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EFFECTS OF TEMPERATURE ON THE SHORT CIRCUIT CURRENT OF A SILICON SOLAR CELL, WHILE TAKING INTO ACCOUNT THE EXCITONS

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ABSTRACT

We have studied the temperature's effects on the short circuit current of a silicon solar cell .For this, we have considered Green's theoretical model which considers excitons as charge carriers. In this study, we have defined two effective diffusion lengths L1 and L2, and a coefficient b, characteristic of coupling electron- exciton. The electrons are weakly bound excitons for small values of b, so that the coupling is very strong for high values of this coefficient. Furthermore, this study has allowed us to define an optimal temperature T_0 at about 450 K, corresponding to the maximum value of the photocurrent. Moreover, the temperature has two contrasted effects on the short-circuit current depending on whether its value be lower or higher than the optimal temperature: The short-circuit current increases for temperature inferior to T_0 and decreases for temperature superior to T_0.It is also important to point out that the temperature has no effect on the effective diffusion lengths L1 and L2 when the coupling electron-exciton is weak. However L1 decreases according to the temperature for a strong coupling.

Keywords: binding coefficient, exciton, short circuit current

INTRODUCTION

Generally, in classical theories applied to semi-conductors, only generation, recombination and the transport of free carriers (electrons and holes) are taken into account. Nevertheless, it was pointed out that the density of the free exciton in silicon at room temperature has an impact on the density of minority carriers [1].Thus, the free exciton theory in the operation of the device is its importance, which has been shown theoretically by R. Corkish and al and by Y. Zhang and al, for a silicon device [1]-[2]. However, these authors have not had the curiosity to study the behavior of these excitons in the silicon solar cell for various values of the temperature.

As a complement to the work of Kane and Swanson and Corkish, Chan, and Green we examine the effect of excitons on a silicon solar cell, particularly on the short circuit current for various values of the temperature.

To do this we consider a simplified model of n + p where the contribution of the emitter is neglected and we adopt the following assumptions solar cell:

- The excitation energy is low ,
- Recombination in the depletion area are neglected
- Minority carriers in bulk regions are assumed to flow predominantly by diffusion.

THEORY

Theoretical model

Let us make again theoretical model of Y. Zhang and al [1] - [2].

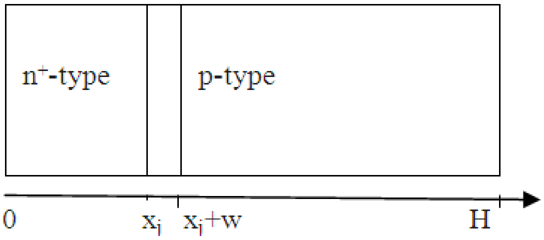

Fig.1 schema of the solar cell

In this basic model, only the minority carriers in the p -type base are considered. The problem consists of determining the densities of electrons and excitons in the band $X_j + W \leq x \leq H$. These densities are given by the following two differential equations [1]- [2].

$$D_n d^2 \frac{\Delta n_n}{dx^2} = \frac{\Delta n_n}{\tau_n} + b(\Delta_n N_A - \Delta n_{ex} n^*) - G_n \exp\left[-\alpha(x - x_j - W)\right] \quad (1)$$

$$D_{ex} d^2 \frac{\Delta n_{ex}}{dx^2} = \frac{\Delta n_{ex}}{\tau_{ex}} - b(\Delta_n N_A - \Delta n_{ex} n^*) - G_{ex} \exp\left[-\alpha(x - x_j - W)\right] \quad (2)$$

Subscripts n and ex denote electron and exciton, respectively. Δn_n and Δn_{ex} are respectively the densities of electrons and excitons. The calculation of the densities of electrons and excitons through the resolution of the two coupled differential equations. The solution of this differential equation system is done by these expressions calculated in detail in the paper of Y. Zhang and al [2].

$$\Delta n_n = \frac{1}{2\sqrt{\delta}}\left[(\sqrt{\delta} - M_\Delta)F(L1, D_n, G_n) - 2M_{12}F(L1, D_{ex}, G_{ex})\right]$$
$$+\left[((\sqrt{\delta} + M_\Delta)F(L2, D_n, G_n) + 2M_{12}F(L2, D_{ex}, G_{ex})\right] \quad (3)$$

$$\Delta n_{ex} = \frac{1}{2\sqrt{\delta}}\left[(\sqrt{\delta} + M_\Delta)F(L1, D_{ex}, G_{ex}) - 2M_{21}F(L1, D_n, G_n)\right]$$
$$+\left[(\sqrt{\delta} - M_\Delta)F(L2, D_{ex}, G_{ex}) + 2M_{21}F(L2, D_n, G_n)\right] \quad (4)$$

Short circuit current density of the electron/exciton coupled system.

