International Journal of Science, Environment
and Technology, Vol. 1, No 4, 2012, 331 - 340

DETERMINATION IN 3D MODELLING STUDY OF THE WIDTH EMITTER EXTENSION REGION OF THE SOLAR CELL OPERATING IN OPEN CIRCUIT CONDITION BY THE GAUSS'S LAW

E. SOW[1], S. MBODJI[1, 3], B. Zouma[2], M. Zoungrana[2], I. Zerbo[2], A. Sere[2] and G. SISSOKO[1]

[1]Laboratoire des Semi-conducteurs et d'Energie Solaire, Département de Physique, Faculté des Sciences ET Techniques, Université Cheikh Anta Diop, Dakar, Senegal
[2]Laboratoire de Matériaux et Environnement, Département de Physique, Unité de Formation et de Recherche en Sciences exactes et Appliquées, Université d'Ouagadougou, Burkina Faso
[3]Section de Physique, UFR SATIC, Université Alioune Diop de Bambey, Sénégal, BP 30 Bambey-Sénégal

E-mails: msenghane@yahoo.fr; senghanem@gmail.com; senghane.mbodji@uadb.edu.sn

Abstract: In this article, we are discussing the Gauss's law used to determine the width emitter extension region of the solar cell operating in open circuit condition. Taking into account the grain size (g), the grain boundary recombination velocity (Sgb) and the emitter doping density ($N_{emitter}$), the Gauss's Law helped us to calculate the width emitter extension region of the solar cell operating in open circuit condition.
To determine the width emitter extension region, we first showed that grain size (g), grain boundary recombination velociy (Sgb) are oppesite effects and concluded that best solar cells are characterized by low junction extension region width observed only with high grain size (g) and low grain boundary recombination velocity (Sgb).
In a second way using Gauss's law, we deduced that the ratio R of the width emitter extension region on the base extension region is equal to the ratio of the base doping density to emitter doping density. We concluded that when $N_{emitter} < 1.5 \cdot 10^{15} cm^{-3}$, the ration R is practically constant and when $10^{16} cm^{-3} \le N_{emitter} \le 5 \cdot 10^{16} cm^{-3}$ the ration R variation is soft and we finely saw that the emitter contribution to the photoccurent can be neglected for emitter doping density greater than $10^{17} cm^{-3}$.
Key words: doping density, extension region width, grain size, grain boundary recombination velocity.

Introduction

Considering AlGaAs/GaAs heterojunction emitter bipolar transistor grown with emitter thickness varied from 300 to 900 $\overset{0}{A}$, *Chen et* al [1] showed that current gain decreases by increasing emitter thickness but the offset voltage variation depends to interval value of the emitter thickness.

In other works, Tadayon et al [2] experimented the effects of AlGaAs layer thickness and GaAs cap layer thickness in the emitter of abrupt npn AlGaAs/GaAs heterojunction bipolar transistor. These authors showed that only $500\overset{0}{A}$ of $Al_{0.25}Ga_{0.75}As$ layer in the emitter is enough to produce high injection efficiency and a small current gain of more than 1100.

For an n^+- p- p^+ solar cell structure in work done by [3] it is shown that if the stucture doping density under the selective emitter is very high compared to the field (non selective) region, then the width of the emitters fingers strongly influences V_{oc}. But if the surface doping density under the selective emitter is only slightly high compared to the field region, then the influence on V_{oc} is modest.

Introducing Sf as a junction recombination velocity some researchers [4-5] showed that there is an extension region width Z_0 which is the distance between two diffusion capacitance's plane electrodes of the solar cell's junction [4-5]. Z_0 is calculated on the base and varies with the grain size, the grain boundary recombination velocity, the wavelength and the type of illumination modes (front side, rear side or both front and rear sides) of the n^+- p- p^+ of solar cell structure. These results are obtained without emitter contribution to the photocurrent and the photovoltage [4-5]

So in this paper, considering the base extension region width ($Z_{B,}$), we are going to calculate the emitter extension region width (Z_E) when the solar cell is in steady state and under open circuit operating conditions. Effects of grain size (g), grain boundary recombinaation velocity (Sgb) and the emitter doping density on Z_E will be investigated.

