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Research Paper

Influence of Magnetic Field on the Capacitance of a Vertical Junction Parallel Solar Cell in Static Regime, Under Multispectral Illumination

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Abstract: *A theoretical study of a vertical parallel junction silicon solar cell under magnetic field, leads to diffusion capacitance determination versus magnetic field, junction recombination velocity and base thickness.*

Keywords: Parallel vertical junction- solar cell-magnetic field-capacitance.

I. Introduction

The performances of solar cells are often limited by recombination of photo generated carriers before crossing the junctions and contribute to the photo current. Thus several techniques of determination of recombination parameters (B. Mazhari and H. Morkoç, 1993) in the bul and on the surfaces are investigated ad lead to: lifetime, diffusion length, junction recombination velocity Sf, backside recombination velocity Sb, and grain boundaries recombination velocity Sgb). Electrics parameters are also derived (H. El Ghitani and S. Martinuzzi, 1989) and give: series and shunt resistances, capacitance, space charge region. Different silicon solar cell types (A. Cuevas, 2005) were elaborated such as monofacial, bifacial, and vertical junction. Solar cells are studied under steady or dynamic state (frequency and transient states) (A. Corréaet al, 1994), frequency dynamic regime (A. Diao, 2014) or transient (C.D. Thurmond, 1975; J. Roos Macdonald, 1994).

Determining the influence of these parameters on the functioning of the solar cell assesses the performance.

Our study deals with the influence of magnetic field on the vertical junction parallel solar cell capacitance in static regime, and under multispectral illumination. Continuity equation related to photo generated carrier's density in the base region of the solar cell is solved. From the expression of the minority carrier's density, photocurrent, photo voltage and diffusion capacitance are deduced. The influence of magnetic field on these parameters is then studied.

II. Theory

The vertical junction cell is designed such that the incident illumination is parallel to the plan of the space charge region (SCR).The structure of a typical parallel vertical junction solar cell can be represented with $n^+ - p - n^+ - p$ (M.M. Dione et al, 2009; M.I. Ngom et al, 2012).

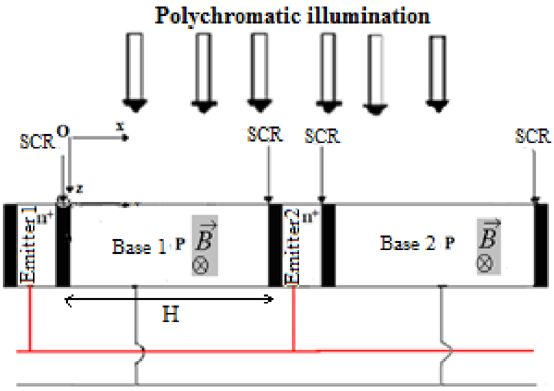

Figure 1: Parallel vertical junction solar cell under magnetic field

The magnetic field B is represented perpendicularly to the plane (xoz).

When the solar cell is illuminated, there is photo generated carriers (electron) in the p-base. The phenomena of generation, diffusion and recombination of the minority carriers in the base are governed by the continuity equation (1):

$$\frac{\partial^2 \delta(x)}{\partial x^2} - \frac{\delta(x)}{L^{*2}} = -\frac{G(z)}{D^*} \qquad (1)$$

G(z) is the carriers generation rate for the polychromatic illumination and whose expression (Jose Furlan and Slavko Amon, 1985)is given by following equation:

$$G(z) = n \sum_{i=1}^{3} a_i e^{-b_i z} \qquad (2)$$

n is the illumination level called sun number (n=1 for the studied case), a_i and b_i are the coefficients from modelling of the generation rate (S.N. Mohammad, 1987)overall radiation in solar spectrum to AM 1,5.

D* is the minority carriers diffusion in the base under magnetic field (A. Dieng et al 2009; Th. Flohr and R. Helbig 1989; A. Dieng et al 2007). we obtain (3):

$$D^* = \frac{D}{[1 + (\mu B)^2]} \qquad (3)$$

D is the diffusion constant without magnetic field and μ is the minority carrier mobility in the base; L* is the minority carrier diffusion length. We obtain:

$$L^* = \sqrt{\tau D^*} \tag{4}$$

τ is the minority carrier lifetime.

