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External Magnetic Field Effect on Bifacial Silicon Solar Cell's Electrical Parameters

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Abstract

The aim of this work is to present a theoretical study of external magnetic field effect on a bifacial silicon solar cell's electrical parameters (peak power, fill factor and load resistance) using the J-V and P-V characteristics. After the resolution of the magneto transport equation and continuity equation of excess minority carriers in the base of the bifacial silicon solar cell under multispectral illumination, the photo-current density and the photovoltage are determined and the J-V and P-V curves are plotted. Using simultaneously the J-V and P-V curves, we determine, according to magnetic field intensity, the peak photocurrent density, the peak photovoltage, the peak electric power, the fill factor and the load resistance at the peak power point. The numerical data show that the solar cell's peak power decreases with magnetic field intensity while the fill factor and the load resistance increase.

Keywords

Bifacial Silicon Solar Cell, Fill Factor, Load Resistance, Magnetic Field, Peak Power

1. Introduction

The efficiency of a solar cell depends on its electrical parameters such as series and shunt resistances, peak power and fill factor. For the determination of the series and shunt resistances many authors [1]-[3] used the photocurrent density-photovoltage (J-V) characteristic of a solar cell while other authors [4] used simultaneously the photocurrent density-photovoltage (J-V) and the electric power-photovoltage (P-V) characteristics for the determination of electrical parameters such as peak power, fill factor and load resistance. In a previous work we have studied the influence of magnetic field intensity on a bifacial silicon solar cell's electric power and conver-

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sion efficiency using the electric power curves versus junction dynamic velocity [5].

In this work, we study the influence of magnetic field intensity on a bifacial silicon solar cell's electrical parameters (peak power, fill factor and load resistance). Using simultaneously the J-V and P-V curves, we determine the peak power, the fill factor and the load resistance at the peak power point according to magnetic field intensity. Then, we relate the resistance at the peak power point (R_{MPP}) to the junction dynamic velocity at the maxi mum power point (Sf_{MPP}) calculated in the previous article [5].

2. Theory

2.1. Excess Minority Carriers' Density

This study is focused on the base region of a polycrystalline back surface field bifacial silicon solar cell (**Figure 1**) in the quasi-neutral base assumption [5] [6].

When the bifacial silicon solar cell is illuminated simultaneously on both sides, the solution of excess minority carriers' continuity equation [7] is:

$$\delta(x,B) = A_1 \cdot \mathrm{ch}\left(\frac{x}{L_n^*}\right) + A_2 \cdot \mathrm{sh}\left(\frac{x}{L_n^*}\right) + \sum_{i=1}^{3} K_i \cdot \left[\mathrm{e}^{-b_i \cdot x} + \mathrm{e}^{-b_i (H-x)} \right] \tag{1}$$

with $K_i = -a_i \cdot \left[D_n^* \cdot \left(b_i^2 - \frac{1}{L_n^{*2}} \right) \right]^{-1}$.

In Equation (1), L_n^* and D_n^* are respectively electrons' diffusion length and diffusion coefficient in the presence of a magnetic field, coefficients a_i and b_i are tabulated values obtained from modelling of the generation rate considered for over all the solar radiation spectrum under Air Mass 1, 5 standard conditions [8] and H is the base thickness.

Constants A_1 and A_2 are determined solving the boundary conditions [5] [7]. Thus, the excess minority carriers' (electrons) density will be completely determined.

2.2. Photocurrent Density

Since the excess minority carriers' density is known, from Fick's law applied at the solar cell junction, we can derive the photocurrent density expression as:

$$Jph(Sf,B) = q \cdot D_n^* \cdot \left. \frac{\partial \delta(x,Sf,B)}{\partial x} \right)_{x=0} . \tag{2}$$

2.3. Junction Photovoltage

Knowing the excess minority carriers' density, the photovoltage across the solar cell junction is also expressed

