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DETERMINATION OF THE LIFETIME INFLUENCE UPON THE CONVERSION EFFICIENCY OF THE PHOTOVOLTAIC SILICON SOLAR CELLS

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Abstract. ***If the electrons and holes in excess are created in a semiconductor, either by means of light absorption, or using other methods, the thermic balance is disturbed, therefore these electrons and holes should be nullified after the source had been stopped. This process is named recombination. There are three main recombination types: radioactive, Auger and deep energy level recombination. All three are based on the doping concentration to a certain point. The life time is determined using the three recombination processes in semiconductor.***

Keywords: lifetime, conversion efficiency, solar cell, silicon, open circuit voltage, Matlab.

1. INTRODUCTION

The photovoltaic effect was remarked the first time by A.E. Becquerel in 1839 and had been later on developed by the British researchers W.G. Adams and R.E. Day in 1877 [1-2].

Up to 1949, when the semiconductor was invented, the photovoltaic effect was no more used [3-4]. Afterwards, Chapin, Fuller and Pearson, in 1954, had developed in USA the first photovoltaic solar cell formed on silicon crystals [5]. Next years the efficiency had been raised up to 10%.

The main reason for extending the use of photovoltaic effect to the main energetic sources was the oil crisis in 1973. After that moment, began to be developed specific research institutes all over the world. In the early 80s years it was already accepted that the photovoltaic cells are most important for lowering down the costs of alternative energy systems. From now on, research and development were focused on obtaining a much greater efficiency [6-11] (Figure 1).

Silicon crystals are even now number one in top of the photovoltaic industry market, representing 90% of the material used for producing photovoltaic cells; 44% are manufactured using mono crystals of silicon, and 46% are using multi crystals of silicon [6-11].

This phenomenon is based upon the photonic absorption, in given conditions, in a semiconductor wafer, that determines generation of an electric current. The conversion criterion is depended on the electrons occupying far positions in rapport of the core can be transformed in free moving conduction electrons. This way it is generated simultaneously a positive electric gap and a negative electric carrier.

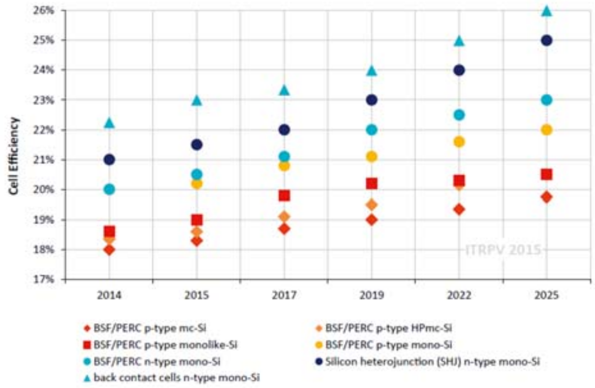

Figure 1. ITRPV roadmap April 2015: cell efficiency curves [11]

In case of crystal silicon, the electric carriers obtained this way, can reach this potential barrier due to the thermic vibrations. The lifetime resulting is one factor to determine the efficiency of photovoltaic energy generation.

According to the actual information, solar energy is created by the nuclear fusion reaction between hydrogen and helium that takes place within the Sun at a couple of millions Celsius. The mass difference existing in this process is transformed in energy. The Sun is in a state of radiation balance with cold Universe, its surface temperature being 5900 Kelvin. The solar energy that reaches Earth surface is determined by the rapport (relation) between the Sun and Earth diameters and by their independent distance. If there are not taken into account the deviations resulting from Earth rotation around the Sun, the most recent measurement of the radiation power outside the atmosphere is D_0=1,353 KW/m^2. Value D_0 is known as solar constant. This radiation is partly absorbed and diffused by its way through the atmosphere becoming this way alleviated. In the infrared zone, this alleviation is caused by the water and carbon dioxide contained by the air, while the absorption in the human-eye visible zone is mainly caused by the oxygen content, and in the ultraviolet zone by the ozone content. In the radiation also exists a spectral deviation, similar to the diminution process. In the next figure (Figure 2) is presented the spectral distribution of solar energy.

