A Highly Efficient InGaN Single Junction Solar Cell Using MATLab

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***Abstract*—Though the expenditure of world energy is increasing exponentially, it is obvious that a solution of renewable energy must be utilized. In order to fulfill the energy demand of the mankind, utilization of the huge energy of the sun by transforming it into electricity is an emerging alternative way. Recently developed InGaN is a direct band gap solar photovoltaic material that has an amazing tunable band gap of 0.7 eV to 3.4 eV and a high optical absorption coefficient over 10^5 /cm. In this paper, numerical simulations has been done using MATLab to explore the unknown potential of this promising material to design a high performance InGaN solar cell.All the required parameters for simulation were determined from the theory, literature and in some cases reasonable estimation. This simulation were done with different ratio of In and Ga content for the single junction solar cell and found a high conversion efficiency of 27.3% with this InGaN compound material.**

Keywords—Renewable energy; Solar photovoltaic; InGaN; MATLab; Conversion efficiency.

I. INTRODUCTION

Worldwide civilization requires low-priced, dependable and sustainable energy sources. With the increased technological development, the energy expenditure has enlarged steadily. More and more energy consumption is expected in future to withstand the present human development. Solar cells is the best way to utilize energy from the sun that is exactly the boundless source of renewable and clean energy. The initial efforts for progress of photovoltaic (PV) cells were focused towards space applications, and PV cells are still today the main source of power in space. InGaN based PV cells are the most potential candidate for solar energy conversion into electricity as there are possibilities of higher cell conversion efficiency and low cost fabrication. InGaN has near the ideal band gap of 0.7 eV to 3.42 eV [1, 2, 3] and higher optical absorption coefficient greater than 10^5/cm, which indicates the better absorption of the sun spectrum. It is a very potential material for ultra-thin solar cells in space application. The layers of an InGaN solar cell might be deposited using the various techniques, namely Metal Organic Chemical Vapor Deposition (MOCVD), Molecular Beam Epitaxy (MBE), Metal OrganicVapor Phase Epitaxy (MOVPE) [4]. In 2007, Xiaobin Zhang published the conversion efficiency of single junction InGaN solar cell was 20.284% [5] and the same group published the efficiency of 24.95% in 2008 [6]. In 2011, S. Ben Machiche has achieved efficiency of 24.88% for a single junction InGaN solar cell [7]. The III-V group materials are widely used for tandem materials cells for the space application, in 2009 InGaP/GaAs double Junction and InGaP/GaAs/Ge triple Junction cells were designed. Triple junction structure of GaInP/GaAs/Ge shown efficiency of 41.6% [8] but it should be noted that the 0.66eV indirect band gap energy of Ge is not optimal band gap of lower sub cell of a triple junction cell. In recent times, in 2012 a latest structure of GaInp/GaAs/GaInNAs shows efficiency of 44%, which is the world highest [9]. But the problem of this structure is more complex quardinary alloy system of the cell and the toxicity and the cost of As material are the biggest barrier of these material system.

However, there were no major work using MATLab with this excellent material though it can save time and cost by designing high efficient cell. There are scopes to minimize the thickness to save materials and to increase the conversion efficiency with improved short circuit current density (*Jsc*), open circuit voltage (*Voc*) and fill factor (*FF*) with different proportion of In(x) in $In_xGa_{1-x}N$ material system [10]. All the above ideas were modeled in this work and numerical analysis was done by using MATLab to achieve the best possible structure of InGaN single junction solar cell for higher efficiency which is the basic component of tandem solar cell. The conversion efficiency has been found in this research work were 27.3% for the single junction solar cell from MATLab Simulation.

II. MODELING AND MATLAB SIMULATION

Numerical simulation is the first way to calculate the effect on cell performance [10] and to test the possibility of the proposed structure. Modeling is widely used in the analysis of solar cells due to its complex and very costly fabrication method. Figure.1 illustrates the proposed structure of aInGaN based single junction solar cell. From Fig. 1, it is clear that this structure consists a p layer and an n layer InGaN along with a TCO and back contact to achieve thin InGaN layer.

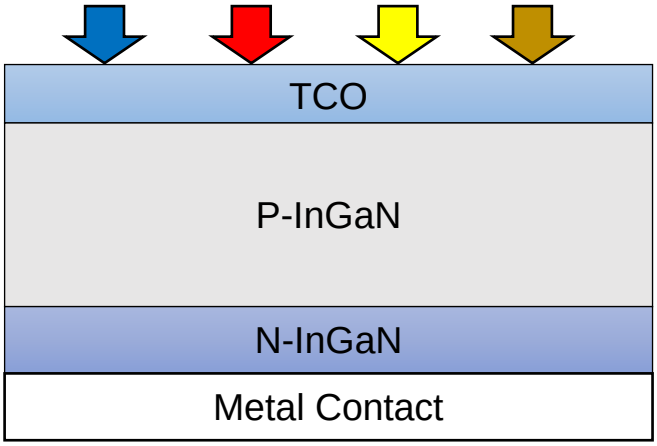

Fig.1: Proposed structure of single junction solar cell

MATLab simulations were done in this work to design the cell structure and the required equations were collected from the theory of solar cells. The equations required for this simulations are shown here.

