EFFECT OF THE FSF AND BSF LAYERS ON THE PERFORMANCES OF THE GaAs SOLAR CELL

A. HEMMANI[a*], B. DENNAI[a], A. NOURI[a,b], H. KHACHAB[a], B. DEKKICH[a]
[a]*Department of Matter Sciences, Faculty of Exact Sciences, University of TAHRI Mohamed, Bechar, BP 417, Bechar, ALGERIA*
[b]*LabMat Laboratory, ENP, BP 1523 EL-M'naouer 31000, Oran, ALGERIA*

The objective of the present work is the study by numerical simulation, of the FSF and BSF (Front Surface Field and Base Surface Field) layers effect on the electrical characteristics of the GaAs photovoltaic cell.
In order to better understand the influence of fields' addition (BSF, FSF) on the performance of GaAs solar cell, their own effect is studied firstly. In the second part, the impact of the internal parameters of the BSF and FSF layers, such as doping and the thickness, on the electrical parameters of solar cells is studied. The results obtained allow us to optimize the physical and geometrical parameters of the solar cell to reach an increase of 25.74% for the conversion efficiency (with FSF) and 29.47% (with FSF and BSF) in comparison with GaAs standard solar cell**.**

(Received July 25, 2017; Accepted November 3, 2017)

Keywords: Solar cell; GaAs; Back Surface Field; Front Surface Fiel; High-low junction.

1. Introduction

The conversion efficiency of the photovoltaic cell is limited by various physical and technological factors that may prevent the complete conversion of light energy into electricity [1-4].

Currently, many theoretical and experimental innovations are suggested by researchers to find adequate solutions of photovoltaic structures [5, 6].

In this spirit is done this work, so, we are interested to simulate the bifacial (FSF and BSF) GaAs-based solar cell.

The addition of the FSF and/or BSF layer to the front/back surface in the interface of the ohmic contact shows an improvement in the performance of the GaAs photovoltaic cell [7, 8].

2. The GaAs solar cell

Gallium arsenide (GaAs) is a semiconductor composed of a mixture of two elements, gallium (Ga) and arsenic (As). This material is very promising for photovoltaics conversion because of its important properties; namely direct band gap, high mobility of free carriers and large diffusion length [9, 10].

GaAs-based solar cells are widely used, particularly in space applications, because of their high efficiency and low degradation caused by spatial irradiation [11]. But despite the advantages of GaAs, this material has several disadvantages; the major one is the high rate of surface recombination. Several investigation have been initiated in order to minimize the losses and to improve the cell's performance [12, 13].

[*]Corresponding author: hemani1973@yahoo.fr

3. GaAs Solar cell with Front (FSF) and/or Back (BSF) surface Fileds

The front/back surface field (FSF/BSF) of solar cell was first reported by Mandelkorn et al. [14]. They showed the improvement of conversion efficiency over conventional solar cells. In the FSF/BSF solar cell structures, a heavily doped layer is incorporated at the front/back of the standard solar cell, which leads to much higher efficiency.

3.1 GaAs Solar cell with Back Surface Field layer (BSF)

The back surface field is a highly doped zone area the whole back surface of the solar cell with a doping of the same type as that of the base to obtain the nn^+ structure. By thus creating an acceptor gradient on the back face of the cell, it is possible to obtain:

- Increase of short-circuit current.
- Increase in spectral response at long wavelengths.
- Reduction of contact resistance.

The potential barrier induced by the difference of the doping level between the base n and the BSF n^+ tends to confine the holes (minority carriers) in the base, which makes it possible to keep them away from the back face, this face often characterized by a very high recombination rate Sp [15-18].

Figure 1 illustrates the structure of GaAs solar cell with a back contact field (BSF).

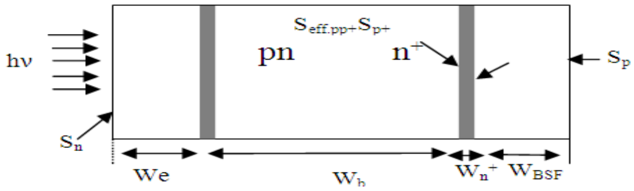

Fig. 1. Structure of a GaAs solar cell with BSF layer.

