Effects of doping profile and temperature on the solar cell performances

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***Abstract*—In this paper, an optimization of the structure of a silicon solar cell is presented. This study takes into account the effects of temperature and doping level of each region of the device. As the simulation with the COMSOL software allowed us to demonstrate the link between the technological structure of an N + NP type solar cell and the various characteristics and parameters obtained at the output when it is subjected to a polarization. Thus, we considered different doping levels and thicknesses of the N + layer. It has been observed that the effects of temperature are negligible for low doping levels of the N + layer. However, in heavy doping, the benefit of reducing its thickness below 0.018 µm is demonstrated, especially for the high temperature operating range. Concerning the base, we observed that its thickness must be maintained in the order of 100 µm.**

Keywords—Solar Cell, optimization, temperature

I. INTRODUCTION

Currently, the efficiency of solar cells is in the order of 20% to 30%. In order to improve it, various solutions have been provided such as, for example, the use of multi-junctions [1,2]. However, the disadvantage of this solution is its relatively high price compared to that of uni-junction cells technologies.

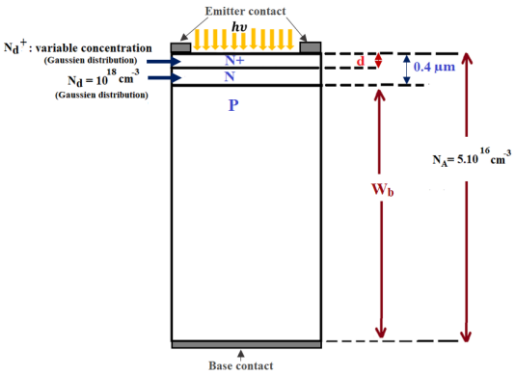
To improve the efficiency of solar cells in the production of electricity, several models based on the techniques of emitter region optimizing [3-5] are proposed. Therefore, this quest made it possible to achieve great breakthroughs in the emitters design philosophy as well as to lead to solar cells exhibiting increasingly interesting yields, especially among those which are based on the use of silicon in their production.

In this paper, we present an optimization of silicon solar cell structure taking into consideration the operating

II. THE STUDIED STRUCTURE

The general structure and doping profile of the silicon solar cell studied are presented on Fig. 1 and table I. This one consists of three layers :

- One P-type layer forming the substrate and doped with boron.
- One phosphorus doped N-type layer with a Gaussian profile
- One layer of N + type also doped with phosphorus and a Gaussian profile.



(a)

(b)

Fig.1. Structure of the silicon solar : a) general structure, b) doping profile

TABLE I. PHYSICAL PARAMETERS VALUES

Solar cell parameter	n-p (conventional)	n^+- n -p
Surface concentration	N_d=1. $10^{18}cm^{-3}$	N_d^+ is variable
Emitter doping profile	Gaussian W_{Nd} = 0.4 µm	Gaussian on Gaussian W_{Nd+} = d
Base doping concentration Base thickness	Na= 5. $10^{16}cm^{-3}$ W_b	

III. DESCRIPTION OF NUMERICAL MODEL

The equations governing the transport phenomena in the solar cell are [6]:

$$div \cdot (\varepsilon \cdot \overrightarrow{gradV}) = -\rho \quad (1)$$

$$g_n - r_n = -\frac{1}{q} \cdot \vec{\nabla} \overrightarrow{J_n} \quad (2)$$

$$g_p - r_p = \frac{1}{q} \cdot \vec{\nabla} \overrightarrow{J_p} \quad (3)$$

$$\overrightarrow{J_n} = q \cdot n \cdot \mu_n \cdot \vec{E} + q \cdot D_n \cdot \vec{\nabla} n \quad (4)$$

$$\overrightarrow{J_p} = q \cdot p \cdot \mu_p \cdot \vec{E} - q \cdot D_p \cdot \vec{\nabla} p \quad (5)$$

With

- ρ : The charges density;
- **ε** : Material permittivity
- $J_{n,p}$: Current density for electrons, holes;
- $D_{n,p}$: Diffusion constant for electrons, holes
- $\mu_{n,p}$: Mobility of electrons, holes;
- KB : Boltzmann constant
- T : The temperature
- $r_{n,p}$: recombination term for electrons, holes
- $g_{n,p}$: photo generation term for electrons, holes

The recombination term $r_{n,p}$ takes into account Schockley-Read-Hall (SHR) type recombination and Auger effect [6-8].

