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JUNCTION RECOMBINATION VELOCITY DETERMINATION INITIATING THE SHORT-CIRCUIT AND LIMITING THE OPEN CIRCUIT OF A MONOFACIALE SOLAR CELLS CONTAINING THIN FILM Cu(In,Ga)Se$_2$(CIGS) UNDER HORIZONTAL ILLUMINATION IN STATIC MODE

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ABSTRACT

A theoretical study of thin layer CIGS solar cells (for the CIGS low in copper i.e. $\frac{[Cu]}{[Ga]+[In]}=0,9$ **[1]**) under monochromatic illumination in static regime at the front surface is presented.We propose a method of junction recombination velocity determination, initiating the short-circuit (Sfsc) and limiting the open circuit (Sfoc).
The determination of Sfoc is obtained from the curve of *photovoltage* versus *Sf*, and the determination of Sfsc is through from the curve of the photocurrent density according to *Sf*.

KEYWORDS: *solar cell monofaciale,CIGS,junction,recombination velocity*.

INTRODUCTION

The development of the thin layer solar cells, particularly the chalcopyrite solar cells such as *Cu(In, Ga)S*, *Se$_2$*, had very significant progress with an efficiency of about 20% in laboratory **[1].**

This efficiency depends on several phenomenologic parameters among which the *diffusion* length *(L)*, the diffusion coefficient (D), the junction recombination velocity (Sf), the reflexion coefficient (R) and the absorption coefficient (α) **[2,3,4].**

Consequently several methods were developed for the determination of these parameters**.**

In this work, we present a method of junction recombination velocity determination initiating the short-circuit (*Sfsc)* and limiting the open circuit (*Sfoc)* for a solar cell containing thin film *CIGS* to one dimension.The study will be done primarily in the base because the contribution of the transmitter is negligible

THEORETICAL STUDY

A n+-p-p+ CIGS solar cell type is schematized on figure 1:

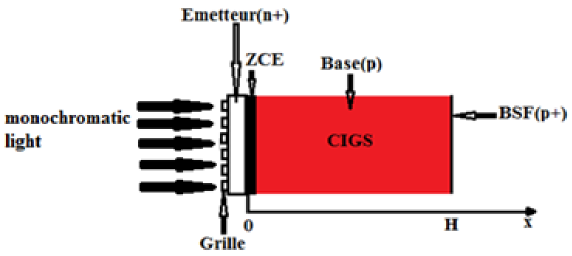


Figure 1: Solar cell ($n^+ pp^+$) containing CIGS under monochromatic illumination at the front surface

When the solar cell is illuminated, different process take place in the base: We can mention generation, recombination and diffusion of excess minority carriers, etc…

The continuity equation for all these phenomena in static regime is given by the expression below:

$$\frac{\partial^2\delta(x,\lambda,Sf,Sb)}{\partial x^2}-\frac{\delta(x,\lambda,Sf,Sb)}{L^2}=\frac{G(x,\lambda)}{D} \qquad (1)$$

In which $\delta(x,\lambda,Sf,Sb)$ is the excess minority carrier's density in the base

L: Diffusion length of the minority carriers
D: diffusion coefficient of the minority carriers (Which translates the more or less good capacity of the material to let broadcast the carriers).
G(x,λ): is the carrier generation rate.

The carrier generation rate for a monochromatic illumination is given by the relation (2) :

$$G(x,\lambda)=\alpha(\lambda).\phi(\lambda).(1-\mathrm{R}(\lambda)).e^{-\alpha(\lambda)x} \qquad (2)$$

α: is the absorption coefficient;
R:is the reflexion coefficient
AM: 1.5
Φ :is the flow of carriers

The diffusion coefficient is constant and it is given by the relation (3) **[5]**:

$$D=\frac{KT}{q}\times\mu_n \qquad (3) \quad D=2.59cm^2.s^{-1}$$

The diffusion length is given by (4) :

$$L_n=\sqrt{D.\tau_e} \qquad (4)$$

$$L_n=4{,}5\mu m$$ for a solar cell of $3\mu m$ **[6]**

$\tau_e=7{,}8.10^{-8}s$ is the minority carriers lifetime

The general solution of the continuity equation is given by the expression (5):

$$\delta(\mathrm{x},\lambda,\mathrm{Sf},\mathrm{Sb})=\mathrm{F}.\mathrm{ch}(\frac{x}{L})+C.sh(\frac{x}{L})+$$
$$\frac{L^2.\alpha(\lambda).\Phi(\lambda)(1-\mathrm{R}(\lambda))}{D.(\mathrm{L}^2.\alpha(\lambda)-1)}\cdot e^{-\alpha(\lambda).x} \qquad (5)$$