In open circuit operating condition, the ratio of the width emitter extension region on the base extension region width will be studied.

Study is made with some hypothesis:

The grain boundary recombination velocity (Sgb) is the same in the base and the emitter;

The columnar orientation is considered and we focused on an isolated grain; g_E is the thickness of the emitter and g is the thickness of base;

Sf_0 is the intrinsic junction recombination velocity [4, 5]. It is the second term of the junction recombination velocity (Sf); other one is Sf_j which is related to the external charge. In open circuit operating condition, Sf_j=0 and Sf is equal to Sf_0. The intrinsic junction recombination velocity characterized losses at the junction. Hence the diode photocurrent, the series and shunt resistances depend strongly to this parameter [6]. For ideal solar cell, Sf_0 reaches to zero but for a non ideal solar cell, Sf_0 isn't null and is related strongly to the extension region of the base [7] at the junction;

Z_E is the emitter extension region in open circuit operating condition;

Z_B is the base extension region in open circuit operating condition;

Theory: Materials and Methods

In this study, we apply the Gauss's law in the solar cell's junction which is considered as a plane capacitor with two identical plane electrodes. For an ideal solar cell characterized by a higher shunt resistance R_{sh} [8], the thickness of these two electrodes is very low and for a non ideal solar cell, characterized by a low shunt resistance R_{sh} [8], meaning higher current lost at the junction corresponding to an extension region of the junction. Usually, the emitter contribution on the photocurrent is neglected and hence, the extension region of this region is not included in all our studies. So that, in figure 2, we considered Z_B and Z_E as base and emitter extension region in open circuit operating condition of the solar cell, respectively. It is clear that Z_B depends strongly on the grain size and the grain boundary recombination velocity [4-5]. We demonstrated that for a good solar cell under steady state and in open circuit voltage operating condition, these electrodes are separated by junction's extension region width [4-5].

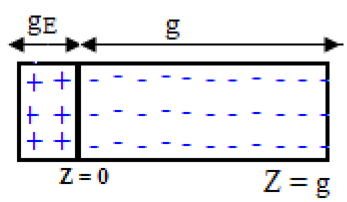

Figure 1. Ideal solar cell in open circuit operating condition

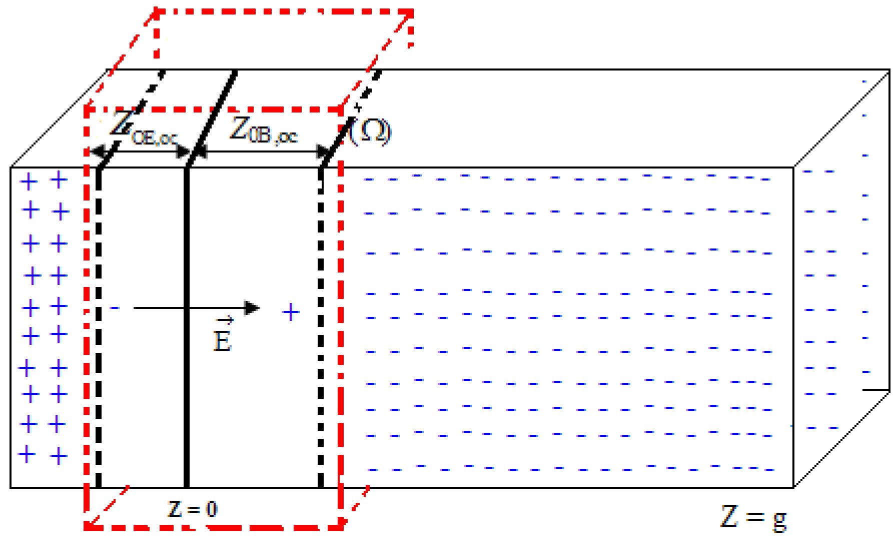

Figure 2. Non ideal solar cell in open circuit operating condition

The negative and positive charges show the nature of the doping.

