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Variation of Excess Excitons Density in Function to Silicon Solar Cell Parameters

Mamadou Niane*, Saliou Ndiaye, Modou Faye, Modou Pilor, Moulaye Diagne, Nacire Mbengue, Omar. A. Niasse, Bassirou Ba

Laboratoire de Semi-conducteurs et d'Energie Solaire, Département de Physique, Faculté des Sciences et Techniques (UCAD-SENEGAL).

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Abstract

The generation of minority carriers in the silicon base is accompanied by a phenomena of excitons generation. The variations of the excitons density are dependent to the cell parameters. In this article, we studied the variation of this excitons density in function to the base depth when the coupling between electrons and hole is strong. This study shows that the excess excitons density is most important in the base depth because in this region the coulomb interactions between electrons and holes are very high causing a strong increase of the excitons density. Its low value at the rear face is due to a increase of the recombination velocity caused by the metal contact. At the junction, the density of excitons is almost zero. In fact, excitons reaching the junction are dissociated into electrons and holes by the electric field prevailing in the space charge zone. In depth, the density of excitons increases in function of the coupling coefficient between electrons and excitons. He is independent to the latter at the junction.

NOMENCLATURE

symbols	*Name and unit*
Δn	Excess minority carriers density, cm^{-3}
Δn_x	Excess excitons density, cm^{-3}
b	Binding coefficient, cm^{3}.s^{-1}
G_{eh0}	direct generation rate of carrier pairs, cm^{-3}.s^{-1}
G_{x0}	Excitons generation rate at the semiconductor surface, cm^{-3}.s^{-1}
Δn_{oe}	Excess minority carriers density at the junction, cm^{-3}
x	The base thickness, cm
N_A	Doping level, cm^{-3}
D_e	Diffusion coefficient for electron, cm^{2}.s^{-1}
D_x	Diffusion coefficient for excitons, cm^{2}.s^{-1}
T_e	Electrons lifetime, s
T_x	Excitons lifetime, s
H	base Thickness, cm
n^*	Equilibrium constant, cm^{-3}
α	Absorption coefficient, cm^{-1}

Introduction

Understanding the phenomena of an excitons generation in of monocrystalline silicon cells, in polarization, is of utmost importance for a good improved quantum efficiencies of photovoltaic cells.

To do so, we will study the variation in the of excess excitons density in the base based in function to some parameters of the cell. We will do as a study of this excitons density depending to the base depth for different high values of the coupling coefficient. This study will allow us to now that the influence of the electrical interactions level between excess minority carriers (electrons) and majority carriers (holes) on the density of excess carriers. The expressions given in the theoretical study were calculated by Corskish and Al. And M. Niane and Al. [1, 2]

Theory

The continuity equations governing the transport excess minority carriers and the excess excitons in the base of a solar cell are governed by the following equations:

$$D_e\frac{d^2\Delta n_e}{dx^2}=\frac{\Delta n_e}{\tau_e}+b\left(\Delta n_e N_A-\Delta n_x n^*\right)-G_{oe}\exp(-\alpha x) \tag{1}$$

$$D_x\frac{d^2\Delta n_x}{dx^2}=\frac{\Delta n_x}{\tau_x}-b\left(\Delta n_e N_A-\Delta n_x n^*\right)-G_{ox}\exp(-\alpha x) \tag{2}$$

The resolution of this system proposed by R. Corkish and Al. **[2]** have provided us with the following terms of the excess excitons density in the base when the cell is in polarization and in illumination.

