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Influence of the Wavelength on the Series and Shunt Resistances of a Polycrystalline Silicon Solar Cell n+-p-p+ in Frequency Modulation

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ABSTRACT

A study of the illumination wavelength effect on the series and shunt resistances of a serial vertical junction silicon solar cell in frequency modulation is done. From the continuity equation of the minority carriers' density, the expressions of the minority carriers' density, the photocurrent density, and the photovoltage, are determined. The curves of the I-V characteristic permit us to deduce the series and shunt resistances which depend on the wavelength and frequency modulation. A few values of series and shunt resistances in short and long wavelengths are determined respectively at the open circuit and the short circuit situation.

Keywords: Vertical junction cell, Frequency modulation, Wavelength, Series resistance, Shunt resistance.

Introduction

Determining the series resistances (Rs) and the shunt (Rsh) is very important, in order to improve the quality of the materials of a solar cell and its conversion yield. These parasitic resistances play a significant role and cannot be ignored. The series resistance is mainly due to the volume resistance of the semiconductor, to the metal contacts and interconnections, to the transport of carriers through the diffusion layer, to the resistances contact between the metal and the electrodes [1-5] while the shunt resistance is related to impurities near the junction to the dangling bonds at the semi-conductors surfaces and to the leakage of the minority carriers' that causes a photocurrent drop in the junction [1-5]. A few pieces of research [2-9] have shed light on the effects of shunt and series resistances on the performance of the solar cell.

They show how parasitic series resistance (Rs) and shunt resistance (Rsh) can affect the performance of solar cells and photovoltaic modules. Other works on series and shunt resistance in static regime [10-12], transient regime [13,14], and frequency modulation [15-17] have been done. The aim of this paper is to study the influence of wavelength on (Rs) and (Rsh) of a serial vertical junction silicon photocell in a fixed frequency.

Theoretical study

Figure 1 shows a unit of an n+-p-p+ serial vertical junction silicon solar cell [18] under monochromatic illumination:

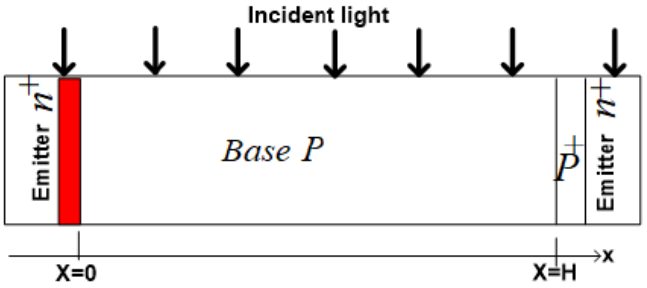


Figure 1. A serial vertical junction solar cell.

This study is based on a vertical junction silicon solar cell, with the following assumptions: the thicknesses of the space charge region and the emitter are very small compared to that of the base; their contributions are then neglected so that only the contribution of the base is considered.

When the solar cell is under an incident light excitation, the phenomena of generation, recombination and diffusion occur in the base. The photogenerated minority carriers in the base, are governed by the following continuity equation in the frequency modulation [19-20].

$$D^*.\frac{\partial^2\delta(x,z,t)}{\partial x^2}-\frac{\delta(x,z,t)}{\tau}=-G(z,t).+\frac{\partial\delta(x,z,t)}{\partial t}(1)$$

Where x and z, represent the depth along the horizontal and that along the vertical, respectively; D^* [21] is the complex electron scattering diffusion coefficient as a function of modulation frequency; τ is the average lifetime of the minority charge carrier and t is the time.
The overall generation rate is given by [22]:

$$G(z,t)=g(z).e^{i\omega t}(2)$$

With g(z) is the spatial component and $e^{i\omega t}$the temporal component; ω the angular frequency and i the pure imaginary.

The expression for the generation rate g(z) is:

$$g(z)=\phi.\alpha.(1-R)e^{-\alpha.z}(3)$$

Where ϕ is the monochromatic incident flux of light; α the monochromatic absorption coefficient of the material, and R is the monochromatic reflection coefficient of the material. The minority carriers' density can be put into the form [22, 23]:

$$\delta(x,z,t)=\delta(x,z).e^{i\omega t}(4)$$

Where $\delta(x,z)$ is the spatial part.