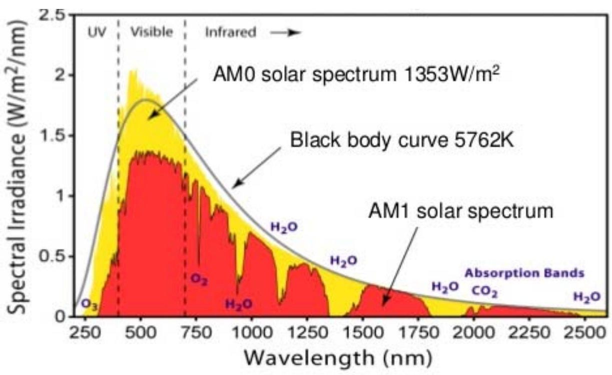

Figure 2. Spectral distribution of solar energy

The photovoltaic conversion can be made using the photovoltaic devices usually known as solar cells [12-13]. By setting and serial and parallel connecting of a number of the same type of solar cells on photovoltaic panels are realised the solar batteries.

2. DETERMINATION OF THE LIFETIME

The equation for the conversion efficiency η in the solar cell [14-18] is:

$$\eta = \frac{J_{sc} \times V_{0c} \times f}{P_{solar}} \tag{1}$$

Where:
J_{sc} – short-circuit current density;
V_{0c} - open circuit voltage;
f - fill factor;
P_{solar} – power density.

In radiation conditions AM 1.5, 28^0 C, we have:

$$P_{solar} = 0{,}1 \text{ W/cm}^2 \tag{2}$$

and the maximal value of the J_{sc} is:

$$J_{sc} = 40 \text{ mA/cm}^2 \tag{3}$$

This measure being possible to be considered, relatively independent in correlation with internal characteristics of the silicon board. An optimised configuration of the superficial geometry of the solar cell can ensure a fill factor f = 80% [9, 10].

In this situation, conversion efficiency rises direct proportionally with open circuit voltage, given by the relation:

$$V_{0c} = \frac{kT}{q} \ln\left(\frac{J_{sc}}{J_0}\right) \tag{4}$$

Where J_0 is the density of saturation current of the cell, which in case of usage of a p^+n junction and is:

$$J_0 = \frac{q n_i^2 D_p}{N_D L_p} \tag{5}$$

With

$$L_p = \sqrt{\tau D_p} \tag{6}$$

The physical characteristics appearing in this relation have the following meanings:
n_i – intrinsic carrier concentration of silicon, $n_i = 10^{10}$ cm^{-3};
q – electronic charge;
N_D – doping concentration of the N region;
L_p – length of diffusion gaps from N region;
τ – lifetime of the gaps in N region;
D_p – diffusion coefficient of the gaps in N region.

The next step was to calculate using Matlab [18], the variations of these essential parameters of the solar cell, manufactured at IPRS – Baneasa, in correlation with the dimension of the lifetime, for the given situation $N_D = 10^{16}$ cm^{-3}.

At this value of concentration, the diffusion coefficient of the gaps is determined by the relation ([19])

$$D = \frac{D_0}{1 + \left(\frac{N_D}{10^{17}}\right)^{0.6}} + D_1 \tag{7}$$

Where for the silicon type p, D_0=35, D_1=1.8 and we get a value: D_p = 10,99 cm^2/s.

The components for the lifetime for the chosen research concentration $N_D = 10^{16}$ cm^{-3} are:
τ_R – radiative lifetime:

$$\tau_R = \frac{1}{BN_D} = \frac{1}{2 \times 10^{-15} \times 10^{16}} = 5 \times 10^{-2} \text{ s} = 50 \text{ ms} \tag{8}$$

τ_A - Auger lifetime:

$$\tau_A = \frac{1}{c_p N_D^2} = \frac{1}{2{,}8 \times 10^{-31} \times 10^{32}} = 3{,}5 \times 10^{-2} \text{ s} = 35 \text{ ms} \tag{9}$$

τ_K - Shockley-Read-Hall lifetime, corrected with the effect introduced by the doping concentration level:

$$\tau_K = \frac{\tau_0}{1 + \frac{N_D}{7 \times 10^{15}}} = \frac{\tau_0}{1 + \frac{10^{16}}{7 \times 10^{15}}} = 0{,}4\tau_0 \tag{10}$$

Where τ_0 - Shockley-Read-Hall lifetime (SRH), given by the recombination on the deep energetic layers, introduced in silicon by the technological contamination metallic impurities.

