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Characterization of InGaN Solar Cells

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Abstract

The III-V materials are extensively studied for *optoelectronic applications* in the *blue* and *UV* spectral regions. InGaN ternary alloy is considered for its wide spectral coverage, good electrical characteristics and appreciable resistance to high electrical currents. For this purpose, the operation of InGaN photovoltaic cells was studied by 2D numerical simulation under AM1.5 spectrum illumination, using the software Silvaco and the two environments Athena/Atlas.

Keywords

Silvaco, Indium Gallium Nitride, Solar Cells, Numerical Simulation, Atlas/Silvaco

1. Introduction

Silvaco's simulation was based on the digital resolution of the three fundamental equations of charge transport in semiconductors; these are Poisson's equation, continuity and transport equations for electrons and holes.

After defining the mesh of the studied structure, the materials and the chosen numerical models, the software Silvaco was used to numerically solve these equations at each node of the mesh and determine the current-voltage characteristic under the standard illumination conditions (AM1.5G), between 0.32 to 1.32 nm, at a temperature of 300 K.

The present study aims at finding the technological parameters that give the best output characteristics for each region of the cell. Therefore, the doping profiles and the thicknesses of these regions were varied while choosing the parameters for the best results.

2. Description of the Procedure

2.1. Simulation Parameters

The material used in this work (InGaN) was defined from the parameters in the literature (**Table 1**).

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Table 1. Simulation parameters at 300 K [1].

Parameters	Expressions	Values
Forbidden E_g (eV)	$E_g = 0.74x + 3.4(1 - x) - 1.43(1 - x)x$	1.32
Permittivity	$\varepsilon_r = 14.6x + 10.4(1 - x)$	13.13
Electronic affinity χ (eV)	$X = 4.1 + 0.7(3.4 - E_g)$	5.56
State electron density N_c (10^{18} cm^{-3})	$N_c = 0.9x + 2.3(1 - x)$	1.39
State hole density N_v (10^{18} cm^{-3})	$N_v = 5.3x + 1.8(1 - x)$	4.075
Lifetime of electrons and holes T_{n0} and T_{p0} (ns)	$T_{n0} = T_{p0}$	6.5
Surface recombination speed s_n *and* s_p *(cm/s)*	$s_n = s_p$	1000

2.2. The Cell Structure

A single-junction InGaN solar cell, with a total thickness d = 420 nm and a width of 500 microns, was selected for this study; d_E is the thickness of layer P (Emitter-acceptor), d_B is the thickness of layer N (base-donor). The electrodes are placed at the top and bottom of the structure.

2.3. Physical Models

- **Mobility**

The model of Caughey-Thomas was used. The mobility depends on the carrier concentration:

$$\mu_i(N) = \mu_{\min,i} + \frac{\mu_{\max,i} - \mu_{\min,i}}{1 + \left(N \mid N_{g,i}\right)^{\gamma_i}}$$

With
i represents either electrons or holes;
N: doping concentration (cm^{-3});
N_g: material-dependent critical doping (cm^{-3});
γ: constant (s.d.).

- **Recombination**

The recombinations of Shockley-Hall were considered. They are defined by the following expression [2]:

$$R_{SRH} = \frac{pn - n_{ie}^2}{\tau_p\left[n + n_{ie}\exp\left(E_{trap} \mid KT_L\right)\right] + \tau_n ie\left[p + n_{ie}\exp\left(-E_{trap} \mid KT_L\right)\right]}$$

With
n and p: concentrations of electrons and holes, respectively (cm^{-3});
n_{ie}: intrinsic electron concentration (cm^{-3});
T_n and T_{p0}: lifetime of electrons and holes, depending on defect density (s);
E_{trap}: energy difference between position of energy defect and intrinsic Fermi level (eV);
k: Boltzmann constant (eV·K^{-1});
T_L: temperature (K).

1) Influence of doping

The cell efficiencies are calculated for different values of the doping concentration N_a of the emitter (P layer), and various values of the N_a ($N_d = N_a$, $N_d = 3N_a$ and $N_d = 9N_a$). The results are shown in **Figure 1**.