In dark :

$$\Delta n_{x_p}(x)=\frac{M_{21_p}}{\sqrt{\delta_p}}\left\{\begin{array}{l}\exp\left(-E_{p+}^{\frac{1}{2}}x\right)\\-\exp\left(-E_{p-}^{\frac{1}{2}}x\right)\end{array}\right\}n_{oe}\exp\left[\frac{qV_a}{kT}\right] \tag{3}$$

In illumination:

Corresponding author. Tel.: (221) 77352390
E-mail address: futuringe@gmail.com

$$\Delta n_{xp_L}(x)=\gamma_p R_p \exp\left(-E_{p+}^{\frac{1}{2}}x\right)+\eta_p S_p \exp\left(-E_{p-}^{\frac{1}{2}}x\right)+\Delta n_{x_\alpha}(x) \quad (4)$$

Avec

$$\delta_p = M_{\Delta_p}^2 + 4M_{12_p}M_{21_p}$$

$$M_{\Delta_p} = M_{11_p} - M_{22_p}$$

$$R_p = \left\{ \begin{array}{l} \frac{G_{eh}}{D_e}\left[\eta_p\left(M_{22_p}-\alpha^2\right)+M_{21_p}\right] \\ -\frac{G_{x_p}}{D_x}\left(\eta M_{12_p}+M_{11_p}-\alpha^2\right) \end{array} \right\} \frac{M_{12_p}}{\delta_p^{\frac{1}{2}}\chi_p(\alpha)}$$

$$S_p = \left\{ \begin{array}{l} \frac{G_{eh}}{D_e}\left[\gamma_p\left(M_{22_p}-\alpha^2\right)+M_{21_p}\right] \\ -\frac{G_x}{D_x}\left(\gamma_p M_{12_p}+M_{11_p}-\alpha^2\right) \end{array} \right\}$$

$$\gamma_p = \frac{1}{2M_{12_p}}\left[\left(M_{\Delta_p}^2+4M_{12_p}M_{21_p}\right)^{\frac{1}{2}} - M_{\Delta_p}\right]$$

$$\eta_p = \frac{1}{2M_{12_p}}\left[\left(M_{\Delta_p}^2+4M_{12_p}M_{21_p}\right)^{\frac{1}{2}} + M_{\Delta_p}\right]$$

The application of these results to a monocrystalline silicon solar cell is done. There are using various expressions of the excess excitons density obtained after solving this system of differential equations. The variation of excitons base in function to the base depth will be investigated assuming a high level of interaction between electrons and holes (the coupling is strong: the value of the coupling coefficient is high $b \geq 10^{-9}$ $cm^3.s^{-1}$) [3-5]. A comparative study of these profiles with those excess minority carriers in the base has to understand their variation depending on the interaction level of electrons and hole.

Variation of Excess Excitons Density in Function to the Base Thickness

The study of the variation in the excess excitons density of in function to the base depth, when the latter is in darkness and in polarization give the following profiles (Fig. 1 a,b). Note that this study are done using high values of the binding coefficient 10^{-10} $cm^3.s^{-1} \leq b \leq 10^{-7}$ $cm^3.s^{-1}$; in considering strong the level of interaction between electrons and holes [6-11]

Analysis of these profiles of the excitons density shows an increasing exciton density depending to the base depth. The density starting with a zero value at the junction increases to 10^{13} cm^{-3} in depth [12, 13]. The exciton density is also dependent to the coupling coefficient which shows the level of binding between electrons and holes. We note that when the interactions become stronger (becoming stronger nature of the coupling), it follows an increase of the excess excitons density in the base.

The zero value of the excess excitons density at the junction confirms the conditions defined at limits. This zero value at the junction shows that excess minority carriers in the base (electrons) at the junction do not interact with the majority carriers in the base (hole). The excitons generation is zero at the junction of the base and the space charge zone. The presence of the electric field in this region leads to a nearly total dissociation of all excitons arriving in this region.

