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Simulation of a single-junction solar cell based on InGaN

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***Abstract*— InGaN-based alloys are extensively utilized in light-emitting diodes (LEDs)and laser diodes(LDs).In recent years, InGaN-based alloys have also been considered for use in solar cells because of their favorable photovoltaic properties ,including a direct band gap, a high absorption coefficient at the band edge(of the order of 10^5 cm^{-1}), high carrier mobility, superior radiation resistance, thermal stability, and, most importantly, the wide band gap of the InN /GaN alloy materials from 0.7eV to 3.4eV,which covers almost all of the solar spectrum.**
The objective of this work is to study the key properties of a solar cell based on InGaN, including I-V characteristic, band structure, electric field.....

***Keywords*— III–V materials, InGaN solar cells, Silvaco's ATLAS software.**

I. INTRODUCTION

The III-nitrides have continued to develop as the pre-eminent universal compound semiconductor material that has shown the ability to replace traditional III–V materials in many applications. GaN, for example, has many superior material properties compared to other III–V materials; it is mechanically and thermally stable, it can sustain high breakdown voltages (5×10^6 V cm^{-1}), it exhibits a high saturation velocity (2×10^7 cm s^{-1}) and when alloyed with indium to form InGaN ($In_xGa_{1-x}N$) it has tunable direct bandgap [1]. Recent revision of band gap of InN indicates that the band gaps of the $In_xGa_{1-x}N$ alloys can extend continuously from 0.7 eV (InN, in the near IR) to 3.4 eV (GaN, in the mid-UV). This opens the possibility of fabricating superhigh efficiency multi-junction solar cells based solely on InGaN ternary alloy [2]. Additional advantages of this material system include low effective mass and high mobility of electrons and holes, high peak and saturation velocities, high absorption coefficients and radiation tolerance. These features not only enable InGaN to be exploited for large-stack tandems, but they can also be explored for applications such as quantum-dots and intermediate bands for third generation photovoltaics [3]. However, due to the difficulties of growing high quality InGaN film, especially phase separation and p-type doping of In-rich InGaN, InGaN-based solar cells are in their very early development stage [2].

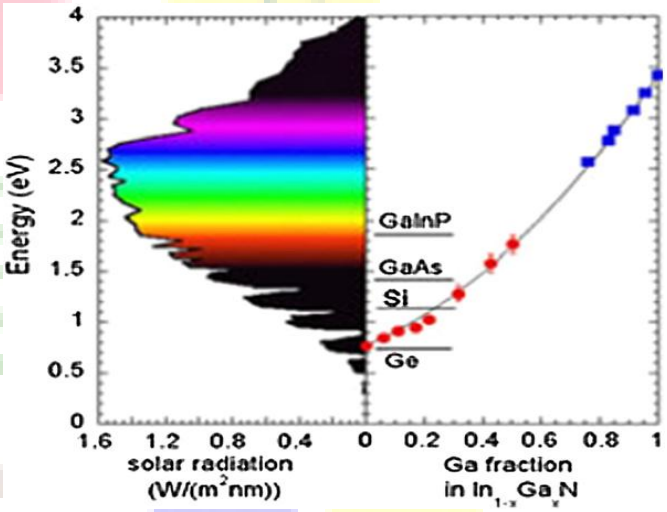

Fig. 1 Bandgap energies of the InGaN alloy system cover the entire AM1.5 solar spectrum [1]

II. SIMULATION AND MODELING

A. Silvaco Atlas

The simulations were carried out using Silvaco's ATLAS software. It is a physically-based two and three-dimensional device simulator. It predicts the electrical behavior of specified semiconductor structures and provides insight into the internal physical mechanisms associated with device operation [3].

B. Material parameter equations used in the simulation

Because of the difficulty in collecting III-nitride material parameters, $In_xGa_{1-x}N$ material parameters used for the simulations are calculated by the following equations.

