EXTENDED ELECTRICAL AND THERMAL PROPERTIES OF SINGLE JUNCTION SILICON SOLAR CELLS

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ABSTRACT

This paper reports an electrical measurement of the single junction solar cells based on silicon technology. Defects of these samples are often local and can result in lower efficiency or shorter solar cell lifetime. Consequently, we can observe many of defects in electric characteristics of solar cells. Measured IV-characteristics and noise signals provide information for defects classification and/or identification. The results of two basic types of the silicon solar cells measurements at very low temperatures are presented in this paper. Used types of solar cells differ above all in the surface texturing and dopand concentration. The cryogenic system is used to accurate setting of temperature with wide range of operating temperatures. The microscopic study of the samples surface is presented, too.

1. INTRODUCTION

The field of our research is focused on non-destructive testing of the silicon single-crystal and the single junction solar cells. The noise measurement is one of the methods of non-destructive device testing and enough cases of laboratory experiments are reported in the literature, [1]. It is necessary pointed out that greater parts of reported experiments are focused on devices which exploited relatively small active area. However, the solar cell's *pn* junction area is typically quite large (even more than 100 cm^2). In addition, surface of the solar cells is textured in order to maximize absorption of the incident radiation. Due to this fact the *pn* junction area is extended up to 60 % (it holds in case of pyramidal textured samples). Hence, measured characteristics are very complicated and we have to analyze minute details in order to explain samples behaviour. What we need is differentiate various current transport mechanisms. Knowledge which may be obtained during study of transport mechanisms can be used for explanation of reverse and/or forward biased solar cells noise signals.

2. DEVICE PROPERTIES AND MICROSCOPY SURFACE INVESTIGATION

We study, as mentioned earlier, silicon solar cells. The single-crystal silicon solar cells are manufactured by the diffusion technology. On the whole, the total thickness of samples is approximately 250 µm and the *pn* junction thickness is 0.6 µm (on condition zero apply voltage). The top layer of the solar cell is doped by phosphorus for creation a thin *n*-type semiconductor. The *p*-type semiconductor is doped by boron. We carried out experiments with two types of solar cells. One of them has a pyramidal texture and other has so-called “table” texture. Thanks to an appropriate texture, multiple reflections and better radiation absorption are achieved. Figure 1, 2 shows the texture of studied solar cells. Topography image has been obtained by SNOM (scanning near-field optical microscope). With regard to the similar results, there are only pyramidal textured solar cell results presented.

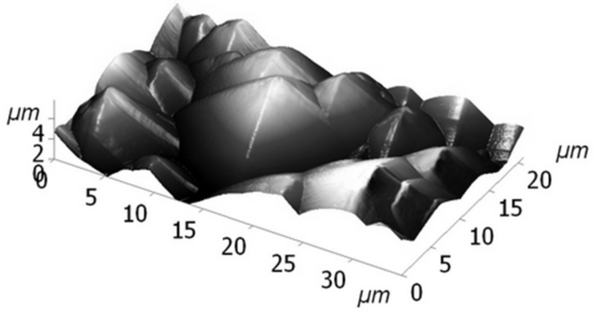


Figure 1: The solar cell surface topography image, SNOM, pyramidal texture

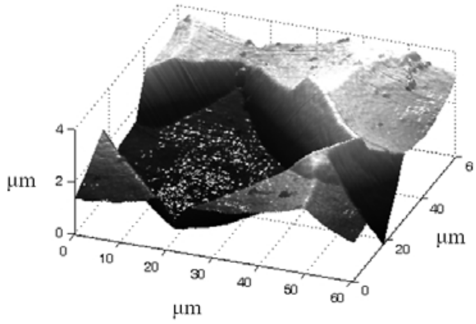


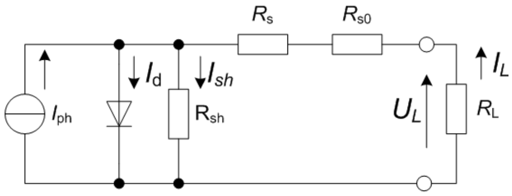
Figure 2: The solar cell surface topography image, SNOM, table texture

3. EXPERIMENTAL SET-UP

A helium based cryogenic system has been used in order to cooling and temperature stabilization of our sample. A measured sample of solar cell is placed between two conductive electrodes and it is in contact with a cold head of cryogenic system by means of heat-conductive paste (see Fig. 4). This unit is based on cooling of the measured sample by means of high-pure He. A special-purpose pump compresses He gas. High thermal energy originates by this way and it is removed by means of water based cooling system. The cool medium is transferred into the two-shield hose with high vacuum thermal isolation. The temperature of measured sample is stabilized through using of couple PID regulators. The accuracy of the sample temperature is approximately 0.01 K. Top and bottom side contacts of solar cells are taken out of vacuum system via coaxial cable. I-V curves are measured by means of a remote controlled power supply E3631A and a precision multimeter 34401A (used as an ampere meter). The measurement setup provides relatively fine measurement of the sample.