The short – circuit current is equal to the sum of short circuit respectively generated by the electrons and excitons.

$$J_{scc} = J_n + J_{ex} \quad (5)$$

$$J_n = qD_n \left.\frac{d\Delta n_n}{dx}\right|_{x_j + W} \quad (6)$$

$$J_{ex} = qD_{ex} \left.\frac{d\Delta n_{ex}}{dx}\right|_{x_j + W} \quad (7)$$

We obtain:

$$J_n = \frac{qD_n}{2\sqrt{\delta}} \exp\left[-\alpha(x_j + w)\right] + \left[\begin{array}{l} \left(\frac{1}{L1} - \alpha\right)\left[\frac{(\sqrt{\delta} - M_\Delta)G_n}{\left(\frac{1}{L1^2} - \alpha^2\right)D_n} - \frac{2M_{12}G_{ex}}{\left(\frac{1}{L1^2} - \alpha^2\right)D_{ex}}\right] \\ \left(\frac{1}{L2} - \alpha\right)\left[\frac{(\sqrt{\delta} + M_\Delta)G_n}{\left(\frac{1}{L2^2} - \alpha^2\right)D_n} + \frac{2M_{12}G_{ex}}{\left(\frac{1}{L2^2} - \alpha^2\right)D_{ex}}\right] \end{array}\right] \quad (8)$$

$$J_{ex} = \frac{qD_n}{2\sqrt{\delta}} \exp\left[-\alpha(x_j + w)\right] + \left[\begin{array}{l} \left(\frac{1}{L1} - \alpha\right)\left[\frac{(\sqrt{\delta} + M_\Delta)G_{ex}}{\left(\frac{1}{L1^2} - \alpha^2\right)D_{ex}} - \frac{2M_{21}G_n}{\left(\frac{1}{L1^2} - \alpha^2\right)D_n}\right] \\ \left(\frac{1}{L2} - \alpha\right)\left[\frac{(\sqrt{\delta} + M_\Delta)G_{ex}}{\left(\frac{1}{L2^2} - \alpha^2\right)D_{ex}} + \frac{2M_{21}G_n}{\left(\frac{1}{L2^2} - \alpha^2\right)D_n}\right] \end{array}\right] \quad (9)$$

Binding coefficient of the exciton

The coupling coefficient in other words the linking coefficient of excitons is written down by b .According to its values, high or low we can have a strong or low electron-exciton coupling.

Thus, we consider in this article, two different expressions of b as a function of temperature.

The first, described by Green and al, corresponding to strong coupling is given by[1]:

$$b(T) = 10^{-3}T^{-2} + 2{,}5 \times 10^{-6}T^{-1/2} + 1{,}5 \times 10^{-7} \quad (10)$$

And the second deduced from the first materializes the weak coupling. It has been given by:

$$b(T) = 10^{-9}\left[10^{-3}T^{-2} + 2{,}5 \times 10^{-6}T^{-1/2} + 1{,}5 \times 10^{-7}\right] \quad (11)$$

RESULTS AND DISCUSSION

Diffusion length of electrons and excitons

this section talks about the temperature's effect on the effective diffusion lengths L1 and L2 depending on whether the electron-exciton coupling is weak or strong.

Let's consider an excitement wavelength of a value enough high (λ= 1010nm) which allows an important generation of carriers in the base region, its thickness fixed to H=1000µm and its doping level $N_A = 10^{16}$ cm^{-}

Weak coupling case

We trace in Fig.2, the curves of variation of the characteristics diffusion length L1 and L2 of the coupling electron – exciton according to temperature, compared with the own diffusion length Ln and Lex for very low values of the binding coefficient b.