Band gap $E_g(x) = 0.7x + 3.4(1-x) - 1.43(1.x)$ T=300k

Electron affinity: $\chi = 4.1 + 0.7 \times (3.4 - E_g)$

Carrier mobility: $\mu_i(N) = \mu_{min,i} + \frac{\mu_{max,i} - \mu_{min,i}}{1 + (N/N_{g,i})^{\gamma i}}$

Effective density of states in the conduction band:

$$N_C = 0.9x + 2.3(1 - x)$$

Effective density of states in the valence band:

$$N_V = 5.3x + 1.8(1.x)$$

Relative permittivity: $\varepsilon_r = 14.6x + 10.4(1 - x)$

The above formulae with asterisk were obtained from the linear fitting of the corresponding parameters of InN and GaN. The carrier mobility of InGaN is assumed to be similar to GaN, where i= n, p denotes electrons and holes, respectively, and *N* the doping concentration, while the model parameters $\mu_{max,i}$, $\mu_{min,i}$, $N_{g,i}$ and γ_i , depend on the type of semiconductor.

TABLE I
$In_{0.39}$ $Ga_{0.61}$ N PARAMETERS [4]

x	e_g	χ	*Nc* (e18)	*Nv* (e19)	ε_r	μ_n ($cm^2/V/s$)	μ_p ($cm^2/V/s$)
0.39	**2**	**5.08**	**1.75**	**3.165**	**12.04**	**685**	**153.3**

C. Cell structures of the simulated solar cell

The structure of the cell is schematically represented in Figure 2. The mesh of this cell is shown in Figure 3. A non-uniform mesh was used. The cell is based on a p-n junction.

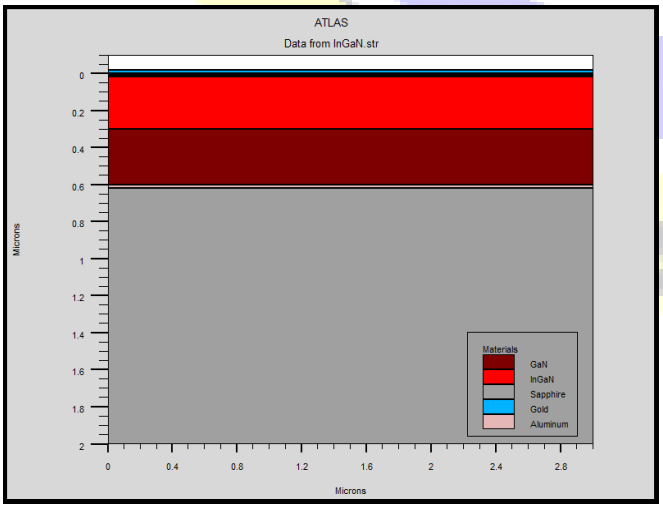

Fig. 2 Schematic structure of the solar cell

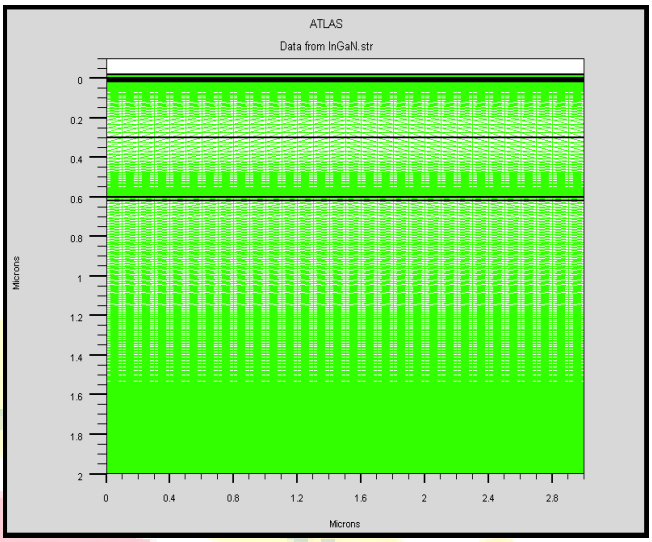

Fig. 3 The mesh of the structure

Figure 4 shows the doping used for each layer. We have assumed the doping of 1e18, 1e17, 1e18 and 1e20, respectively for layers, p-GaN, p-InGaN, n-InGaN and n-GaN.

