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A HIGH PERFORMANCE $In_XGa_{1-X}N$ SINGLE JUNCTION SOLAR CELL FROM NUMERICAL ANALYSIS

N. Akter[1], M. A. Matin[2] and N. Amin[3,4]

[1] International Islamic University Chittagong, Chittagong, Bangladesh
[2]Chittagong University of Engineering and Technology, Chittagong, Bangladesh
[3]Department of Electrical, Electronic and System Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600, Bangi, Selangor, Malaysia
[4]Center of Excellence for Research in Engineering Materials (CEREM), College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia

Abstract*- InGaN is a recently developed novel material for the realization of high efficiency solar cells. It has very attractive tunable ideal band gap in the range of 0.7 eV to 3.4 eV and high optical absorption coefficient over 10^5/cm. Numerical simulations were conducted with InGaN material utilizing AMPS simulator to explore the hidden potential of this promising material for high performance solar cells. 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 cells and it has been found that the maximum conversion efficiency is 25.02% (Voc= 0.925V, Jsc= 30.883mA/cm^2 and FF= 0.876). Finally, the stability of the proposed cell has been investigated and found that the temperature coefficient (TC) is -0.04%/ºC which indicates the higher stability of the cell in stressed condition.*

Keywords: Renewable Energy**,** Solar Cell, Single Junction, InGaN, High Performance, AMPS-1D

1. INTRODUCTION

Solar cells still remains the best way yet determined to harness energy from the Sun which is almost unlimited sources of renewable and clean energy all over the world. The early efforts for development of photovoltaic (PV) cells were directed towards space applications and PV cells are still today the main source of power in space. InGaN based solar cell is one of the most promising candidates for PV energy conversion due to the possibilities of higher conversion efficiency and low cost. InGaN has near ideal band gap of 0.7 eV to 3.42 eV [1, 2] and high optical absorption coefficient over 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 a InGaN solar cell can be deposited using the cost effective techniques, such as Metal Organic Chemical Vapor Deposition (MOCVD), Metal Organic Vapor Phase Epitaxy (MOVPE), Molecular Beam Epitaxy (MBE) [3].

In 2007 Xiaobin Zhang et al. published the conversion efficiency of InGaN single junction solar cell was 20.284% [4] and the same group published the efficiency of 24.95% in 2008 [5]. In 2011 S. Ben Machiche has achieved efficiency of 24.88% for a single junction InGaN solar cell [6]. The III-V group materials are widely used for tandem solar cells for the space application, such as InGaP/GaAs double Junction and InGaP/GaAs/Ge triple Junction cells were developed in 2009. Triple junction structure of GaInP/GaAs/Ge shown efficiency of 41.6% [7] but it should be noted that the 0.66 eV indirect band gap energy of Ge is not optimal as the material for the bottom sub cell in a triple junction cell. Recently, in 2012 a new structure of GaInP/GaAs/GaInNAs shows efficiency of 44%, which is the world highest [8]. But the problem of this structure is more complex quardinary alloy system of the cell and the toxicity as well as the cost of As material are the biggest barrier of these material system. However, there are scopes to reduce the thickness to save materials and to increase the conversion efficiency by improving short circuit current density (*Jsc*), open circuit voltage (*Voc*) and fill factor (FF) with different proportion of x in $In_xGa_{1-x}N$ material system. All the above ideas were modeled in this work and numerical analysis was done by using AMPS 1D simulator to achieve the best possible structure of InGaN single junction solar cell for higher efficiency and stability which is the basic component of tandem solar cell. The conversion efficiency has been found in this research work were 25.02% for the single junction solar cell and with the temperature coefficient (TC) of -0.04%/ºC.

2. MODELING AND SIMULATION

Numerical simulation of solar cell is an important

way to predict the effect on cell performance [9] and to test the viability 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 a InGaN based single junction solar cell. It is clear from Fig. 1 that this structure consists of TCO and back contact to achieve thin InGaN layer. The doping concentration ($5\times10^{17}cm^3$) used in the earlier study has been changed to ($1\times10^{16}cm^3$) more effective and today's practically achievable values for higher efficiency. Higher watt function metals such as Au/Ni/Pt need to be used for back contact as InGaN has high electron affinity. In this design back contact material Nical (Ni) has used with back contact barrier height of 1.3 eV. In this work, Analysis of Microelectronic and Photonic Structures (AMPS-1D) has been used to investigate the cell performance with $In_xGa_{1-x}N$.

