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RESEARCH ARTICLE

STUDY OF THE CAPACITY OF A MANOFACIAL SOLAR CELL BASED ON CIGS UNDER HORIZONTAL MONOCHROMATIC ILLUMINATION IN FREQUENCY DYNAMIC MODE: THE EFFECT OF THE WAVELENGTH.

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Abstract

In the present work, we make a theoretical study of the wavelength effect on the capacity of a solar cell based on CIGS subjected to horizontal monochromatic light in frequency modulation. Based on the expression of the density of minority charge carriers, we study the photovoltage and capacity. A gap of 1.34eV corresponding to gallium ratio of 0.28 is selected. We find that efficiency is reduced by the increase in wavelength. Thus diffusing capacity results from the variation of the minority charge carriers in the base of the solar cell. The results show that the effectiveness of capacity decreases when the wavelength increases.

Introduction:-

The development of solar PV is characterized by the diversity of these technologies. Among these, the solar cells in thin layers, in particular those based on CIGS offer significant advantages with a 21.7% record yield obtained by laboratory, 15.9% for large modules and 12.13% for commercial modules [1], [2] and [3]. The composition of a CIGS solar cell is through the determination of certain properties, such as optical, structural and electrical ones [4], [5] and [6].

The electrical properties are based generally on the determination of the photocurrent, the photo voltage, series and shunt resistors and the capacity of the solar cell [3]. The parameters usually employed are: the diffusion length (L), the diffusion coefficient (D), the recombination rates at the front side (Sf) and the rear side (Sb), the reflection coefficient (R) and the absorption coefficient (α) [4]. In this present article, the ability of a CIGS solar cell and effectiveness will be determined from the density of minority charge carriers. The influence of the wavelength is highlighted.

Theoretical study:-

In our study, we consider a solar cell presented by the figure 1. The contribution of the transmitter is ignored and we consider the quasi-neutral basis (QNB). When the solar cell is illuminated, there is creation of electron-hole pairs in the active database. The density of generated minority charge carriers follows the next continuity equation [4]:

$$\frac{\partial^2\delta(x,t)}{\partial x^2}-\frac{\delta(x,t)}{L(\omega)}=-\frac{G(x,t)}{D(\omega)}+\frac{\partial\delta(x,t)}{\partial t} \quad (1)$$

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δ (x, t) and G (x, t) are respectively, the density and the generation rate of minority charge carriers in function of the thickness x and the time factor t. Their expressions are [4]:

$$\delta(x,t) = \delta(x) \cdot \exp(i\omega t) \quad (2)$$

$$G(x,t) = g(x) \cdot \exp(i\omega t) \quad (3)$$

$\delta(x)$ and $g(x)$ are the respective spatial components of the density and the generation rate.

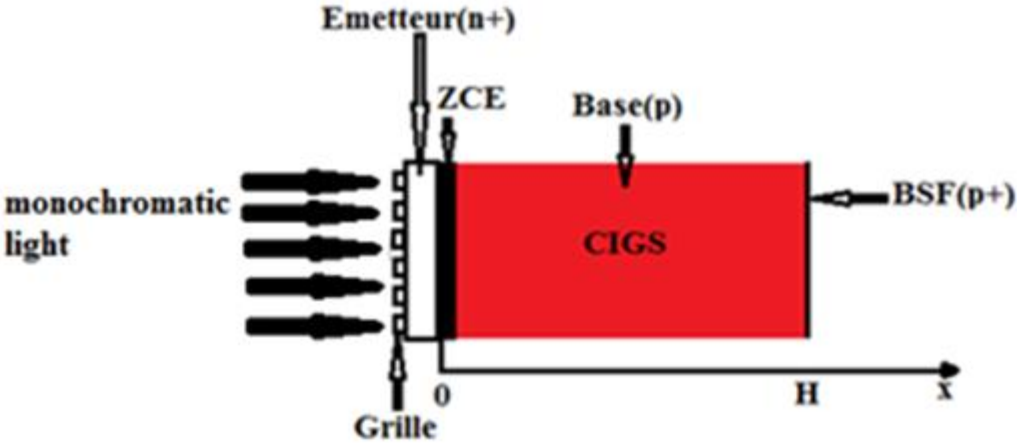

Figure 1:- The solar cell (CIGS n + -p-p +) under illumination monochromatic to the front side.