Substituting equations (2), (3) and (4) into equation (1), we obtain:

$$\frac{\partial^2\delta(x,z,\lambda,\omega)}{\partial x^2}-\frac{\delta(x,z,\lambda,\omega)}{L^2(\omega)}=-\frac{g(z)}{D(\omega)} \quad (5)$$

We pose:

$$L^2(\omega)=\tau.D(\omega) \quad (6)$$

With $L(\omega)$ the diffusion length of the minority carriers. The general solution of equation (6) is:

$$\delta(x,z,\lambda,\omega)=K_1.e^{\frac{x}{L(\omega)}}+K_2.e^{-\frac{x}{L(\omega)}}+\frac{L^2(\omega)}{D(\omega)}.\phi.\alpha.(1-R)e^{-\alpha.z}(7)$$

The coefficients $K_1$and $K_2$are determined by the following boundary conditions [24, 25].

- at the Emitter-base junction (x = 0):

$$D(\omega).\frac{\partial\delta(x,z,\lambda,\omega)}{\partial x}\Big|_{x=0}=Sf.\delta(x,z,\lambda,\omega)|_{x=0} \quad (8)$$

- in the middle of the base (x = $\frac{H}{2}$):

$$\frac{\partial\delta(x,z,\lambda,\omega)}{\partial x}\Big|_{x=\frac{H}{2}}=0 \quad (9)$$

With H is the thickness of the base of the solar cell along the horizontal; Sf is the junction recombination velocity [26, 27].

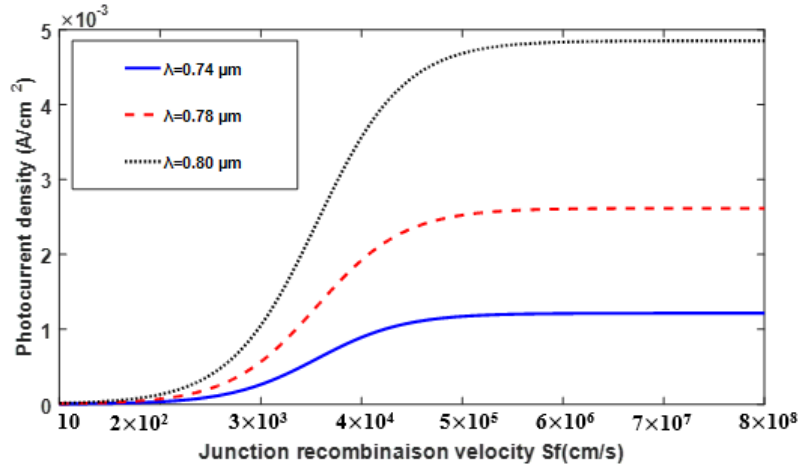
Result and Discussion
Photocurrent Density

The excess minority carriers in the base will flow towards the two junctions by diffusion. The obtained photocurrent density is given by [28, 29]:

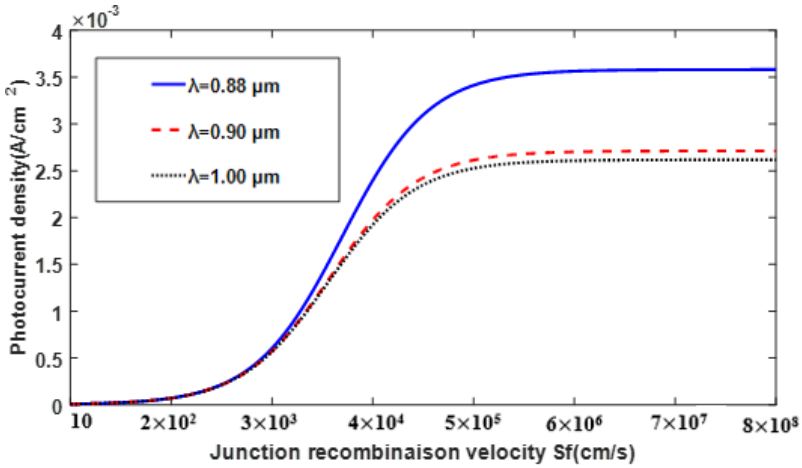
$$J_{ph}(x,z,\lambda,\omega) = q.D(\omega)\frac{\partial\delta(x)}{\partial x}\Big|_{x=0} \quad (10)$$

Where q is the elementary charge

Figures 2-a) and 2-b) show the photocurrent density profile as a function of the recombination velocity at the junction for different wavelengths.