Under illumination, the photo generation rate for each wavelength λ is calculated by the equation [9]:

$$G(\lambda \cdot x) = \alpha(\lambda) \cdot I_o(\lambda) \cdot e^{-\alpha(\lambda) \cdot x} \quad (6)$$

Where I_o (λ) is the intensity of photons at the cell surface (x = 0), I_o (λ,x) the intensity of photons at point x and α(λ) the absorption coefficient at λ wavelength.

The total photo generation rate is the integral of G (x) over all wavelengths forming the solar spectrum

IV. RESULTS AND DISCUSIONS

Fig.2 and Fig. 3 show respectively the variations of the light-generated current density (or photocurrent density), ΔJ_{ph1}, and the Variation of the increase in the conversion efficiency, $\Delta\eta_1$, as functions of the thickness d, for different surface doping levels and temperatures.

$\Delta J_{ph1}=J_{ph}-J_{ph0}$ and $\Delta\eta_1=\eta-\eta 0$ where J_{ph} and η are respectively the n^+- n –p light-generated current density and the conversion efficiency and J_{ph0} the light-generated current density without the N+ layer i.e with a 0.4 µm type N emitter and a metal contact directly taken on this layer. For this case, Wb is set to 100 µm

Fig. 2 demonstrates that overall, the increase in the surface doping of the N + region induces a growth of the photocurrent. However, for a given value of this surface doping and over a small thickness d (d <d_o), first, we observe an increase in the photocurrent but from a certain limit of d_o, this one decreases. Thus, for a surface doping less than 5.10^{19} cm^{-3}, d_o is in the order of 0.08 µm but for surface doping greater than 5.10^{19} cm^{-3}, d_o is in the order of 0.03 µm.

Regarding the effects of temperature, its influence is not remarkable until the surface doping level exceeds $10^{19}cm^{-3}$. Indeed, from this limit, an increase in temperature induces a decrease in the photocurrent. In addition, this phenomenon is even more accentuated when the thickness of the layer N +, d, increases.

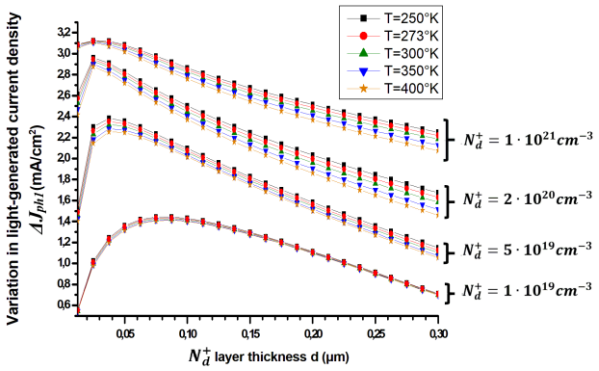


Fig.2. Variation of the increase in the light-generated current density with a high-low junction emitter versus n+-layer thickness for different surface doping concentration N_d^+ and temperatures.

Regarding the conversion efficiency, Fig.3 shows that, like the case of photocurrent, the influence of temperature is small when the doping level of the order of 10^{19} cm^{-3} (or less).

However, for average doping surface concentration ($5.10^{19}cm^{-3}$≤ Nd <2.10^{21} cm^{-3}), the increase in temperature leads to a decrease in the $\Delta\eta$ for thicknesses d in the order of 0.03 µm but for greater thicknesses (d> 0.1 µm), the variation of this factor is very small.

For high doping levels of the order of 10^{21} cm^{-3}, a net decrease in the variation of the conversion efficiency is observed for thicknesses d in order of 0.018 µm. This factor stabilizes when d exceeds 0.15um.

Thus, at high temperature and doping levels, the thickness of the layer must be kept low to ensure good performance.

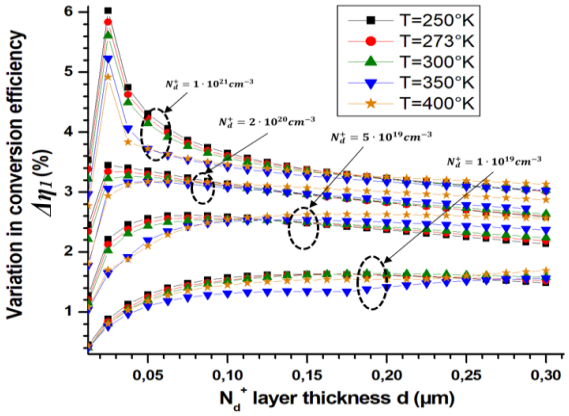


Fig.3. Variation of the increase in the conversion efficiency with a high-low junction emitter versus n+-layer thickness for different surface doping concentration N_d^+ and temperature.