4. INTRODUCED ELECTRICAL MODEL AND MATHEMATIC DESCRIPTION

In order to characterize measured data sets and solar cells itself it is necessary to define the basic numerical and electrical model (see Fig. 3). The solar cells main parameter are open circuit voltage U_{oc} and short circuit current I_{sc}. Both parameters are function of temperature T and light intensity E. It is possible to say that U_{oc} is only weakly dependent on E and increase of temperature leads to U_{oc} reduction. On the contrary to U_{oc}, I_{sc} is directly proportional to E and it is practically independent on temperature. Therefore, solar cells act as a constant current source and this is a way how it can be modeled. Figure 3 shows so-called one-diode model.



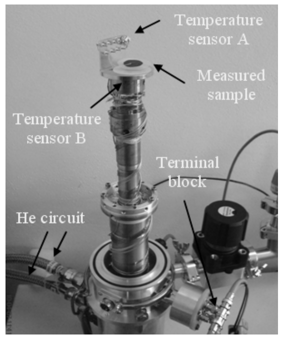


Figure 3: One-diode solar cell equivalent model

Figure 4: He based cryogenic system

The proposed model makes the connection between two input parameters: light intensity $E \sim I_{ph}$, ambient temperature T and two output parameters: load current I_L and load voltage U_L. By means of Kirchoffs law we can obtain the equation that describes function of the solar cell (more in [2], [3])

$$I_{ph} + I_L = I_0 \left[\exp\left(\frac{e\left[U_L - (R_s + R_{s0}) I_L\right]}{nkT} \right) - 1 \right] + \frac{U_L - (R_s + R_{s0}) I_L}{R_{sh}} . \tag{1}$$

Here I_{ph} is photocurrent, I_L operating current, I_0 saturation current, U_L operating voltage, R_s R_{s0} series resistance, n ideality factor, k Boltzmann constant, e charge of electron, T temperature, R_{sh} shunt resistance.

The equation (1) is an transcendent equation of load current I_L (what we need, is mathematic model of I-V curves). The solution of this equation is possible by means of an iterative method, Lagrang inverse theorem or Lambert W-function W(x). The W-function is defined as

$$W(x)e^{W(x)} = x . \tag{2}$$

For an computer-assisted numerical solution is W-function very useful tool. Fitting results (mentioned below) have been obtained in Matlab computing environment and cftool.

5. EXPERIMENTAL RESULTS AND ANALYSIS OF SAMPLES PROPERTIES

The defect-free sample has been measured and has been labeled as B1. This pyramidal textured solar cell has a total sample area S_{B1} = 79.088 mm^2. Measured result applies to defect-free table textured samples, too.

Figure 5 demonstrates measured I-V curves in semilogarithmic scale. There is interesting temperature-dependent increase of reverse current. A forward biased I-V curve make evident influence of series resistance (I-V curve is deformed for relatively high forward voltage) and only one linear area conformed to the one current transport mechanism, [3]. Let's pay attention to a forward characteristic.

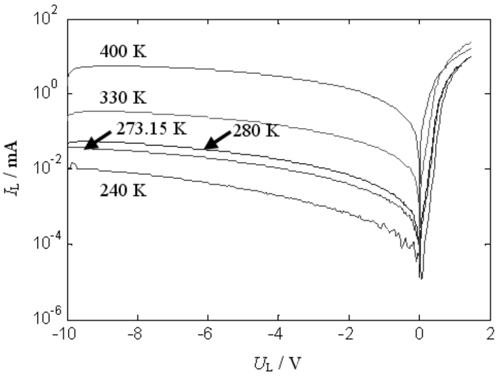


Figure 5: I-V curves of solar cells, sample B1, S_{B1} = 79.088 mm^2, under zero illumination, $p = 10^{-5}$ Pa

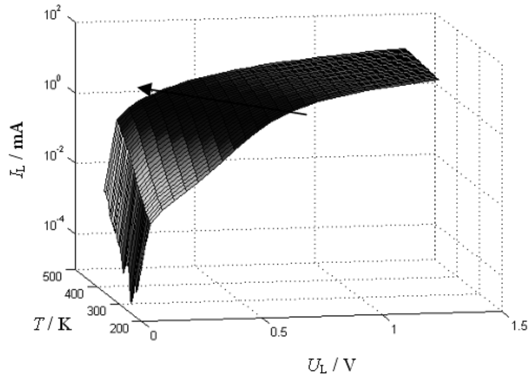


Figure 6: I-V curves of forward biased solar cells, sample B1, under zero illumination, $p = 10^{-5}$ Pa

Figure 6 depicts forward biased I-V curves as a function of temperature. The measured step of temperature was ΔT = 5 K and temperature range was $T = 270 \div 420$ K. Temperature trend indicated by arrow is caused by temperature dependence of saturation current in equation (1). Figure 6 make evident that series resistance is independent on temperature and that there is really only one linear section. In fact this statement has a cardinal importance. In equation (1) this fact represents only one exponential term. It means that there is only one transport mechanism [3]. Functional model has been developed in Matlab in order to approximate the measured I-V curves. The obtained results are depicted in Fig. 7. The presented curves applies to T = 270 K and zero incident light.

