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# MODELING OF INGAN SOLAR CELL FOR BETTER USAGE USING SILVACO ATLAS

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**ABSTRACT**

With the advancement in every field in the world the global energy expenditure is increasing exponentially, so the demand for improvising our existing renewable energy solutions and finding out more of these kinds has become an important topic for mankind. In accordance with this, InGaN solar cells have proved to be the next big advancement in the field of solar energy. The band gap of 0.7 - 3.4 eV of InGaN has been helpful in the realization of high efficiency solar cells. In this work, different numerical simulations were performed with the help of Silvaco Atlas. In this, InGaN has been used to create a single junction solar cell with different parameters and the work has been compared to some of the existing theoretical work. These simulations are done with varying band gaps. The plot of the IV curve is executed with the help of TonyPlot. The maximum efficiency achieved was with the band gap of 2.66 eV of about 19-20%. This experiment helped in finding out the various parameters of the material and giving a start to research into InGaN as a material for the solar cells.

**Keywords:** InGaN, silvaco, TonyPlot, varying band gap, high efficiency.

## INTRODUCTION

Photo-Voltaic cell is a type of p-n junction by which we can convert solar radiations directly into electricity. It follows the principle of photoelectric effect i.e. when light falls on material, the electron absorbs the photon from light and gets excited and moves to higher energy level.

Light is made up of energy packets called photons. The energy of these photons depends on the color (wavelength) of light [2-3].

$$\mathcal{E} = hc/\lambda \qquad (1)$$

Where, h=Planck's constant, c=speed of light, and $\lambda$=wavelength of light.

Materials can be divided into three categories-metals, insulators and semiconductors [2-3].

The valence and conduction band of conductors are overlapping and hence the electrons easily flow from valence band to conduction band without need of any external energy Insulators are the materials with a wide gap of about 9eV between their conduction and valence band. These require very large amount of energy for such transition.

Semiconductors are the materials with a band gap difference of approximately 1 eV which are feasible to extract and convert sunlight to electricity.

There exist two types of semi-conductive materials: Elemental and Compound semiconductors.

Elemental semiconductors are the group IV elements of the periodic table like germanium and silicon.

Group IV has 4 electrons in its outer most band and requires 4 more electrons to get stable. So semiconductor materials forms a covalent bond with another element by sharing of electrons and completing the required and number and be stable. Si-Si or Ge-Ge forms a covalent bond with itself and act as a semiconductors. These are called the elemental semiconductors.

Compound Semiconductors are the materials with different elements sharing electrons. There are several compound semiconductors used e.g. GaAs, GaN, GaP, InN etc. $In_xGa_{1-x}N$ is an example of compound semiconductor which has the potential of giving a high efficiency solar cell. High efficiency solar cells are very helpful in space applications as increasing the efficiency of a solar cell helps reduce the number of solar panels required to generate the same amount of power as it will help in reducing the overall weight that is required to be launched into the space and it will further help in cost-reduction over the life of space power system. Moreover there are also benefits of using Indium Gallium Nitride solar cell as the radiation level InGaN can withstand is two orders of magnitude greater than the current materials used in solar cells.

This paper is organized in the following manner. Section II introduces Indium Gallium Nitride, Section III covers the Theoretical Modeling of InGaN structure, Section IV presents the Modeling Software - Silvaco Atlas that has been used in this paper for simulating the solar cell, and Section V shows modeling results and conclusion.

## INDIUM GALLIUM NITRIDE

InGaN has a wide-band gap ranging from about 0.7 - 3.4 eV, which can fit almost full solar spectrum [4-6]. With this quality of InGaN it has a very good potential for photovoltaic related applications. InGaN can be used in multi-junction solar cells where the composition of this material can be changed accordingly for the optimum performance. If we look into the past efficiencies of the multi-junction InGaN solar cells with optimized band gaps and thickness the solar cells tend to have 30-35% conversion efficiencies [4-6]. Since, the InGaN solar cells are still in its initial stage of research so there are many possible solutions on which the research is underway. These researches with theoretical studies are under careful investigations so as to optimize the performance of these cells.

Although, due to it being in development stage it is not possible to fully investigate all the factors but in this study, we have focused on calculating the short circuit current, open circuit voltage, fill factor and the conversion efficiency of the single junctions with different composition of InGaN.