In which F and C are coefficients determined starting from the boundary conditions:

□□At the Junction(x=0) **[7]**

$$D.\frac{\partial\delta(x,\lambda,Sf,Sb)}{\partial x}\Big|_{x=0}=Sf.\delta(x,\lambda,Sf,Sb)\Big|_{x=0} \qquad (6)$$

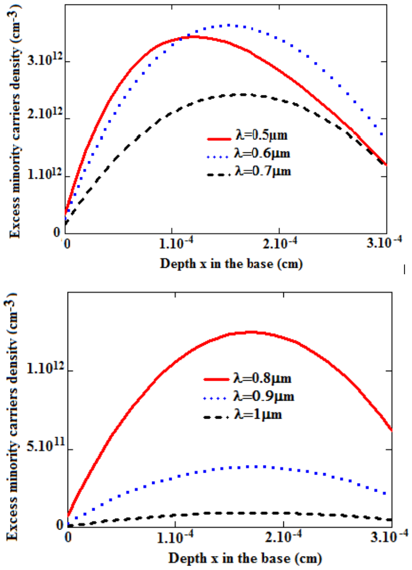
□□At the back surface (x=H) **[7]**

$$D.\frac{\partial\delta(x,\lambda,Sf,Sb)}{\partial x}\Big|_{x=H}=-Sb.\delta(x,\lambda,Sf,Sb)\Big|_{x=H} \qquad (7)$$

In which H is the total thickness of the solar cell *CIGS* ,Sf and Sb are respectively junction recombination velocity and back side recombination velocity .

PROFILE OF EXCESS MINORITY CARRIER'S DENSITY

The profile of the excess minority carrier's density is given by figure 1.



<u>Fig. 1:</u> Excess minority carrier's density versus thickness in base of CIGS for different wavelength value

For a given wavelength, the curve presents three parts:

The density of the excess minority carrier's increases until reaching a maximum which corresponds to a depth x_0 in the base.Beyond the value x_0 the excess density minority carrier's density decreases.

Thus we distinguish two zones:

The zone corresponding to the increase of the minority carrier's density i.e. to the positive gradient: that is due to the crossing of the minority carrier's charge to the junction which take part in the photocurrent.

The zone corresponding to the reduction in the excess minority carrier's density i.e. to the negative gradient; the minority carrier's density undergo in depth and the surface recombination.

The maximum corresponds to the null gradient which indicates a storage of carriers density

It is also seen that for the low wavelength (λ) values, absorption is done close to the junction whereas for the big wavelengths values, absorption moves in-depth.

The expression of the excess minority carrier's density enables us to obtain that the photocurrent density starting from the relation of *Fick [7]***.**

PHOTOCURRENT DENSITY

The photocurrent density of solar cell is obtained starting from the gradient of excess minority carrier's density to the junction and it is given by the following expression (8) **[7]**:

$$J_{ph}(\lambda,\mathrm{Sf},\mathrm{Sb}) = q.D.\frac{\partial\delta(x,\lambda,Sf,Sb)}{\partial x}\Big|_{x=0} \qquad (8)$$

In which q is the elementary charge $q = 1.6\times10^{-19}C$

Figure 2 illustrates the variation of photocurrent density versus junction recombination velocity for various wavelength values.

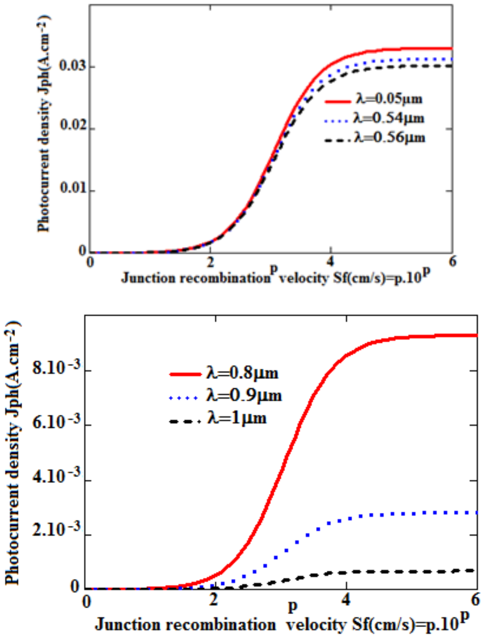


Figure 2: Photocurrent density versus the junction recombination versus for various wavelength values

($K_B = 1.38\times10^{-23}J.K^{-1}$) and T is the temperature ($T=300K$).