We get τ – total lifetime:

$$\frac{1}{\tau}=\frac{1}{\tau_R}+\frac{1}{\tau_A}+\frac{1}{\tau_K}=\frac{100}{5}+\frac{100}{3,5}+\frac{1}{0,4\tau_0} \tag{11}$$

It can be observed that, in normal physical conditions, with lifetime values varying from 1ns - 1ms, the radiative recombination processes and the Auger recombination ones are very low in silicon, lifetime values being in this case very big (around 50 ms). It results that the effective silicon lifetime is given, practically, only by the Shockley-Read-Hall recombination processes,

$$\tau \approx 0,4\tau_0 \tag{12}$$

Where:

$$\tau \approx \tau_K \tag{13}$$

It has been used a range of values for the lifetime from τ=1 ns (typical for a weak/bad technology) to τ = 10 ms (typical for a very good technology).

In Figure 4 we represented the variation of the saturation current. The current dramatically decreases, varying with three orders of dimension (Table 1). A weak saturation current is obtained for big lifetime values, namely for a poor recombination in silicon.

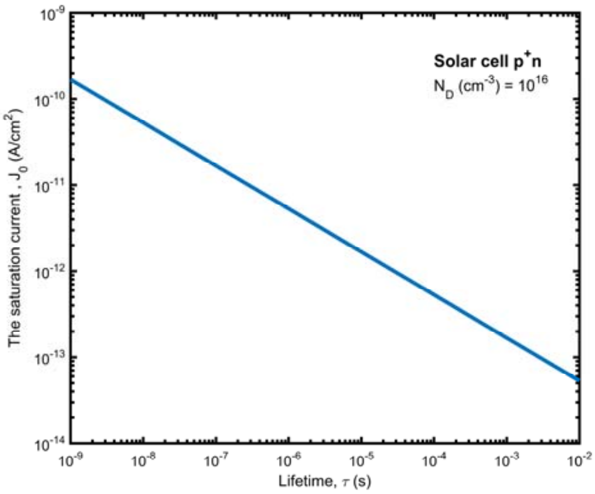

Figure 4. Variation of the saturation current depending on lifetime for a silicon solar cell type p$^+$n.

In Figure 5 is represented the open circuit voltage. For a little value of the lifetime (powerful recombination) voltage has a value of 0,500 V, but rises up to 0,710 V for a big value of the lifetime (poor recombination) (Table 1). If the lifetime value rises, the saturation current of the junction lowers and the open circuit voltage rises, too.

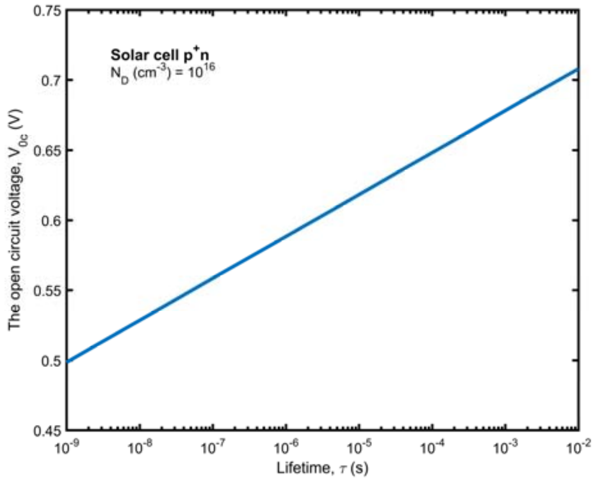

Figure 5. Variation V_{0c} depending on τ for a silicon solar cell type p$^+$n.