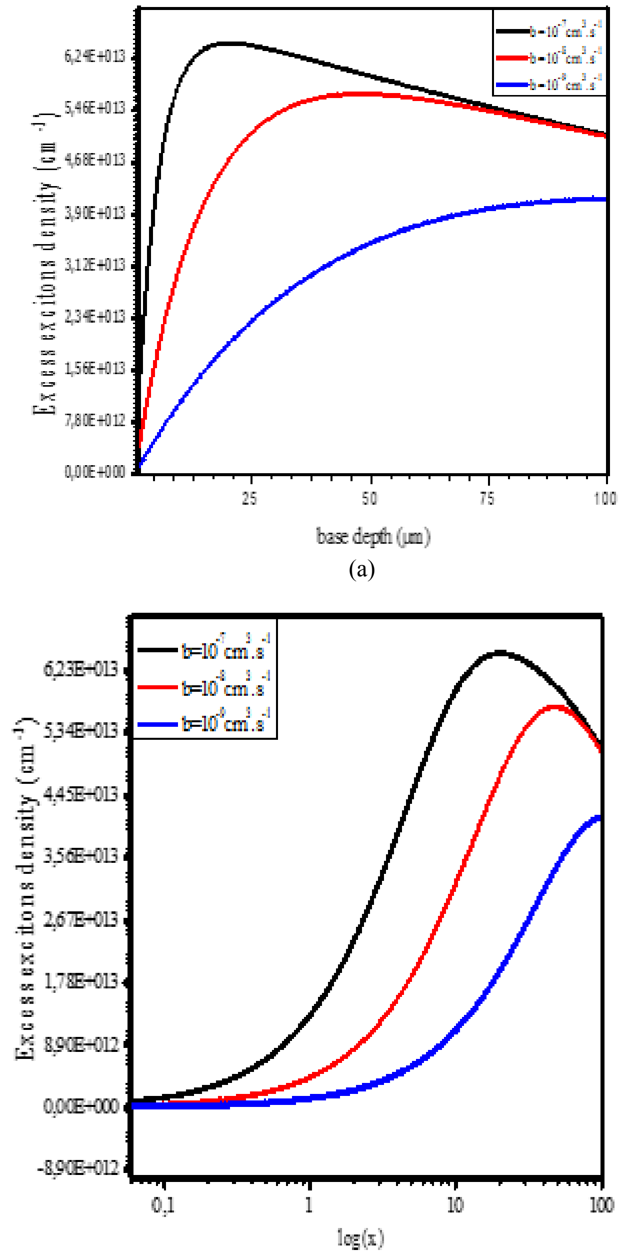


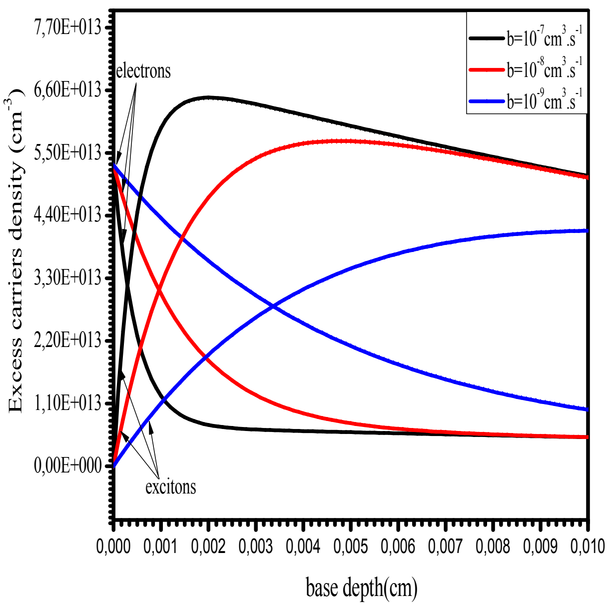
Figure 1: Variation of excess excitons density in function to the base thickness: $n_i=1.5.10^{10}$ cm^{-3}, $D_e=33$ $cm^2.s^{-1}$, $D_x=17$ $cm^2.s^{-1}$, T=300K, $\tau_e=4.10^{-6}$ s, $\tau_x= 6.69.10^{-6}$ s, $V_a=0.5V$, $N_A=10^{16}$ cm^{-3}

The increasing of the excitons density in function to the base depth is done by the increasing of the electrical interactions with excess minority carriers and the holes in the base region. This interaction cause a reduction in the electron mobility thereby promoting the formation of exitons in the cell.

