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RESEARCH ARTICLE

EFFECT OF THE MAGNETIC FIELD ON THE SPECTRAL RESPONSE AND EXTERNAL QUANTUM EFFICIENCY OF A BIFACIAL SILICON SOLAR CELL

Amadou Diao[1], Mountaga Boiro[1], Ibrahima Toure[1], Adama Ndiaye[1] and Senghane Mbodji[2]

1. Semi Conductors and Solar Energy Laboratory, Department of Physics, Faculty of Sciences and Techniques, Cheikh Anta Diop University, Dakar / Senegal.
2. Research Team in Renewable Energies, Materials and Laser, Department of Physics, UFR SATIC, Alioune Diop University, Bambey / Senegal.

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Abstract

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In this paper, a theoretical study of a constant magnetic field effect on spectral response and external quantum efficiency of a bifacial silicon solar cell, is done. Considering a steady-state regime, we use the continuity equation that is related to the photogenerated minority carriers in the base of a solar cell in order to determine the expression of the minority carriers' density according to the wavelength, the magnetic field and the junction recombination velocity. Based on the expression of minority carriers' density, we established the expressions of the photoconductivity and the photocurrent density from which the spectral response and the external quantum efficiency have been deduced according to the excitation and phenomenological parameters of the solar cell. We found that, as the magnetic field increases, both the spectral response and external quantum efficiency decrease; what shows a degradation of the intrinsic properties of the solar cell.

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Introduction:-

Renewable energies have become an unavoidable alternative energies sources to meet the energy demand of the world's population. Among these renewable energies, photovoltaic energy plays an important role in reducing atmospheric emissions by limiting greenhouse gas emissions and climate change. However, the output energy of the cell depends on weather environment, installation techniques of the solar panels and their energy conversion efficiency,manufacturing technology and nature of the solar cells that are used [1]. Therefore, many developed techniques and methods have been used to solar cells characterization in order to enhance the energy conversion efficiency. Thus, the parameters like the photoconductivity [2-13], the spectral response [14] and the quantum efficiency [15-21] have been widely used as characterizing techniques to many of solar cells. Furthermore, a few authors as Andrés Cuevas et al. [22] and Vasiliki Paraskeva et al. [23] have used respectively the photoconductivity on the 'emitters' layers of solar cells andthe shunt resistances effects on a germanium multi-junction solar cells in order to measure their quantum efficiencies. Also, Giorgio Bardizza et al. [24] and Mauro Pravettoni et al. [25] have characterized dye-sensitive solar cells (DSSC) in frequency modulation and concentrated crystalline solar cells using the spectral response technique, respectively. For Baishali Talukdar et al. [26], the shading effect of several cells is shown on spectral response and quantum efficiency.

Corresponding Author:- Amadou Diao
Address:- Semi Conductors and Solar Energy Laboratory, Department of Physics, Faculty of Sciences and Techniques, Cheikh Anta Diop University, Dakar / Senegal.

In this work, we carry out a theoretical study of an applied magnetic field effect on the spectral response and external quantum efficiency of a bifacial silicon solar cell. We note that the magnetic field, which is perpendicularly applied, degrades some electrical properties of the solar cell.

Theory

We use a n^+-p-p^+ type of a bifacial silicon solar cell [29-30] that is modelled as shown in figure 1:

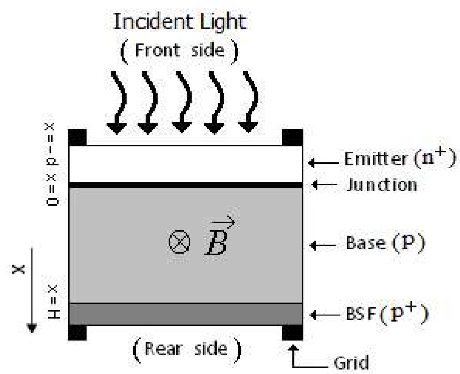

Figure 1:- A simplified scheme of bifacial silicon solar cell under a magnetic field effect.

Where d and H are respectively the emitter and the base thicknesses.
We consider, at first, a one-dimensional study of the solar cell, along the x-axis.