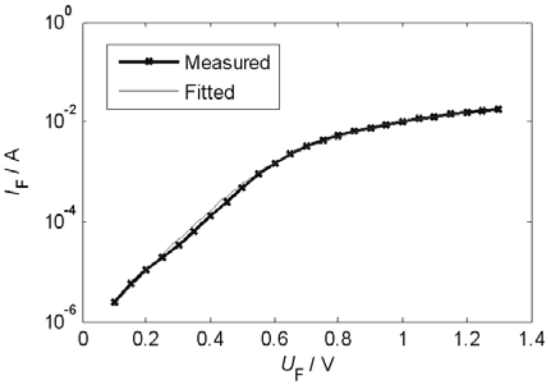


Figure 7: I-V curves of forward biased solar cells and approximation, sample B1, under zero illumination, $p = 10^{-5}$ Pa

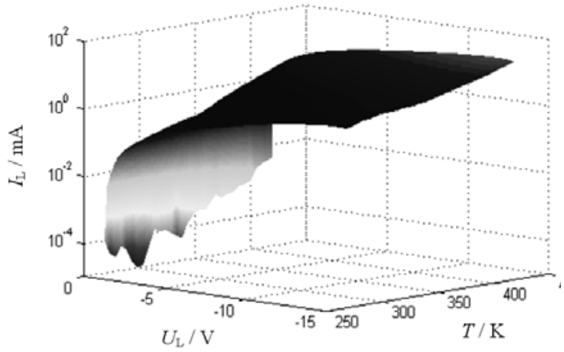


Figure 8: I-V curves of reverse biased solar cells, sample B1, under zero illumination, $p = 10^{-5}$ Pa

Levenberg-Marquardt algorithm has been selected as an approximation method. Agreement of measured and fitted curve is very good and we obtained values of following parameters

- series resistance $R_{sx} = R_s + R_{s0}$ = 17.2 Ω (resistance of the sample and the lead-in cable),
- ideality factor $n \approx 3$,
- saturation current $I_0(T) = 5.4 \cdot 10^{-7}$A @ T = 270 K.

The values of series resistance have to be corrected because of resistance of lead-in cables. We found out that R_s is approximately equal 4.78 Ω. The value of ideality factor is interesting, too. It is clear that this transport mechanism is not according to a diffusion process and due to temperature dependence of I-V curves there is not a tunneling process. It may be a recombination-generation mechanism (in case of forward biased sample only a recombination mechanism [2], [3]). Ideality factor $n \approx 3$ is probably a result of a deep recombination traps in a structure or non-symmetry quasi-Fermi levels in a band gap (symmetry means location against intrinsic Fermi level). This can be result of impurities presence in a semiconductor. Figure 8 demonstrates the same sample as in previous case but reverse biased. High reverse current and dominant increasing with temperature is interesting. Here we expect the generation process maybe assisted by means of the same traps or recombination centers as in previous case.

6. CONCLUSION

We study I-V curves and temperature properties in order to understanding solar cells behaviour. We carried out experiments in the He cryogenic system with high accuracy operation temperature. We obtained very interesting I-V curves with relatively non traditional properties (probably due to the large sample area). A plausible numerical and electrical model conformable with our laboratory results has been also suggested. We obtained values of the equivalent series resistance, the ideality factor and temperature dependence of saturation current. The solar cell degradation goes hand in hand with deviation of these parameters. The present research tends to identification transport mechanism in the sample. We suggest the physical model of the carriers recombination affected by deep traps in a structure or non-symmetry quasi-Fermi levels in the band gap. It should be note that the distributed series resistance may affect the transport mechanism (the finger shaped contacts may lead to lateral current densities in top layer and this leads to current crowding under the contact and can be considered to be reduction in the junction area at high currents) in the similar way as a trap assisted carriers recombination. This fact is still subject of our research and it is appropriate the aforementioned experimental results to replenish with the additional C-V or noise measurement.

7. ACKNOWLEDGMENTS

This research has been supported by the Grant Agency of the Czech Republic within the framework of the project GAČR 102/09/H074 and MSM 0021630503.

REFERENCES

[1] Koktavy, P., Šikula, J. Reverse Biased P-N Junction Noise in GaAsP Diodes with Avalanche Breakdown Induced Microplasmas. *Fluctuation and Noise Letters*, ISSN 0219-4775, 2002, Vol. 2, No 2, p. L65 – L70.

[2] Petreus D., Ciocan I., Farcas C.: An Improvement on Empirical Modelling of Photovoltaic Cells, *31st International Spring Seminar on Electronis Technology*, May 2008, pp. 612-617, ISBN 978-963-06-4915-5.

[3] Sze S. M.:Physics of Semiconductor Devices, *John Wiley & Sons, New York,* November 2006, ISBN 978-0-471-14323-9.