The solution of the continuity equation (1) can be written as:

$$\delta(x, z, B, Sf) = A\cosh\left(\frac{x}{L^*}\right) + E\sinh\left(\frac{x}{L^*}\right) + \sum_{i=1}^{3} K_i e^{-b_i z} \tag{5}$$

With

$$K_i = \frac{a_i L^{*2}}{D^*} \tag{6}$$

The coefficients A and E are determined by the boundaries conditions:

- At the junction base1-emitter1 (x=0):

$$\left.\frac{\partial\delta(x)}{\partial x}\right|_{x=0} = \frac{Sf}{D^*}\delta(x)|_{x=0} \tag{7}$$

Where Sf is the minority carriers recombination velocity at the junction (G. Sissoko et al 1992; H. L. Diallo et al, 2008).

- At the middle of the base (x=H/2), the carrier's density gradient remained zero:

$$\left.\frac{\partial\delta(x)}{\partial x}\right|_{x=\frac{H}{2}} = 0 \tag{8}$$

III. Results and Discussions

Excess Minority Carriers Density

The curve of excess minority carriers density versus base depth x and magnetic field is represented on figure 2.

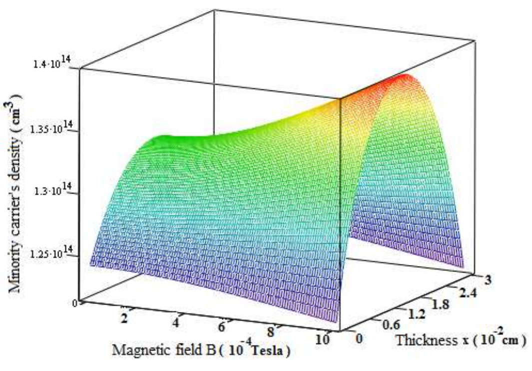

Figure 2: Excess minority carriers density in the base versus thickness in the base and magnetic field $z = 0{,}002\text{cm};\ Sf = 3.10^3\text{cm.s}^{-1}\ ; D = 26\text{cm}^2.\text{s}^{-1};\ H = 0{,}03\text{cm};\ \tau = 10^{-5}\text{s}$

Way whatever the applied magnetic field intensity value, the minority carrier's density is maximum in the middle of the base (x=H/2), thus giving a null gradient of the density. The positive gradient for x< H/2 and negative for x> H/2 testify many activities to minority carrier recombination's at the base-emitter junctions.

When one moves away from the junctions, the minority carrier's density in the base increases with the magnetic field intensity. When the solar cell is illuminated, there is coexistence of the phenomena of generation, of diffusion and of conduction into the cell. The two last are very inhibited by strong magnetic fields (B= 10^{-3}T), thus all the minority carriers who are generated become more and more quasi-motionless in the middle of the base where their high number. By decrease the magnetic field intensity, the diffusion phenomena of is intensifying; the minority carriers decrease because they move towards the junctions and cross them.

The curve of excess minority carrier's density in the base versus both, base depth x and junction recombination velocity Sf, is represented on figure 3:

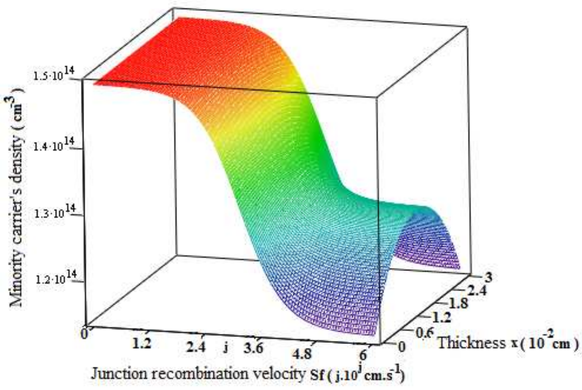

Figure 3: Excess minority carriers density in the base versus thickness in the base and junction recombination velocity$B = 3.10^{-4}T$; $z = 0{,}002cm$; $D = 26cm^2.s^{-1}$; $H = 0{,}03cm$; $\tau = 10^{-5}s$