The modeling of the BSF layer requires the determination of the effective recombination rate [16, 17]. The effective recombination rate $S_{eff.pp+}$ in the highly doped region (nn^+) is determined by the equation:

$$S_{eff,pp^+} = \frac{N_d}{N_d^+}\frac{D_p^+}{L_p^+}\frac{\frac{S_p L_p^+}{D_p^+}+th\left(\frac{W_{n^+}}{L_p^+}\right)}{1+\left[\frac{S_p L_p^+}{D_p^+}\right]th\left(\frac{W_{n^+}}{L_p^+}\right)} \quad (1)$$

Where:

N_d: Concentration of the electrons in the emitter.

N_{d+}: Concentration of the electrons in the BSF layer.

Lp+: Diffusion length of holes in BSF layer.

Dp^+: Minority holes diffusion coefficient in BSF layer.

Sp: Recombination rate in the base.

W_{n^+}: High-low junction BSF layer length.

In the case of an infinite Sp recombination velocity, the effective recombination velocity is expressed by:

$$S_{eff,pp+} = \left[N_d^+ D_p^+ / N_d^+ L_p^+\right] coth\left[W_{n^+}/L_p^+\right] \quad (2)$$

3.2. GaAs Solar cell with Face Surface Field layer (FSF)

As, the Back Surface Field, the FSF is a highly doped region on the entire front face of the solar cell with a doping of the same type as that of the emitter.

The important role of the Front Surface Field layer is to reduce the effect of surface recombination and consequently to increase the number of charge carriers created contributing to the total photocurrent. The figure 2 shows a schematic representation of GaAs solar cell with FSF.

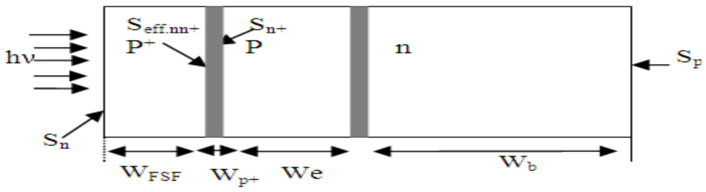

Fig. 2. Structure of the GaAs solar cell with FSF layer

In this case, another effective recombination rates can be determined.

The actual recombination rate $Seff_{.nn+}$ in the highly doped region is expressed as follows [15]:

$$S_{eff.nn^+} = \left(\frac{N_a}{N_a^+}\right)\left(\frac{D_n^+}{L_n^+}\right)\left\{\frac{\frac{S_n L_n^+}{D_n^+}+th\left(\frac{W_{p^+}}{L_n^+}\right)}{1+\frac{S_n L_n^+}{D_n^+}th\left(\frac{W_{p^+}}{L_n^+}\right)}\right\} \tag{3}$$

Where:

Na: Concentration of the holes in the base.
Na^+: Concentration of the holes in the FSF layer.
Ln^+: Diffusion length of electrons in FSF layer.
Dn^+: Minority electron diffusion coefficient in FSF layer.
Sn: Recombination rate in the emitter.
W_{p^+}: High-low junction FSF layer length.

The physical significance of $S_{eff.nn+}$ is that it takes into account the effects of the p^+ region on the minority carriers from the p (or p^+) region.

4. Photocurrent density calculation

4.1. Internal parameters of studied solar cells

The simulation treated four cases, GaAs solar cell without FSF or BSF layers (standard), solar cell with FSF, solar cell with BSF and solar cell with both layers BSF and FSF.

The selected internal parameters are reported in Table 1.

Table 1. Internal parameters of the GaAs Solar Cell

Symbol	Parameter	Value	Unit
t_p	Lifetime of electrons in the base	0.1	s
t_n	Holes Lifetime	0.1	s
μ_p	Holes mobility on the transmitter	400	$m^2V^{-1}.s^{-1}$
μ_n	Holes mobility at the transmitter	3000	$m^2V^{-1}.s^{-1}$
D_p	Minority holes diffusion coefficient	10	cm^2s^{-1}
D_n	Minority electrons diffusion coefficient	60	cm^2s^{-1}
L_p	Length of diffusion of holes	2	µm
L_n	Length of diffusion of electrons	10	µm

4.2. Photocurrent density in the standard GaAs solar cell

The total density of the illumination current per wavelength is the sum of the currents density in the three regions constituting the photovoltaic cell:

$$J(\lambda) = J_p(\lambda) + J_n(\lambda) + J_{dr}(\lambda) \quad (4)$$

Where:

J_p (λ): Current density of the current of the holes in the quasi-neutral zone n.