In Figure 6 is represented the variation of the conversion efficiency. Its value is approximately 16,04% for a lifetime value of 1 ns and rises up to 22,74% for a lifetime value of 10 ms (Table 1). A performant solar cell can be obtained if the lifetime of the electrons in the base layer is bigger than 1 ms.

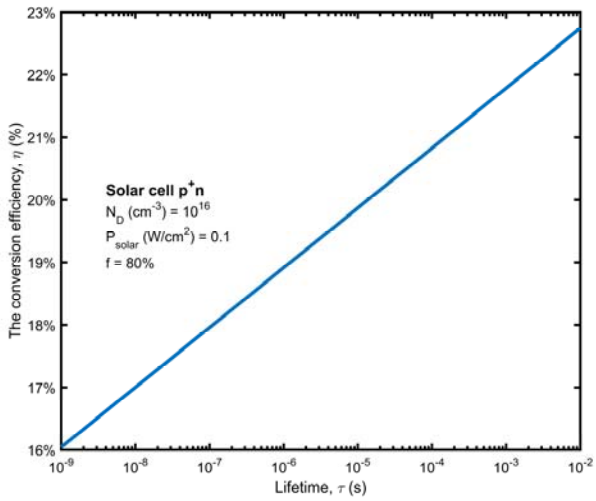

Figure 6. Variation of the conversion efficiency depending on the lifetime for the silicon solar cell type p$^+$n.

Table 1. The values obtained for the J_0, V_{oc} and η for the silicon solar cell type p$^+$n.

J_{sc} (A/cm^2)	f (%)	τ (s)	J_0 (A/cm^2)	V_{oc} (V)	η (%)
0,04	80	10^{-9}	$1.677\cdot10^{-10}$	0,500	16,04
		10^{-2}	$5.304\cdot10^{-14}$	0,710	22,74

A solar cell p$^+$n with a high efficiency (over 20%) can be obtained only if the silicon board has a final value of the lifetime of 1-10 ms. This can be obtained by applying special treatments in order to get out the contamination metallic impurities from the semiconductor during the technological process.

Second case of our research was represented by the silicon solar cell type n$^+$p, manufactured at IPRS – Baneasa, with a doping concentration of the base layer p,

$N_A = 10^{16}$ cm^{-3}.

From the relation 7, and taking into account that for silicon type n, D_0=12,5, D_1=1 we obtain a value: D_n=29,74 cm^2/s.

The saturation current will have a new relation:

$$J_0 = \frac{q n_i^2 D_n}{N_A L_n} \tag{14}$$

Where the electron diffusion length L_n is:

$$L_n = \sqrt{\tau D_n} \tag{15}$$

The results are presented in Figures 7-9 and Table 2.

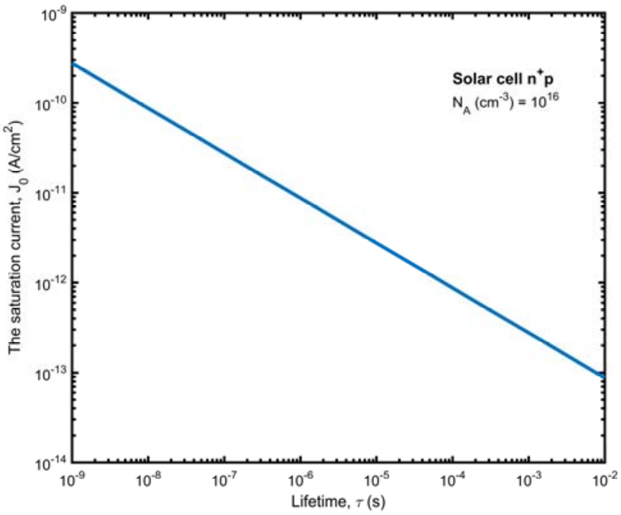

Figure 7. Variation of the saturation current depending on lifetime values for the silicon solar cell type n$^+$p.