For junction recombination velocity low values (Sf<2.10^{2}cm/s), the minority carrier's density is maximum: minority carriers are storage at the junctions. For high junction recombination velocity values (Sf>4.10^{4}cm/s), minority carriers decrease by crossing the base-emitter junctions and contribute to the photocurrent.

The curve of excess minority carrier's density in the base versus both, base thickness z and depth x is represented on figure 4:

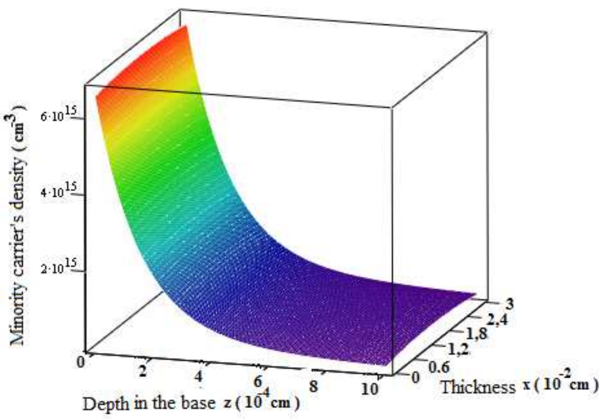

Figure 4: Excess minority carrier's density in the base versus thickness z and depth x $B = 10^{-3}T$; $Sf = 3.10^{3}cm.s^{-1}$; $D = 26cm^2.s^{-1}$; $H = 0{,}03cm$; $\tau = 10^{-5}s$

One can observe an exponential decrease of the minority carrier's density with the base depth z. This is due the fact that the incident photons flux responsible for the minority carrier's generation decreases with the depth z (Beer-Lambert law).

Photocurrent Density

The photocurrent density results from the diffusion of the minority carriers across the junction. The expression is given by:

$$\mathrm{Jph} = 2\mathrm{q}D^{*}\left.\frac{\partial\delta(x,z,B)}{\partial x}\right|_{x=0} \qquad (9)$$

Where q is the elementary charge; the coefficient 2 results from the two junctions of the parallel vertical junction solar cell.

The photocurrent density curve versus thejunction recombination velocity Sf and magnetic field is represented on figure 5.

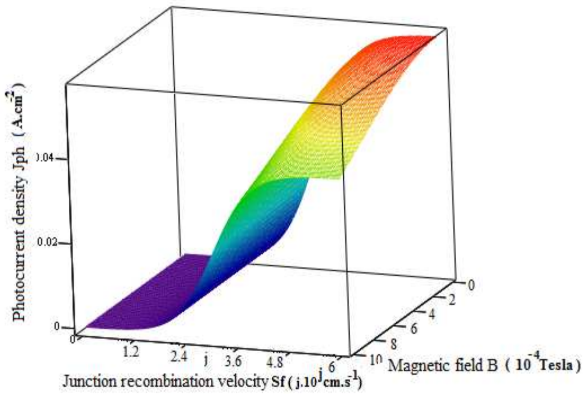

Figure 5: Photo current density versus junction recombination velocity and magnetic field
$z = 0{,}002\mathrm{cm}\ ; D = 26\mathrm{cm}^2.\mathrm{s}^{-1};\ H = 0{,}03\mathrm{cm};\ \tau = 10^{-5}\mathrm{s}$

The photocurrent density increases with the junction recombination velocity. However there are two stages of quasi-null gradients. The first for the low values of the junction recombination velocity (Sf<10cm/s) corresponding with the situation of open-circuit where there is storage of minority carrier at the junctions. The second for the strong junction recombination velocity values (Sf>4.10^4cm/s) corresponding with the situation of short-circuit where more minority carrier crossed the junctions to generate more current.