The generation rate of electron-hole pairs per the wavelength is equal to the photons rate of disappearance of the material [5]:

$$g(x) = \phi(\lambda) \cdot \alpha(\lambda) \cdot (1 - R(\lambda)) \cdot \exp(-\alpha(\lambda) \cdot x) \quad (4)$$

With: $\phi(\lambda)$ = the incidental monochromatic flux

$\alpha(\lambda)$ = the coefficient of monochromatic absorption

$R(\lambda)$ = the coefficient of monochromatic reflection

$L(\omega)$ and $D(\omega)$ respectively are the diffusion length and the diffusion coefficient, complex functions of the angular frequency, given by the following reports:

$$L(\omega) = \sqrt{\tau \cdot D_O} \cdot \sqrt{\frac{1 - i\omega\tau}{1 + (\omega\tau)^2}} \quad (5)$$

And

$$D(\omega) = D_0 \left[\frac{1 + \omega^2\tau^2}{(1 - \omega^2\tau^2)^2 + (2\omega\tau)^2} \times (1 - i\omega\tau) \right] \quad (6)$$

L_0 and D_0 represent the intrinsic diffusion length and the intrinsic diffusion coefficient. The term D_0 is given by the Einstein formula [7]:

$$D_0 = \mu \cdot \frac{K_b \cdot T}{q} \quad (7)$$

with μ which represents the mobility of the material, K_b the Boltzmann constant, T the temperature of the cell and q the elementary electron charge. The general solution of the continuity equation is the equation (8):

$$\delta(x) = A.Cos\left(\frac{x}{L(\omega)}\right) + B.Sin\left(\frac{x}{L(\omega)}\right) - \frac{\alpha(\lambda).\phi(\lambda).(1 - R(\lambda)).L(\omega)^2}{D(\omega).(\alpha(\lambda)^2.L(\omega)^2 - 1)} \exp(-\alpha(\lambda).x) \quad (8)$$

The coefficients *A* and *B* are obtained from the following boundary conditions: [4]

- At the junction at x = 0
$$\left.\frac{\partial \delta(x,\lambda)}{\partial x}\right|_{x=0} = \frac{S_f}{D(\omega)} \cdot \delta(x,\delta)\Big|_{x=0} \quad (9)$$

- At the rear side of the cell:
$$\left.\frac{\partial \delta(x,\lambda)}{\partial x}\right|_{x=H} = -\frac{S_b}{D(\omega)} \cdot \delta(x,\lambda)\Big|_{x=H} \quad (10)$$

S_f and S_b respectively represent the recombination speeds at the front side and the rear side of the absorber.

Absorption coefficient:-

CIGS is used in photovoltaic devices due to its direct gap [8]. Thus, we represent the CIGS absorption coefficient as a function of the wavelength of the incident photons in Figure 2:

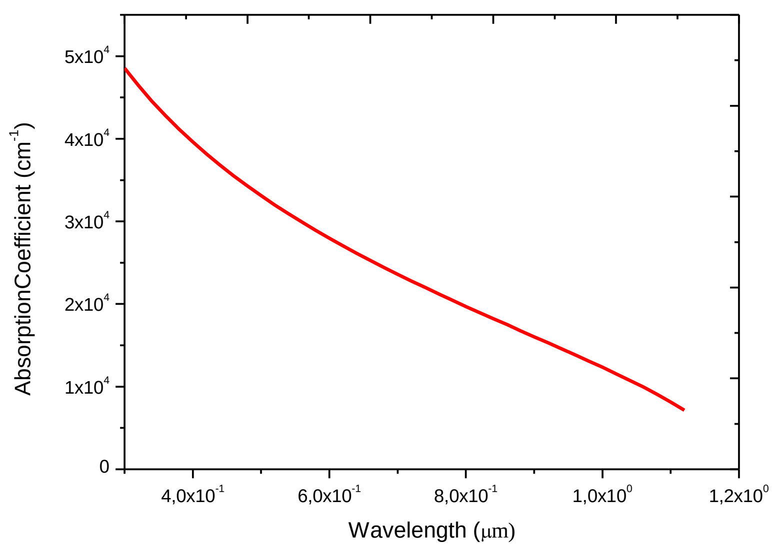

Figure 2:- CIGS absorption coefficient as a function of the wavelength

This figure shows that the absorption coefficient decreases with increasing wavelength. Consequently the generation of electron-hole pairs increases with the increasing of the wavelength. The magnitude of the CIGS absorption coefficient is of 104cm^{-1}, which explains its use in thin layer. Therefore, it takes some micrometer CIGS to absorb the entire incident light [9].

Study of the density of minority charge carriers:-

We present in the following four figures the density of minority carriers according to the base thickness x with different wavelengths of visible range and infrared range respectively open circuit and short circuit.

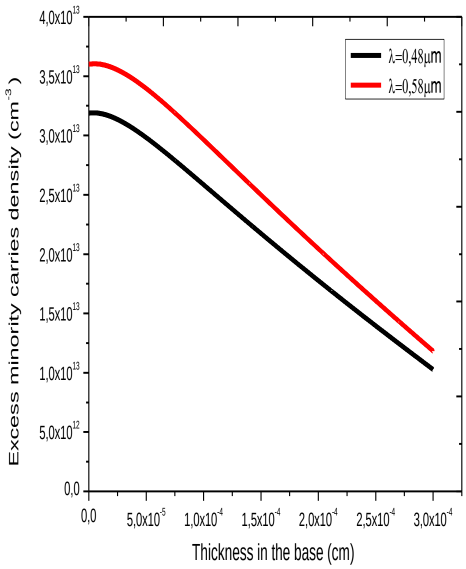

Figure 3:- Profile densities of minority carriers according to the thickness in the base for different wavelength values of the visible.
Sf = 10cm.s^{-1} (open-circuit)

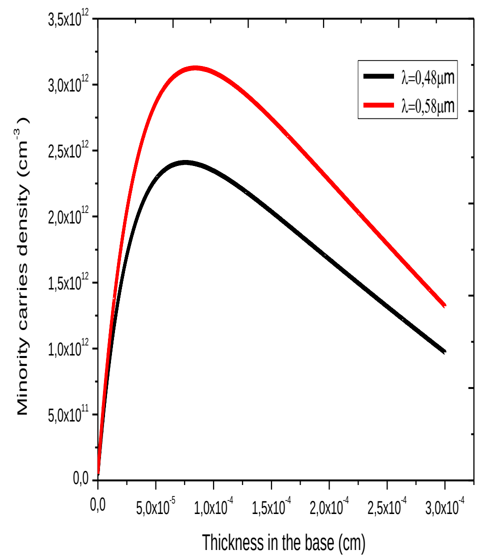

Figure 5:- Density profile of minority charge carriers depending on the thickness in the base for different wavelength values of the visible.
Sf = 6.10^{6}cm.s^{-1}(Short- circuit)

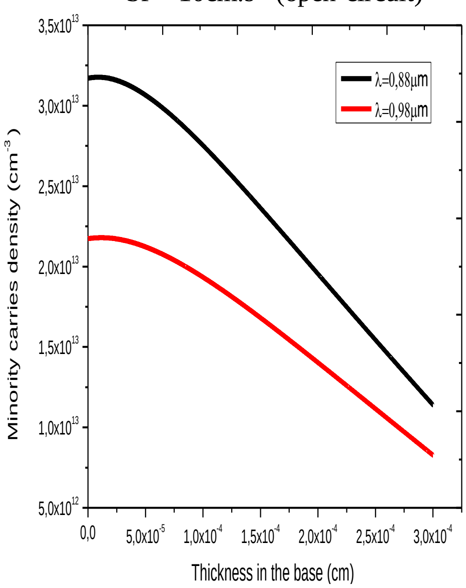

Figure 4:- Profile of the density of minority charge carriers in function of the thickness in the base for different wavelength values of the infrared. Sf = 10cm.s^{-1} (open-circuit)