The Short circuit current density, $J_{sc} = J_n^p + J_p^n$ [11]

Where J_n^p and J_p^n are the photocurrent collected by p type and n type materials. The total the photocurrent collected by p type material is equal to

$$J_n^p = \int_0^{\lambda_1} j_n(\lambda)\, d\lambda$$

Where λ_1 is the absorption wavelength of InGaN which can be varied from 0.7eV to 3.4 eV. The photo generated electron current density is

$$j_n(\lambda) = qF(\lambda)[1 - R(\lambda)]\frac{a_n(\lambda)}{\propto_n(\lambda)^2 - 1}\beta_n$$

$$\left[b_n + a(\lambda) - exp\left(\frac{-Z_p\, a_n(\lambda)}{L_n}\right)\left[[b_n + a_n(\lambda)]\cosh\left(\frac{Z_p}{L_n}\right) + [1 + b_n a_n(\lambda)]\sinh\left(\frac{Z_p}{L_n}\right)\right]\right].$$

Where q is the absolute value of electronic charge,

$$\beta_n = [\cosh\left(\frac{Z_p}{L_n}\right) + b_n\left(\frac{Z_p}{L_n}\right)].$$

Spectral distribution of the solar flux is

$$F(\lambda) = 3.5 * 10^{21}\lambda^{-4}\left[e\left(\frac{hc}{KT_1\lambda} - 1\right)\right]^{-1}$$

Where h is plank's constant, c is the velocity of light.

For n type material, total photocurrent collected is

$$J_p^n = \int_0^{\lambda_1} j_p(\lambda)d\lambda$$

Where λ_1 is the absorption wavelength of InGaN which can be varied from 0.7eV to 3.4 eV. The photo generated electron current density is

$$j_{p(\lambda)} = qF(\lambda)[1 - R(\lambda)]\frac{a_p(\lambda)}{\propto_p(\lambda)^2 - 1}\beta_p$$

$$\left[b_p + a(\lambda) - exp\left(\frac{Z_n a_p(\lambda)}{L_p}\right)\left[[b_p + a_p(\lambda)]\cosh\left(\frac{Z_n}{L_p}\right) + [1 + b_p a_p(\lambda)]sinh\left(\frac{Z_n}{L_p}\right)\right]\right].$$

Where, $\beta_p = [\cosh\left(\frac{Z_n}{L_p}\right) + b_p\left(\frac{Z_n}{L_p}\right)]$

Open circuit voltage V_{oc} is defined as

$$V_{oc} = \frac{KT}{q}ln\left(\frac{J_{sc}}{J_0} + 1\right) \quad [12]$$

Where j_o is the reverse saturation current and the equation is,

$$J_0 = Q\left(\frac{D_n}{L_n N_A} + \frac{D_p}{L_p N_D}\right)n_i^2 \quad [13]$$

Where

$$n_i^2 = N_c N_v e\left(-\frac{E_g}{KT}\right)$$

N_c and N_v are the effective density of state. N_A and N_D are the doping concentration of p type and n type materials. The equation of mobility of electron is

$$\mu_i(N) = \mu_{min,i} + \frac{\mu_{max,i} - \mu_{min,i}}{1 + (\frac{N}{N_{g,i}})^{\gamma_i}} \quad [14]$$

The equation of fill factor is[14]

$$FF = \frac{v_{oc} - ln(v_{oc} + 0.72)}{v_{oc} + 1}$$

Where, $v_{oc} = \frac{q}{nKT}V_{oc}$, n is the ideality factor that can be considered 1.

Finally the efficiency of a solar cell is related with short circuit current density, open circuit voltage and fill factor of a cell.

$\eta = J_{sc}.V_{oc}.FF.$

The power input is 1000 W/m^2 at 1 sun.

Table 1 show all material parameters used in this modeling, which were determined based on literature, theory or in some cases reasonable estimations to get better cell performance.