2-a



2-b

Figure 2: The photocurrent density profile as a function of the recombination rate at the junction. 2-a: short wavelength, 2-b: long wavelength
$\omega_r = 1.75\times10^7$; z=0.002 cm

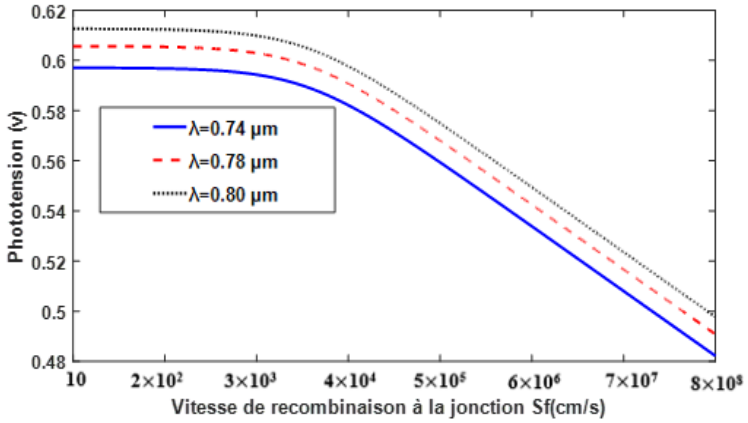
In Figure 2, the photocurrent density is almost zero for low values of the recombination rate at the Sf junction. It increases until it reaches its maximum with the junction recombination velocity Sf. We notice that the photocurrent density increases with the wavelength in the short wavelength range. This is due to the increase in the generation rate (because the short wavelengths generate more carriers in the base of the solar cell). The photocurrent density decreases in the long wavelength range. This decrease is related to the low absorption of the photocell when the incident flux decreases. The effect of the wavelength on the photocurrent density is more sensitive in the short circuit than in the open circuit. The behaviour of the photocurrent density depends on the value of the generation rate which varies according to the different wavelength ranges.

The Photovoltage

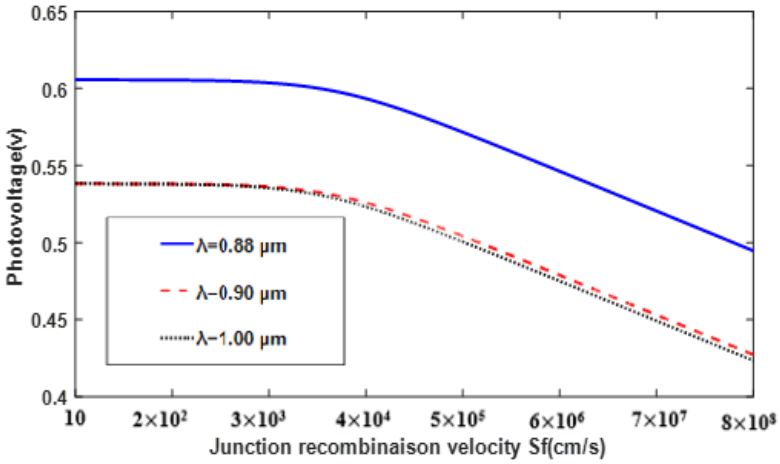
The photovoltaic voltage across the junction, according to the BOLZMANN relation, is obtained as:

$$V_{ph}(x,z,\lambda,\omega) = V_T.\ln\left(1+\frac{N_b}{n_i^2}.\delta(x,z,\lambda,\omega)|_{x=0}\right) (11)$$

Where V_T the thermal voltage, N_b the doping rate in the base, n_i the intrinsic carrier density. Figure 3-a and 3b gives the photovoltage profile as a function of the recombination velocity at the junction for different wavelength:



3-a



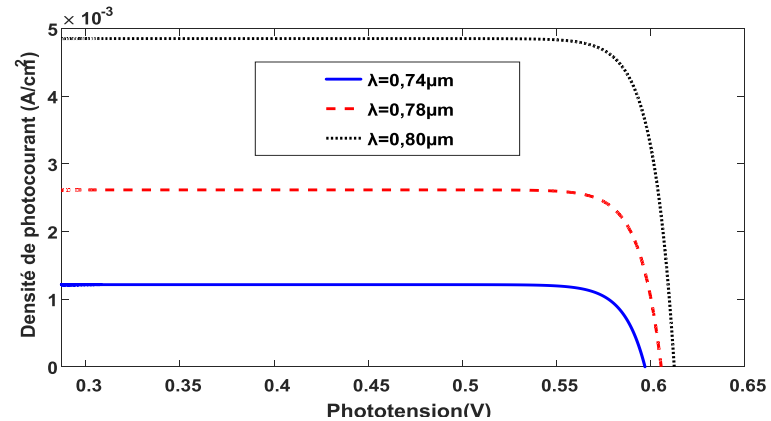
3-b

Figure 3: Photovoltage versus recombination rate at the junction.
3-a: short wavelength, 3-b: long wavelength
$\omega_r = 1.75\times10^7$; z=0.002 cm

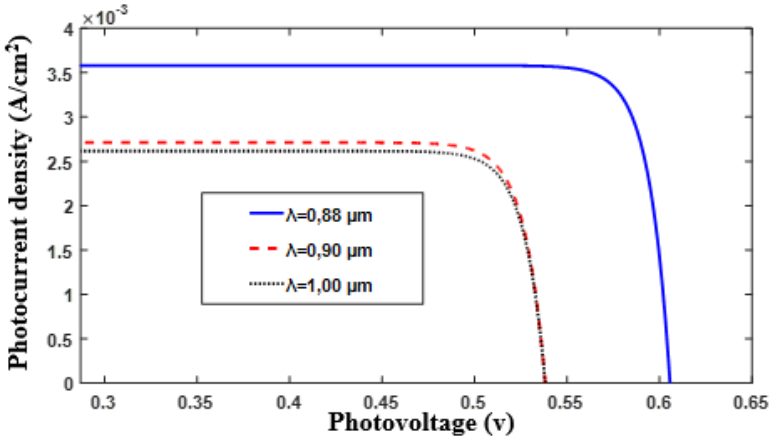
In figures 3-a) and 3-b), the profiles of the photovoltage as a function of the recombination velocity, show the same curves. In figure 3-a), an increase in the wavelength, involves a consequent absorption of the incident photons by the base of the solar cell. This leads to a photogeneration of minority carriers and then a high photovoltage. However, in figure 3-b), the absorption of the base of the incident photons corresponding to the long wavelengths, is weak to the point that the material constituting the solar cell becomes transparent. This implies a photovoltage that decreases since the photogeneration of minority carriers is low.

The Jph-Vph characteristic

Figures 4-a and 4b give the profile of the character in the function of the junction recombination velocity for different wavelengths.



4-a)



4-b)

Figure 4: Characteristic Jph-Vph for different values of the wavelength. a) Short wavelength b) Long wavelength ω_r= 1 .75.10^7 rad/s; z=0.002 cm

In figure 4, we obtain the same curves of the Jph-Vph characteristics at a well-given applied magnetic field and illumination depth.

In the short wavelength range, that is in figure 4-a), the amplitude of the short circuit photocurrent density and the open circuit photovoltage increases with the wavelength. This corresponds to a high absorption of incident photons by the solar cell followed by an increased photogeneration of minority carriers with enough kinetic energy to cross the junction.

On the other hand, in the interval of long wavelengths, the amplitude of the photocurrent and the open circuit photovoltage, decrease when the wavelength increases. At this level, we note a weak absorption of incident photons by the solar cell; this leads to a weak photogeneration of minority carriers and their probable recombination in volume.