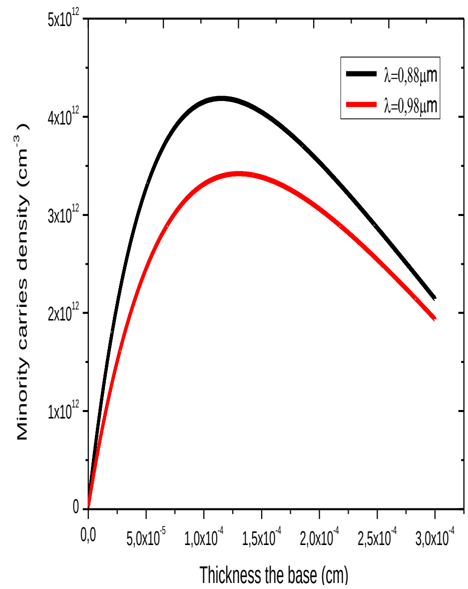

Figure 6:- Density profile of minority charge carriers depending on the thickness in the base for different wavelength values of the infrared.
Sf = 6.10^{6}cm.s^{-1} (Short- circuit)

To Figures 3 and 4, all the curves start with a maximum and then decrease gradually. The maximum density corresponds to a gradient of carries equal to zero. Then this density decreases with the depth x in the database of the base. Therefore, carriess can not cross the junction to generate a photocurrent. They will recombine. This decrease or the negative gradient corresponds to the recombination of minority carriers in the basis. [11]

To Figures 5 and 6, for a given wavelength, we find two levels:
At the first level, the density of minority carriers increases with the thickness in the basis to a maximum; this corresponds to the crossing of minority carriers at the junction to participate in the generation of photocurrent. [12]

At the second level, the density of minority carriers decreases with the basis thickness; this corresponds to the recombination surface and volume of carriers that do not cross the junction. [12]

The modulus of the density of minority carriers at short-circuit as open-circuit increases with the wavelength. The increase in the module of the density with wavelength corresponds to an increase of the carriers generated in the basis since the absorption decreases with the increasing wavelength. It is also seen that for low values of the wavelength (λ), the absorption is near the junction while for large values of λ, the absorption moves in depth. The obtained profiles of the figures 3, 4, 5 and 6 are due to the fact that CIGS has a reduced thickness in the micrometer range. [4]

To Figures 7 and 8, we represent the relative density of minority charge carriers in function of the thickness in the base to the various wavelength values respectively in open circuit and short circuit:

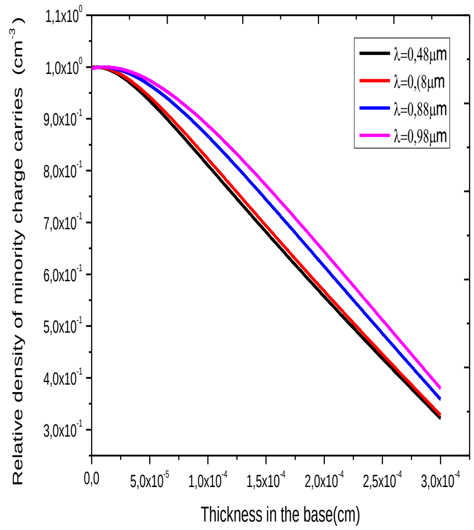

Figure 7:- Density profile on minority charge carriers in function of the thickness in the base for different values o the wavelength. Sf = 10cm.s^{-1} (open-circuit)