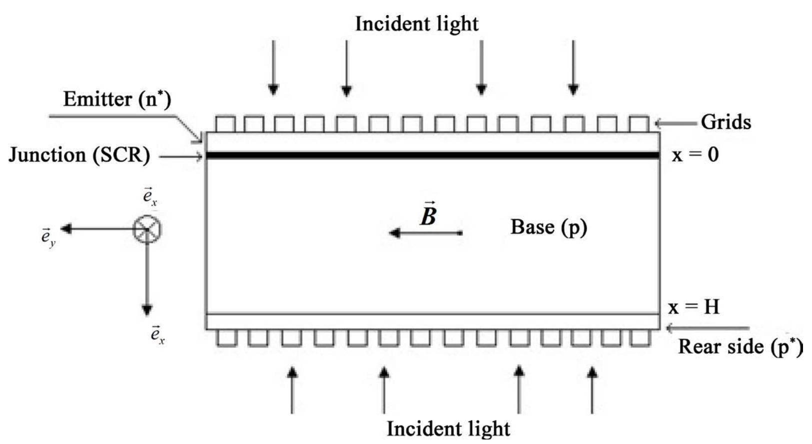

Figure 1. Bifacial silicon solar cell illuminated by multispectral light and under magnetic field influence.

using Boltzmann's relation:

$$Vph(Sf,B) = V_T \cdot \ln\left(N_B \frac{\delta(x=0,Sf,B)}{n_i^2} + 1 \right) \quad (3)$$

V_T is the thermal voltage, n_i is the intrinsic carriers' density at thermodynamic equilibrium and N_B is the base doping density.

2.4. Photocurrent Density-Photovoltage Characteristics (Jph-Vph)

The photocurrent density and the photo-voltage depend on junction dynamic velocity Sf. While taking the junction dynamic velocity as parameter, we plot in **Figure 2** the solar cell Jph-Vph characteristic curves for different values of magnetic field intensity.

The shapes of the different curves in **Figure 2** show that the short circuit photocurrent density is a decreasing function of magnetic field while the open circuit photovoltage is an increasing function of the same magnetic field. We note that the short circuit photocurrent density decreases strongly while the open circuit photovoltage increases slightly.

Each curve is characterized by three remarkable points: the short circuit photocurrent density J_{sc}, the open circuit photovoltage V_{oc} and a point named "knee" or peak power point [4] which has J_m (or J_p) and V_m (or V_p) as coordinates [1] The peak power ($P_p = J_p \times V_p$) is the maximum electric power ($P_m = J_m \times V_m$) that a solar cell can delivered to an external circuit; so the peak power point is the operating point that permits to obtain the maximum electric power from a solar cell [4]. We note a displacement of the peak power point, towards large values of photovoltage and low values of photocurrent density, when the magnetic field intensity increases and that situation corresponds to a displacement of the solar cell's operating point and so an increase of the load resistance at the peak power point.

2.5. Electric Power-Photovoltage Characteristics (P-Vph)

The expression of electric power delivered by the base of the bifacial solar cell to an external circuit is:

$$P(Sf,B) = Vph(Sf,B) \cdot Jph(Sf,B)_T \quad (4)$$

with $Jph(Sf,B)_T = q \cdot Sf_j \cdot \delta(x=0,Sf,B)$ which is the photocurrent density that crosses the external load resistance.

The electric power delivered by the bifacial silicon solar cell to an external circuit depends also on the junction dynamic velocity Sf. While taking the junction dynamic velocity as parameter, we plot in **Figure 3** the solar cell P-Vph characteristic curves for different values of magnetic field intensity.