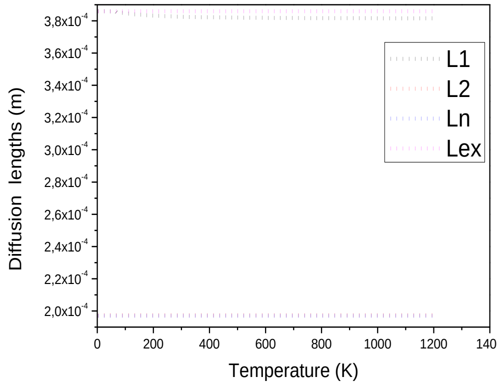

Fig.2. characteristics diffusion length L1 and L2 for the coupled electron-exciton system as a function of the temperature at doping Level $N_A = 10^{16}$ cm^{-3} and $10^{-16} \leq b \leq 10^{-13}$

We find that the temperature has a negligible effect on the characteristic diffusion lengths. These are more and less equal to the own diffusion length Ln and Lex.

This is explained by the fact that an increase in temperature decreases the value of the coupling coefficient b, whereas the coefficient b is already low because we are in the case of weak coupling.

Strong coupling case

We trace in Fig.3, the curves of variation of the characteristics diffusion length L1 and L2 of the coupling electron – exciton according to temperature, compared with the own diffusion length Ln and Lex for high values of the binding coefficient b.

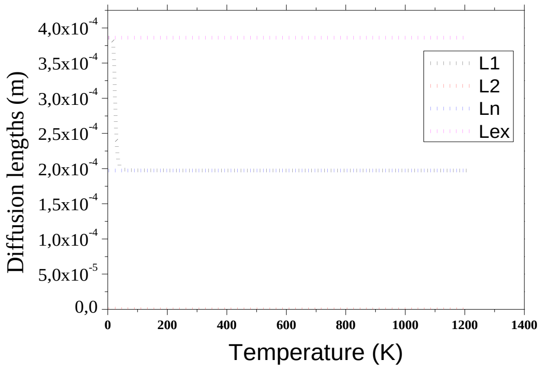

Fig.3. characteristics diffusion length L1 and L2 for the coupled electron-exciton system as a function of the temperature at doping level $N_A = 10^{16}$ cm^{-3} and $10^{-7} \leq b \leq 10^{-4}$

On weak values of the temperature, the effective diffusion length L1 is equal to the own diffusion length of exactions Lex. Moreover, this diffusion length, characteristic for the coupling, decreases progressively and stays equal to Ln towards 60K. The diffusion length L2 can be neglected whatever the temperature's value.

As an application, we will say that the temperature's increase reduces the coupling coefficient .This is confirmed by the equation (11).This value decreases of b can bring about a progressive falling of L1.

Short circuit current of the coupled electron/exciton

- **weak coupling case**

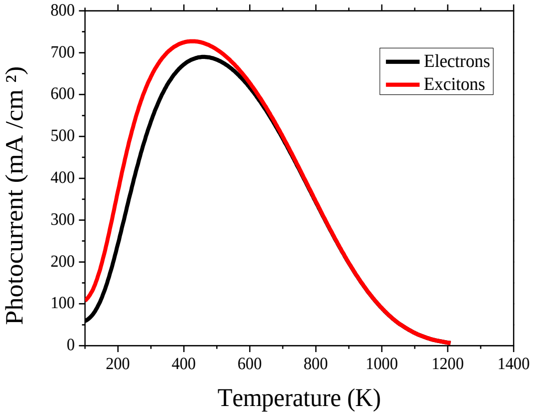

Fig.4. short-circuit current generated by excitons, electrons and electron - exciton all as a function of the temperature for $10^{-}10^{-16} \leq b \leq 10^{-13}$ and a doping level $N_A = 10^{16}$ cm^{-3}

The profile shows an increase in the photocurrent of the latter up to an optimal temperature T_0 = 450 K; beyond this temperature the photocurrent decreases.

Indeed, this variation of the photocurrent is independent of the characteristic diffusion lengths L1 and L2, for we have shown in Fig.2, in these circumstances, the characteristic diffusion lengths of the coupling electron- exciton remain confused to own diffusion lengths Ln and Lex.

However, the interpretation of the curves would come to generation's rate Gex and Gn, which increases with temperature [3]. Also if the temperature exceeds the optimal temperature, the carriers charges are heavily generated, so the events recombination and shielding increase.