When a solar cell is placed under optical excitation, absorbed incident photons create minority carriers which can recombine or diffuse in the base. This process of the minority carriers, in steady-state, is governed by the continuity equation :

$$D_n \frac{\partial^2 \delta_n}{\partial x^2} - \frac{\delta_n}{\tau_n} = -G \qquad (1)$$

WhereD_n is the minority carriers diffusion coefficient given by :

$$D_n = \frac{D_o}{1 + \mu_o^2 B^2} \qquad (2)$$

WithD_o being the minority carriers diffusion coefficient without magnetic field; G is the minority carriers generation rate [31, 32] at position x, whose expression is :

$$G = \alpha(\lambda)\phi(\lambda)(1 - R(\lambda))e^{-\alpha(\lambda)x} \qquad (3)$$

Where the parameters $\alpha(\lambda)$, $R(\lambda)$ and $\phi(\lambda)$ are respectively the absorption coefficient, the reflection coefficient and the incident photons flux at wavelength λ and $\tau_n$is the average lifetime; $m$is the effective mass of electrons in the base; δ_n is the excess minority carriers' density in the base.
A solution of equation (1) is given by :

$$\delta_n = Ae^{-\frac{x}{L_n}} + Ce^{\frac{x}{L_n}} - \frac{\alpha(\lambda)L_n^2\phi(1 - R(\lambda))e^{-\alpha(\lambda)x}}{D_n(\alpha(\lambda)^2 L_n^2 - 1)} \qquad (4)$$

with :

$$L_n = \sqrt{D_n \tau_n} \text{ and } (\alpha(\lambda)^2 L_n^2 - 1) \neq 0 \qquad (5)$$

Where L_n is the minority carriers' diffusion length in the base.
The following boundary conditions [32, 33] are used to determine the coefficients A and C :

- at the junction (x = 0)

$$D_n \cdot \left.\frac{\partial \delta_n}{\partial x}\right|_{x=0} = Sf \cdot \delta_n|_{x=0} \qquad (6)$$

- at the back side (x = H)

$$D_n \cdot \frac{\partial \delta_n}{\partial x}\bigg|_{x=H} = -Sb \cdot \delta_n|_{x=H} \qquad (7)$$

Where *Sf* and *Sb* are respectively the junction recombination velocity and the back surface recombination velocity.

Expression of the photocurrent density

The photocurrent density is determined according to the photoconductivity as following :

$$J_{ph} = \frac{1}{\gamma}\left(\sigma_{ph} - \beta\left(e^{-\alpha(\lambda)H} - 1\right)\right) \qquad (8)$$

Where γ is a coefficient that depends on geometrical parameters of the solar cell and the nature of the incident illumination ; β a coefficient which expression is :

$$\beta = \frac{q\mu_o\phi(\lambda)(1 - R(\lambda)){L_n}^2}{D_o(\alpha(\lambda)^2 L_n^2 - 1)} \qquad (9)$$

And σ_{ph} is the photoconductivity which is given by [34]:

$$\sigma_{ph} = \frac{q^2\tau_n\delta_n}{m(1 + \mu_o^2 B^2)} \qquad (10)$$

whereq is the elementary charge.

Expressions of the spectral response and the external quantum efficiency

The spectral response (SR) is the ratio of photocurrent density J_{ph} to incident power P_i and its expression is given by [35, 36] :

$$SR = \frac{J_{ph}}{P_i} \qquad (11)$$

with :

$$P_i = \frac{hC}{\lambda}\phi_i \qquad (12)$$

where ϕ_i is the incident photons flux (ϕ(λ)), h is the Planck's constant and C the light celerity in the vacuum. Substituting equations (8) and (12) into equation (11), we get :

$$SR = \frac{\lambda}{\gamma hC\phi(\lambda)}\left[\sigma_{ph} - \beta\left(e^{-\alpha(\lambda)H} - 1\right)\right] \qquad (13)$$

From the relationship between spectral response and external quantum efficiency (EQE) [37],we obtain :

$$SR = \frac{q\lambda}{hC}EQE \qquad (14)$$

We deduce, from equation (14), the expression of the external quantum efficiency as below :

$$EQE = \frac{\left[\sigma_{ph} - \beta\left(e^{-\alpha(\lambda)H} - 1\right)\right]}{q\gamma\phi(\lambda)} \qquad (15)$$

Results and Discussion:-

5-1°) Profile of the photocurrent density

In figures 2-a and 2-b, the photocurrent density versus the junction recombination velocity is represented respectively in short and long wavelengths:

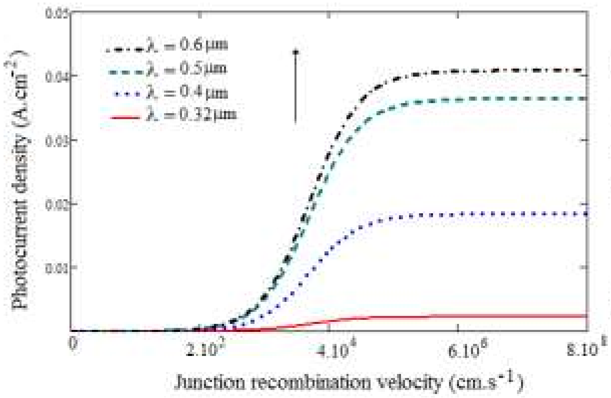

Figure 2-a:- For short wavelength with B = 0 T

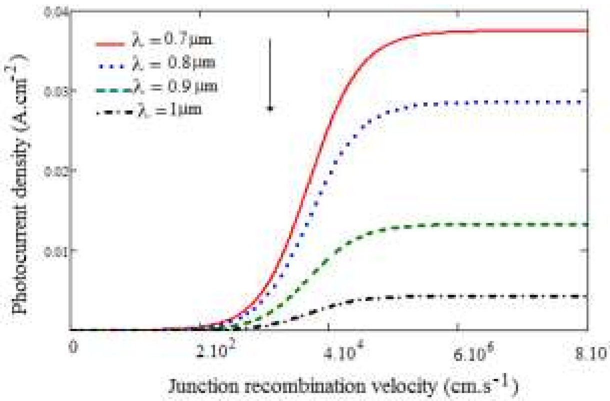

Figure 2-b:- For long wavelength with B = 0 T.

We have three zones of the solar cell functionment. The first, in the interval of the junction recombination velocity [0 $m.s^{-1}$; 2.10^2 $m.s^{-1}$[where the photocurrent is almost zero and corresponds to that of open circuit situation; the second, in the interval]5.10^5 $m.s^{-1}$; 8.10^8 $m.s^{-1}$] where the photocurrent is maximum and equals to that of short circuit situation and the third, in the interval] 2.10^2 $m.s^{-1}$; 5.10^5 $m.s^{-1}$] where the photocurrent varies with the operating point that is correlated to the junction recombination velocity.

In short wavelengths interval [0.3µm; 0.7µm], the photocurrent amplitude increases since the incident photons are strongly absorbed by the base of the solar cell. However, in long wavelengths interval [0.7µm; 1.2µm], the incident photons are weakly absorbed because the base becomes transparent especially of those whose energies are very low.

5-2°) Profile of the spectralresponse (SR)

In figure 3, we represent the spectral response according to the wavelength for different values of the magnetic field :

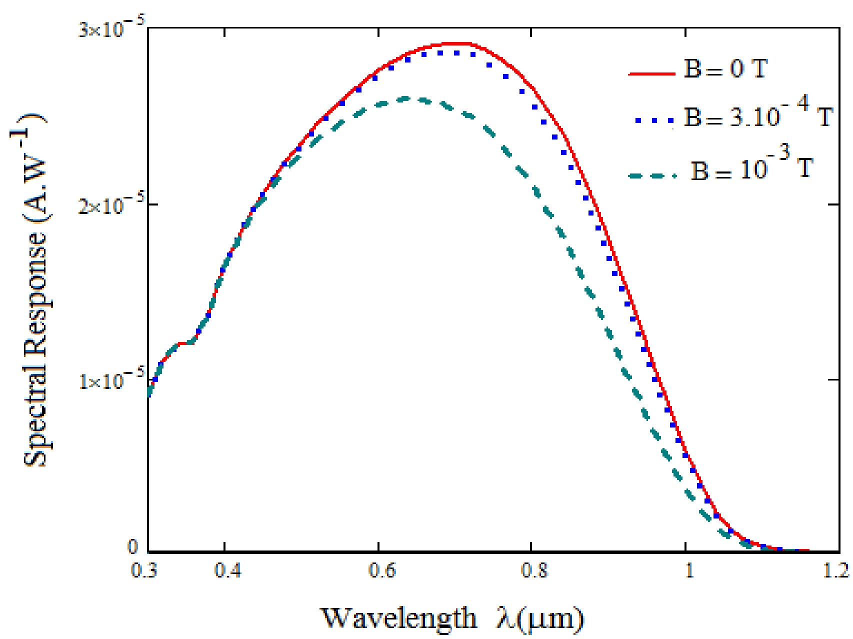

Figure 3:- Spectral response versus wavelength for different magnetic field values.