The Gauss's law is expressed as [9]:

$$\oint_{(\Omega)} \vec{E} \cdot \vec{dS} = \frac{Q}{\varepsilon} \quad (1)$$

Using the well known Quasi- Neutral Base assumption (QNB), we set that the electric field $\vec{E}$ in the base and emitter is null.

Ω is the Gauss surface, Q is the bulk global charge contained in the surface Ω and $\varepsilon = \varepsilon_r \cdot \varepsilon_0$

ε_0 $8.85 \cdot 10^{-14}\,F \cdot cm^{-1}$ is the permittivity for the vacuum and $\varepsilon_r = 12$ is the relative dielectric constant of the semiconductor.

Hence in the base and the emitter, the electric field is null, equation (1) become:

$$0 = \frac{(e \cdot N_{emitter} \cdot Z_E - e \cdot N_{Base} \cdot Z_B) \cdot S}{\varepsilon} \quad (2)$$

S is the area of the identical plane electrodes;

$N_{emitter}$ is the emiter doping density. Its values range from 10^{17} to 10^{19} cm^{-3} [10];

N_{base} is the base doping density and the doping ranges 10^{15} to 10^{17} cm^{-3}. [10];

$e = 1.6 \cdot 10^{-19}\,C$.

Here when calculating, we suppose that the diffusion capacitance plane electrodes have a surface whose its value is S=1cm^2.

Considering equation (2) we deduced:

$$Z_E = \frac{N_{Base}}{N_{emitter}} \cdot Z_B \qquad (3)$$

Z_B is determined by simulation process with MathCAD software, using normalized excess minorty carriers density and reference voltage method [4-5] after resolving the continuity equation and deducing the excess minority carriers density. The reference voltage is the constant voltage at position $z = Z_B$. It characterized the diffusion capacitance in the Shockeley's model. So that, with the fixed value of the reference photovoltage and general expression of photovoltage, Z_B is calculated when equalizing theses two photovoltages [4-5].

Results and discussions

When doing a simulation process, we first presented in table 1, different values of the extension region of the emitter Z_E corresponding to one of the base when the grain size varies and for different values of the emitter dopage. And in the second table (table 2), we fixed the grain size parameter and we vary the grain boundary recombination velocity and did the same work as in table 1.

Setting R as the ratio of the emitter's extension region Z_E against the one of the base, Z_B, we plotted this ratio versus the grain size for different values of the emitter dopage $N_{emitter}$

Table 1: Values of the extension regions of the emitter and the base of the solar cell operating in open circuit condition. The grain boundary recombination velocity Sgb = 10^3cm.s^{-1} is a fixed value

g (μm)	Z_B (μm)	$N_{emitter} = 1 \cdot 10^{15}\,cm^{-3}$ Z_E(nm)	$N_{emitter} = 1.3 \cdot 10^{15}\,cm^{-3}$ Z_E(nm)	$N_{emitter} = 1 \cdot 10^{16}\,cm^{-3}$ Z_E(nm)
20	25.42	2.54	3.304	25.419
23	18.55	1.85	2.412	18.556
26	16.49	1.64	2.143	16.489
29	15.17	1.51	1.972	15.176
32	14.21	1.42	1.848	14.216
35	13.46	1.34	1.750	13.462

38	12.84	1.28	1.669	12.843
41	12.31	1.23	1.601	12.316
44	11.85	1.18	1.541	11.859
47	11.45	1.14	1.488	11.453
50	11.08	1.10	1.441	11.088
53	10.75	1.07	1.398	10.755

Table 2: Values of the extension regions of the emitter and the base of the solar cell operating in open circuit condition. The grain size g = 40µm is a fixed value.