The photocurrent density decreases with the magnetic field intensity. One have seen higher that more the field is the strong, less there are minority carrier close to the junctions which are likely to cross them especially that they are already quasi motionless. This is due to the decreasing of the photocurrent density with the magnetic field intensity.

The photocurrent density curve versus magnetic field and the depth z is represented on figure 6:

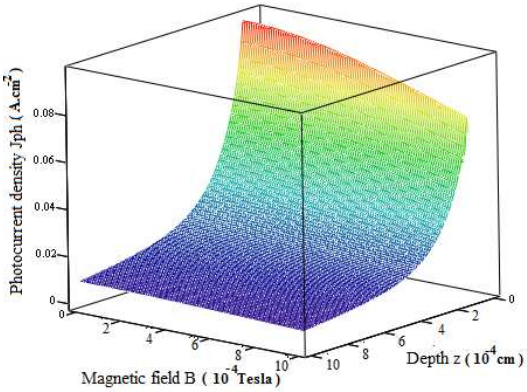

Figure 6: Photocurrent density versus magnetic field and the depth
$\mathrm{Sf} = 3.10^3 \mathrm{cm}.s^{-1}$; $\mathrm{D} = 26\mathrm{cm}^2.\mathrm{s}^{-1}$; $\mathrm{H} = 0{,}03\mathrm{cm}$; $\tau = 10^{-5}\mathrm{s}$

For a given magnetic field value, an exponential decrease of the photocurrent density with the solar cell depth z ,is observed. This is due the fact that the minority carrier's generation is low with the depth and leads to the reduction of the minority carrier's flux that cross the junctions to generate current.

Photovoltage

From Boltzmann law, the photovoltage expression can be written as:

$$\mathrm{Vph} = \mathrm{V_T} \ln\left[1 + \frac{\mathrm{Nb}}{\mathrm{No}^2}\delta(\mathrm{x} = 0, \mathrm{z})\right] \qquad (10)$$

$$\text{avec} \quad \mathrm{V_T} = \frac{\mathrm{KT}}{\mathrm{q}} \qquad (11)$$

Where No is the intrinsic carrier's concentration, Nb the base doping density and $\mathrm{V_T}$ the thermal voltage.

K is the Boltzmann constant, T the absolute temperature.

The photovoltage curve versus the junction recombination velocity Sf and magnetic field is represented on figure 7:

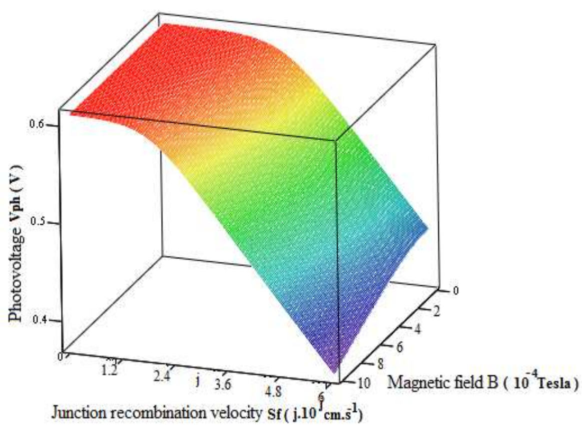

Figure 7: Photovoltage versus the junction recombination velocity Sf and magnetic field
$\mathrm{z} = 0{,}002\mathrm{cm}$; $\mathrm{D} = 26\mathrm{cm}^2.\mathrm{s}^{-1}$; $\mathrm{H} = 0{,}03\mathrm{cm}$; $\tau = 10^{-5}\mathrm{s}$

For a given magnetic field value, the photovoltage decreases with the junction recombination velocity. For low junction recombination velocity values (Sf<10cm/s) the photovoltage is maximum and quasi-constant, it's the situation of open-circuit where there is storage of minority carriers at the junctions. When the junction recombination velocity increases, many minority carrier cross the junctions which decreases the quantity of carrier stored, thus the photovoltage.