$J_n(\lambda)$: Current density of the electron current in zone P.

$J_{dr}(\lambda)$: Current density in the Depletion Region area.

4.3. Photocurrent density in the highly doped region nn+ (BSF)

The photocurrent generated in the nn^+ region is given by the following relation [17]:

$$J_{BSF} = -\left(\frac{qD_{p+}}{L_{p+}}\right)\left(\frac{N_a+N_d}{n_{BSF}} - n_p\right).\cosh(\frac{W_{BSF}}{L_{p*}}) \quad (5)$$

Where:

n_p: Holes concentration in n region.

$n_{BSF,}$ and W_{BSF} are respectively the minority carrier's concentration in BSF layer and the BSF thickness.

The photocurrent density generated in the Back contact (BSF) is added to the three photocurrent density contributions of the standard GaAs solar cell; then the total photocurrent density produced by the solar cell is equal to the sum of the photocurrent density generated in each region of the cell.

It is given by the equation:

$$J_{ph}(\lambda) = J_n(\lambda) + J_p(\lambda) + J_{dr}(\lambda) + J_{BSF}(\lambda) \quad (6)$$

4.4. Photocurrent density of the highly doped region pp+ (FSF)

The photocurrent density generated at pp^+ region and in the space charge area is determined from the solution of the continuity equation using the special boundary conditions.

The density of the total photocurrent density delivered by the solar cell with FSF is given by:

$$J_{ph}(\lambda) = J_n(\lambda) + J_{dr}(\lambda) + J_p(\lambda) + J_{FSF}(\lambda) \quad (7)$$

The carriers generated in the space charge area of the high-low junction (nn^+) are accelerated out of that region. Similarly, this photocurrent must reach the collectors to be collected.

5. Results and discussion

5.1. Spectral Response

The spectral response makes it possible to evaluate the quantum efficiency of a solar cell as a function of the wavelength of the incident light [19].

This value consists in illuminating the solar cell with a monochromatic spectrum varied in the absorption range of the material.

In order to show the BSF and FSF layers effect, a study is made by the variation of the spectral response of the solar cell based on GaAs for the four cases cited above as shown in figure 3.

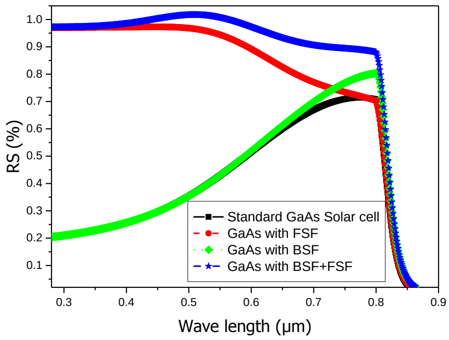

Fig. 3. The spectral response of the GaAs solar cell (standard cell, with BSF, with FSF and with (BSF+FSF)).

The analysis of the results in figure 3 shows a very net improvement of the spectral response for the solar cells with FSF and/or BSF comparing with the standard GaAs solar cell.

The addition of the BSF layer improves the quality of the spectral response in a wavelength range between 0.55μm and 0.88μm, whereas the effect of the FSF layer is very remarkable for the lower wavelengths of 0.77μm.

5.2. Influence of doping of the heavily doped layer on the potocurrent density.

In order to treat the effect of the heavily doped layers, the doping variation of the FSF and BSF layers on the total photocurrent delivered by the four cell types is studied.

Figures 4 and 5 represent the variation of the photocurrent density as a function of the doping of the back and frond highly doped layers in comparison with that of GaAs standard solar cell.

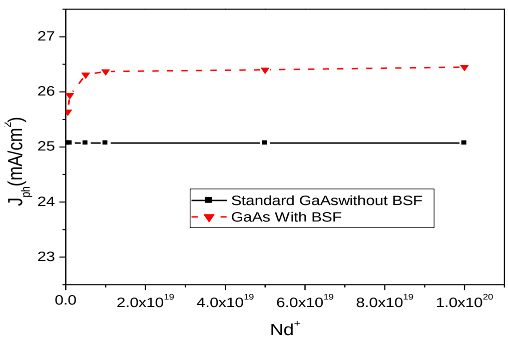

Fig. 4. Variation of the photocurrent density as a function of the doping of the BSF layer.