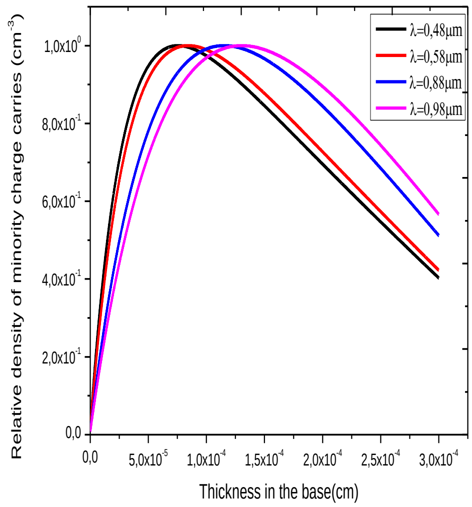

Figure 8:- Density profile of minority charge carriers in function of the thickness in the base for different values of the wavelength.
$Sf = 6.10^6 cm.s^{-1}$(Short-circuit)

The figures 7 and 8, the thickness of the cell where the modulus of the density of minority carriers is maximal corresponds to the extension of the space charge zone. It is noted that the thickness of the latter expands with increasing the recombination rate at the junction Sf. This is due to the fact that carriers are stored in open circuit in short circuit [5]. To a recombination velocity value Sf junction fixed in the vicinity of the short circuit (figure8) enlargement of the space charge zone is more important with large wavelength values. We can say that the short wavelengths provide a thickness of the space charge region reduced compared to longer wavelengths.

Photovoltage:-

The photovoltage is given by the following Boltzmann equation [4]:

$$V_{ph} = V_T \ln\left[\frac{N_b}{n_i^2}\delta(0) + 1\right] \quad (11)$$

N_b and n_i are respectively the doping density and the intrinsic density of minority charge carriers is given by the following relationship [6]: $n_i^2 = N_c N_V \exp\left(-\frac{E_g}{k_b T}\right)$ (12)

N_C and N_V are respectively the densities of states in the conduction band and valence band. E_g is the energy gap of the material. Thermal stress is given by equation (13) [4]:

$$V_T = \frac{K_b T}{q} \quad (13)$$

The photo voltage influences the diffusion capacity.

Diffusion capacity:-

When excess minority carriers diffuse into the base of a solar cell, they do not pass through all, the junction. Therefore they induce in the base equivalent capacity which is diffusing capacity whose expression is given as follows [5]: $C = \frac{dQ}{dV_{ph}}$ (14)

where: $Q = q\delta(0)$ is the number of carriers per unit area. (b)
By Q substituting its value is obtained:

$$C = q\frac{d\delta(0)}{dV_{ph}} \quad (15) \qquad \Rightarrow \qquad C = q\frac{d\delta(0)}{dS_f}\frac{1}{\frac{dS_f}{dV_{ph}}} \quad (16)$$

From the expression of the photo voltage, we finally get the following equation:

$$C = q\frac{n_i^2}{N_b V_T} + q\frac{\delta(0)}{V_T} \quad (17)$$

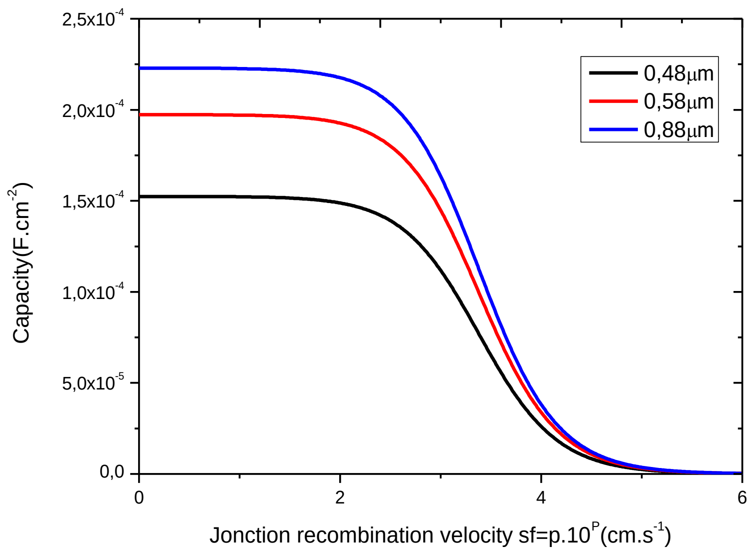

Figure 9:- Capacity as a function of the recombination rate at the junction for different values of the wavelength.

