Effect of Gaussian doping profile on the performance of a thin film polycrystalline solar cell

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Abstract. A two-dimensional (2D) analytical model based on the Green’s Function method is applied to an n+–p thin film polycrystalline solar cell that allows us to calculate the conversion efficiency. This model considers the effective Gaussian doping profile in the p region in order to improve cell efficiency. The dependence of mobility and lifetime on grain doping is also investigated. This model is implemented through a simulation program in order to optimize conversion efficiency while varying thickness and doping profile in the base region of the cell. Compared with n+–p standard structure, our proposed structure shows a 43% improvement in conversion efficiency for a polycrystalline solar cell.

PACS. 85.30.De Semiconductor-device, characterization, design and modelling.
88.40.hj Efficiency and performance of solar cells.

Nomenclature

- \( I_{ph} \): total photo generated current (A).
- \( I_{sd} \): saturation diffusion dark current (A).
- \( I_{sr} \): saturation recombination dark current (A).
- \( V_{oc} \): open circuit voltage (V).
- \( R_s \): series resistance (Ω).
- \( R_{sh} \): shunt resistance (Ω).
- \( I \): output current (A).
- \( V \): voltage delivered by the cell (V).
- \( I_m \): current at maximum power point (A).
- \( V_m \): voltage at maximum power point (V).
- \( q \): electron charge (1.6 \times 10^{-19} \text{C}).
- \( T \): cell temperature (K).
- \( \alpha_i \): absorption coefficient related to the incident wavelength \( \lambda_i \) (µm^-1).
- \( \mu \): minority carrier diffusion length in the emitter region (cm).
- \( \varepsilon_r \): relative silicon permittivity.
- \( \varepsilon_0 \): emptiness permittivity (F cm^-1).
- \( \kappa \): Boltzmann’s constant (J/K).
- \( n_i \): Silicon intrinsic carrier concentration (cm^-3).
- \( D_n \): diffusion constant of electrons (cm^2/s).
- \( D_p \): diffusion constant of holes (cm^2/s).
- \( P_{1} \): incidence irradiance under AM1 illumination condition on the PV cell surface (W/m^2).
- \( N_e \): concentration doping density of emitter (cm^-3).
- \( H \): thickness of semiconductor (µm).
- \( d \): grain width (µm).
- \( g_0 \): the silicon generation rate related to the incident wavelength \( \lambda_i \) (µm^-3 s^-1).
- \( V_T \): thermal voltage (V).

- \( L_n \): diffusion length of electrons (cm).
- \( L_p \): minority carrier diffusion length in the emitter region (cm).

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### 1 Introduction

The important factor in photovoltaic production is cell cost. One of the promising ways of reducing this cost is by reducing direct material cost. So polycrystalline silicon is actually the most convenient and most used material for solar cells because of its low production cost as well as its reasonable conversion efficiency [1,2]. Several techniques have been used to increase the efficiency of polysilicon solar cells. Some techniques are meant to reduce recombination at grain boundary by the process of preferential doping [3], others use bulk and surface passivation [4] with ionic implantation or thermal diffusion [5,6]. Other techniques are used to reduce the effect of back surface recombination velocity by means of the Back Surface Field technique (BSF) [7]. These techniques have to be used to improve the collection of photo generated carriers at the depletion edge so as to increase the conversion efficiency of the cell.

In this work, we propose a new technique to reduce the minority carriers’ recombination at rear contact and improve the open circuit voltage. We develop a two-dimensional analytical model which enables us to calculate the photocurrent and the dark current in each region of the $n^+ - p$ structure in the case of Gaussian doping profile in p region. We use a two-diode electrical model in order to determine the conversion efficiency of the considered cell. We compare the performance of the considered cell with standard structure.

### 2 Theory development

#### 2.1 Physical model of an elementary solar cell

The structure of the thin film Polycrystalline solar cell presented in Fig. 1 is divided into three main regions: (emitter ($n^+$), space charge region ($n^+ - p$) and base region ($p$)). According to this model, the thickness of these regions is $W_e$, $W$ and $W_b$, respectively.

The following considerations have been introduced in order to simplify our model:

(i) The grains are considered as columnar and perpendicular to the $n^+ - p$ junction [9], and their electrical properties are homogeneous (doping concentration, minority carrier mobility, lifetime and diffusion length).