The result from paper [7] that were taken to make a comparison between the experimental and the theoretical results were also helpful in calculating out the efficiencies for different percentages of InGaN solar cell and find out the best composition. The values for the result from the paper [7] are given in Table-1:

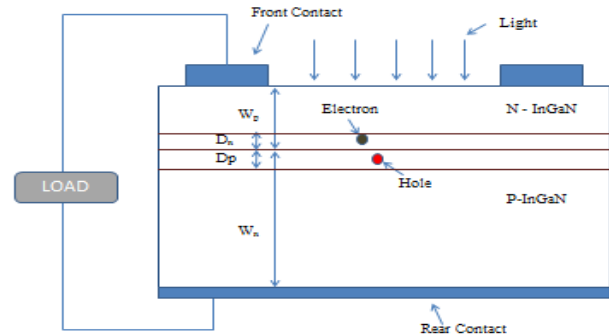**Table-1.** Theoretical results of InGaN Solar Cell [7].

| Material | $Jsc$ ($mA/cm^2$) | $Voc$ (V) | Fill factor | η (Efficiency) |
|---|---|---|---|---|
| $In_{0.46}Ga_{0.54}N$ | 14.1 | 1.39 | 90.8% | 17.8% |

The IV plot of the InGaN solar cell from the theoretical results of paper [7] is given in Figure-1:
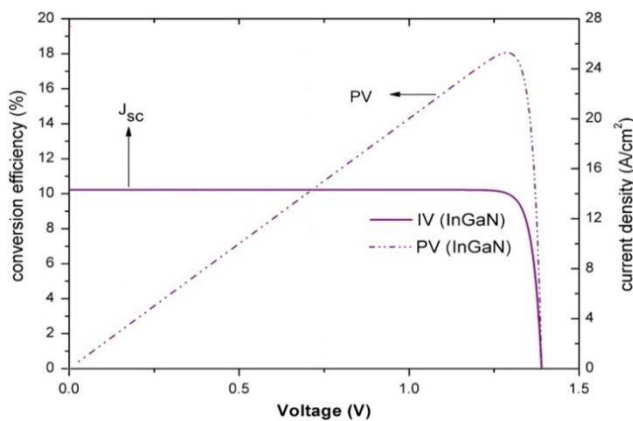


**Figure-1.** Plot of IV curve for $In_{0.46}Ga_{0.54}N$ [7].

## THEORETICAL MODELING OF INDIUM GALIUM NITRIDE SOLAR CELL



**Figure-2.** Theoretical structure of InGaN p-n junction solar cell.

Figure-2 illustrates the theoretical model of single junction InGaN solar cell in which the $W_n$ and $W_p$ are the widths of the p-type and the n-type junctions, $D_n$ and $D_p$ are the widths of the depletion region of the p-type and n-type junctions, respectively. In this we have assumed the light to be of AM0 spectrum that is incident on the N-type of the InGaN solar cell.

In order to simulate a solar cell we need to set some parameter values for the materials. Energy band gap, at room temperature of the $In_xGa_{1-x}N$ solar cell is given by [8]:

$$Eg(x) = 3.42x + 0.77(1 - x) - 1.43x(1 - x) \qquad (2)$$

Where x defines the proportion of the in content and (1-x) proportion of Ga content in $In_xGa_{1-x}N$. InGaN has a band gap between 0.7 eV to 3.4 eV as InGaN is formed by combining two different semi-conducting materials i.e. Gallium Nitride (GaN) and Indium Nitride (InN) and the band gap of GaN is 3.4 eV and that of InN is 0.7 eV.

With the help of Eg we can find out the electron affinity of the InGaN. It is given by following relation [8]:

$$\chi = 4.1 + 0.7(3.4 - Eg) \qquad (3)$$

Where, $\chi$ is the electron affinity and Eg is the band gap from previous equation.

Absorption coefficient of InGaN is given by following relation and it is associated with the wavelength and energy band gap [8]:

$$\alpha(\lambda) = 2.2 \, X \, 10^5 \sqrt{\frac{1.24}{\lambda} - Eg} \qquad (4)$$

Where $\alpha$ is the absorption coefficient and $\lambda$ is the wavelength.

The conduction band and valence band, effective density of states are given as under, respectively [8]:

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$$Nc = 0.9x + 1.8(1 - x) \qquad (5)$$

$$Nv = 5.3x + 1.8(1 - x) \qquad (6)$$

Relative permittivity is calculated as:

$$\varepsilon_r = 14.6 + 10.4(1 - x) \qquad (7)$$

With the help of these above formulae various combinations of band gaps were tried and the result was taken for the best energy band gaps.

Table-2 shows the parameters used for the simulation of the InGaN single-junction solar cell.

