration in conformity with Ohms law from the reverse direction of I-V curve which is the case of investigated samples. The result acquired by this determination is shown in Fig.7. The temperature influence seems to be very low increasing with rising temperature and it can be neglected but in general the values of R_P are too small. One would expect values about hundreds to thousands of R_P, but finally the quantity is also dependent on the arrea of the cell. It confirms the presence of some amount of defects which occurs and shunt currents at the grain boundary areas.

V. CONCLUSIONS

The poly-Si samples are strongly affected by its grain structure (dimensions of grains) and its transport properties. The microscopic properties such as the resistivity of grain boundaries influence the resistivity of whole sample as the parallel resistance of considered circuit (one-diode) model. The compared parameters confirm that the charge collection from the grain boundary influences the properties (elements of circuit model) much more than in the case of standard electrode design. I-V curves of investigated samples show that the collection of charges is very much depended on the amount of defects within the grain boundary which causes the potential barriers and it contribute to the overall output values obtained on illuminated cells. For better understanding of the grain boundary behaving further investigation of the physics is necessary with using other methods like impedance spectroscopy which shows the response in wide frequency spectra of the cells.

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