We present at fig.3 the profile of the *photovoltage versus*junction recombination velocity for different wavelength values:

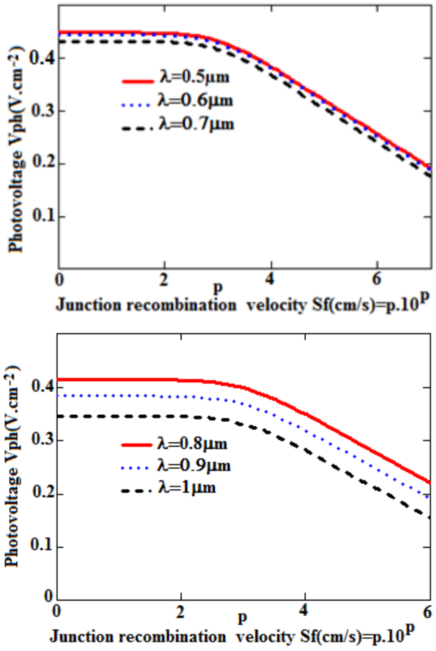


Figure 3: Photovoltage versus junction recombination velocity for differentwavelength values

We observe in this case that:

For the low values of the junction recombination velocity**,** the photovoltage is maximum:the solar cell is in situation of open circuit

Whereas for the great values of the junction recombination velocity, the photovoltage decreases and tends towards zero: the solar cell is in situation of short-circuit.

The representation of the photocurrent density and that of the photovoltage versus the junction recombination velocity, give two stages in general corresponding to the operation of solar cell in short-circuit or in open circuit. -Whereas for the great values of the junction recombination velocity, the photovoltage decreases and tends towards zero: the solar cell is in situation of short-circuit.

The representation of the photocurrent density and that of the photovoltage versus the junction recombination velocity, give two stages in general corresponding to the operation of solar cell in short-circuit or in open circuit.

For each stage, we can make to correspond several values of junction recombination velocity (Sf).

What leads us in this work to propose a method of junction recombination velocity determination initiating the short-circuit Sfsc and limiting the open circuit Sfoc.

RESULTS AND DISCUSSION

JUNCTION RECOMBINATION VELOCITY DETERMINATION INITIATING THE SHORT-CIRCUIT Sfsc AND LIMITING THE OPEN CIRCUIT Sfoc

Iinitiating the short-circuit Sfsc

This method of determination of Sfsc consists in projecting the experimental value of the photocurrent density of short-circuit of solar cell containing CIGS on the axis corresponding at the junction recombination velocity. The found value is the junction recombination velocity initiating the short-circuit for a given wavelength. The figure 4 confirms this method.

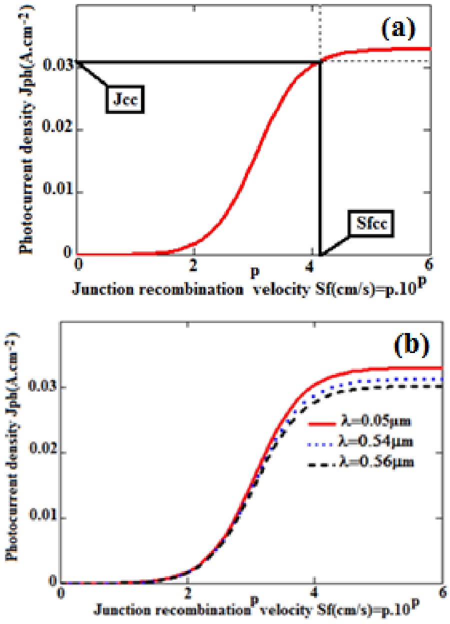


Figure 4:Technique of determination of the photocurrent density for λ=0.5µm (a) and for low wavelengths (b)

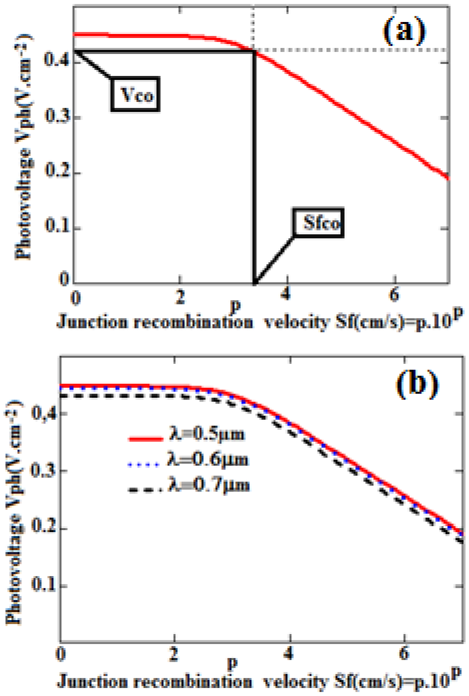
The following table represents various values of junction recombination velocity initiating the short-circuit for different wavelengths values.