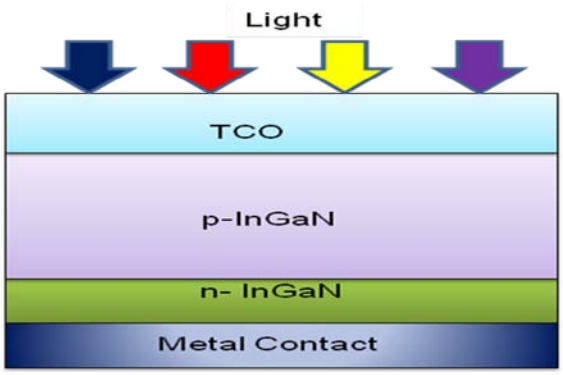

Fig.1: Proposed structure of single junction solar cell

Table 1 show all material parameters used in this modeling, which were determined based on literature, theory or in some cases reasonable estimations. In this analysis p-InGaN absorber layer thickness was varied from 0.1 µm to 1.5 µm, n-InGaN layer thickness was changed from 30 nm to 0.15 µm by keeping all other parameters at the fixed values as shown in Table 1 aiming to achieve the highly efficient single junction solar cells.

Table 1: Simulation parameters of InGaN solar cell

Parameters for Simulation	p-InGaN	n-InGaN
x	0.64	0.64
E_g (eV)	1.34	1.34
ε_r	13.09	13.09
χ (eV)	5.54	5.54
Nc 10^{18} cm^{-3}	1.40	1.40
Nv 10^{19} cm^{-3}	4.04	4.04
N_A cm^{-3}	10^{16}	0
N_D cm^{-3}	0	10^{16}
μ_n	955	955
μ_p	169.8	169.8
D (µm)	0.5	0.1

3. RESULT AND DISCUSSION

This numerical analysis has been done aiming to improve the cell perfomance of the InGaN single junction solar cell structure which is the basic component of a tandem cell. The dependency of the cell performance on the absorber layer thickness from 0.1 µm to 1.5 µm and on temperature effect from 25ºC to 100ºC has been simulated by employing AMPS-1D simulator.

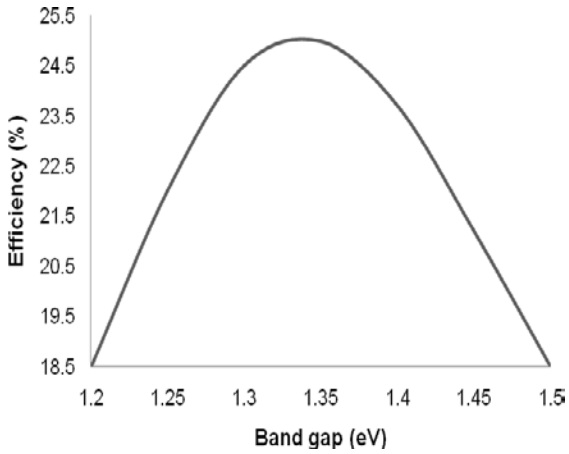

Fig.2: Optimization of efficiency with band gap

In this numerical analysis, simulattions were done for different proportion of In and found the efficiency of 15.75%, 19%, 20%, 22%, 23%, 24% for In ratio 52%, 57%, 60% 62%, 63%, 64% respectively. From this analysis bangap of the single junction solar cell was optimized at 1.34 eV.

The dependency of the cell performance on the ratio of In in $In_xGa_{1-x}N$ from 0% to 100% , absorber layer thickness from 0.1 µm to 1.5 µm has been simulated by employing AMPS-1D. It has been observed from the simulation result shown in Fig. 2 that the efficiency is highest in the range of 1.2 eV to 1.5 eV that indicate the Indium ratio of 57% to 70% corresponding the following equation of band gap with Indium proportion. Proposed single junction solar cell configuration is optimized at $In_{0.64}Ga_{0.36}N$.

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

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

The effects of p-InGaN absorber layer thickness variation from 0.1 µm to 1 µm on the cell output parameters are shows Fig. 3, with the parameters of Table 1. From the Fig. 3, it is clear that solar cell efficiency is affected by the absorber layer thickness of p-InGaN. However, Voc and FF are not affected and *Jsc* is increased with the increment of p-InGaN absorber layer thickness. Thus, from the combined effect, the efficiency is increased with increment of layer thickness until 0.5 µm but above 0.5 µm there is no significant change, this may be attributed that the electric field strength diminishes above 0.5 µm.