The photovoltage decreases when the magnetic field intensity increases. But the impact of magnetic field on the photovoltage is weak.

The photovoltage curve versus magnetic field and the depth z is represented on figure 8:

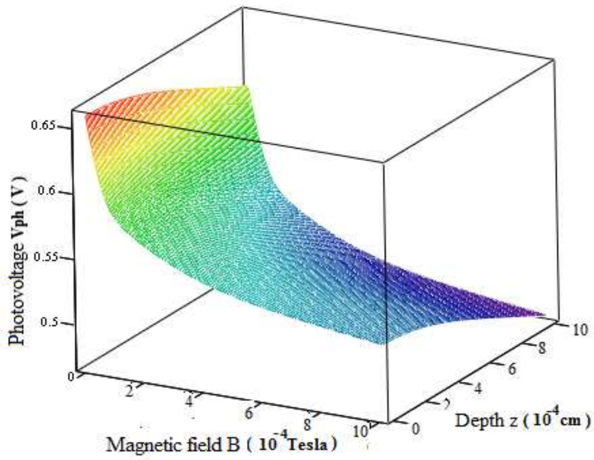

Figure 8: Photovoltage versus magnetic field and the depth z
$\mathrm{Sf} = 3.10^3 \mathrm{cm}.s^{-1}$; $\mathrm{D} = 26\mathrm{cm}^2.\mathrm{s}^{-1}$; $\mathrm{H} = 0{,}03\mathrm{cm}$; $\tau = 10^{-5}\mathrm{s}$

The decrease of the photovoltage versus magnetic field (when one is out of open-circuit) is more sensitive on this figure 8.

One note also that the photovoltage decreases with the depth z of the solar cell. This is due to the decrease of the minority carrier's photo generation with the depth, thus a decrease of minority carrier near the junctions for generated photovoltage.

Capacitance

The diffusion capacitance of solar cell results from the diffusion processes of minority carrier (F.I. Barro et al 2008; A. Hamidou et al, 2013).

This capacitance expression can be written as:

$$C = \frac{q.\delta(O,z,B)}{Vph} \qquad (12)$$

The capacitance curve versus both, junction recombination velocity Sf and magnetic field is represented on figure 9:

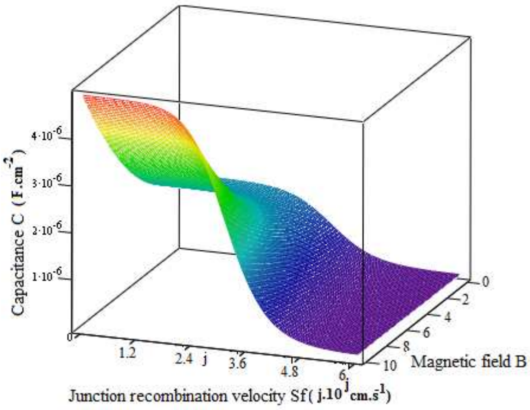

Figure 9: Capacitance versus the junction recombination velocity and magnetic field
$z = 0{,}002\text{cm}\ ;\ \ D = 26\text{cm}^2.\text{s}^{-1};\ H = 0{,}03\text{cm};\ \tau = 10^{-5}\text{s}$

The capacitance decreases with the junction recombination velocity Sf. The capacitance is maximum and quasi-constant for low junction recombination velocity value ($Sf<2.10^2$cm/s), which corresponds to solar cell under open-circuit condition. This is due to the important stocked minority carrier near the junction which contracts the space charge region (SCR) and thus increases the capacitance. For strong Sf values ($Sf>4.10^4$cm/s) low capacitance value is obtained and corresponds to short-circuited solar cell situation. This is due to the important number of minority carrier who crosses the junction base-emitter: widening of the space charge region.

The capacitance increases with magnetic field. More magnetic field is intense, more the minority carrier are quasi-static near the junction, the space charge region contract, thus the increase of the capacitance. This increase is low near to short-circuit.