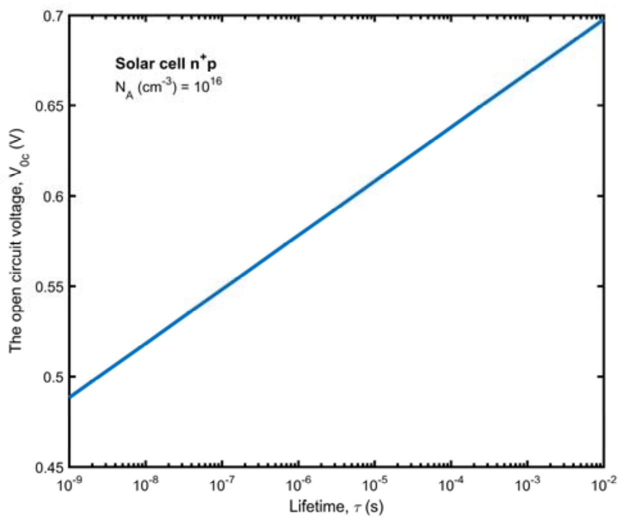

Figure 8. Variation of the open circuit voltage depending on lifetime values for the silicon solar cell type n$^+$p.

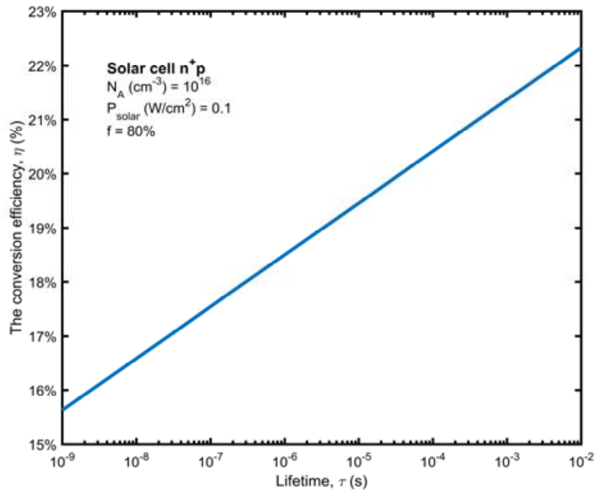

Figure 9. Variation of the conversion efficiency depending on lifetime values for the silicon solar cell type n$^+$p.

Table 2. Values obtained for the J_0, V_{oc} and η of the of the solar cells type n$^+$p

J_{sc} (A/cm^2)	f (%)	τ (s)	J_0 (A/cm^2)	V_{oc} (V)	η (%)
0,04	80	10^{-9}	$2.76 \cdot 10^{-10}$	0,488	15,63
		10^{-2}	$8.73 \cdot 10^{-14}$	0,697	22,33

Given the fact that the diffusion coefficient of the minority carriers from the base layer is in this case three times bigger, the conversion efficiency does not have a significant modification (Figure 7-9 and Table 2). Solar cells type p$^+$n and n$^+$p has, practically, the same conversion efficiency, in conditions of an identic doping concentration of the base layer.

3. CONCLUSIONS

The maximum efficiency, theoretically possible, of a silicon photovoltaic cell is 29% in standard conditions of light AM 1.5 (100 mW/cm^2). For years, though, the solar cells used in the photovoltaic industry have an efficiency of approximately 15%. The difference of 14% is represented by the parasite losses in the internal structure of the cell, from which 10% being the losses generated by recombination on the deep energetic levels.

Usage of a cheaper silicon board supposes the acceptance of a higher level of initial impurity of them with metallic atoms. They introduce deep energetic levels in the forbidden energetic layer of silicon and reduce the lifetime of the charge carriers by the means of growth of recombination phenomena type Shockley-Read-Hall (SRH). This situation is solvable if, during the technological process of the solar cell, are introduced supplementary phases of getting out the initial metallic impurities. It is important to state the fact that the other two fundamental phenomena of recombination, Auger recombination and radiative recombination are natural processes that cannot be controlled in practice. Their influence in silicon is though less important.

The growth of the lifetime value from the volume and from the surface of silicon board will determine the improving of the collection efficiency of the carriers generated by light, namely the arousal of the energetic transformation efficiency of the solar cell.

A greater attention should be given to the decrease/diminution of the top contact region and to the losses determined by the reflexion in order to generate higher densities of short circuit current.

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