TABLE 1 PARAMETER USED IN SIMULATION

Parameters for Simulation	**Unit of measure**	**Value**
Surface recombination velocity for electron (S_n)	cm s^{-1}	1000
Surface recombination velocity for hole (S_p)	cm s^{-1}	1000
Surface reflection coefficient (R_λ)		0.1
Absorption coefficient (α_λ)	cm^{-1}	5x10^5
Effective density of state at conduction band (Nc)	cm^{-3}	1.40x10^{18}
Effective density of state at valence band (Nv)	cm^{-3}	4.04x10^{19}
Acceptor concentration ($N_{A)}$)	cm^{-3}	10^{16}
Donor concentration ($N_{D)}$)	cm^{-3}	10^{16}
Electron mobility ($\mu_{n)}$)		955
Hole mobility ($\mu_{p)}$)		169.8
Ideality factor		1

III. Result and Discussions

The number of parameters that can be varied is more than 50 in a solar cell. So it is ambiguous to solve such variable model. This numerical analysis has been done aiming to improve the cell perfomance of the InGaN single junction solar cell structure. All the required equations were simulated using MATLab to find the stable structure of a single junction InGaN solar cell.

The dependency of the cell performance on the ratio of In in $In_xGa_{1-x}N$from 0% to 100% has been simulated by MATLab. It has been observed from the simulation result shown in Fig. 2 that the efficiency is highest in the range of Indium ratio of 55% to 75% corresponding the following equation of band gap with Indium proportion. [15, 16]

$$E_g(x) = 0.7x + 3.4(1-x) - 1.43x(1-x).$$

Where $E_g$is the band gap and x is the proportion of In in $In_xGa_{1-x}N$.

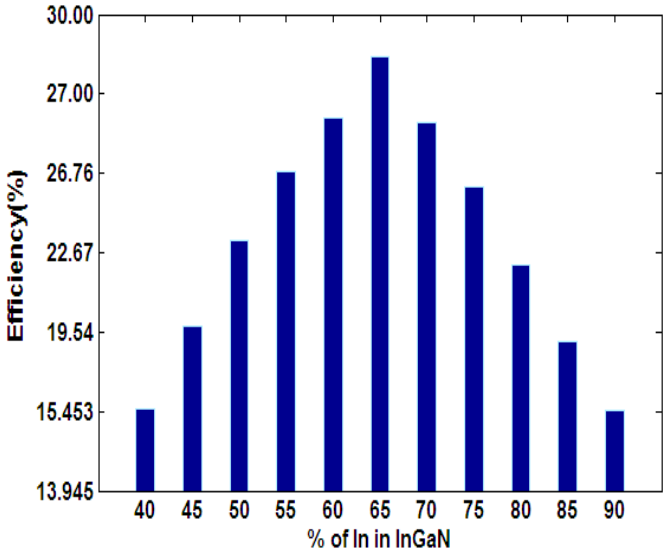

Fig.2: Efficiency vs percentage of In in InGaN of the proposed single junction solar cell

Fig.3 shows the output J-V characteristic curve of the designed cell. After doing rigorous simulation, efficiency of 27.3% was found (J_{sc}=34.15mA/cm^2,V_{oc}=0.89V and FF=0.88). MATLab is more effective tools that requires less time to simulate more data.Regorous simulation can be done from which best result can be fitted. In AMPS, for each data we need to simulate the cell saparately. But in MATLab, it can be done by using the equation with the range of data and then best cell structure can be selected.

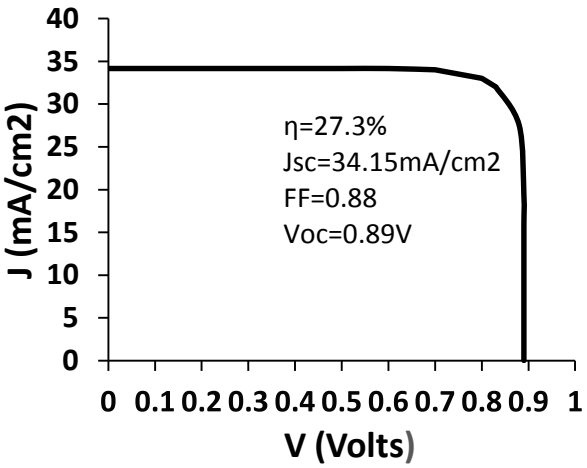

Fig.3: J-V curve of the proposed InGaN single junction solar cell

IV. CONCLUSION

A single junction solar cell of InGaN material has been designed with conversion efficiency of 27.3% (Jsc=34.15mA/cm^2, Voc=0.89V, FF=0.88). Here MATLab is introduced to design such kind of InGaN solar cell. Though the fabrication method is very complex and costly, MATLab simulation is usefull to design this highly efficient cell that can save time and cost. This designed basic cell of InGaN with its tunable bandgap can be used to design multijunction tandem solar cells for space application.

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