The capacitance curve versus magnetic field and depth z is represented on figure 10.

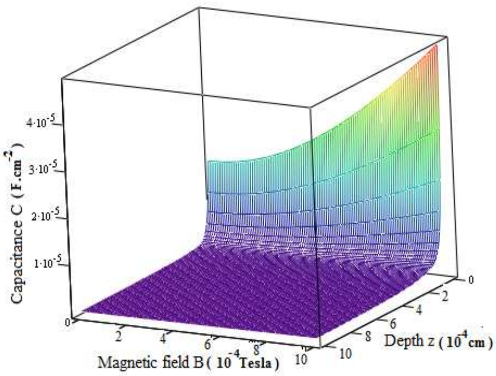

Figure 10: Capacitance versus magnetic field and the depth
$Sf = 3.10^3\text{cm}.s^{-1}\ ;\ \ D = 26\text{cm}^2.\text{s}^{-1}; H = 0{,}03\text{cm};\ \tau = 10^{-5}\text{s}$

For a given magnetic field values, an exponential decrease of the capacitance with the depth z is observed. The increase of the depth decreases the minority carrier's density. Thus a decrease of stocked carriers at the junction leads to a decrease of the capacitance.

Dark Capacitance

The solar cell capacitance expression can be written also as:

$$C(z,B,Sf) = \frac{dQ}{dVph} = q.\frac{d\delta(x=0)}{dVph} \qquad (13)$$

With Q the total charges in the vicinity of the junction.

Equation (13) becomes:

$$C(z,B,Sf) = Co + q.\frac{\delta(x=0)}{V_T} \qquad (14)$$

Where Co is the solar cell capacitance under dark.

Equation (14) can be rewritten in the form:

$$C(z,B,Sf) = Co\exp\left(\frac{Vph}{V_T}\right) \qquad (15)$$

With the logarithm function, we rewrite equation (15) as:

$$lnC - lnCo = \frac{Vph}{V_T} \qquad (16)$$

Equation (16) can be expressed as follows:

$$lnC(z,B,Sf) = \frac{1}{V_T}.Vph(z,B,Sf) + lnCo \qquad (17)$$

The logarithm of the capacitance curves versus photovoltage for various magnetic field values are given at the figure 11:

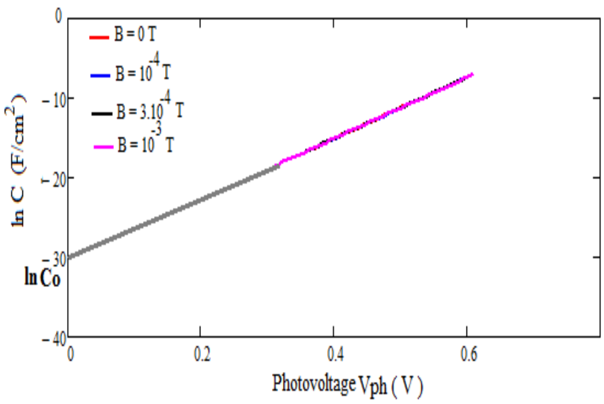

Figure 11: The logarithm of the capacitance versus photovoltage for various magnetic field values $z = 0{,}002\,;\; D = 26cm^2.s^{-1};\; H = 0{,}03cm;\; \tau = 10^{-5}s$

The logarithm of the capacitance versus photovoltage for various magnetic field values is a straight line of slop $1/V_T$. The intercept point obtained with the capacitance axis is the dark capacitance value (G. Sissoko et al., 1998). The obtained value with this method is$Co = 9{,}358.10^{-14}F/cm^2$.

Conclusion

A theoretical study of a solar cell with parallel vertical junction in static regime under multispectral illumination and under magnetic field is presented. From different studies, we could establish that the magnetic field favors the presence of photo generated electrons in the base by inhibiting their diffusion and their conduction. The diffusion capacitance of the solar cell increases with the magnetic field. In finally, the dark capacitance of the solar cell was obtained for any magnetic field value.

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