**Table-2.** Parameters used for InGaN solar cell modeling.

| Material | $Eg$ (eV) | $\chi$ (eV) | Nc x $10^{18}$ cm$^{-3}$ | Nv x $10^{19}$ cm$^{-3}$ | $\varepsilon_r$ |
|---|---|---|---|---|---|
| In$_{0.20}$Ga$_{0.80}$N | 2.66 | 4.632 | 1.62 | 2.5 | 22.92 |
| In$_{0.57}$Ga$_{0.43}$N | 1.559 | 5.3887 | 1.287 | 3.795 | 19.07 |
| In$_{0.68}$Ga$_{0.32}$N | 1.3068 | 5.56524 | 1.188 | 4.18 | 17.92 |
| In$_{0.78}$Ga$_{0.22}$N | 1.1076 | 5.705 | 1.098 | 4.53 | 16.89 |

For calculating the efficiency of the solar cell, below are the formulas that are useful for this purpose. These calculations can be directly calculated in the code.

$$P_{max} = I_{mp}V_{mp} \qquad (8)$$

$$FF = \frac{P_{max}}{I_{sc}V_{oc}} = \frac{I_{mp}V_{mp}}{I_{sc}V_{oc}} \qquad (9)$$

$$\eta = \frac{P_{max}}{P_{in}} = \frac{I_{mp}V_{mp}}{P_{in}} \qquad (10)$$

Some definitions which are helpful in understanding the concept of calculating efficiency are [9-10]:

**Short-circuit current**

Usually denoted as *Isc*, it is the current through the electrical circuit or through the solar cell when it is short circuited or when the voltage across it is zero.

**Open-circuit voltage**

Denoted as Voc, it is the voltage at maximum level available from the circuit when the net current is zero.

**Fill factor**

Though Isc and Voc are the maximum current and voltage values individually but the power at these points is zero. Here, it is when the fill factor comes in play. It is the parameter which helps in finding out the maximum power and can be defined as the ratio of maximum power to the product of Isc and Voc.

## MODELING SOFTWARE-SILVACO ATLAS

This paper uses the Silvaco Atlas for the modeling of Solar Cell and calculating the various parameters required for knowing the efficiency of the Solar Cell. Silvaco has various products that help in delivering and supporting TCAD and integrated EDA software in various markets such as Digital CAD, Custom IC CAD, and Interconnect Modeling etc. [13-14].

In this paper, Silvaco Atlas was used extensively to execute the code in which we had modeled the multi-junction solar cell and input the parameters accordingly so as to maximize the output efficiency. Simulations as well as curves were viewed in TonyPlot and output log files were produced. Figure-3 shows the atlas inputs as well as outputs.
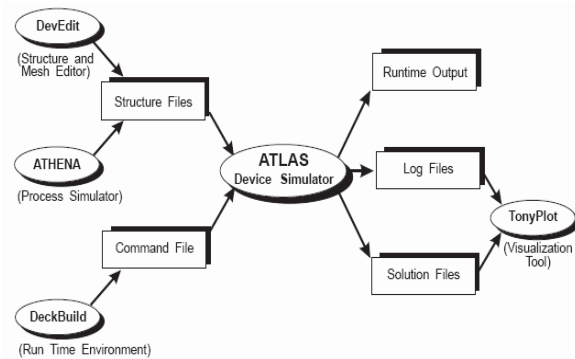


**Figure-3.** Inputs and outputs in Silvaco atlas.

There are set of steps that need to be followed while writing a Silvaco Atlas code. Figure-4 gives an insight to what these steps are [13-14].

**Figure-4.** Steps of command groups in Silvaco atlas.

Structure is made up by defining all the boundaries and the points in the structure and also defining the electrodes and the concentration of doping.

After the structure, specification of material model is the next. In this the material parameters, physical models such as mobility, recombination, and tunneling, and the material interface and contact are defined.

Next is the numerical method selection that is of three types:

- **Decoupled** (GUMMEL)**:** Solves for every unknown while keeping other unknowns constant.

- **Fully coupled** (NEWTON)**:** Solves all unknowns simultaneously.

- **BLOCK:** Solves with GUMMEL and NEWTON both.

Solution specification is divided into following four parts. LOG that saves all the characteristics to a file. After it is saved AC, DC or the transient data is generated by SOLVE. Next statement that is LOAD helps in entering the solution of previous files and the SAVE file enters all these information in the output file.

At last result analysis helps first in extracting the device parameters and then plotting the curves or the curve with the help of TonyPlot.

**RESULTS AND CONCLUSIONS**

The results of the efficiency, short circuit current, open circuit voltage, Vm and Im are obtained by simulation of various percentages of InGaN and are given in Table-3:

**Table-3.** Comparison of four different band gap InGaN solar cells.0.

| Material | $Isc$ (A) | $Voc$ (V) | $Vm$ (V) | $Im$ (A) | Fill factor | η (Efficiency) |
|---|---|---|---|---|---|---|
| $In_{0.20}Ga_{0.80}N$ | 0.00157 | 2.0013 | 1.9 | 0.00149 | 0.90 | 19.4157% |
| $In_{0.57}Ga_{0.43}N$ | 0.00223 | 0.913785 | 0.8 | 0.00214 | 0.8145 | 11.7312% |
| $In_{0.68}Ga_{0.32}N$ | 0.00246 | 0.662611 | 0.55 | 0.00240 | 0.8098 | 9.04281% |
| $In_{0.78}Ga_{0.22}N$ | 0.00251 | 0.464125 | 0.4 | 0.0024 | 0.8240 | 6.59083% |

