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Numerical simulation for the current density of p-n like-type solar cells♣

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Numerical simulation is an important tool allowing an easy interpretation of physical phenomena and direct control of the involved parameters in a photovoltaic device. The paper deals with solar cells which consent to a p-n junction modeling under AM0 standard solar spectrum. The charge transport and Poisson's equations in one dimension are solved in terms of electron density, hole density and electrostatic potential using a finite-element approach. The current density model considers both the diffusion in neutral regions and the drift within depletion layer. The calculations are done for equilibrium and under forward bias voltage. The aim of the numerical computations is to obtain the J-V curves and the conversion efficiency. Results of numerical simulation concerning the influence of the most important material parameters on the cell performances are reported.

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1. Introduction

The conversion of sunlight directly to electric power is dominated by solid state junction devices. Due to continue increasing interest in using "clean" energy, the development of this type of devices was subject of a large technical and theoretical interest. At the theoretical level, an important direction of the scientific activity is focused on the developing and improvement of the models describing the transport phenomena inside the converter. In the last 20 years, computer modeling has become a necessary element in solar cell design and analysis. Simple analytical models provide only limited information to understand and optimize cells. A limitation of analytical models lays in the need of simplified assumption on the physics of the device, which may only be accepted in order to reduce the complexity in the calculation. Numerical treatment offers a deeper comprehension of the structure, achieving a complete control on the various parameters and defining their role in the device operation. Some articles consider only the charge due to impurity ions [1,2], but generally the space-charge density modifications arise from impurities as well as from free charge of electrons and holes [3-6]. In particular, our analysis is based on the numerical solution of Poisson's equation in the depletion layer of an abrupt Si p-n junction, but the computation could be easily extended to other types of devices presenting the p-n junction structure. The space-charge density ρ involved in our calculations considers both the charge due to impurities and free charge of electrons and holes. Because the solar cell operates in forward bias voltage, our study was particularly focused in how the problem variables (potential and charge concentrations) could change under this type of biasing. A numerical model has been developed to find the current density by solving the transport and continuity equations. The role of the device geometry and dopant concentrations on the conversion efficiency of the solar cell is studied.

2. Theoretical model

In our computations we considered a one dimensional p-n junction solar cell illuminated from p-side, as presented in Fig. 1.

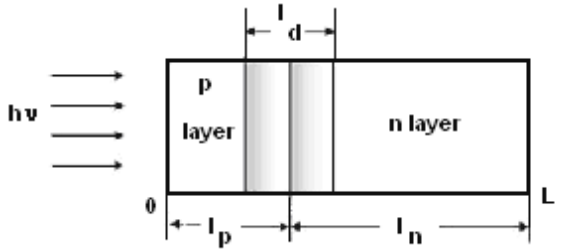

Fig. 1. p-n junction solar cell illuminated from p-side

The distribution of electric potential is described by the Poisson's equation:

$$\frac{d^2\phi}{dx^2} = -\frac{1}{\varepsilon} q\left(N_d(x) - N_a(x) + p(x) - n(x)\right) \qquad (1)$$

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where ϕ is the electric potential, ε is dielectric constant, *p(x)* and *n(x)* are the concentration of free charge of holes and electrons respectively, $N_d(x)$ and $N_a(x)$ are the concentration of ionized donors and acceptors and *x* is the depth in the depletion layer [3].

The current density was obtained by the solution of the electron and hole continuity equations:

$$-\frac{1}{q}\frac{dJ_n(x)}{dx} = G(x) - R(x) \tag{2}$$

$$-\frac{1}{q}\frac{dJ_p(x)}{dx} = G(x) - R(x) \tag{3}$$

where

$$J_n = -q\mu_n n(x)\frac{d\phi}{dx} + qD_n\frac{dn(x)}{dx} \tag{4}$$

and

$$J_p = -q\mu_p p(x)\frac{d\phi}{dx} - qD_p\frac{dp(x)}{dx} \tag{5}$$

are the electron and hole current densities. *G(x)* is the generation rate, *R(x)* is the recombination rate, μ_n and μ_p are the mobility of free electrons and holes, D_n and D_p are the diffusion coefficients of electrons and holes respectively.

The generation rate *G(x)* of charge carriers in the semiconductor layer at the depth *x* is given by:

$$G(x) = \int_{\lambda_{\min}}^{\lambda_{\max}} [1 - R(\lambda)]\alpha(\lambda)N_{ph}(\lambda)e^{-\alpha(\lambda)x}d\lambda \tag{6}$$

where α(λ) is the absorption coefficient, $N_{ph}(\lambda)$ is the incident photon flux, $R(\lambda)$ is the reflection coefficient at front surface. $\lambda_{\min}$ and $\lambda_{\max}$ are the minimum and maximum wavelengths of the considered solar spectrum. The recombination rate *R(x)* is related to the excess electron ($\Delta n(x)$) and hole ($\Delta p(x)$) concentrations and the lifetime of electrons (τ_n) and holes (τ_p) as follows [7]:

$$R(x)_n = \frac{\Delta n(x)}{\tau_n};\ R(x)_p = \frac{\Delta p(x)}{\tau_p} \tag{7}$$

3. Numerical results

The system (1)-(3), together with appropriate boundary conditions [3,4] was solved using the finite element method. Considering an abrupt p-n junction, the doping profile of the impurity is assumed uniform throughout each semiconductor up to the junction. Three different values for the dopant concentrations ($N_a = N_d$ = 1.5 10^{15}, 7.5 10^{15} and 1.5 10^{16} cm^{-3} respectively) and three length values for the p and n regions ($l_p=l_n=0.5L$; $l_p=0.25L$, $l_n=0.75L$ and $l_p=0.125L$, $l_n=0.875L$ respectively), for a fixed length of the device, $L=3.33$μm. The material parameters used for numerical computations were specific to Si at 300 K [3] and remained constant for all the simulations.