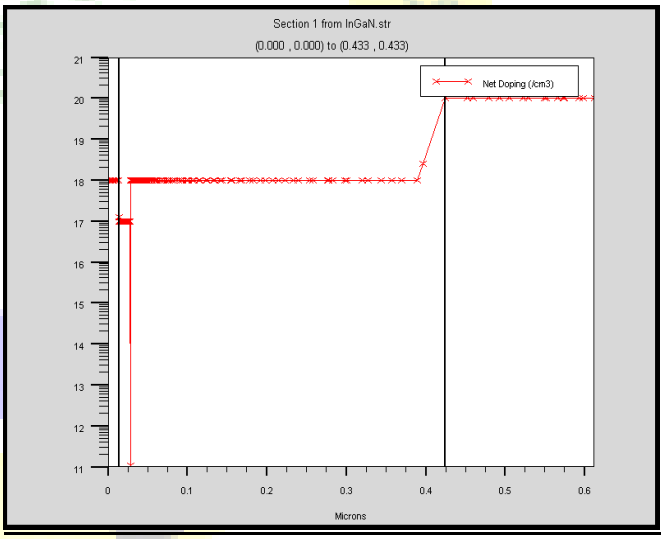

Fig. 4 Net Doping of the structure

III. RESULTS AND DISCUSSIONS

Figure 5 presents the IV characteristics of the cell. For this model we reach a short circuit current equal to 0.015 mA/cm2 and an open circuit voltage equal to 1.880V.

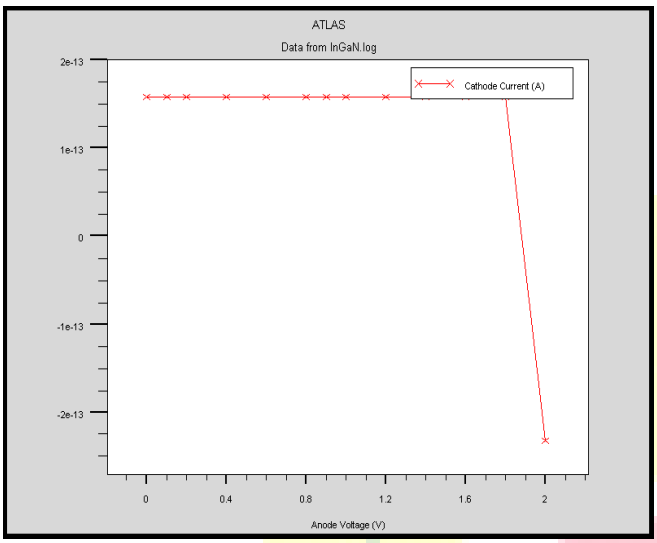

Fig. 5 I-V characteristic of the solar cell

Figure 6 shows the band diagram of the cell. For this model, we did not take into account the effect of polarization and ohmic contacts are used where the electrodes cover the entire surface of the cathode and the anode.

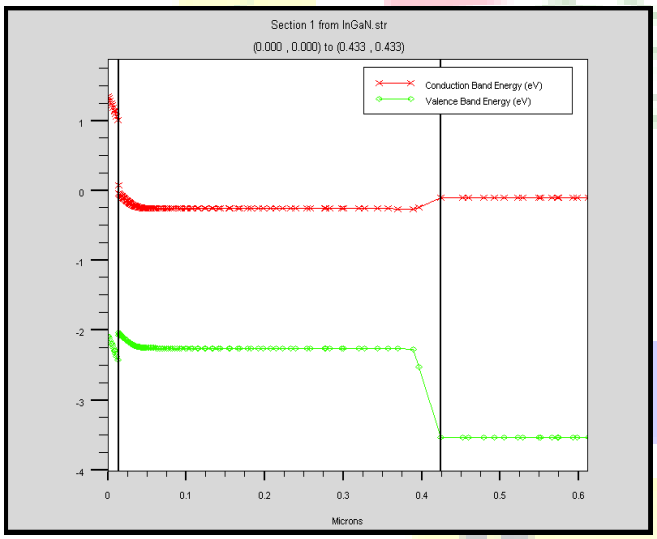

Fig. 6 Band gap of the solar cell

The simulation of electric fields in Figure 7 shows that the electric field reaches its maximum at the interface between the p-InGaN and n-InGaN layers, about 4e5 V/cm.