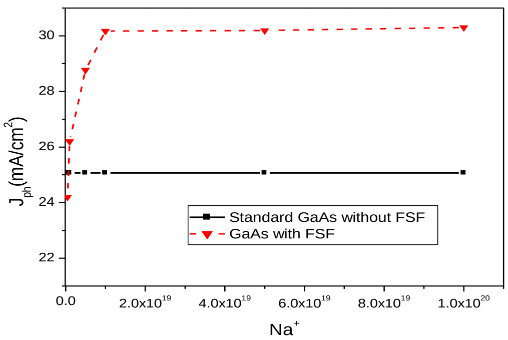

Fig. 5. Variation of the photocurrent density as a function of the doping of the FSF layer.

From figures 4 and 5, we notice that:

• The photocurrent density is increased as a function of the doping up to a limit value which corresponds to approximately 2.10^{19} cm^{-3}. This result is in agreement with the results obtained by Belghachi et al [8].

• The two layers BSF and FSF improve the total photocurrent density, this is justified by the increase in the number of load carriers created and collected in both sides.

• The cell performs better for the highest level of doping.

• Comparing the doping effect of the both front and back layers, the influence of the front field is very dominant comparing with the back field (BSF).

Thus the addition of an electric field to the front and/or back surface in the vicinity of the ohmic contact has a very important role to improving the photocurrent density of the solar cell.

The two fields allow decreasing the recombination current by the electric field. This field induces the separation of the carriers, these latter repel towards the space charge zone and then diffuse towards the quasi-neutral zones before they are collected to contribute to the photocurrent density.

5.3. Influence of the thickness of the FSF, BSF layers on the efficiency of a GaAs solar cell

In order to treat the impact of the thickness of the highly doped layers (FSF and BSF) on the performances of the GaAs solar cell, theses layers were varied from 0.2 to 0.5 μm.

Figure 6 illustrates the variation of the conversion efficiency as function of the thicknesses W_{FSF} and W_{BSF} of the GaAs solar cell.

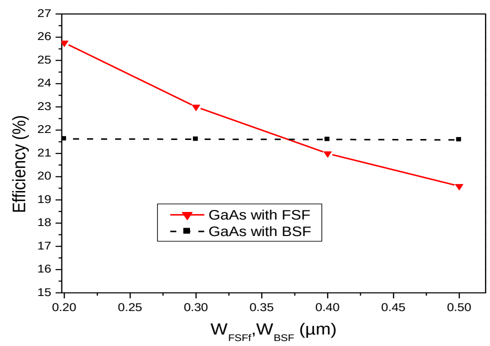

Fig. 6. Influence of the BSF, FSF thickness layers on the effenciency

The above figure shows that the increasing of the FSF thickness leads to remarkable decreasing of the efficiency. On the other hand, no significant effect is remarkable of the GaAs solar cell efficiency with BSF.

This decrease is related to the fact that the FSF thickness increasing contributes the increasing of emitter thickness which induces the increasing of recombination bulk rate especially for photons of short wavelengths. This phenomenon causes the decreasing of the short-circuit current provided by the solar cell.

As conclusion, the solar cell with the best characteristic is that with weak thickness (FSF, BSF). For this purpose, 0.1 μm is considered the value of (W_{FSF} or W_{BSF}) corresponding to the optimal thickness of the highly doped layer.

5.4. The GaAs solar cell J(V) characteristic

The figure 7 shows the comparison of J(V) characteristic of the GaAs solar cell with the two layers (FSF and BSF) and without theses layers.

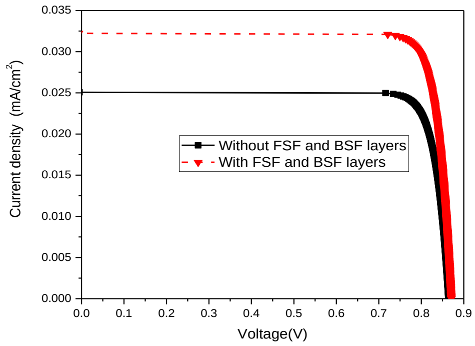

Fig. 7. Characteristics J (V) of the GaAs solar cell without and with layers FSF and BSF.

From figure 7, the improvement of current density for the cell with BSF and FSF is clearly shown.

The results of simulation are summarized in the table below.

Table 2. Electrical characteristics of the GaAs solar cell..

