# IMPACT OF TUNNEL HETEROJUNCTION (InGaP/GaA) DOPING CONCENTRTION ON THE PERFORMANCE OF InGaP/GaAs TONDEM SOLAR CELL USING SILVACO-ATLAS SOFTWARE

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The effect of tunnel heterojunction doping in tandem solar cells is determined. For this, the current–voltage measurements of solar cell devices carried out at room temperature under radiation (AM1.5) using SILVACO ATLAS simulator software. The tunnel junction (InGaP/GaAs) designs for multijunction (InGaP/GaAs) solar cells studied to determine their electrical performances as a function of the tunnel doping concentration. We report the design of InGaP/GaAs solar cell using tunnel heterojunction with varied p+-InGaP concentration doping, this concentration to be in the range of $10^{19}$–$10^{20}$ $cm^{-3}$. The results of this investigation revealed that n-InGaP concentration doping have effect on the conversion efficiency, short circuit current density and open circuit voltage. This study, after the step of improvement, allowed the conversion of energy efficiency to 23.97% compared to existing studies.

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*Keywords:* Solar cell, InGaP/GaA, Tunnel heterojunction, Tondem solar cell, Silvaco-atlas

## 1. Introduction

III-V semiconductors in particular GaAs and InGaP used for many different electronic applications, such as high power and high frequency devices, laser diodes and high brightness LED and III-V heterostructure is one of the most promising materials for various applications such as solar cells. Multi-junction solar cells involve several p-n-junctions of different semiconductor materials with different band gap shaving. The ability to absorb a large part of the solar energy spectrum Compared with single-junction solar cells. Which provide, in the same conditions, nearly twice the efficiency based on elements of III-V groups, multi-junction solar cells represent the new technology [1]. then Multijunction solar cells were first introduced by the Research Triangle Institute and by Varian Research Center in the late 1970s to mid-1980s, when dual-junction (2-junctions) devices were formed from an AlGaAs junction stacked or grown on top of a GaAs junction, and interconnected by a semiconductor tunnel junction[2][3].

The lattices parameters must was matches when creating multijunction solar cells is yet another limiting condition. The available band gap and lattice constant for the III–V elements such as N, P, As, and Sb alloys is shows in Fig. 1. Lines that connect the binary alloys represent ternary alloys blended between the binary constituents. Since the substrate forms the lowest junction, all junctions formed on top must have higher band gap [4].

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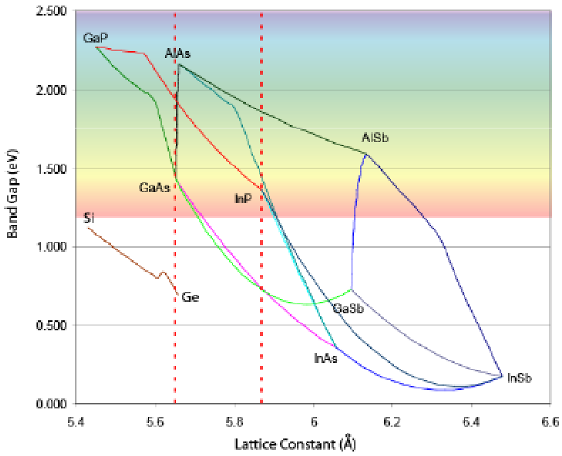



*Fig. 1. Band gap and lattice constant for various III–V and group-IV material alloys.*

Understanding the factors that limit photovoltaic parameters such as short-circuit current (Jsc) and open-circuit voltage (Voc), helps to optimize material and device structures, leading to higher efficiencies. In addition, the Numerical modeling and simulation help to optimize the solar cell structure. Silvaco–Atlas 2D simulator used to develop the numerical simulations for multijunction solar cell. ATLAS is a physically based two and three-dimensional device simulator.

In this work, we have investigated the performance evaluation of the InGaP/GaAs solar cell structure with the integration of InGaP/GaAs tunnel heterojunction. This work reports the effect of doping concentration of tunnel heterojunction (p+-InGaP) on the performance of p+-InGaP /n+- GaAs multijunction solar cell using ATLAS simulator from SILVACO international.

## 2. Device structure

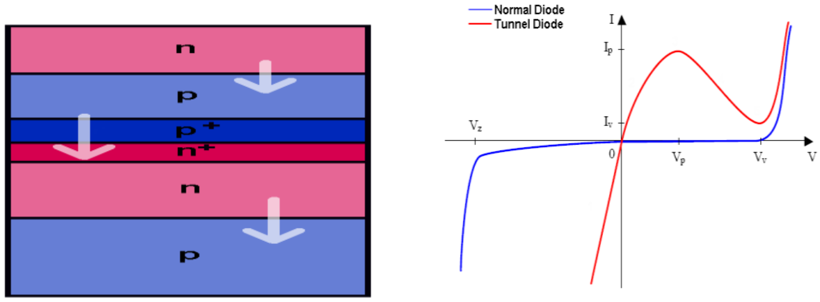
### 2.1. Tunnel junction

An important key feature of the tandem solar cell is the tunnel junction interconnecting both top and bottom sub-cells. These cells require an interface between the n-p layers to prevent [5].