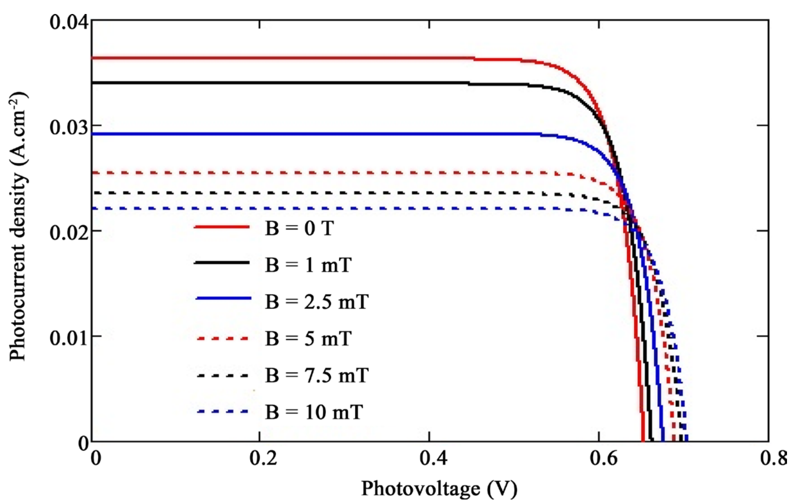

Figure 2. Photocurrent density-photovoltage curves for various magnetic field intensity (L = 0.02 cm; H = 0.03 cm; D = 26 cm^2/s; μ_n = 1000 cm^2/V.s).

The curves in **Figure 3** show that the peak power decreases with magnetic field increase and that corresponds to a displacement of the bifacial solar cell's operating point towards large values of photovoltage. This means that the increase of magnetic field leads to an increase of the load resistance at the peak power point.

3. Results and Discussion

3.1. Method of Electrical Parameters Determination

For that, we plot in the same axes system (**Figure 4**), Jph-Vph and P-Vph characteristics for a given magnetic field intensity.

Using the two characteristics, we determine the values of peak power P_p, peak photovoltage V_p, peak photocurrent density J_p, short circuit photocurrent density J_{sc} and open circuit photovoltage V_{oc} according to magnetic field intensity.

Then we calculated the solar cell fill factor (FF) using the formula below:

$$FF = \frac{V_p \cdot J_p}{V_{oc} \cdot J_{sc}}. \tag{5}$$

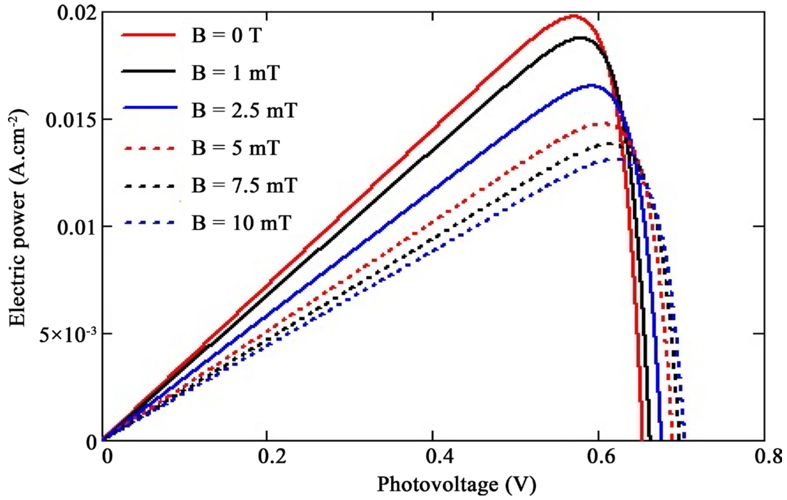

Figure 3. Electric power-photovoltage curves for various magnetic field intensity (L = 0.02 cm; H = 0.03 cm; D = 26 cm^2/s; μ_n = 1000 cm^2/V.s).

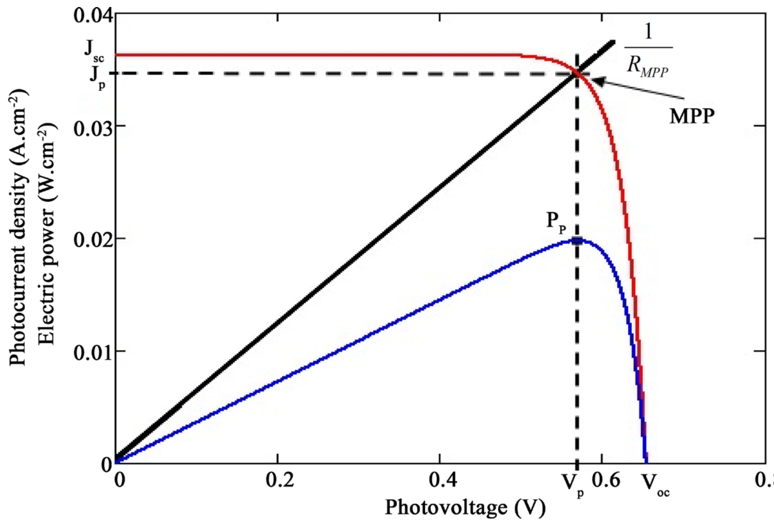

Figure 4. Electrical parameters determination using Jph-Vph and P-Vph characteristics.