(ii) The minority carrier mobility and lifetime in base and emitter regions depends only on the doping level for the corresponding region.

(iii) Grain boundary recombination is negligible in the heavily doped emitter [9] and in the space charge region [10]. This is in agreement with Green [11].

(iv) We assume that low-level injection conditions prevail.

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**Symbols and Definitions**

$W_e$: emitter thickness ($\mu$m).

$W$: space charge region width ($\mu$m).

$\mu$: mobility of holes ($\text{cm}^2 \cdot \text{V/s}$).

$S_r$: recombination velocity at the frontal surface ($\text{cm/s}$).

$W_b$: base layer thickness ($\mu$m).

$N_{a1}$: doping density in $p$ region at the space charge layer limit ($\text{cm}^{-3}$).

$N_{a2}$: doping density at the limit of rear contact ($\text{cm}^{-3}$).

$N_d$: concentration doping density of emitter ($\text{cm}^{-3}$).

$N_{a3}$: doping density at the limit of rear contact ($\text{cm}^{-3}$).

$V_g$: effective recombination velocity at the grain boundary in base and emitter region ($\text{cm/s}$).

$A$: the cell area ($\text{m}^2$).

$\tau_n$, $\tau_p$: electrons lifetime (s), holes lifetime (s), respectively.

$S_p$: recombination velocity at the frontal surface ($\text{cm/s}$).

$S_n$: recombination velocity at rear contact ($\text{cm/s}$).

$I_{ph}$: total photo generated current ($\text{A}$).

$I_{sd}$: saturation diffusion dark current ($\text{A}$).

$H$: thickness of semiconductor ($\mu$m).
2.2 Photo generated current

The minority carrier density $\Delta n$ generated in the base region can be obtained by solving the two-dimensional continuity equation for the electron given by:

$$\frac{\partial^2 \Delta n}{\partial z^2} + \frac{\partial^2 \Delta n}{\partial x^2} + \frac{\Delta n}{V_T} \frac{\partial E}{\partial z} + \frac{E}{V_T} \frac{\partial \Delta n}{\partial z} - \frac{\Delta n}{L_n^2} = - \frac{g(z)}{D_n} \tag{1}$$

Where:

$$g(z) = g_{j,0} \exp(-\alpha_j z) \quad \text{and} \quad V_T = \frac{KT}{q}$$

The Gaussian doping profile in the base region is considered. $N_a(z)$ is given by:

$$N_a(z) = N_{a2} \exp \left( -\left( \frac{z - H}{\delta} \right)^2 \right) \tag{2}$$

$\delta$ is the characteristic coefficient of the Gaussian function given by:

$$\delta = \frac{W_b}{\sqrt{\ln \left( N_a / N_{a1} \right)}} \tag{3}$$

In this condition, there is an impurity concentration gradient that induces an electric field $E$ in the base region given by:

$$E(z) = \frac{V_T}{N_a(z)} \frac{dN_a(z)}{dz} \tag{4}$$

We note that $L_n$, $D_n$ and $E$ depend on the doping density which depends on the distance $z$. Consequently, equation (1) is in the second order differential equation that is not easy to solve when the coefficients depend on $z$. To simplify our study, we consider the average value of $N_a$, $D_n$, $L_n$ and $E$ given by:

$$\overline{N_a} = \frac{1}{W_b} \int_{W_p}^{W_p} N_a(z)dz \tag{5}$$

$$\overline{L_n} = \sqrt{\overline{E_n D_n}} \tag{6}$$

$$\overline{D_n} = \mu_n V_T \tag{7}$$
Where $\mu_n$ and $\tau_n$ are respectively the electrons mobility and lifetime given by [12-13]:

$$\mu_n = 232 + \frac{1180}{1 + \left( \frac{N_a}{8 \times 10^{16}} \right)^{0.9}}$$

$$\tau_n = \left( 3.54 \times 10^{-12} N_a + 0.95 \times 10^{-31} N_a^{-2} \right)^{-1}$$

Under these conditions equation (1) can be rewritten as:

$$\frac{\partial^2 \Delta n}{\partial z^2} + \frac{\partial \Delta n}{\partial x^2} + \frac{\bar{E}}{V_T} \frac{\partial \Delta n}{\partial z} - \frac{\Delta n}{L_n^2} = \frac{g_i(z)}{D_n}$$