Sgb (µm)	Z_B (µm)	$N_E=10^{15}cm^{-3}$ Z_E(nm)	$N_E=1.3\cdot10^{15}cm^{-3}$ Z_E(nm)	$N_E=1\cdot10^{16}cm^{-3}$ Z_E(nm)
10	9.647	0.964	1.254	9.647
13	9.667	0.966	1.256	9.667
16	9.692	0.969	1.259	9.692
20	9.724	0.972	1.264	9.723
25	9.764	0.976	1.269	9.763
32	9.814	0.981	1.275	9.813
40	9.877	0.987	1.283	9.876
51	9.956	0.995	1.294	9.956
63	10.057	1.005	1.307	10.05
79	10.184	1.018	1.323	10.18
100	10.344	1.034	1.344	10.34
126	10.546	1.054	1.371	10.54
158	10.804	1.080	1.404	10.80
200	11.132	1.113	1.447	11.131
251	11.553	1.153	1.501	11.553
316	12.100	1.209	1.572	12.099
398	12.822	1.282	1.666	12.822
501	13.805	1.380	1.794	13.804

630	15.218	1.521	1.978	15.218
794	17.514	1.751	2.276	17.513
1000	25.420	2.541	3.304	25.419

We plotted in figure 3, R versus the grain size g of the solar cell's base for various values of the doping density of the emitter which took $1.10^{15}\,cm^{-3}, 1.1\cdot10^{15}\,cm^{-3}, 1.5\cdot10^{15}\,cm^{-3}, 1.\cdot10^{16}\,cm^{-3}$, $1.5\cdot10^{16}\,cm^{-3}, 3\cdot10^{16}\,cm^{-3}$, $5\cdot10^{16}\,cm^{-3}$ and $1\cdot10^{17}\,cm^{-3}$. The grain boundary recombination velocity $Sgb = 10^3 cm.s^{-1}$ is a fixed value.