The formation of a parasitic p-n junction that would formed if the layers were simply stacked on top of one another. Tunnel junctions are key for developing multijunction solar cells (MJSC). It is important to develop tunnel junctions that can ensure peak currents well above the maximum photocurrent generated by the light spot in the multijunction solar cell, so that the tunnel junctions operate in their linear region in which the voltage drop is low.

In 1958, the Japanese scientist Leo Esaki created a p–n junction using highly doped materials with impurity concentration around $10^{18}$:$10^{19}$ making them degenerate [6]. The new junction develops a region of differential negative resistance, not seen in any other device. This is caller tunnel junction. The inclusion of tunnel junctions in the simulation is of great important. This intersection helps to achieve low electrical resistance, high optical permeability and high peak current tunnel density [7], [8].

The tunnel junction is use when connecting the different layers of a multijunction solar cell [9]. Fig. 2. (a) Shows a dual junction solar cell with a highly doped tunnel junction in the middle and a normal and tunnel diode I-V curve




a ) b)

*Fig.2 (a) Shows a dual junction solar cell with a highly doped tunnel junction in the middle. (b) Shows a normal and tunnel diode I-V curve [10].*

The tunnel junction is a critical component of a multijunction solar cell and interconnects generally used within multijunction solar cells result in losses, which limit the performance of the device. It has shown that, theoretically, the efficiency of MJ solar cells increases as it incorporates increasingly junctions [11.12].

### 2.2. Structure and simulation model

It consisted of two solar cells where the In0.49Ga0.51P wide bandgap top cell had a small thickness and a large band gap (Eg=1.74 eV) in contrast to the GaAs low band-gap bottom cell, which had a usual thickness for a GaAs cell and a band- gap value (Eg=1.42 eV) close to the optimal values of best cells [13]. This design is intends to convert a wider range of photons incident on the solar cell and generate therefore a maximum power output.

The $In_{0.5}Ga_{0.5}P$ top cell connected to the GaAs bottom cell by a tunnel heterojunction (p+ $In_{0.49}Ga_{0.51}P$ /n+ GaAs). The schematic diagram of the solar cell structure represented in Fig. 3.

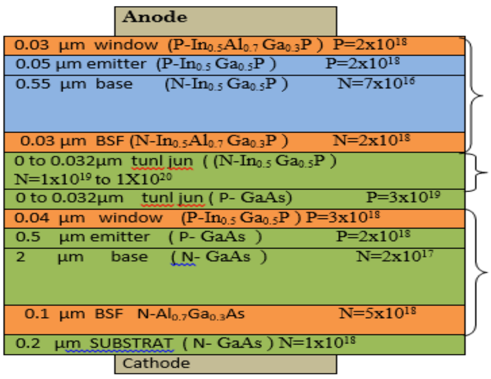



*Fig.3. The schematic diagram of the solar cell structure.*

## 3. Modeling process

Numerical simulations of solar cells represent important tools for research and development because they can allow investigation of a much wider parameter space at a fraction of the cost and time of experimental studies.

SILVACO, ATLAS used for simulation. BLAZE is a general-purpose 2-D device simulator for III-V, II-VI materials, and devices with position dependent band structure (i.e., heterojunction) [5]. The simulator works on mathematical models which consist of fundamental equations such as Poisson's equation, continuity equation, and transport equations. A simulation program for proposed p-InGaP/n-GaAs heterojunction solar cell structure has developed in ATLAS simulator from SILVACO international to obtain various electrical and optical characteristics.

The first step in modeling the device is specifying the mesh on which the device will constructed, (Fig. 4). This mesh or grid covers the physical simulation domain. The mesh is defined by a series of horizontal and vertical lines and the spacing between them.