Equation (12) is subjected to the following boundary conditions when the device is operated under short circuit:

$$\Delta n(x, z = H - W_b) = 0$$

$$\left. \frac{\partial \Delta n}{\partial x} \right|_{z=H} + \frac{\bar{E}}{V_T} \Delta n(x, z = H) = \frac{-S_b}{D_n} \Delta n(x, z = H)$$

$$\left. \frac{\partial \Delta n}{\partial x} \right|_{x=0} = \frac{V_g}{2D_n} \Delta n(x = 0, z)$$

$$\left. \frac{\partial \Delta n}{\partial x} \right|_{x=d} = \frac{-V_g}{2D_n} \Delta n(x = d, z)$$

In order to calculate the total minority carrier density generated in the base region using AM1 illumination condition, we consider the assumption proposed by Mohammed et al. [14] which decomposes the solar spectrum into four wavelengths. The absorption coefficient and generation rate in AM1 illumination condition $\alpha_i ( \mu m^{-1})$ and $g_{i,0} (cm^3 s^{-1})$ are listed in Table 1 [15].

| $\alpha_i ( \mu m^{-1})$ | $g_{i,0} (cm^3 s^{-1})$ |
|--------------------------|--------------------------|
| 6.33079×10^3            | 6.46746×10^19            |
| 1.02664×10^2            | 5.54674×10^18            |
| 7×10^{-4}               | 9.26415×10^{17}          |
| 1.76058                 | 2.03553×10^{21}          |

Using the Green function [16,17], the excess minority carrier density of electron is given by:

$$\Delta n(x, z) = \sum_{i=1}^{d} \sum_{k=1}^{\infty} f_{k,i}(z) M_k \cos \left( C_k \left( x - d/2 \right) \right)$$

The $C_k$ coefficients are obtained by the following transcendental equation [9,16]:
The general solution of \( f_{k,i} \) is given by:

\[
f_{k,i}(z) = \frac{g_{i,0}}{D_n \left( \mu_k^2 + 2 \alpha_k \beta - \alpha_k^2 \right)} \left\{ e^{\mu_k z} - e^{\beta \left( H - z \right)} e^{\alpha_k^2 \left( \left( H - z \right) \left( H - W_b \right) \right)} \right\} + \frac{\alpha_k}{\beta} \left[ v_k c_h \left( v_k (H - z) \right) + \left( y - \beta \right) s_h \left( v_k (H - z) \right) \right] - \frac{\alpha_k}{\beta} e^{\beta \left( H - W_b \right) - z} \left[ v_k c_h \left( v_k W_b \right) + \left( y - \beta \right) s_h \left( v_k W_b \right) \right]
\]

where:

\[
\beta = \frac{E}{2V_T}; \quad \mu_k = \left( C_k^2 + \frac{1}{L_n} \right)^{1/2}; \quad \gamma = \frac{E}{V_T} + \frac{S_n}{D_n}; \quad v_k = \left( \beta^2 + \mu_k^2 \right)^{1/2}; \quad M_k = \frac{4 \sin \left( C_k d / 2 \right)}{C_k d + \sin \left( C_k d \right)}
\]

The carrier density in the base region is calculated for \( k \) varying from 1 to 10, which has been found to be sufficient to obtain a good convergence whatever the grain dimensions and the superficial recombination velocities.

\[
J_0 = \frac{q \mu_n E}{d} \int_0^d \Delta n(x,z) \left| z=H-W_b \right. \right. dx + \frac{q D_n}{d} \int_0^d \frac{\partial \Delta n(x,z)}{\partial z} \left| z=H-W_b \right. \right. dx
\]

In the emitter region, we consider the uniform doping level. Using the same method, the current density \( J_e \) generated in the emitter region can be written as:

\[
J_e = \sum_{i=1}^{A} \sum_{j=1}^{\infty} \left[ -8q \delta_{i,0} \sin \left( \frac{C_j d}{2} \right) \frac{L_j}{C_j d + \sin \left( C_j d \right)} \left( \alpha_k^2 L_j^2 - 1 \right) \times B_{i,j} \right]
\]

\[
B_{i,j} \text{ is given by:}
\]

\[
B_{i,j} = \left[ \frac{D}{S_p} \alpha_j + 1 \right] + e^{-\alpha_j^2} \left[ \frac{c_h \left( W_e \right)}{L_j} + \frac{D}{L_j S_p} \frac{c_h \left( W_e \right)}{L_j} \right] - \left[ L_j \alpha_j e^{-\alpha_j^2 W_e} \right]
\]