The efficiency of a solar cell depends on the density of the short-circuit current I_{CC}, open-circuit voltage V_{CO} and the Fill Factor FF as follows:

$$\eta = \frac{FF \cdot V_{co} \cdot I_{cc}}{P_{in}}$$

It is noted that the cell efficiency slightly increases then decreases for increasing values of the doping concentration N_a. The efficiency goes through a maximum value η = 21.70% for $N_a = 1 \times 10^{17}$ cm^{-3}, for the ratio $N_a/N_d = 1$.

2) Influence of the emitter thickness

The collection efficiency increases as the thickness of the layer P decreases, because the distance between the surface and the space charge region ZCE diminishes. The results are shown in **Figure 2**.

Nevertheless, the efficiency is low when the space charge region is too close to the surface. The curve shows that the best efficiency is obtained for a 60 nm-thick transmitter.

3) Influence of the diffusion length

The diffusion length is varied from 0.22 to 2.35 µm. The graph (**Figure 3**) shows that increasing the diffusion length allows a remarkable improvement in the cell parameters. Indeed, the efficiency increases from 16.2% to 22%.

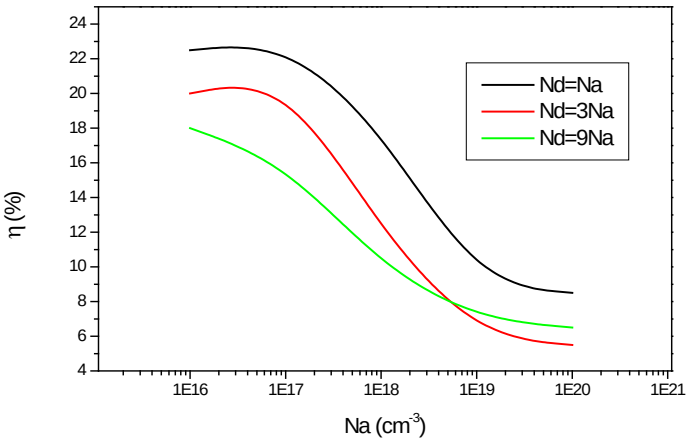

Figure 1. Influence of emitter doping on efficiency.

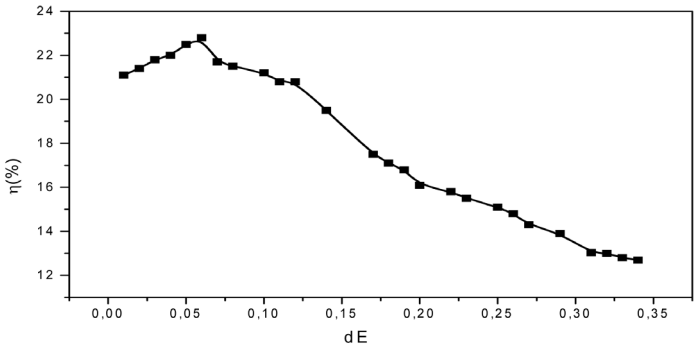

Figure 2. Influence of the emitter thickness on the cell efficiency.

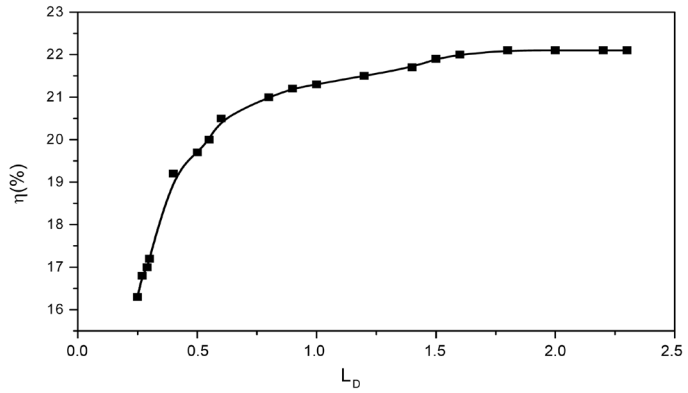

Figure 3. Influence of the diffusion length on the efficiency of the cell.

3. Conclusion

We tried to optimize the efficiency of the mono-junction solar cell by changing the technological parameters (doping and thickness) for each of its regions.

References

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