The IV curves for an InGaN solar cell using different band gaps that are formed by TonyPlot are given in Figure-5 to Figure-8.
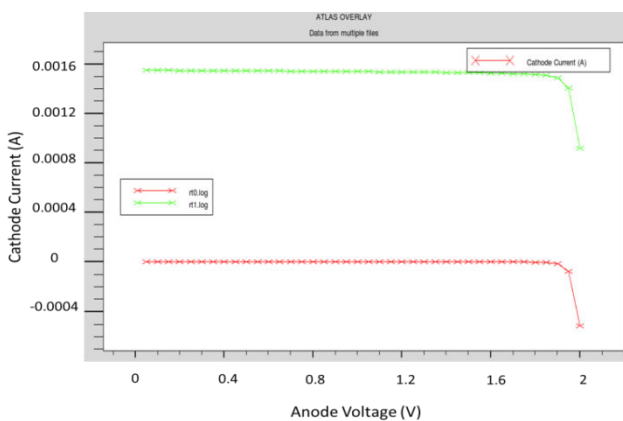


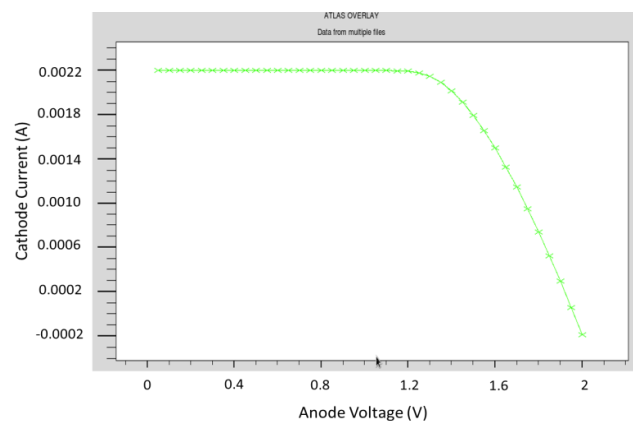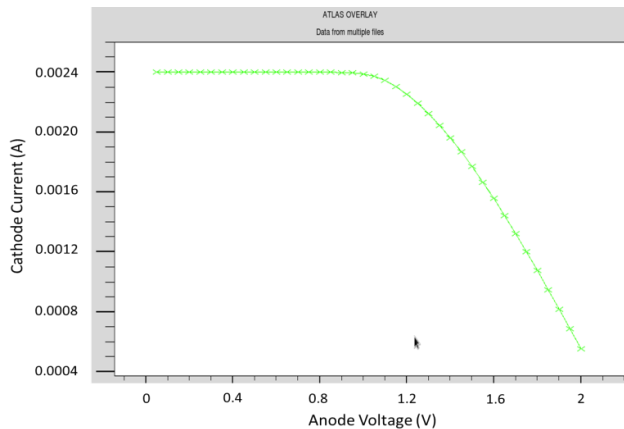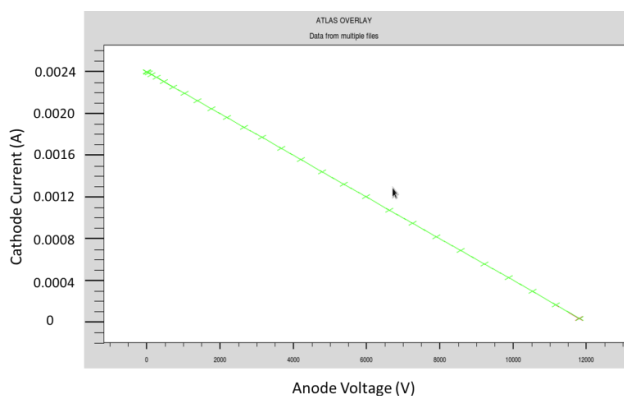**Figure-5.** Plot of IV curve for $In_{0.20}Ga_{0.80}N$.



**Figure-6.** Plot of IV curve for $In_{0.57}Ga_{0.43}N$.

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**Figure-7.** Plot of IV curve for $In_{0.63}Ga_{0.37}N$.



**Figure-8.** Plot of IV curve for $In_{0.78}Ga_{0.22}N$.

InGaN has the potential to be used as a good semiconductor material in photovoltaic devices. With the results of the InGaN solar cell it attracts the attention to look into more of the research on this materials solar cell. The efficiency of 19-24% is one of the highest performed for single junction using Silvaco Atlas [18]. And, moreover, the benefits of using InGaN solar cell as discussed in the paper helps in using this as a future material for the production of solar cell.

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