The Series Resistance (Rs)

The current-voltage characteristic in the vicinity of the open circuit is an oblique line. Whereas for an ideal voltage generator, this current-voltage characteristic is a vertical line. Since the current-voltage

characteristic above is not a vertical line, we deduce that the solar cell behaves like a real voltage generator. This voltage is comparable to the open circuit photovoltage. As the solar cell is not ideal, it has ohmic losses. These are characterized by the presence in the equivalent circuit of a series resistor (Rs), connected in series with the voltage source. The equivalent electrical circuit of the solar cell operating in an open circuit situation is shown in figure [30].

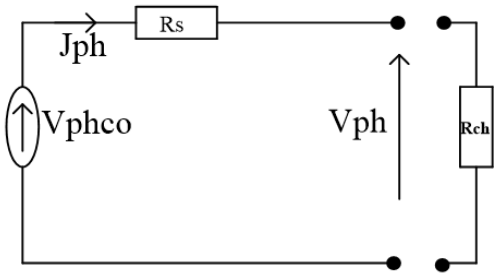


Figure 5: Equivalent electrical circuit of the solar cell operating in an open circuit situation

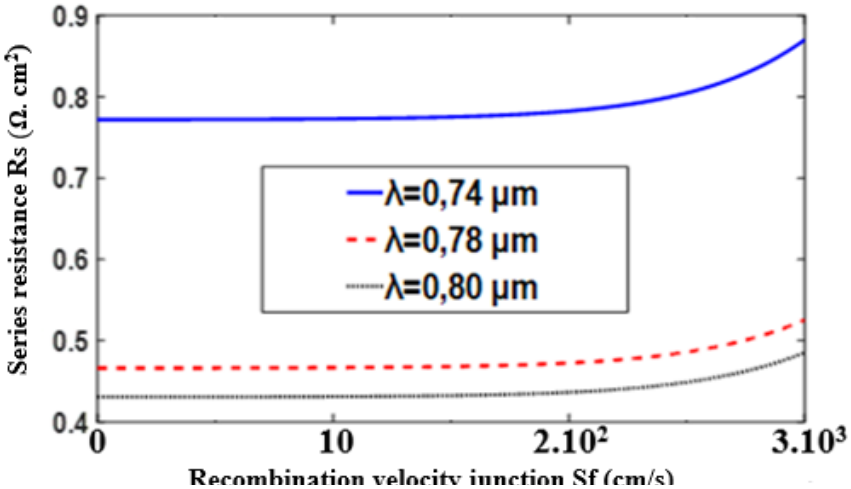
Where Vco is the open circuit photovoltage, and Rch is the load resistance. By applying the law of meshes we find the series resistance [31, 32]:

$$V_{ph}(\omega,\lambda,z,Sf) = V_{phco}(\omega,\lambda,z) - Rs(\omega,\lambda,z,Sf) \times J_{Ph}(\omega,\lambda,z,Sf) \quad (12)$$

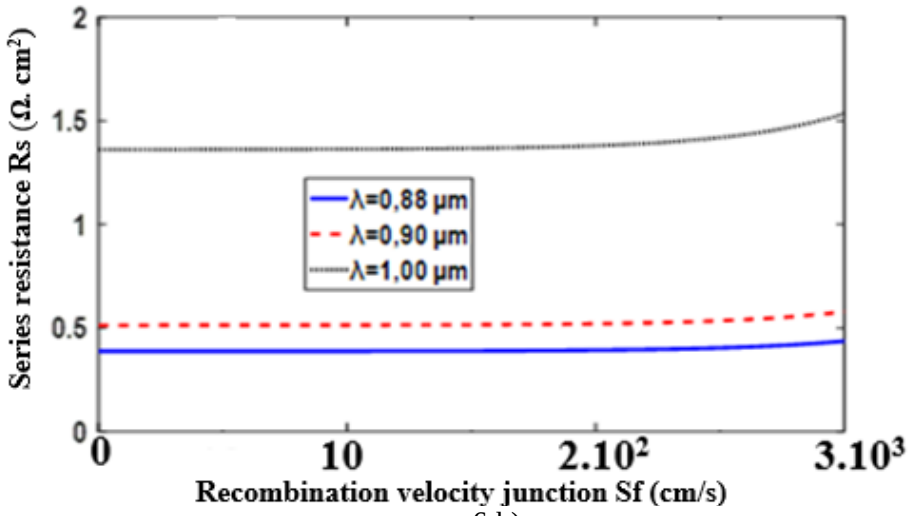
So we have:

$$Rs(\omega,\lambda,z,Sf) = \frac{V_{phco}(\omega,\lambda,z) - V_{ph}(\omega,\lambda,z,Sf)}{J_{ph}(\omega,\lambda,z,Sf)} \quad (13)$$

