Numerical simulation of graded band gap GaAs/AlGaAs heterojunction solar cell by AMPS-1D

Hassane Ben slimane[1], B. Dennai, A. Helmaoui,
Laboratory of Semiconductors Devices Physics, Physics Department,
University of Bechar, Algeria
[1]E-mil: hassane_ben@Yahoo.fr

Abstract

The conduction band discontinuity or spike in an abrupt heterojunction p^+ GaAs / $NAl_{0.4}$ $Ga_{0.6}As$ solar cell can hinder the separation of hole-electron by electric field. This paper analyzes the GaAs /$Al_xGa_{1-x}As/Al_{0.4}Ga_{0.6}As$ based solar cell performance by AMPS-1D numerical modeling. The affect of graded band gap region in the interface between the emitter (GaAs) and base ($Al_{0.4}Ga_{0.6}As$) on the solar cell's performance is investigated. Among the factors studied are thickness of graded band gap region, thickness of emitter layer of the cells. In this study, a width 0.14µm has been required to eliminate the spike and improved the performance of solar cell.

Keywords: heterojunction solar cell; graded band gap; AMPS-1D.

1. Introduction

It is known that the dark current play an important role in limiting single heterojunction solar cell open-circuit voltage (V_{oc}) fill factor (FF), and conversion efficiency (η) [1]. So in dark condition the dominant current transport mechanism (at low current density) is the current due to recombination of carriere via deep levels in the space charge region.

Because the losses of carrier recombination in the space charge region reduces the efficiency of a similar heterojunction cell, and the conduction band discontinuity or spike in an abrupt heterojunction p^+ GaAs / $NAl_{0.4}$ $Ga_{0.6}As$ solar cell can hinder the separation of hole-electron by electric field of junction, a graded layer inserted between the emitter (p^+ GaAs) to base ($NAl_{0.4}$ $Ga_{0.6}As$) is used to eliminate the spike and reduces recombination in space charge region [2-5]. The folowing figures show the different between graded and abrubte héterojunction , They show the band diagram of graded and non graded heterojunction, the band diagrams of figures (1-a, 2-a) ignore electrostatic potentials due to arrangement of free carriers which occur near the compositional junction after the semiconductor are placed in contact.

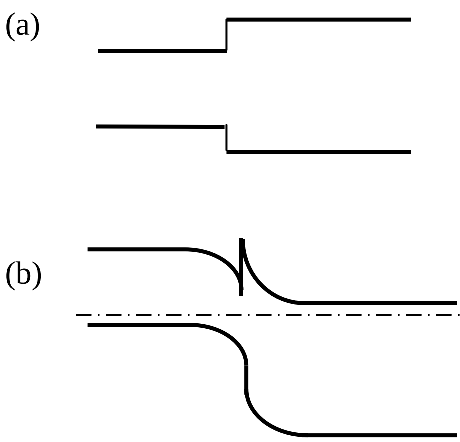

Figure 1- P-GaAs/ N-$Al_{0.4}$ $Ga_{0.6}As$ heterojunction before contact (b) after contact (P)

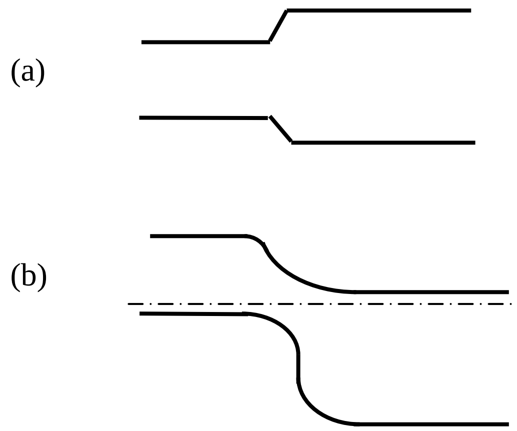

Figure 2- P-GaAs/ n-$Al_xGa_{1-x}As$ /N-$Al_{0.4}$ $Ga_{0.6}As$ heterojunction
(a) before contact (b) after cotact

In this present work, a one dimensional simulation program called analysis of microelectronic and photonic structures (AMPS-1D) [6] is used to simulate the $Al_xGa_{1-x}As$ graded band gap inserted between the emitter and base of heterojunction solar cell shown in figure 3.