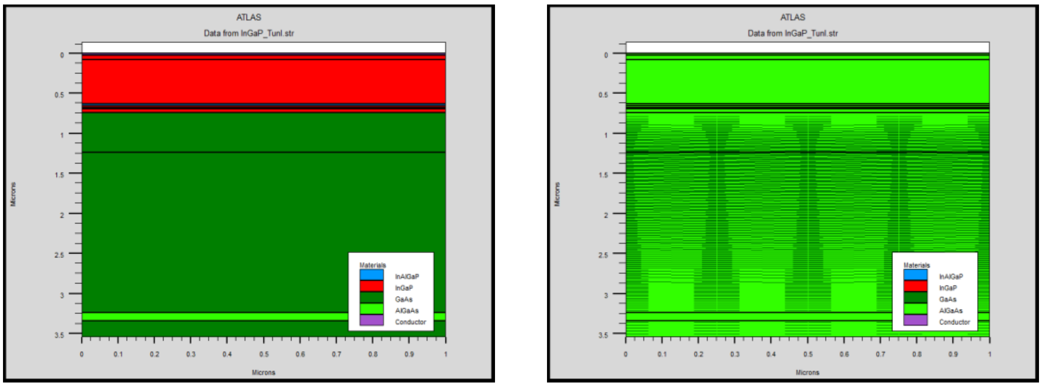



*Fig. 4. Mesh specification of solar cell tandem structure.*

Once the mesh, geometry, and doping profiles defined, you can modify the characteristics of electrodes, change the default material parameters, and choose which physical models ATLAS will use during the device simulation. These actions accomplished using the CONTACT, MATERIAL, and MODELS statements respectively.

Once a solar cell simulated in ATLAS, it may illuminated with a constant wavelength of light or a complex spectrum such as AM1.5 (Fig. 3). An optical beam modeled as a collimated source using the BEAM statement.

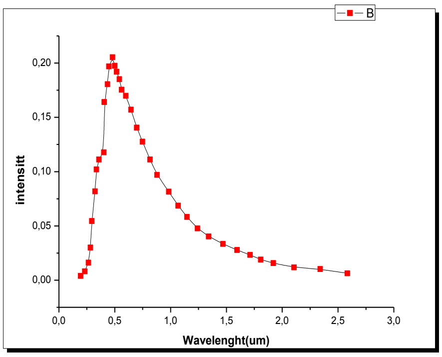



*Fig. 5 Standard Solar Spectrum (AM1.5G) used as source of light.*

## 4. Result and analysis

To study how the solar cell parameters vary as a function of effective doping concentration, the current–voltage profile must simulated for each given effective doping concentration. ATLAS greatly aids in this process by providing I-V characteristics and spectral responses. When the I-V curve is examined it can be seen that a compromise of current and voltage values can be met that will deliver the maximum power for a given light intensity.

In this work, we have investigated the performance evaluation of the GaInP/GaAs solar cell structure with the integration of p-InGaP/n-GaAs tunnel heterojunction. The performance the short circuit ( Jsc mA/cm2 ) , the open circuit voltage ( Voc Volt ) and the efficiency $\eta$(%). Of the solar cell structures significantly depends p+-InGaP concentration doping. Electrical measurements performed using a solar simulator with AM1.5 global 1-sun illumination (1 kW/m2).

### 4.1. Open Circuit Voltage Analysis

From our simulation, the following profile of open circuit voltage was found with changing the concentration doping in layer p+-InGaP of tunnel heterojunction. In figure 3.5, It is clear that open circuit voltage increases with the increase in concentration of layer p+-InGaP up to the value 7.1019 cm-3 after a saturation between the7.1019 to 1020. The open circuit voltage can be written as:

$V_{oc}=Vt_{op}+V_{bot}-V_{th}$ with ($V_{top}$: voltage of top cell, $V_{bot}$: voltage of bottom cell and $V_{th}$: voltage of tunnel heterojunction)

The simulation result shows that Voc remains fixed from doping concentration of $7 \times 10^{19}$ $cm^{-3}$ (Fig 6).

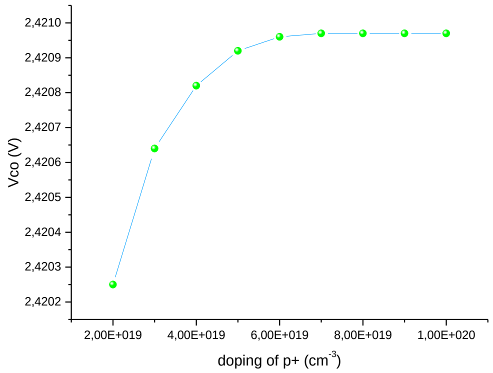



*Fig. 6. Open Circuit Voltage versus the concentration doping in layer p+-InGaP of tunnel heterojunction.*

This Voc result indicates that the bonding process does not degrade the cell material quality since any generated crystal defects that act, as recombination centers would reduce Voc [14, 15].

### 4.2. Short Circuit Current Analysis:

According to simulation, the profile of short circuit current density with respect to the concentration doping in layer p+-InGaP of tunnel heterojunction presented in the following Fig. 7.