The series resistance as a function of recombination velocity for different values of the wavelength is represented in Figure 6:



6-a)



6-b)

Figure 6: Profile of the series resistance as a function of the recombination velocity at the junction.
a) Short wavelength b) Long wavelength $\omega_r = 1.75.10^7$ rad/s; z=0.002 cm

In figures 6-a) and 6-b), we obtain the same calibration curves of the series resistance as a function of the recombination rate at the Sf junction. In figure 6-a) the amplitude of the series resistance decreases when the wavelength increases. A large absorption of the incident photons by the base of the solar cell causes an increased photogeneration of the minority carriers; this results in a low resistivity of the solar cell and consequently a series resistance which decreases. On the other hand, in figure 6-b), the amplitude of the series resistance increases because of a weak absorption of the incident photons by the base, it is as if the solar cell presents a repulsive character of the flow of incident photons, hence a resistivity which becomes high.

The Shunt Resistance (Rsh)

To determine the shunt resistance of the photocell, we use the current-voltage characteristics of the figure. This part of the curve corresponds to the short-circuit situation. Under these circumstances, the characteristics of the solar cell are similar to a short-circuit current generator in parallel with the shunt resistor and a load resistor [31]. The equivalent electrical circuit of the photocell operating in a short-circuit situation is shown in Figure 7:

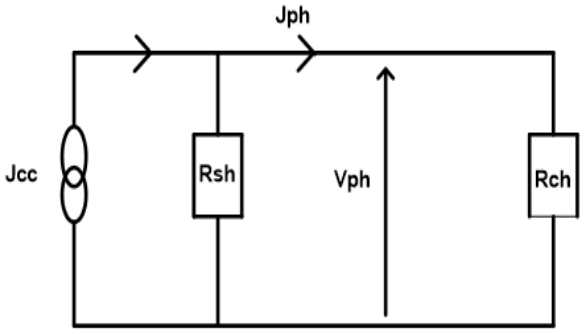


Figure 7: Equivalent electrical circuit of the solar cell operating in a short-circuit situation

By applying the law of meshes to this circuit, we determine the shunt resistance [1, 12]:

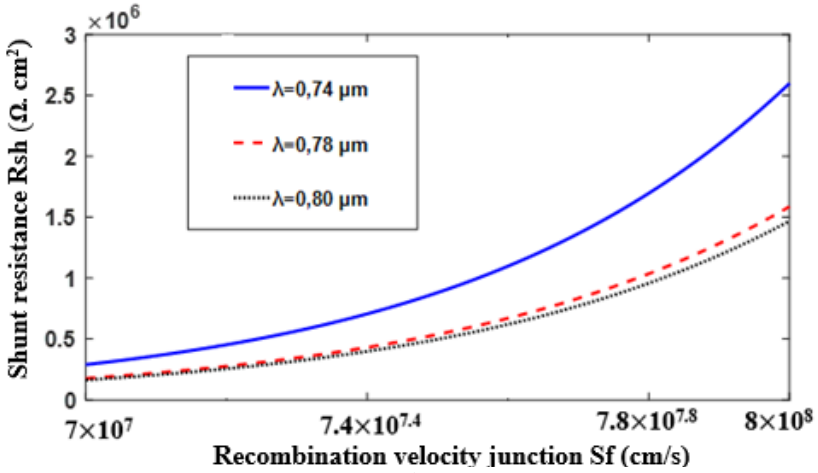
$$V_{ph}(\omega,\lambda,z,Sf) = Rsh(\omega,\lambda,z,Sf) \times (Jphcc(\omega,\lambda,z) - Jph(\omega,\lambda,z,Sf)) \quad (14)$$

We have the shunt resistance given as follows:

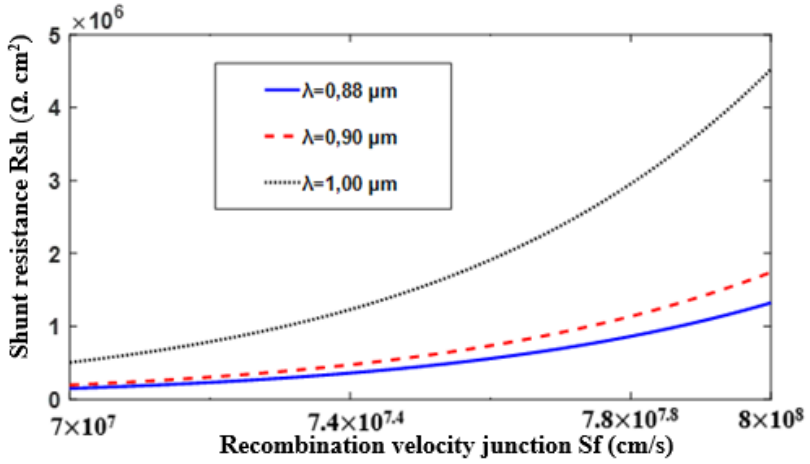
$$Rsh(\omega, \lambda, z, Sf) = \frac{V_{ph}(\omega,\lambda,z,Sf)}{Jphcc(\omega,\lambda,z) - Jph(\omega,\lambda,z,Sf)} \quad (15)$$

Where Jcc is the short circuit photocurrent density.

The shunt resistance as a function of the recombination velocity at the junction for different values of the wavelength is shown in Figure 8:



8-a)



8-b)

Figure 8: Profile of the shunt resistance as a function of the recombination velocity at the junction. a) Short wavelength b) Short wavelength
ω_r= 1,75.10^7 rad/s; z=0.002 cm

In figures 8-a) and 8-b) the calibration curves of the shunt resistance as a function of the recombination velocity at the junction, show the same gaits. For a given curve, the shunt resistance increases with the recombination velocity junction Sf. For figure, 8-a) the shunt resistance decreases when the wavelength increases: we note that the leakage photocurrent increases and this presages possible recombination of the photogenerated minority carriers at the surfaces. On the other hand in figure 8-b), the shunt resistance increases with the wavelength. It is as if there is an important photogeneration of the non-recombined minority carriers which have a certain kinetic energy to cross the junction.

In table 1 we give some values of series and shunt resistances, for a given value of the magnetic field and angular frequency.

Table 1: Values of Rscomax (Ω.m2) and Rshccmax (Ω.m2) for different wavelength, ωr=1.75.10^6 rad/s

	Gamme des courtes longueurs d'onde			Gamme des grandes longueurs d'onde		
λ (µm)	0,74	0,78	0,80	0,88	0,90	1,00
Sf=3. 10^3 cm/s / Rscomax	0,87	0,52	0,48	0,43	0,58	1,53
Sf=8. 10^8 cm/s / Rshccmax	2,63.10^6	1,47.10^6	1,46. 10^6	1,32. 10^6	1,72. 10^6	4,55. 10^6

(Rscomax) and (Rshccmax) are respectively the series resistance in maximum open circuit condition and the shunt resistance in maximum short circuit condition. The parasitic resistances change according to the range of wavelengths considered. A decrease of (Rsmax) and (Rshmax) with the wavelength in the case of short wavelengths and the opposite effect is observed with long wavelengths.

Conclusion

In this work, we have studied the influence of the illumination wavelength on the series and shunt resistance of a polycrystalline silicon solar cell with a vertical series junction under a constant magnetic field, in frequency modulation. The carrier density and the current-voltage characteristic were then determined, and the series and shunt resistances as a function of the recombination rate at the junction for different wavelengths, under a magnetic field, were calculated and theoretically studied. The contribution of the emitter is neglected. For short wavelengths, as the wavelength increases, the series and shunt resistances decrease. For long wavelengths, as the wavelength increases, the shunt and series resistances increase. With the range of short wavelengths, we have more generations of carriers, thus promoting the phenomenon of diffusion. It is the opposite phenomenon for long wavelengths. Therefore, a study of the scattering capacity under the influence of these same parameters is possible.

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