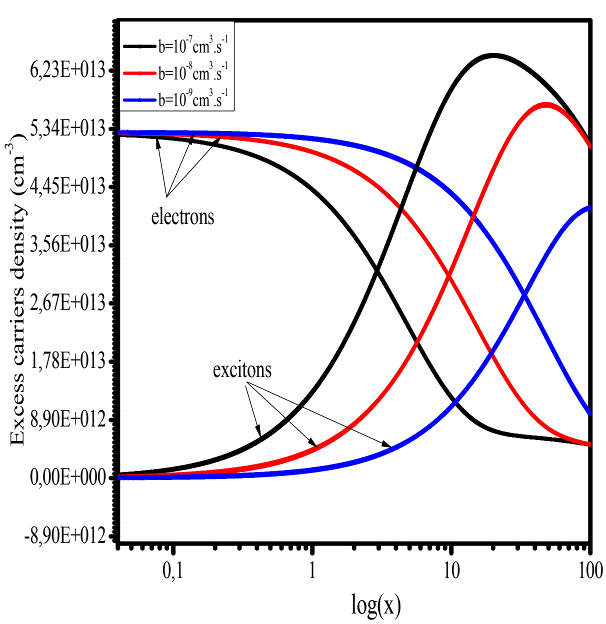
The decrease of the excess excitons density when it approaches the gate is comprehensible because this region is a recombination and collect center of the excess holes. These decreases are due to a lack of an adhesion metal contact. It should also be noted that the reduction of the holes density and the excess minority carriers reduces the coulomb interactions between them, hence the observed decrease in the density of excitons in this region [14].

Comparative Study of The Variation of Electron in Function to the Base Thickness

A comparative study of the profiles of the excess excitons density and the excess minority carriers in the base, when the cell is in polarization allowed to have the following figures. These figures highlight the profiles of the variation of the two carrier's density as a function to the base depth for a strong interaction between electrons and holes (strong coupling).



(a)



(b)

Figure 2: Variation of excess excitons density and excess electrons density in function to the base depth: $n_i=1.5.10^{10}$ cm^{-3}, $D_e=33$ cm^2.s^{-1}, $D_x=17$ cm^2.s^{-1}, T=300K, $\tau_e=4.10^{-6}$ s, $\tau_x=6.69.10^{-6}$ s, $V_a=0.5$V, $N_A=10^{16}$ cm^{-3}

Fig.2 (a) and Fig.2 (b) are summaries of the profiles of the excess minority carriers density [11] and that excitons obtained earlier in Figures 1 and 2. The excess electrons density, thereby a value 5.10^{13} cm^{-3} at the junction, decreases progressively until it reaches its minimum value at the rear side. This decrease is due to an increase the interaction level between the electrons and holes. These interactions reduce electron mobility, thus leading their volume recombination.

The excitons density it follows the opposite direction, it starts from zero at the junction increases gradually until it reaches its maximum value in depth before declining slightly to the gate. Its zero value of the excitons density at the junction is due to the intervention of the electric field in the space charge zone which separates the almost all excitons arriving at the junction. Their growth in depth is favored by higher electrical interactions between the carriers (strong coupling). The reduction of the excess excitons density at the rear face is due by a very high recombination in this region. This is caused by a not perfect adhesion at the metal contact.

Conclusions

In this work we have studying the influence of the excitons generation on the excess minority carriers density in a monocrystalline silicon solar cell. This study shows that when the cell is in polarization, the excess exciton density is close to that of the electrons when the interaction between electrons and holes is strong. This study of the excitons variation in function to the base depth has to understand that a strong coupling between electrons and holes increases the excitons density. This is due by the coulomb interaction which exist between these two carriers. Also, it shows that the excitons density is maximum in the depth. At the junction, the electric field prevailing in the space charge region disables all electrical interactions between electrons and holes. At the rear face, a very high recombination due to metal contact greatly reduces the excess excitons density.

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