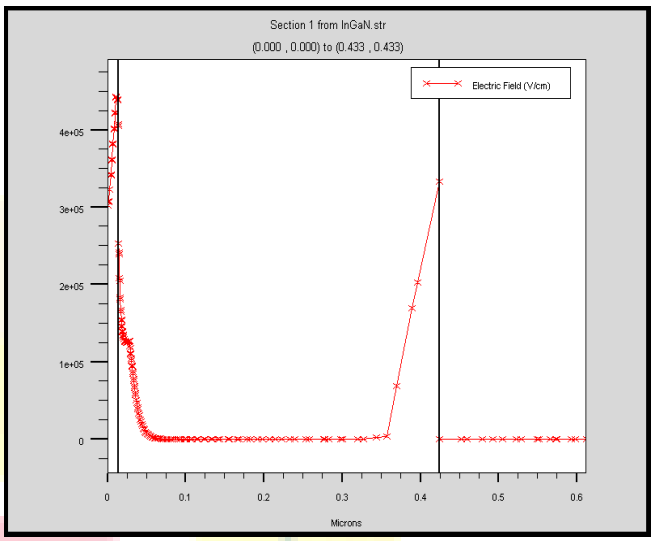

Fig. 7 Simulated electric field of the solar cell

The others figures (figure 8 and figure 9) presents the potential, and current density of the holes and the electrons through the structure.

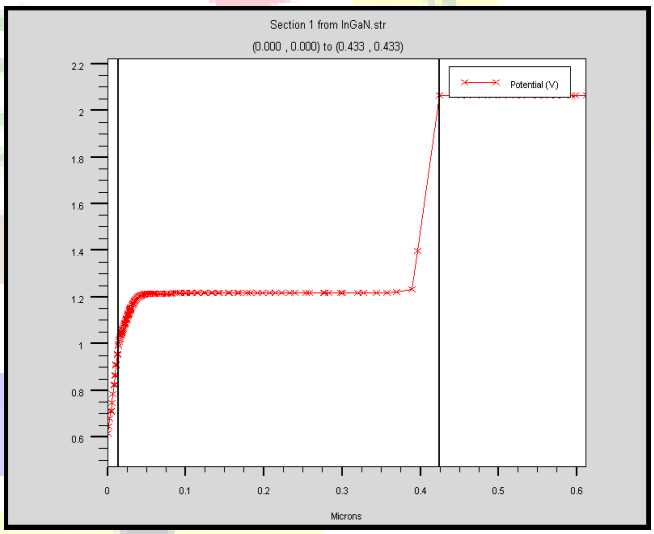

Fig. 8 Potential through the structure

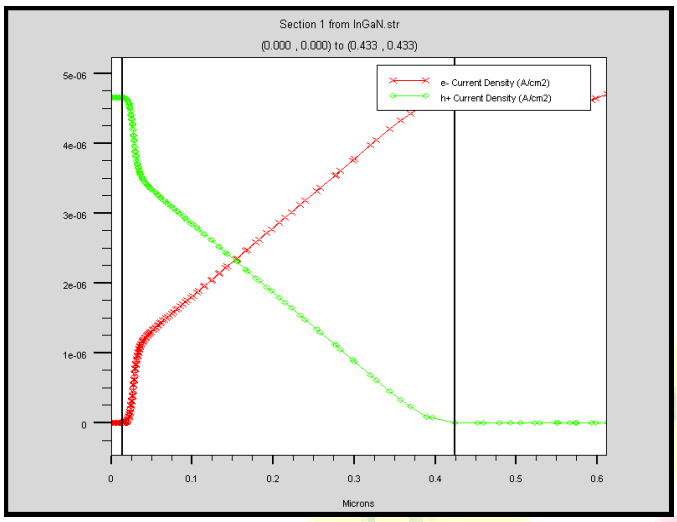

Fig.9 Current density of the holes and the electrons

IV. CONCLUSION

The photovoltaic characteristic of a p-$In_{0.39}Ga0._{61}N$/n-$In_{0.39}Ga_{0.61}N$ single junction solar cell has been demonstrated in this work by employing Silvaco's ATLAS software.

For thicknesses up to 10 nm, 10 nm, 280 nm, 300 nm and a doping equal to 1e18, 1e17, 1e18 and 1e20, respectively for, p-GaN, p-InGaN, n-InGaN and n-GaN layers, we arrive at a short-circuit current and voltage open circuit equal to 0.015 mA/cm2 and 1.880V respectively. The fill factor equal to 0.95.

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