Table 1: junction recombination velocity initiating the current of short-circuit versus wavelength [9]

$J_{cc\,exp}(mA/\mathrm{cm}^2)$	$\lambda(\mu m)$	$Sf_{cc}(cm/s)$
0.0304	0.5	$4.2\times10^{4.2}$
0.0304	0.54	$4.3\times10^{4.3}$
0.0304	0.56	$4.5\times10^{4.5}$

Limiting the open circuit Sfoc

We proceed in the same way as previously for the junction recombination velocity determination beginning to the open circuit. In other words the experimental value of the photovoltage of open circuit is projected on the axis corresponding to the junction recombination velocity.



<u>Fig.5</u>:Technique of junction recombination velocity determination beginning to the open circuit from the CIGS for λ=0.5µm (a) and for different wavelength (b)

<u>Table 2</u>: Junction recombination velocity beginning the current from open circuit versus wavelength [9]

$V_{oc}(V/\mathrm{cm}^2)$	$\lambda(\mu m)$	$Sf_{oc}(cm/s)$
0.421	0.5	$3.3\times10^{3.3}$
0.421	0.6	$3.2\times10^{3.2}$
0.421	0.7	$2.8\times10^{2.8}$

CONCLUSION

The method proposed in this work considers the solar cell under a real operating condition. This is a method of junction recombination velocity determination initiating the short circuit and the junction recombination velocity limiting the open circuit for a solar cell containing thin layer CIGS.
It's noted that Sfsc increases according to the wavelength for an experimental value of the photocurrent density corresponding 0.0304A/cm^2.

It‘s also noted that Sfoc increases conversely versus the wavelength for an experimental value of the photovoltage corresponding 0.421V/cm^2.Any time we can improve these results by incorporating sodium in the base of CIGS.

REFERENCES

[1] W.Thongkhama, A. Pankiew, K. Yoodee, S. Chatraphorn « Enhancing efficiency of Cu(In,Ga)Se2 solar cells on flexible stainless steel foils using NaF co-evaporation » Solar Energy 92 (2013) pp 189–195

[2] M. M. DIONE, S. MBODJI, M. L. SAMB, M. DIENG, M. THIAME, S. NDOYE, F. I. BARRO, G. SISSOKO(Junction Under Constant Multispectral Light:Determination Of Recombination Parameters» 24th European Photovoltaic Solar Energy Conference, 21-25 September (2009), Hamburg, Germany pp.465-468.

[3] H. Ly Diallo, B. Dieng, I. Ly, M. M. Dione,M. Ndiaye, O.H. Lemrabott, Z.N. Bako,A. Wereme and G. Sissoko « Determination of the Recombination and Electrical Parameters of a Vertical Multijunction Silicon Solar Cell » Research Journal of Applied Sciences, Engineering and Technology Maxwell Scientific Organization, (2012) pp.1-6.

[4] H. Yoro BA, B. Seibou, I. GAYE, I. LY, G. SISSOKO «Recombination Parameters Measurement of Silicon Solar Cell Under Constant White Bias Light With Incident Angle» Current Trends in Technology and Sciences (2014)

[5] Barbara Werner,Wlodzimierz Kolodenny, Mariusz Prorok, Andrzej Dziedzi,Tadeusz Z˙danowicz «Electrical modeling of CIGS thin-film solar cells working in natural conditions»Solar Energy Materials and solar cells 95 (2011) pp 2583-2587.

[6] Jian V. Li, Sachit Grover, Miguel A. Contreras, Kannan Ramanathan, Darius Kuciauskas,Rommel Noufi « A recombination analysis of Cu(In,Ga)Se2 solar cell with low and high Ga compositions» Solar Energy Materials & Solar Cells 124 (2014) pp 143–149

[7] K. FAYE, I. GAYE, S. GUEYE, S. TAMBA, G. SISSOKO «Effect of Doping Level of a Silicon Solar Cell Under Back Side Illumination» Current Trends in Technology and Science pp 2279- 0535. Vol. 3, Issue: 5 (August-September. 2014)

[8] M. L. SAMB, M. DIENG, S. MBODJI, B. MBOW, N. THIAM, F. I. BARRO, G.SISSOKO «Recombination Parameters Measurement Of Silicon Solar Cell Under Constant White Bias Light» 24th European Photovoltaic Solar Energy Conference, 21-25 September 2009, Hamburg, Germany P.469-472.

[9] ZHANG Li ,HE Qing , JIANG Wei-Long , LI Chang-Jian , SUN Yun « Cu(In, Ga)Se$_2$ Thin Films on Flexible Polyimide Sheet: Structural and Electrical Properties versus Composition » CHIN. PHYS. LETT. Vol. 26,No. 2 (2009) 026801 pp.1-4.