In order to study the influence of the base thickness, W_b, on the cell current and its efficiency, we consider Nd + = $2.10^{20}cm^{-3}$, d= 0.02µm but with W_b variable. We also put : $\Delta\eta_2=\eta-\eta_0$ and $\Delta J_{ph2}=J_{ph}-J_{ph0}$ where $\eta_0=\eta$ (for Wb=0.1µm) and $J_{ph0} = J_{ph}$(for Wb=0.1µm)

Fig. 4, 5 and 6 show that the variations of the current and the efficiency as well as the open circuit voltage of the cell increase rapidly with the thickness as long as W_b <= 100µm. These effects are due to photo generation phenomena of electron-hole pairs which occur more and more as the base widens. However, when W_b exceeds 100µm, these growths slow down to become almost constant because in this case, less light manages to cross the thick base thus limiting the photo-generation.
Regarding the effects of temperature, the variation of the latter does not have much influence on the photo-current. However, its increase induces a decrease in the open-circuit voltage. This explains the decrease in the variation in injection efficiency with temperature.
From these curves, we can deduce that for a good optimization of the structure, the thickness of the base must be chosen in the order of 100 µm.

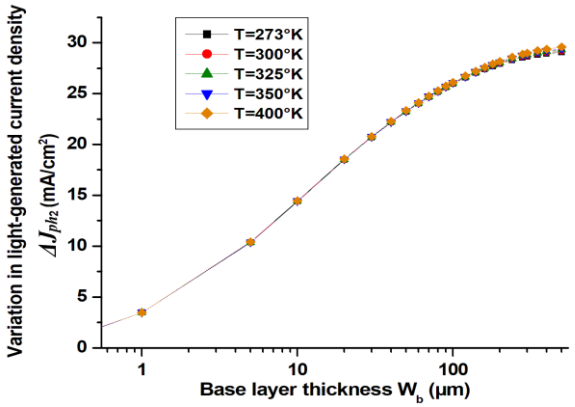


Fig.4. Variation of the increase in the light-generated current density with a high-low junction emitter versus base thickness Wb and temperature.

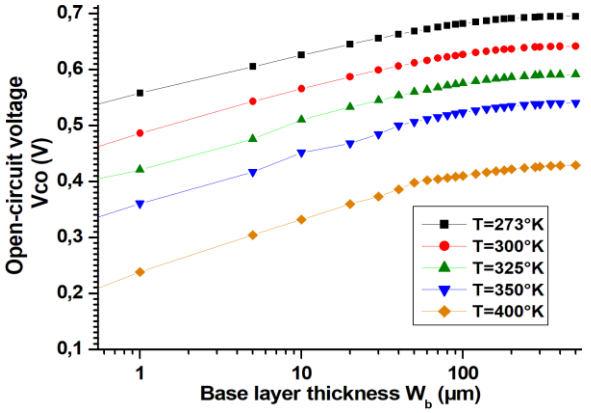


Fig.5. Open-cicuit voltage versus base thickness Wb and temperature.

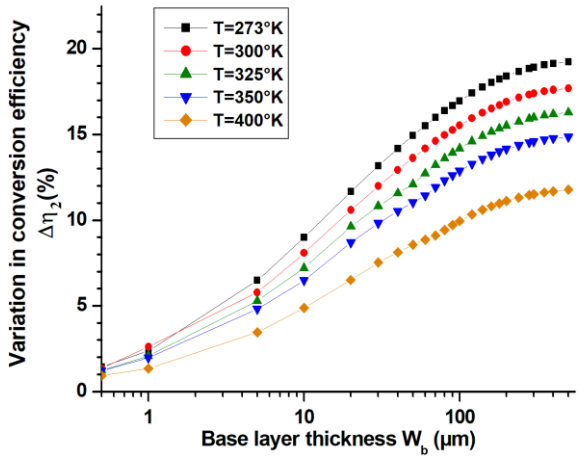


Fig.6. Variation of the increase in the conversion efficiency with a high-low junction emitter versus base thickness Wb and temperature.

V. Conclusion

In order to optimize the solar cell structure, the study of its electrical behaviour shows that the thickness of the base must be in the order of 100 µm. Regarding the emitter region, for high temperature operation, the thickness of the N + region must be kept very low (of the order of 0.018 µm) for high doping levels exceeding 10^{21} cm^{-3}. However, for regions of average doping surface concentration ($5.10^{19}cm^{-3} \leq N_d^+ < 2.10^{21}$ cm^{-3}), the thickness must be of the order of 0.3 µm. For low level doping ($N_d^+ < 5.10^{19}$ cm^{-3}), the temperature variation does not have much effect.

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