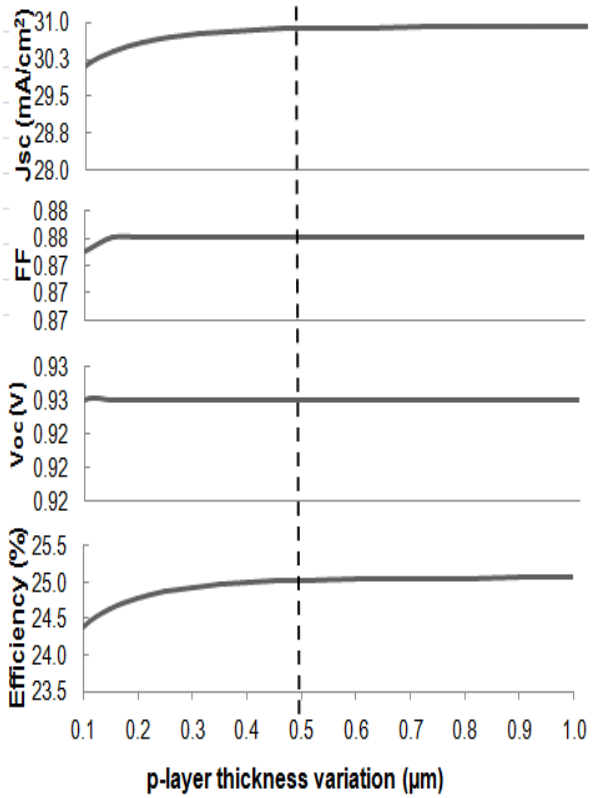

Fig.3: Effect of p-InGaN absorber layer thickness

The simulation has shown higher efficiency over 25.02% for layer thickness in the range 0.1 μm to 1 μm, which is higher than any other reported works on InGaN cells. The reputed results are 20.284% [4], 24.95% [5] and 24.88% [6]. The 0.5 μm InGaN shows the highest conversion efficiency of 25.02% (*Voc*=0.925V, *Jsc*=30.883mA/cm^2, FF=0.876). The improvement in efficiency came from the improved *Jsc* with the reduction of doping concentration, which eliminated the phase separation among InGaN layer. The Fig. 4 shows the effect of solar cell performance on n-InGaN layer thickness variation from 30 nm to 0.12 μm. It is clear from this figure that overall performance of the cell was raised until 0.1 μm and above 0.1 μm it was not changed significantly.

The simulated final cells J-V curve shown if Fig. 5 and it shows that output characteristics are acceptable with low series resistance and high shunt resistance which attributed from high FF of 0.876, along with higher *Jsc*, and *Voc*. The improvement in efficiency has come mainly from the improvement in *Jsc* than any other reported cells [4, 5].

In real cases the operating temperature plays a very important role that affects the performance of the solar cells especially in space application. At higher operating temperature, parameters such as the effective density of states, absorption coefficients, electron and hole mobility, carrier concentrations and band gaps of the materials are affected significantly.