The solar cell is considered illuminated with an AM0 spectrum, divided in 66 energy segments, producing 1358.3 W/m^2. The effect of the illumination on the J-V characteristic is presented in Fig. 2.

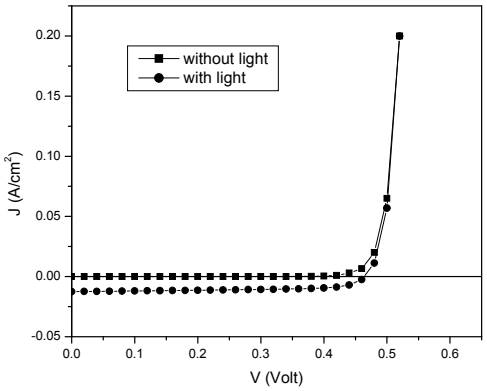


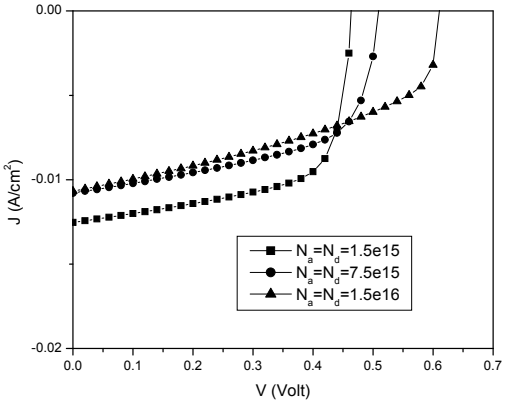
Fig. 2. Calculated J-V characteristics without and under illumination for in case $l_p = l_n = 0.5L$ and $N_a = N_d = 1.5\ 10^{15}\ cm^{-3}$.

In order to characterize the cell performance, the short circuit current density (J_{sc}), the open circuit voltage (V_{OC}), the efficiency (η) and the fill factor (F_f) were determined in each case. The results are synthetically presented in Table 1 and figure 3.

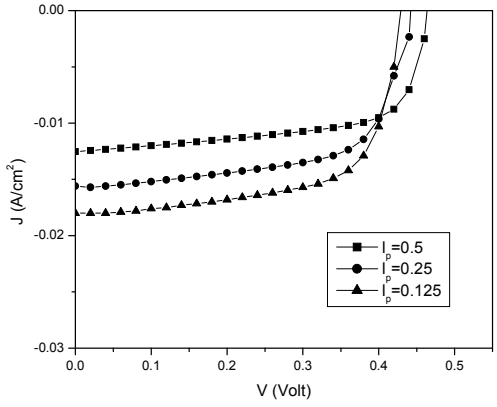
Table 1. Numerical results.

Case	Na (cm^{-3})	Nd (cm^{-3})	l_p (μm)	l_n (μm)	J_{sc} (mA/cm^2)	V_{OC} (V)	F_f (%)	η (%)
1.	1.5 10^{15}	1.5 10^{15}	1.65	1.65	12.5	0.465	65.6	4.3
2.	1.5 10^{15}	1.5 10^{15}	0.825	2.475	15.6	0.443	64.4	5.1
3.	1.5 10^{15}	1.5 10^{15}	0.4125	2.8875	18	0.431	65.9	5.7
4.	7.5 10^{15}	7.5 10^{15}	1.65	1.65	11.2	0.511	58.1	4.4
5.	1.5 10^{16}	1.5 10^{16}	1.65	1.65	10.7	0.614	45.9	4.8

All the results are in perfect accordance with previous works in domain and represent and good validation for our program. The simulations outline two possibilities to improve the efficiency of a solar cell: to increase the dopant concentration and to reduce the width of the emitter (the p region in our case). The computed efficiencies are small, but this is a consequence of the parameter values used for the validation of the program. The program is a part of a multilevel simulator for nanostructured cells with a classical behavior of the carriers (for example, the multiple quantum solar cell in [8]).



(a)



(b)

Fig. 3. Calculated J-V characteristics. Curves in panel (a) consider cells with the same geometry ($l_p = l_n = 0.5L$) but different dopant concentrations; curves (b) represent cells with the same dopant concentration ($N_a = N_d = 1.5\ 10^{15}\ cm^{-3}$) but with different lengths for the p and n regions.

4. Conclusions

In this paper, a set of numerical solutions obtained in the frame of an accurate model for the charge transport in a p-n like-type solar cell is presented. The J-V characteristics analysis shows that the efficiency increases as the dopant concentration increases and/or the emitter width decreases.

Acknowledgements

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References

[1] M. A.Green, , Solar Cells, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, p.66 (1982).
[2] S. C. Tsaur, A. G. Milnes, R. Sahai, D. L. Feucht, in Symposium on GaAs. Inst. of Phys. and Phys. Soc., London, **156** (1972).
[3] Sze, S. M., Physics of Semiconductor Devices, by John Wiley and Sons, Inc. (1981).
[4] Donald A. N., Semiconductor Physics and Devices, IRWIN, Inc, p.247 (1992).
[5] Selberherr S.. Analysis and simulation of semiconductor devices, Berlin, Springer (1984).
[6] Rover D.T., Basore P.A., Thorson G.M.: IEEE, p.703 (1985).
[7] Fonash, S. J., Solar Cell Device Physics, Academic press, Inc, p.150 (1981).
[8] Paulescu M. et al., Internal reflection influence on the multiple quantum well solar cell efficiency, The Proceedings of the International Conference of the Faculty of Sciences, University of Oradea, Romania, November 9-10, (2007)

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