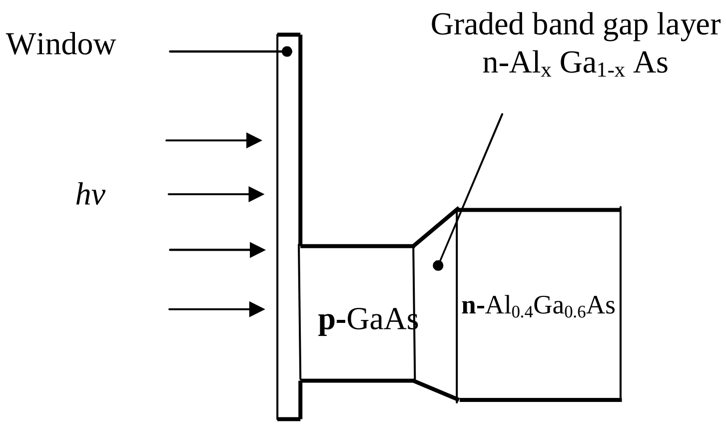

Figure 3 -A schematic diagram of the structure of p-GaAs/n- $Al_xGa_{1-x}As$ /n-$Al_{0.4}Ga_{0.6}As$

2. Modelling

The heterojunction solar-cell structure used in the simulation consists of several layers including the top contact, bottom contact, window p-AlGaAs layer, p-GaAs absorber layer, graded gap n-$Al_xGa_{1-x}As$ interface layer, and the n-$Al_{0.4}Ga_{0.6}As$ base layer. The computer simulation tool, analysis of microelectronic and photonic structures (AMPS)-1D[6] is employed by specifying the semiconductor parameters in each defined layer of the cell structure as input parameters in the simulation.

To proceed with the simulation, the material parameters employed as the inputs are selected based on the reported literature values or constrained to reasonable ranges. The key semiconductor properties of different layers as the input parameters for the simulations are given in Table 1.

Layers / Parameters	Window AlGaAs	p-GaAs	Graded layer(AlGaAs)	n/AlGaAs
Thickness(µm)	0.04	4	0.14	0.5
Dielectricconstant,ε	5.66	13.10	11.76	11.76
Electron mobility μ_n (cm²/Vs)	2956.0000	8500	800	800
Hole mobility μ_p (cm²/Vs)	67.7760	400	100	100
Carrier density,	P: 8.00e+018	1e18	1.00e+016	1.00e+016
Optical band gap, E_g (eV)	1.75	1.42	1.42-1.89	1.92
Effective density, N_c (cm^{-3})	4.82e+018	4.70e+017	5.50e+018	5.50e+018
Effective density, N_v (cm^{-3})	1.73e+019	7.50e+018	4.50e+019	4.50e+019
Electron affinity ,χ(eV)	4.42	4.07	3.65-4.07	3.63

Table 1: Base parameters for P-GaAs/ n-$Al_xGa_{1-x}As$ /N-$Al_{0.4}$ $Ga_{0.6}As$ solar cells.

Although no attempt was made to match the simulation results with the experimental data, the purpose is to analyze the trend in the performance of GaAs /$Al_xGa_{1-x}As/Al_{0.4}Ga_{0.6}As$ cells versus thicknesses of the gradient layer intended to study.

The modelling calculations discussed in the following section uses the software AMPS-1D. It estimates the steady-state band diagram, and caracteristics (current-voltage)

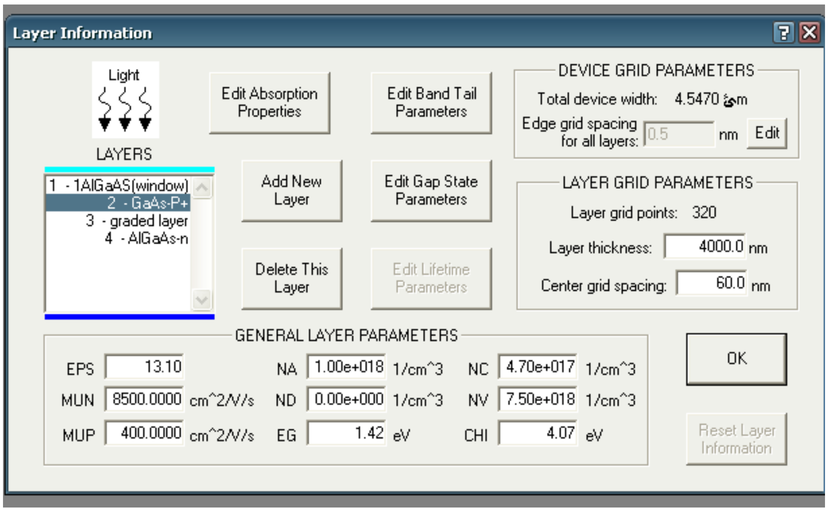

Fig.4. AMPS-1D simulation front panel contains the device and layer grid parameters, and general layer parameters

3. Results

By calculating the energy band profiles of a series of p+(GaAs)-n($A1_{0.4}Ga_{0.6}As$) heterojunctions having different grading widths and doping densities, the barrier height lowering factor is related to grading width and doping density. The energy barrier, which is ≈ 0.4 eV for the abrupt case, is almost zero for a grading width of only 0.14µm (fig 5), when the doping density in the n-region is $10^{16}cm^3$. These values are probably quite realistic in practical heterojunctions.