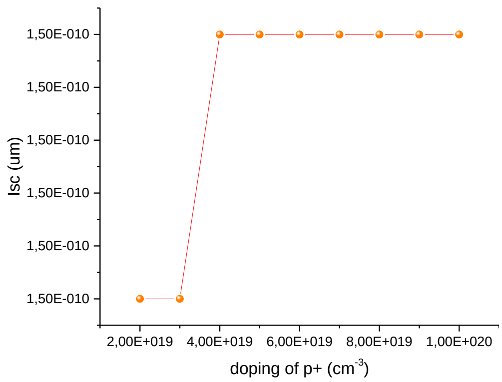



*Fig. 7. Short Circuit Current versus the concentration doping in layer p+-InGaP of tunnel heterojunction.*

The short circuit current (Jsc) determines the amount of current that will flow once the unit is connected to a circuit which is the minimum current between the two cores of the upper cell and the lower cell. The Jsc decreased due to the resistance and any leakage current in the electrical contacts between the sub-cells.

Our data show that the change in the tunnel junction does not give a clear improvement on the Tandem cell J0 (set-up current) and Rsh (resistance shunt), which gives a device with a higher Voc.

### 4.3. Efficiency Analysis

The fuel efficiency is quite interesting for this the multijunction solar cell studied. The profile shown in Fig. 8:

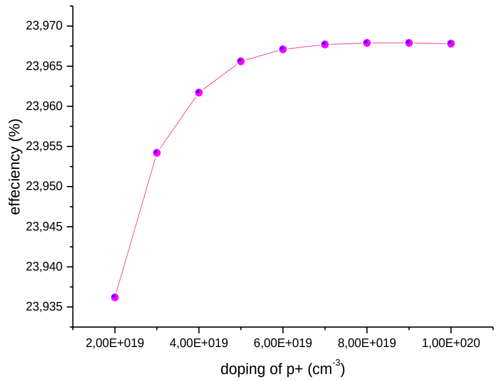



*Fig. 8. Efficiency Circuit Current versus the concentration doping in layer p+-InGaP of tunnel heterojunction.*

According to the figure, the efficiency known to increase with the open circuit voltage. As the Voc increases with the concentration doping in layer p+-InGaP of tunnel heterojunction, The efficiency also increases. However, when the Voc goes from 2.40 V to 2.41 V, The efficiency goes from 23.93% to 23.97%. In other words, the change in The efficiency is not significant compared to the change in Jsc.

### 4.4. Optimal performance of the GaInP/GaAs multijunction solar cell

The optimal performance of the GaInP/GaAs multijunction solar cell with tunnel heterojunction (GaInP/GaAs) found concentration doping in layer p+-InGaP of tunnel heterojunction $7.10^{19}cm^{-3}$.

The results of the efficiency, short circuit current, open circuit voltage, obtained by simulation of various percentages of concentration doping in layer p+-InGaP of tunnel heterojunction are given in Table-1:

*Table 1. Calculated optimal parameters of the GaInP/GaAs MSC.*

| doping in layer p+-InGaP ($cm^{-3}$) | Isc(mA) | Vco(V) | η(%) |
|---|---|---|---|
| $7.10^{19}cm^{-3}$ | 1.501 | 2.42097 | 23.97 |

The IV curves for GaInP/GaAs multijunction solar cell using the optimal tunnel heterojunction p-InGaP/n-GaAs) that are formed by TonyPlot are given in Fig. 5.

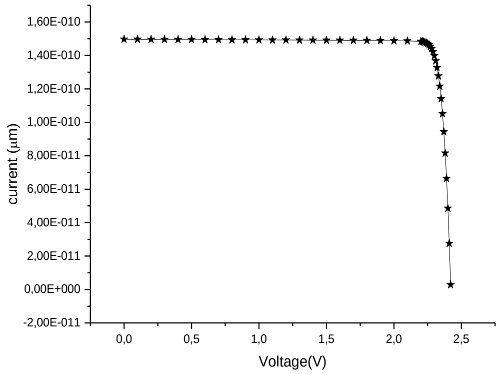



*Fig. 9. I(V) caractéristique of the the GaInP/GaAs MSC with the optimum performance*.

## 5. Conclusion

The calculation of the photovoltaic parameters of the GaInP/GaAs multijunction solar cell using the GaInP/GaAs multijunction solar cell using the tunnel heterojunction p-InGaP/n-GaAs), for the cases of different doping concentrations of the layer p-InGaP in tunnel heterojunction, has allowed to achieve the best solar cell structure with optimum performances. The optimum efficiency, found under normalized conditions (AM1.5G, 0.1 /, and 300°K), is 23.97%.

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