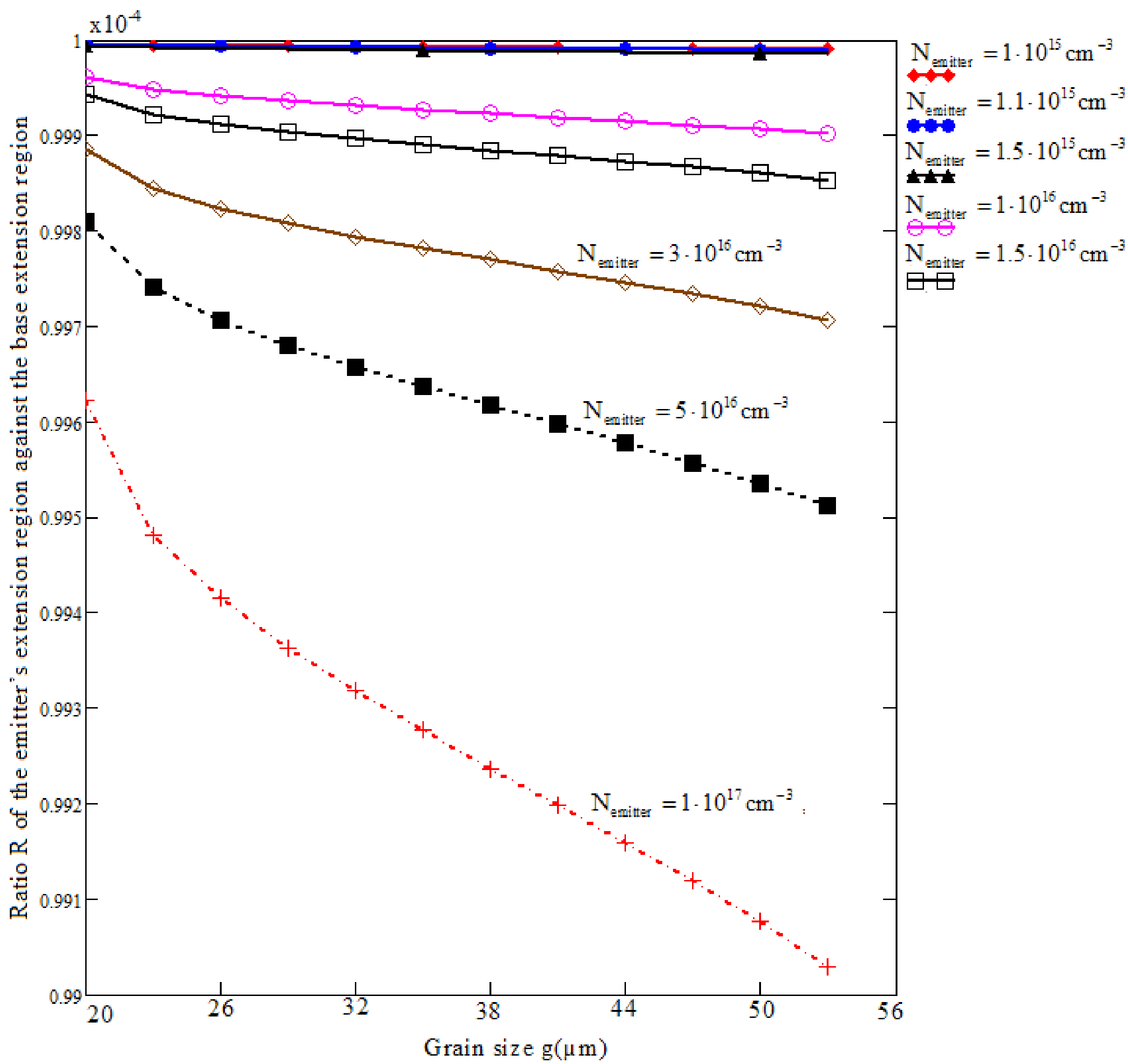

Figure 3: The ratio R of the emitter'extension region against the base extension region versus grain size g when the emitter dopage varies; Sgb = 10^3cm.s^{-1},N_{base}= 10^{17}cm^{-3}.

When the grain size (g) increases, the extension regions of the base and the emitter decreases, corresponding to a decreasing of the global extension region of the junction in open circuit voltage operating condition.We showed that, the displacement of diffusion capacitance's plane electrode and the crossing of excess minority carriers (holes and electrons) depend on the values of extension region in open circuit and short-circuit operating conditions [4]. If these two values are close, diffusion capacitance's plane electrodes displacement are limited and the photocurrent is low and then solar cell efficiency decreases. And for best solar cell, the extension regions (base and emitter zones) values in open circuit and short-circuit must have an important gap apparent only if these values decrease [4]. Tables 1 showed that this situation is observed when the grain size increases.

When the grain boundary recombination velocity increases, the global extension region increases leading to a cutting-off of the displacement of diffusion capacitance's plane elctrodes and then to a reduction of holes and electrons crossing to the junction. Then the photcurrent density, the photovoltage, the power and the efficiency decrease. This is due to the fact that, grain boundary recombination velocity translates losses in bulk of the solar at the grain boundary of the solar cell and their increase lead to the decrease of the photocurrent [6].

In open circuit voltage operating condition, when the emitter doping increases, we noted at table 2 for the range value of $N_{emitter}$<10^{17}cm^{-3} that global extension region of the junction increases. The displacement of diffusion capacitance's plane electrodes is then restricted. Hence, the crossing of charge carriers (holes and electrons) at the junction is low and solar cell efficiency is obviously low if we based to results of [6]

Table 1 and table 2 showed that the grain size effects on the emitter extension region is the same effects of the emitter thickness on the current gain of bipolar transistors [1-2]

In figure 3, we remarked that when $N_{emitter} < 1.5 \cdot 10^{15}\,cm^{-3}$ the ration R is constant. For fixed values$1.5 \cdot 10^{16}\,cm^{-3}$, $1. \cdot 10^{16}\,cm^{-3}$ and $3 \cdot 10^{16}\,cm^{-3}$ of the emitter doping density, the ratio R decreases slightly.