The \( L_j \) coefficients are defined by:

\[
L_j^2 = \left( C_j^2 + L_p^2 \right)^{-1}
\]

\( L_p \) is given by:

\[
L_p = \sqrt{\mu_p \tau_p V_T}
\]

\( \mu_p \) and \( \tau_p \) are defined as [18]:

\[00025-p.5\]
\[
\mu_p = 130 + \frac{370}{1 + \left( \frac{N_d}{8 \times 10^{17}} \right)^{1.25}} 
\]
(24)

\[
\tau_p = \left( 7.8 \times 10^{-13} N_d + 1.8 \times 10^{-31} N_d^2 \right)^{-1} 
\]
(25)

The \( C_j \) coefficients are obtained by the following transcendental equation:

\[
\tan\left( \frac{C_j d}{2} \right) = \frac{V_g}{2C_j D_p} 
\]
(26)

where \( V_g \) is the recombination velocity at \( x=0 \) and \( x=d \).

The contribution of the space charge region is given as follows [19]:

\[
J_{scr} = \sum_{i=1}^{i=2} g_{i,0} \frac{\exp(-\alpha_i W)}{\alpha_i} \left[ 1 - \exp(-\alpha_i W) \right] 
\]
(27)

where \( W \) is given by [19]:

\[
W = \left[ \frac{2eKT}{q^2 N_a} \ln \left( \frac{N_a N_d}{n_i^2} \right) \right]^{\frac{1}{2}} 
\]
(28)

The total photocurrent density generated by the cell is given by:

\[
J_{ph} = J_x + J_b + J_{scr} 
\]
(29)

### 2.3 Dark current

In order to calculate the dark current in the base region, we solve the continuity equation given by:

\[
\frac{\partial^2 \Delta n_n}{\partial z^2} + \frac{\partial^2 \Delta n_n}{\partial x^2} + \frac{\hat{E}}{V_f} \frac{\partial \Delta n_n}{\partial z} - \frac{\Delta n_n}{L_n} = 0 
\]
(30)

with the general solution:

\[
\Delta n_n(x, z) = \sum_{k=0}^{\infty} g_k(z) M_k \cos \left[ C_k \left( x - d / 2 \right) \right] 
\]
(31)

The general solution of \( g_k \) is obtained with the same boundary condition as in the previous study except that equation (12) becomes:

\[
\Delta n_n(x, z = W_x + W) = \frac{n_i^2}{N_a} \times \left[ \exp \left( \frac{V_f}{V_T} \right) - 1 \right] 
\]
(32)

So, \( g_k \) is expressed as follows:
The expression of the dark current density \( J_{b0} \) in the base region is obtained by the same expression in equation (19).

In the same way, the dark current density \( J_{e0} \) in the emitter region can be written as:

\[
J_{e0} = \sum_{j=d} n_j^2 \frac{8q \sin(C_j d / 2) D_p}{N_d} \left[ \frac{ch}{L_j} \left( \frac{W_e}{L_j} \right) + \frac{D_p}{L_j S_p} \frac{sh}{L_j} \left( \frac{W_e}{L_j} \right) \right] \times \left[ \exp \left( \frac{V_j}{V_T} \right) - 1 \right] \tag{34}
\]

The diffusion dark current density \( J_d \) is given by:

\[
J_d = J_{b0} + J_{e0} = J_{ad} \times \left[ \exp \left( \frac{V_j}{V_T} \right) - 1 \right] \tag{35}
\]

The saturation recombination dark current density in the space charge layer can be obtained by [19]:

\[
J_s = \frac{q W n_i}{\sqrt{r_s r_n}} \left[ \exp \left( \frac{V_j}{V_T} \right) - 1 \right] = J_{sr} \left[ \exp \left( \frac{V_j}{V_T} \right) - 1 \right] \tag{36}
\]

### 2.4 Conversion efficiency

The I-V characteristic of the thin film polycrystalline solar cell can be obtained if we consider the equivalent circuit model represented in Figure 2.