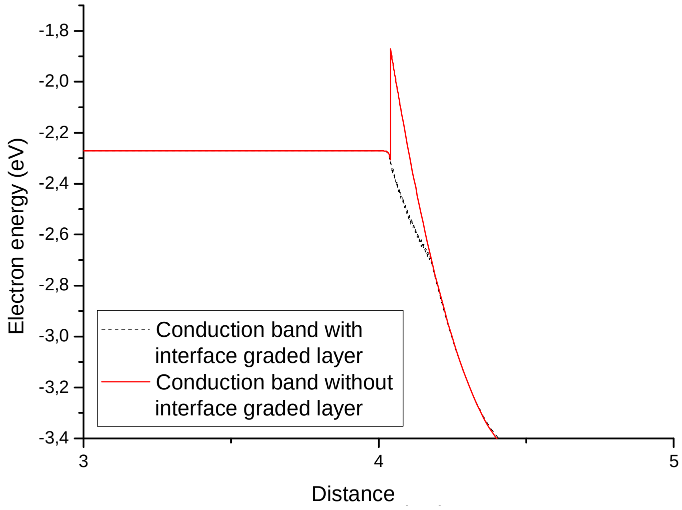

Fig.5. The conduction band profiles of a p^+ GaAs / $Al_xGa_{1-x}As$ /N $Al_{0.4}Ga_{0.6}As$ heterojunction solar cell

Figure 6 shows the J-V characteristics of graded and non graded heterojunction solar cell while Table 2 shows the efficiencies for two cells. The short-circuit current density (Jsc) is reduced due to the spike barrier for photogenerated electrons (≈ 0.40 eV) and recombination at the interface $GaAs/Al_{0.4}Ga_{0.6}As$ in comparison to $GaAs/Al_xGa_{1-x}As/Al_{0.4}Ga_{0.6}As$ cell

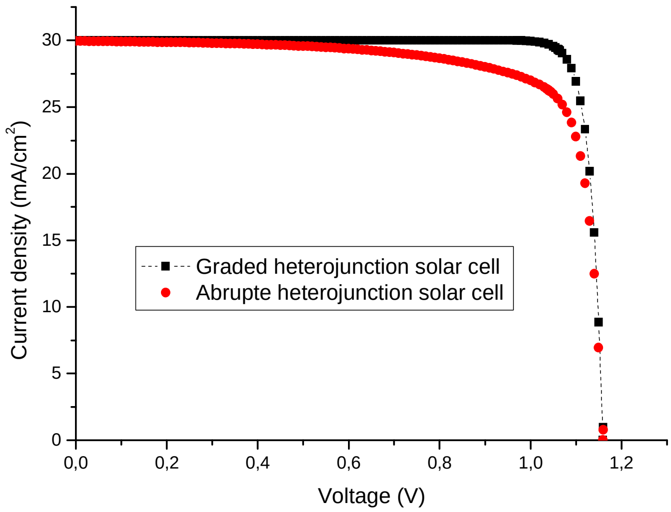

Fig.6. Current density vs. voltage of grabased solar cell

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Photovoltaic characteristics	**$J_{SC}(mA/cm^2)$**	**$V_{CO}(V)$**	**FF**	**(%)η**
Heterojunction solar cell withow graded interface	29.94	1.15	0.787	27.31
Heterojunction solar cell with graded interface	30.01	1.16	0.89	31.11

Table 2: Photovoltaic parameters of graded and non graded heterojunction solar cells.

4. Conclusion

We report on the results of an extensive analysis employing one-dimensional simulation in order to optimize the performances of GaAs /$Al_xGa_{1-x}As/Al_{0.4}Ga_{0.6}As$ graded band gap solar cell. The simulation results of graded heterojunction cell show that when we use sufficient width of graded layer the photovoltaic performance improves remarkably. The best efficiency is obtained for graded thickness equals to 0.14 µm,the energy barrier in the conduction band is reduced from 0.40 eV to zero as the grading layer width increases from zero (abrupt case) to 0.14µm. A graded band gap layer at the interface has a little influence on the heterojunction cells performances. Therefore, the obtained simulation results may offer the possibility of elaborating heterojuncion solar cells with relatively high conversion efficiencies.

Acknowledgments

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5. References

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