- **strong coupling case**

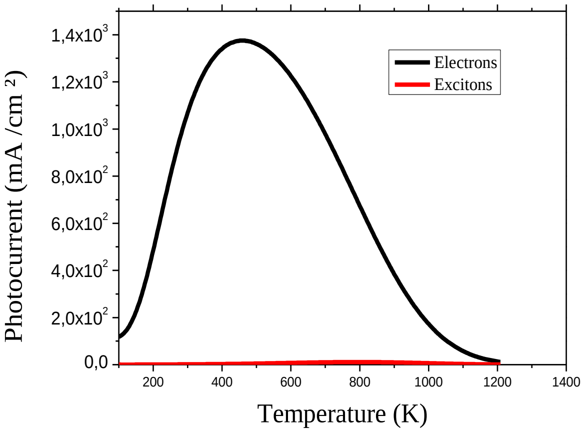

Fig.5. short-circuit current generated by excitons, electrons and electron - exciton all as a function of the temperature for $10^{-7} \leq b \leq 10^{-4}$ and a doping level $N_A = 10^{16}$ cm^{-3}

For values of temperature less than 100K, we note decrease in the photocurrent generated by the carriers charges, larger for electrons. Beyond 100K, you get the same profile as before. However the maximum of the short- circuit current decreases.

As an explanation, we can say that for small values of the temperature, the decrease in L1 predominates over the increase of generation rates G_n and G_{ex}. On the other hand, if the temperature is above 100 K, L1 becomes constant and the generation rates impose their increase on the photocurrent.

Photocurrent according to the binding coefficient of exciton.

This part of the paper discusses the simultaneous effect of the temperature and the binding coefficient of exciton on the short - circuit. To better understand this, we consider two temperatures ranges: The range of temperature below the optimal temperature represented by Fig.6 and the range of temperature above the optimal temperature given by Fig.7. The wavelength is set to 1010 nm.

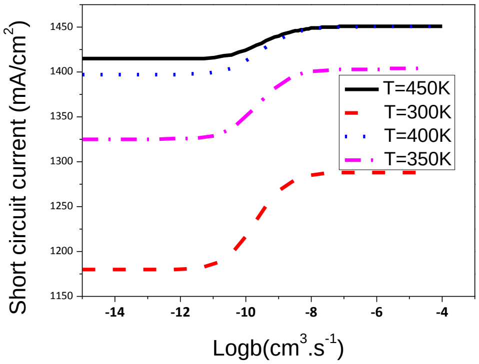

Fig.6. Density of the short – circuit current as a function of the binding coefficient of exciton b in the range of temperatures below the optimal temperature T_0 = 450K, λ=1010 nm, H=1000µm, $N_A = 10^{15}$cm^{-3}

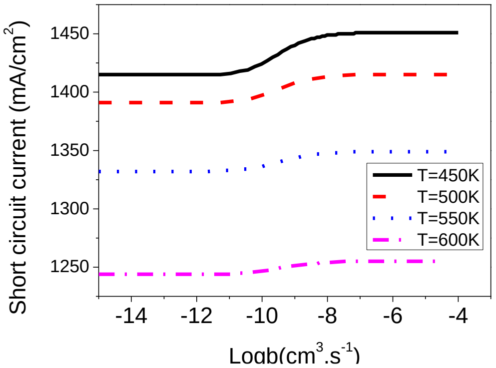

Fig.7. Density of the short – circuit current as a function of the binding coefficient of exciton b in the range of temperatures above the optimal temperature T_0 = 450K, λ=1010 nm, H=1000µm, $N_A = 10^{15}$cm^{-3}

We find that the short – circuit current increases with the binding coefficient of exciton. For low values of the coefficient of bond b ($10^{-15} \leq b \leq 10^{-11}$), there is a significant variation of the short circuit current .This same observation is noted for very high values of the binding coefficient. On the other hand for $10^{-11} \leq b \leq 10^{-8}$ a step of short circuit current is obtained.

We note also that the profile of the photocurrent in Fig.4 and Fig.5 is confirmed by Fig.5 and Fig.6. $T < T_0$, the short circuit current increases with the temperature and $T > T_0$, it decreases.

CONCLUSION

In this paper, we have extended the work of Green and al by studying the behavior of silicon solar cell depending on the temperature.

This study has allowed us to retain two fundamental concepts:

Excitons have a positive effect on the short – circuit current of a silicon solar cell.