![Fig. 2. A two-diode equivalent circuit for PV solar cell.](image)

In this model, we consider the recombination both at the surface and at the bulk expressed by \( R_s \) and \( R_{sh} \) respectively. So, using Kirchhoff’s first law, the current-voltage relationship I-V is expressed by:

\[
I = I_{ph} - I_{ad} \left( \exp \left( \frac{V + R_s I}{V_T} \right) - 1 \right) - I_{sr} \left( \exp \left( \frac{V + R_s I}{V_T} \right) - 1 \right) - \frac{V + R_s I}{R_{sh}} \tag{37}
\]

where \( I = A \times J \), (A=10\(^{-2}\) m\(^2\)).

The conversion efficiency of the cell is given by the formula:
4 Results and discussion

In this section, the results are obtained with the parameter values listed in Table 2. Using these parameters, we determine the conversion efficiency of the considered cell.

Table 2. Physical parameters of an elementary cell used in the computation results.

| Parameters | Value |
|------------|-------|
| T (K)      | 300   |
| $\varepsilon_r$ | 11.8 |
| $n_i$ (cm$^{-3}$) | $1.45\times10^{10}$ |
| $R_{sh}$ (Ω.cm$^2$) | 500 |
| K (J/K)    | $1.3806\times10^{-23}$ |
| $\varepsilon_o$ (F.cm$^{-1}$) | $8.85\times10^{-14}$ |
| $R_s$ (Ω.cm$^2$) | 0.2 |
| $N_d$ (cm$^{-3}$) | $10^{18}$ |
| $S_n$ (cm$^2$/s) | $10^6$ |
| $S_p$ (cm$^2$/s) | $10^2$ |
| $W_e$ (µm) | 0.8 |
| $P_e$ (W/m$^2$) | 925 |

Figure 3 demonstrates the variation of conversion efficiency according to the doping density $N_{a_2}$ in p-region of the cell at rear contact limit for $d=30$ µm and $N_{a_1}=7\times10^{15}$ cm$^{-3}$. The study is developed for a different base thickness $W_b$ (10µm, 20 and 50µm).

It can be seen that conversion efficiency increases with doping density $N_{a_2}$ and reaches maximum value. This result is associated to the Gaussian profile adopted in p-region that can be modulated by multi-junction that improves the open circuit voltage $V_{oc}$.

At high doping density $N_{a_2}$, conversion efficiency decreases. This decrease is more important for a larger base thickness. In fact, the diffusion length decreases considerably when $N_{a_2}$ increases and consequently the short circuit current decreases. The values of doping density $N_{a_2}$ which correspond to the maximum conversion efficiency decrease when base thickness increases.

The optimum value of conversion efficiency can be obtained for a base thickness that is equal to the grain size and for $N_{a_2} = 5\times10^{18}$ cm$^{-3}$. In this case, the conversion efficiency increase from 9.6% for $N_{a_2}=N_{a_1}$ to 13.75% for $N_{a_2} = 5\times10^{18}$ cm$^{-3}$. Finally, it can be concluded that the Gaussian profile in base region considered in our model improves considerably the conversion efficiency and this improvement compared to standard n$^+$-p structure ($N_{a_2}=N_{a_1}$) is equal to 43%. 
Fig. 3. Conversion efficiency as function of doping density at rear contact for different base thickness \((N_{a1}=7\times10^{15}\text{cm}^{-3}, d=30\mu\text{m}, V_g=10^6\text{cm/s})\).

With the same cell parameters, conversion efficiency is presented in Figure 4 as a function of doping density \(N_{a1}\) in p-region at the space charge limit for \(N_{a2}=5\times10^{18}\text{cm}^{-3}\). We remark that conversion efficiency decreases when \(N_{a1}\) increases. This result is related to the decrease in the open circuit voltage of the cell which depends on the gradient concentration in p-region.

At high doping density \(N_{a1}\), we remark a weak dependence of conversion efficiency on base thickness.

At low doping density, conversion efficiency varies with base thickness and the maximum value corresponds to \(W_b=20\mu\text{m}\). In fact, for this value, compromise between bulk generation and grain boundary recombination can be realized.