The capacity decreases with the increase of the recombination velocity at the junction. It is maximum open circuit almost zero shorted. This can be explained in part by the shape of the density of minority charge carriers is maximum open circuit and secondly by the fact that the capacity is proportional to the photo voltage. This last is maximum open circuit and minimum shorted. Referring to a plane capacitor, the capacity is inversely proportional to the thickness of the capacitor. Now we have found that open circuit, the thickness of the space charge zone is minimum contrast shorted wherein the thickness of the space charge zone is maximal. The capacity increases with the wavelength. Increasing the capacity in the wavelength can be explained by the optical properties of CIGS, for example the wavelength and the absorption coefficient.

Effectiveness of capacity:-

The area of collection of minority charge carriers corresponds to an extension of the space charge zone X_0 which depends on the rate of recombination at the junction. However, when the space charge region is considered a planar capacitor, we can write: $U_{cc} = \frac{X_{0,co}}{X_{0,cc}} U_{co}$ (18)

U_{cc} and U_{co} are respectively, the energy when the solar cell is short-circuited and open-circuited. $X_{0,co}$ and $X_{0,cc}$ represent respectively, the thicknesses of the space charge zone when the solar cell is open-circuited and short-circuited. The ability is written in this case:

$$C(\lambda,\omega) = \frac{\varepsilon.S}{X_o(\lambda,\omega)} \quad (19)$$

The effectiveness of cell capacity is given by the following relationship: $$\eta = \frac{\Delta U}{U_{oc}} \quad (20)$$

with ΔU the energy difference in open circuit and short circuit. Thus, the expression efficiency becomes:

$$\eta(\lambda,\omega) = 1 - \frac{X_{o,co}(\lambda,\omega)}{X_{o,cc}(\lambda,\omega)} \quad (21)$$

The Table 1 summarizes the values of the maximum density of the minority carriers, the thickness of the space charge zone and the capacity for different values of the wavelength.

Table 1:- Values of maximum density of the minority carriers, thickness of the space charge zone and capacity according to the wavelength

λ (nm)	δmax,co (10^{13}cm^{-3})	δmax,co (10^{12}cm^{-3})	Xo,co (10^{-2}.µm)	Xo,cc (10^{-2}.µm)	Cco (mF.cm^{-2})	Ccc (µF.cm^{-2})	η (%)
480	3,19	2,41	4,13	75,64	2,14	117,00	94,54
580	3,60	3,13	4,94	84,24	1,79	105,06	94,34
880	3.177	4,19	8,83	115,20	1,00	76,82	92,33
980	2.18	3,42	11,59	130,31	0,76	67,91	91,10

The capacity in open circuit as short-circuit decreases as the wavelength increases. This ability is very low short circuit. It is also noted that the thickness of the space charge zone in open circuit as short circuit increases as the wavelength increases. We also find that the performance of the capacity for long wavelengths is higher than for short wavelengths.

Conclusion:-

In this work, we presented a simulation study using the wavelength effect on the ability of a solar cell based on CIGS subjected to horizontal monochromatic light frequency modulation. The result obtained in this study is the reduction of the efficiency of cell capacity with the increase in wavelength. Thus diffusing capacity results from the variation of the minority charge carriers in the base of the solar cell. Usually the considered parameter in diffusion capacity studies is the characteristics of the junction. In the end we can say that the capacity, which is proportional to the density of minority charge carriers increases with the wavelength

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