	Standard Cell	FSF	BSF	FSF + BSF
Icc (mA/cm^2)	23.07	31.27	26.38	32.25
Vco (V)	0.864	0.870	0.86	0.871
Efficiency (%)	20.53	25.76	21.63	26.58
FF (%)	86.23	86.17	86.22	86.16

From the results of table 2, it is seen that the efficiency improves to 21.63 % and 26.58 % for adding of BSF and FSF to GaAs standard solar cell respectively.

When both layers are added the photocurrent density achieve a maximum of 32.25 $mA.cm^{-2}$ so, an increase of 39.79% which leads to boost the efficiency from 20.53% to 26.58%. These results are much better to those using only the BSF or BSF [8, 20, 21].

6. Conclusions

By numerical simulation the effect of the FSF and BSF layers on the performance of a GaAs solar cell is studied.

These electric fields (BSF and FSF) are realized by implanting highly doped layers on back and front surfaces of the GaAs solar cell to engender a junction n^+n and p^+p respectively.

The analysis of the results obtained from simulations shows that:

• Both FSF and BSF layers lead to the increase in the number of carriers load created and collected in both sides.

•The GaAs solar cell with FSF and BSF layers provides a photocurrent density of 32.25 $mA.cm^{-2}$ and efficiency of 26.58% so, an increase of 39.79% and 29.47 respectively.

References

[1] M. Dhankhar, O. Pal Singh, V.N. Singh, Renewable and Sustainable Energy Reviews 40,214 (2014).
[2] A. Hemmani, A. Nouri, H. Khachab, T. Atouani, International Journal of Renewable Energy Research-IJRER, 7 (2), 525(2017).
[3] M. Berginski, J. Hüpkes, A. Gordijn, W. Reetz, T. Wätjen, B. Rech, M. Wuttig, , Solar Energy Materials and Solar Cells, 92, 1037(2008).
[4] T. Frijnts, S. Kühnapfel, S. Ring, O. Gabriel, S. Calnan, J. Haschke, B. Stannowski, B. Rech, R. Schlatmann, , Solar Energy Materials and Solar Cells, 143, 457(2015).
[5] M A. Green, K. Emery, Y. Hishikawa, W. Warta, E. D. Dunlop,Prog. Photovolt: Res. Appl., 23 (1), doi: 10.1002/pip.2573.
[6] Zhen-Yu. Zhao, Hui-Ji. Yang and Jian. Zuo ,Energy, 124 (1) , 435 (2017).
[7] A. Helmaoui, A. Belghachi et B. Bellali, Revue des Energies Renouvelables CER'07, 153(2007).
[8] A. Belghachi, A. Helmaoui,, Solar Energy Materials and Solar Cells, 92(6), 667(2008).
[9] J. J. Liou and W. W. Wong , Sol. Energy Mater. Sol. Cells 28 (9), (1992).
[10] Liang D, Kang Y, Huo Y, Chen Y, Cui Y, Harris JS, Nano Lett.;13(10),4850(2013).
[11] T. Takamoto, M. Yamaguchia, S. J. Taylora, M-Ju. Yanga, E I, Hiroshi Kuritab, Radiation, Solar Energy Materials and Solar Cell 58, 3 (1999)
[12] D. E. Aspnes, Surf. Sci, 132, (1), 406(1983).
[13] J. Li, L. M. Peter, Journal of Electroanalytical Chemistry and Interfacial Electrochemistry 199 (1), 1(1986).
[14] J. Mandelkorn and J. H. Lamneck, IEEE, New York 6, 66 (1972).
[15] J. del Alamo, J. van Meerbergen, F. D'Hoore, J. Nijs, Solid-State Electronics 24(6), 533 (1981) .
[16] M. P. Godlewski, C. R. Baraona and H. W. Brandhorst, Jr. Proc. 10th IEEE Phot. Spec. Conf, Palo Alto 40(1973).
[17] X.M. Dai, Y.H. Tang Solar Energy Materials and Solar Ceils 43, 363 (1996)
[18] J. R. Hauser and P. M. Dunbar. IEEE Trans. Electron DevED-24, 305 (1977).
[19] K. Emery, D. Dunlavy, H. Field, and T. Moriarty 2nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion Vienna, Austria, (1998).
[20] S. Bothra, J.M. Borrego, Sol. Cells 28, 95 (1990).
[21] M.E. Klausmeier-Brown, J.C. Chen, Conference Record of the 22nd IEEE 1, 220 (1991).