At the figure 3, the spectral response is given according to the wavelength for different magnetic field values. We have the same behavior of the three curves. For a given curve, the spectral response increases with the wavelength until reaching a maximum value SR_{max}at a limit wavelengthλ_L that depends on the magnetic field. From the SR_{max} value, the spectral response decreases with the wavelength. In the interval of wavelength [0.3µm ; λ_L], the increase in spectral response is due to that of photoconductivity [13] which corresponds to a significant absorptivity of the solar cell base; what implies a good sensitivity of this cell. However, in the interval of wavelength]λ_L ; 1.2µm], the spectral response decreases so that we note a decreasingsensitivity of the solar cell since the photoconductivity also decreases in the base.

5-3°) Profile of the external quantum efficiency

In figure 4, the external quantum efficiency is represented according to the wavelength for different magnetic field :

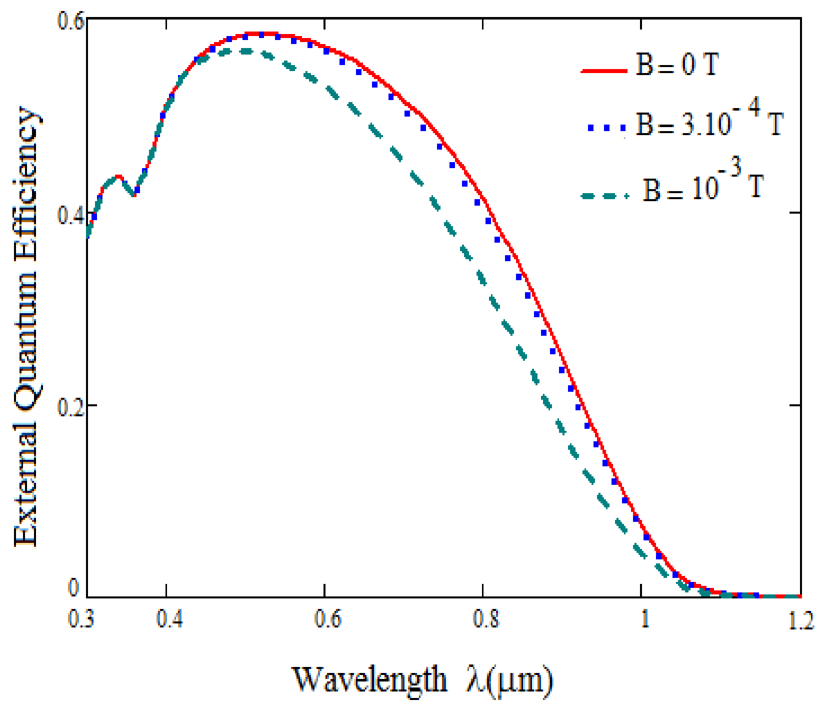

Figure 4:- External quantum efficiency versus wavelength for different magnetic field values.

In figure 4, we note the same behavior of the three curves of external quantum efficiency according to the wavelength for the different magnetic field values. For a given curve, the maximum of the external quantum efficiency is obtained in the visible wavelength domain. Three maximum values of the external quantum efficiency have been obtained : i) the first that corresponds to a wavelength λ_1 = 0.34µm for the three magnetic field values, isEQE_{max1} = 0.422 ; ii) the second corresponds to EQE_{max2} = 0.565 at the wavelength λ_2 = 0.52µm for the two values of magnetic field B = 0 T and B = 3.10^{-4} T ; iii) the third to EQE_{max3} = 0.555 at the wavelength λ_2 = 0.48µm for a value of magnetic field B = 10^{-3} T. Beyond these maximum values, the external quantum efficiency decreases with the increase of the wavelength. From the caracteristic wavelength λ= 0.455µm, the amplitude of the external quantum efficiency decreases with the increase of the magnetic field.

Conclusion:-

In short wavelengths interval, the photocurrent density, the spectral response and the external quantum efficiency increase while in long wavelengths they decrease. The application of a perpendicular magnetic field on the base, leads to a decrease in the amplitude of the photocurrent, the spectral response and the external quantum efficiency; this fact implies a degraded intrinsic properties of the solar cell.

For the future investigation, we will develop a program algorithm that will take into account to all the parameters that have been used in this work. For this purpose, experimental measurements will be carried out on a mono or polycrystalline silicon solar cell under real operating conditions.

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