Knowing the peak photovoltage V_p, and the peak photocurrent density J_p, we calculated the load resistance at the peak power point (Maximum Power Point) using Ohm's law [4]:

$$R_{MPP} = \frac{V_p}{J_p}. \tag{6}$$

3.2. Electrical Parameters Values

The characteristic values of the bifacial solar cell under magnetic field are given in **Table 1**.

These results show that the peak photocurrent density and the short circuit photocurrent density decrease with magnetic field intensity while the peak photovoltage and the open circuit photovoltage increase with the same magnetic field intensity. These results have been observed on the Jph-Vph characteristics. The peak power decreases with the magnetic field intensity while the fill factor and the load resistance at the maximum power point or peak power point increase. The decrease of peak power with magnetic field increase corresponds to a displacement of the bifacial solar cell's operating point towards large values of photovoltage, resulting in an increase of charge resistance at the peak power point.

In **Table 2**, we give the values of maximum electric power delivered by the solar cell to an external circuit and the values of junction dynamic velocity at the maximum power point [5]. We also give the values of the load resistance at the peak power point, determined in this work.

We note that the maximum electric power determined in the previous work [5] is in the same order of size that the peak power determined in this work. One notes also that the junction dynamic velocity at the peak power point and the load resistance at the peak power point evolve in reverse senses. Indeed, when the junction dynamic velocity decreases one evolves towards the open circuit and the load resistance increases. On the other hand, when the junction dynamic velocity increases, one evolves towards the short circuit and the load resistance decreases.

4. Conclusions

In this work, we have presented a theoretical study of magnetic field influence on the electrical parameters of a bifacial silicon solar cell. Taking as parameter the junction dynamic velocity, we plot the solar cell *Jph-Vph* and *P-Vph* characteristics. The peak power, the peak photovoltage, the peak photocurrent density, the short circuit photocurrent density and the open circuit photovoltage are determined by means of the *Jph-Vph* and *P-Vph* characteristics according to magnetic field intensity. Then we calculated the solar cell fill factor (FF) and the load resistance at the peak power point using Ohm's law.

The numerical data are evidence of an increase in the fill factor and the load resistance at the peak power

Table 1. Bifacial silicon solar cell's electrical parameters for different values of magnetic field intensity.

B (mT)	0	1	2.5	5	7.5	10
P_p (mW/cm^2)	19.759	18.757	16.526	14.776	13.810	13.104
V_p (mV)	571.150	578.250	592.120	604.700	612.110	619.460
J_p (mA/cm^2)	34.591	32.437	27.952	24.435	22.561	21.167
V_{oc} (mV)	653.890	662.690	676.430	690.000	698.270	704.400
J_{sc} (mA/cm^2)	36.272	33.909	29.183	25.507	23.512	22.095
FF	0.833	0.835	0.838	0.840	0.841	0.842
R_{MPP} (Ω.cm^2)	16.512	17.827	21.183	24.747	27.177	29.265

Table 2. Bifacial silicon solar cell's recombination and electrical parameters for various magnetic field intensity.

B (mT)	0	1	2.5	5	7.5	10
P_{max} (mW/cm^2)	19.759	18.757	16.526	14.775	13.810	13.104
Sf_{MPP} (cm/s)	2.928×10^4	1.942×10^4	1.027×10^4	5.727×10^3	3.862×10^3	2.922×10^3
R_{MPP} (Ω.cm^2)	16.512	17.827	21.183	24.747	27.177	29.265

point with the increase of the magnetic field intensity but a decrease in the peak power. We interpreted the variation in the load resistance at the peak power point as a variation in the solar cell's operating point. The load resistance at the peak power point has been related to the junction dynamic velocity at the maximum power point determined in a previous work. We noted that the junction dynamic velocity and the load resistance at the peak power point evolve in reverse senses. This last analysis permits to conclude that the junction dynamic velocity defines effectively the solar cell operating point.

Acknowledgements

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