But when the emitter base doping density takes $5 \cdot 10^{16}\,cm^{-3}$and $1 \cdot 10^{17}\,cm^{-3}$, figure 3 showed that the ration R decresaes drastically. Meneaning that emitter extension region can be negleted to those of base's extension region. These results corroborate hypothesis maked in many studies which allowed neglecting the emitter contribution on the photocurent density.

Conclusion

Taking into account the result which considers the solar cell junction as a plane diffusion capacitance, we used the Gauss's law to calculate the junction extension region width including the emitter contribution.

We showed that, the emitter's extension region width in open circuit voltage decreases and increases with de grain size and grain boundary recombination velocity, respectively; meaning that best solar cells are characterized by high grain size and low grain boundary recombination velocity.

On the other hand, we studied the ratio of the emitter extension region width on the base extension region width. We saw that for low values of emitter doping density ($N_{emitter}$) smaller than $10^{16}cm^{-3}$ the emitter contribution to the photocurrent must be taken into account. But, when the doping density ($N_{emitter}$) values are greater than $10^{17}cm^{-3}$, we showed that the emitter contribution to the photocurrent can be neglected.

References

[1] Chen H. R., Lee, C. P., Chang, C. Y., Tsang, J. S., and Tsai, K, L (2009). The study of emitter thickness effect on the heterostructure emitter bipolar transistors, *Jounal of Applied Physics, 74 (2), 1398-1402.*

[2] Tadayon, S., Tadayon, B., Tasker, P. J., Schaff, W. J. and Eastman, L. F (2002). Reduction of emitter thickness in AlGaAs/GasAs heterojunction bipolar transistor, *Electronics Letters, 25 (12), 802-803.*

[3] Rapolu, K. Singh, P. and Shea, S.P (2010). Two dimensional numerical modeling of a silicon solar cell with selective emitter configuration; *Proc. 35th IEEE of Photovoltaic Specialists Conference (PVSC), 2227 – 2232.*

[4] Mbodji, S., Mbow, B., Barro, F. I., and Sissoko, G., (2011). A 3D model for thickness and diffusion capacitance of emitter-base junction determination in a bifacial polycrystalline solar cell under real operating condition, *Turk J Phys 35, 281 – 291.*

[5] Deme, M.M., Mbodji, S., Ndoye, S., Thiam, A. Dieng, A. and G. Sissoko (2010). Influence of illumination incidence angle, grain size and grain boundary recombination velocity on the bifacial solar cell diffusion capacitance *Revue des Energies Renouvelables 13(1), 109 – 121.*

[6] Diallo, H.L., Maiga, A. S., Wereme, A and Sissoko, G. (2008). New approach of both junction and back surface recombination velocities in a 3D modelling study of a polycrystalline silicon solar cell*, Eur. Phys. J. Appl. Phys. 42, 203–211*

[7] S. Mbodji, B.Mbow I.Zerbo and G. Sissoko, *"Analysis of the diffusion capacitance's efficiency of the bifacial silicon solar cell in steady state operating condition "*, Research Journal of Applied Sciences, Engineering and Technology; 4(4): 282-288, 2012.

[8] Mbodji, S., Ly, I., Diallo, H. L., Dione, M.M., Diasse, O. and Sissoko, G (2012). Modeling study of n^+/p solar cell resistances from single I-V characteristic curve considering the junction Rrecombination velocity (Sf*), Research Journal of Applied Sciences, Engineering and Technology 4(1), 1-7.*

[9] Queyrel, J. (1991). Precis de Physique - Electricité 1, Cours et Exercices Résolus Bréal.

[10] Madougou, S., Kaka, M and Sissoko, G. 2010. Silicon Solar Cells: Recombination and Electrical Parameters, *Solar Energy, ISBN 978-953-307-052-0, 69-79.*

.

*Received Sep 6, 2012 * Published Oct, 2012*