There is an optimal temperature T_0 at about 450 K corresponding to the maximum of the short circuit current

It is also important to note that the temperature has negligible effect on the characteristic diffusion length L1and L2 when the coupling electron- exciton is weak. However, L1 decreases with temperature for a strong coupling.

NOMENCLATURES

Symbols	names and units
α	Absorption coefficient, cm^{-1}
G_n	Generation rates of electron, cm^{-3}
G_{ex}	Generation rates of exciton, cm^{-3}
λ	Wavelength, m
T	Temperature, K
b	Binding coefficient of exciton,cm^3 s^{-1}
Lex	Diffusion length for excitons
Ln	Diffusion length for electrons
τ_p	Electron lifetimes,s
τ_{ex}	Exciton lifetimes,s
L1	Effective diffusion length
L2	Effective diffusion length
X_j	Emitter thickness, cm
W	Depletion Region thickness
n^*	Equilibrium constant, cm^{-3}
N_A	The rate of doping, cm^{-3}
D_n	Diffusion coefficient of electron, cm^2.s^{-1}
D_X	Diffusion coefficient of exciton, cm^2.s^{-1}
Δn_n	The densities of electrons, cm^{-3}
Δn_{ex}	The densities of excitons, cm^{-3}
J_{ex}	Short circuit current density of exciton, mA.cm^{-2}
J_n	Short circuit current density of electron, mA.cm^{-2}
J_{scc}	Short circuit current density of electron and excitons, mA.cm^{-2}

REFERENCES

1. Richard Corkish , Daniel S.P.Chan ,Martin A. Green , Excitons in silicon diodes and solar cells: A three-particle theory, Journal of Applied Physics, vol. 79n.1, January 1998, pp. 195-203.
2. Yong Zhang , Angelo Mascarenhas , Satyen Deb , Effects of excitons on solar cells, Journal of Applied Physics, vol. 84n.7,octobre 1998, pp. 3966-3971.
3. Harol J. Hovel, Semiconductors and Semimetals (Solar cells 1975).
4. Azzedine Lazrak, PhD in Physics, Scientific and Medical University of Grenoble, 2007.
5. D. E .Kane, R. M. Swanson, Effect of exciton on visible strip shrinking and transport of semiconductor , Journal of Applied Physics, vol.73 n.3, February 1993, pp.1193 – 1197.
6. J.Barrau, M.Heckmann,M. Brousseau, Experimental determination of exciton formation coefficient in silicon, Journal ofAppliedPhysics. Chem. Solids, vol.34n.11, November1973, pp.1757-2028.
7. S. Zh. Karazhanov, Y. Zhang, A. Mascarenhas, S. Deb, The effect of excitons on CdTe solar cells, Journal of Applied Physics, vol.87n.17, June 2000, pp.8786-8792.
8. M. Burgelman, B. Minnaert, Including excitons in semiconductor solar cell modeling, Thin Solid Films, vol.511 n.512, Junuary 2006, pp.214-218.
9. R. D. Schaller, V. I. Klimov, Multiexciton generation in quantum dots, Physical Review Letters, vol.92 n.18, May 2004.
10. Ching-Fuh Lin, Miin-Jang Chen,Eih-Zhe Liang, W. T. Liu, C. W. Liu, Reduced temperature dependence of luminescence from silicon due to field-induced carrier confinement, Applied Physics Letters,vol.78 n.3,January2001, pp. 261-263.
11. R. Fisher, J. Feldmann, E. O. Gobel, Hot-Exciton Relaxation Cd_x $Zn_{1-x}Te$/ ZnTe Multiple Quantum Wells, Physical Review Letters, vol.67 n.1, July 1991, pp.128-131.
12. J. H. Collet, H. Kalt, L.S. Dang, J. Cibert, K. Saminadayar, Relaxation of excitons in coherently strained CdTe/ZnTe quantum wells,Physical Review B,vol.43 n.8 ,March 1991,pp. 6843-6848.
13. JH Collet, JA Kash, DJ Wolford, J Thompson,Transfer of excitons bound to nitrogen in GaAs1-xPx: N,Journal of Physics C: Solid State Physics, vol.16 n.7 ,March 1983, pp.1283.
14. O.A. Niasse, B. Mbengue, B. BA, A. Ndiaye, I. Youm, Effects of excitons in the quantum efficiency of the solar cell CdS / CdTe by the model of the dielectric function, Review of Renewable Energy vol. 12 n. 3, September 2009, pp. 501 – 512.