Fig. 4: Conversion efficiency as a function of doping density in p-region at space charge limit \((N_{a2}=5\times10^{18}\text{cm}^{-3}, d=30\mu\text{m}, V_g=10^6\text{cm/s})\).

Figure 5 shows the variation of conversion efficiency with respect to grain size \(d\) for \(N_{a1}=7\times10^{15}\text{cm}^{-3}\) and \(N_{a2}=5\times10^{18}\text{cm}^{-3}\).
We notice that conversion efficiency increases with grain size. Indeed, grain boundary recombination decreases then improves the collection of minority carrier at the n⁺-p junction. At low grain width, conversion efficiency weakly depends on base thickness. In fact, grain boundary recombination is important and consequently base contribution in photocurrent becomes weak.

At large grain size, maximum conversion efficiency is obtained for large base thickness. This is due to the improved generation of minority carriers in the base region and the reduction of recombination at grain boundaries.

![Graph showing conversion efficiency as a function of grain size](image)

**Fig. 5**: Conversion efficiency as function of grain size ($N_{a2}=5\times10^{18}\text{cm}^{-3}$, $N_{a1}=7\times10^{15}\text{cm}^{-3}$, $V_g=10^6\text{cm/s}$)

### 5 Conclusion

In this paper, a 2-D model is applied to determine the conversion efficiency of n⁺-p thin film polycrystalline solar cells by imposing a concentration gradient on base region. The influence of solar cell parameters such as base thickness, base doping profile and grain size on conversion efficiency is presented.

The results demonstrate that maximum conversion efficiency is obtained for a base thickness equal to grain dimension. In addition, the base doping profile considerably improves the open circuit voltage and the short circuit current, the optimum value of doping concentration at rear contact limit which corresponds to a maximum of conversion efficiency is equal to $5\times10^{18}\text{cm}^{-3}$.

Finally, we conclude that our proposed technique may be used to improve the conversion efficiency for a thin film polycrystalline solar cell.

### References

1. S. A. Edmiston, G. Heiser, A. B. Sproul, M. A. Green, J. Appl. Phys. 80, 12 (1996)
2. B. Ba, M. Kane, Solid-State Electron. 42, 4 (1998)
3. A. Ben Arab, Solid-State Electron., 41, 9 (1997)
4. A. Slaoui, E. Pihan, I. Ka, N.A. Mbow, S. Roques, J.M. Koebel, Sol. Energ. Mat. & Sol. Cells 90 (2006)
5. S. Martinuzzi, Solar Cells 12 (1984)
6. S. Narayanan, Wenham S. R., Green M.A. Appl. Phys. Lett. 48, 13 (1986)
7. A. Kaminski, B. Vandelle, A. Fave, J.P. Boyeaux, Le Quan Nam, R. Monna, D. Sarti, A. Laugier, Sol. Energ. Mat. & Sol. cells 72, 1-4 (2002)
8. J. Dugas, J. Oualid, Rev. Phys. Appl. 22, 7 (1987)
9. J. Dugas, J.P. Crest, C.M. Signal, J. Oualid, Solid-State Electron. 26, 11 (1983)
10. M. A. Green, Solid-State Electron. 21, 9 (1978)
11. G. Mazetti, M. Severi, S. Solmi, IEEE Trans. On Electron. Dev. 30, 7 (1983)
12. S. Swirhun, Y.H. Kwark, R.M. Swanson, IEDM techn. Dij. (1986)
13. S. N. Mohammed, C.E. Rogers, Solid-State Electron. 31, 8 (1988)
14. S. N. Mohammed, M.A. Sobhan, S. Qutubuddin, Solid-State Electron. 32, 10 (1989).
15. J. Dugas, Sol. Energ. Mat. & Sol. cells, 32, 1 (1994)
16. J. Oualid, C.M. Signal, J. Dugas, J.P. Grest, H. Anzil, J. App. Phys. 55, 4 (1984)
17. J. Del Alamo, S. Swirhun, R.M. Swanson, IEDM techn. Dij. (1985)
18. S. M. Sze, In: Physics of semiconductor devices, (New Jersey, Murry Hill: bell laboratories Inc. (1991)