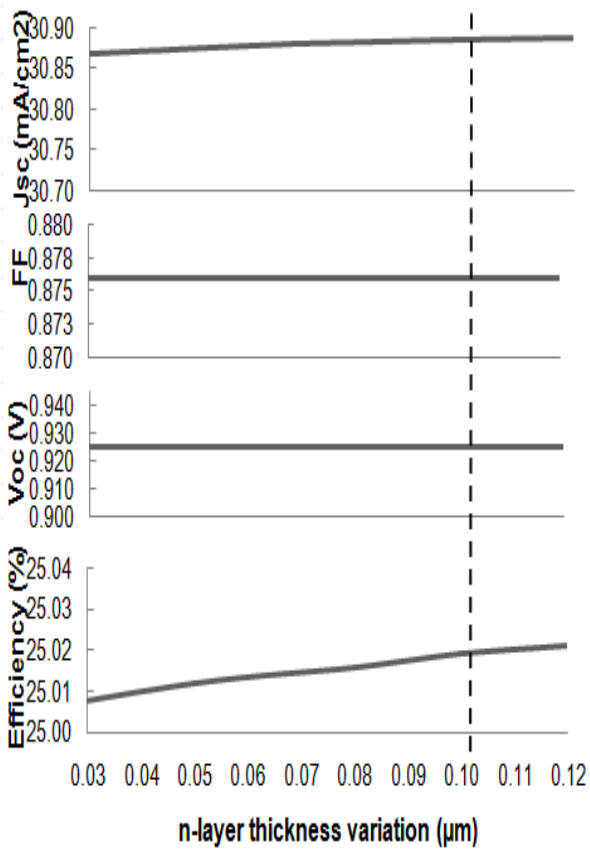

Fig.4: Change in n-InGaN layer thickness

An investigation has been done on normalized efficiency of the final cell to understand the effect of temperature on InGaN tandem solar cell with operating temperature ranged from 25°C to 105°C as shown in Fig. 6. It is evident from the Fig. 6 that the η of the cell linearly decreases at the temperature gradient of -0.04%/°C, with increase of operating temperature, which also indicates the higher degree of stability of the final proposed cell at higher operating temperature or in stressed conditions.

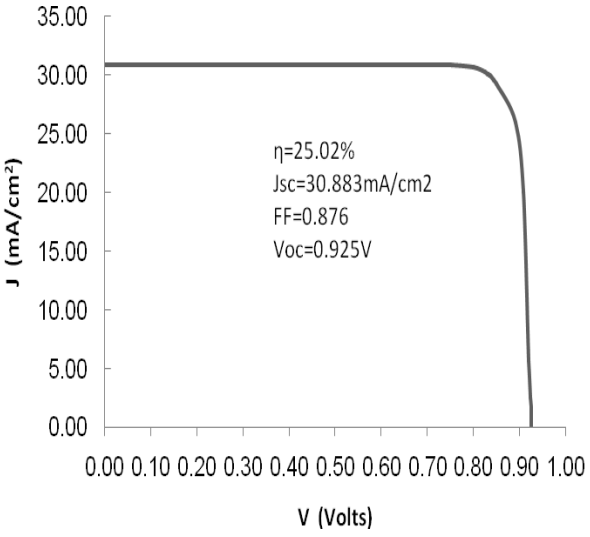

Fig.5: I-V curve for the proposed solar cell

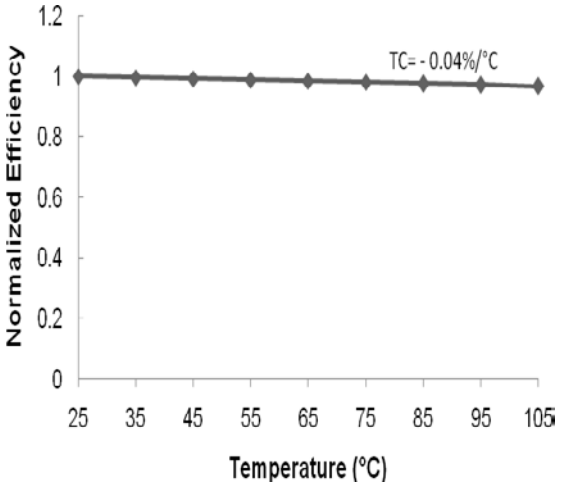

Fig.6: Effect of temperature on cell performance

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4. CONCLUSION

In this numerical analysis, bangaps of single junction $In_xGa_{1-x}N$ solar cell was optimized at 1.34 eV in order to achive the higher conversion efficiency. Layer thickness of the cell were simulated and optimized (0.5 μm for p-InGaN and 0.1 μm for n-InGaN). The designed and optimized single junction InGaN solar cell conversion efficiency is 25.02% (*Jsc*=30.883mA/cm^2, *Voc*=0.925V, FF=0.876) which is highest for single junction reported InGaN solar cells. Finally, to investigate the degree of stability of the designed cell the temperature coefficient (TC) of the InGaN solar cell was found -0.04%/°C that indicates the higher stability of the proposed cell.

6. ACKOWLEDGEMENT

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8. NOMENCLATURE

Symbol	Meaning	Unit
E_g	Bandgap	(eV)
ε_r	Relative permittivity	Dimentionless
χ	Electron affinity	(eV)
N_c	Conduction band	(cm^{-3})
N_v	Valance band	(cm^{-3})
N_A	Acceptor	(cm^{-3})
N_D	Donor	(cm^{-3})
μ_n	Electron mobility	Dimentionless
μ_p	Hole mobility	Dimentionless
D	Thickness	(μm)
x	Proportion of Indium	Dimentionless