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Modeling and Simulation of Highly Efficient Single Junction GaInP Solar Cell

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Abstract—**Gallium Indium Phosphate (GaInP) is III-V semiconductor materials are widely used for the space application and promising material choices for the solar photovoltaic applications owing to its superior optoelectronic properties and very higher performance. The numerical analysis of the single junction GaInP solar cell was carried out by wx-AMPS software to evaluate the cell performance of the proposed cell. The maximum cell conversion efficiency was optimized by the variation of each layer thickness. This research work was done by two steps, firstly the influence the thickness of each layer was investigated for evaluate the cell performance of the single junction GaInP solar cell and secondly the influence of the ZnO layer was analysed by the with and without TCO layer. The possibility of single junction GaInP solar cells was examined and simulated results showed a significant improvement in the higher cell efficiency of 29.47% where J_{sc} is 24.57 (mA/cm^2), V_{oc} is 1.14 V and FF is 0.813 for single junction solar cell. Besides, it was shown a better thermal stability at the gradient of -0.03%/°C, where normalized efficiency of the single junction solar cell was linearly decreased with the increase of operating temperature.**

Keywords— GaInP solar cell; Optoelectronic; ZnO layer; wxAMPS; thermal stability.

I. INTRODUCTION

Energy is a critical requirement for any development in the world. It is very important for the development of modern civilization. The development of modern civilization is mostly dependent on the source of energy. Currently, most of the energy comes from the conventional energy and around 80% power of total uses energy collected from fossil fuel [1]. But it is created the CO_2 emission which is effected on the global environment. Conventional sources are the end of the stage due to its excessive usage to meet up the demand for energy. In this situation, the crucial solution is non-conventional energy which will be stored, earth-abundant, clean and environment-friendly. Solar energy is the most effective form in all sources of energy cause sun energy is continuously incident on the earth surface. Chapin, Fuller, and Pearson were firstly proposed the photovoltaic cell structure where the cell performance was about 6% efficient [2]. With the improvement in the solar cell by the researchers, the hidden potentiality was investigated to increase the performance in a reasonable value. Presently, potential candidate of different types of solar cells are available and many types have been investigated under the development which is low cost, thermally stable and higher performance such as SnS [3], AlSb [4], GaAs [5, 6] , MoS_2 [7] and FeS_2 [8], CdSe [9, 10]

Semiconductor materials are mostly used for the manufacturing of solar photovoltaic device. GaInP is an III-V based homo-junction partner semiconductor material to use as an n-type and p-type in photovoltaic device application. GaInP is the most attractive materials due to it have a high band gap of about 1.9 eV [11] and larger absorption coefficient [12] which absorbs maximum incident photon with a few µm thicknesses. Moreover, it is non-toxic, cost effective and thermally stable solar photovoltaic device to produce an environment friendly clean and green energy. So it is convenient form for modelling of solar cells structure. Many researchers have more concern on the GaInP material for its wide range properties which shows the better performance in the solar cell. GaInP solar cell has been used as a top cell in the multijunction solar cell [13]. In 2005, Takamoto et al. published their paper on single junction GaInP solar cell reporting an efficiency of 18.48% [14]. Stephanie Essig et al. demonstrated the 18.54% cell efficiency for the top GaInP solar cell [15] and then the 20.8% efficiency was overcome by J.F. Geisz et al. [16]. Krishanu reported a cell conversion efficiency of 28.139% for single junction GaInP solar cell [17].

In this research work, a single junction solar cell with the configuration of ZnO/AlInP/GaInP/GaInP/GaInP/GaInP/Mo was analysed by using wxAMPS simulator software to design the high efficiency, thermally stable and low cost solar cells. The influence of the transparent conducting oxide (TCO) layer, thickness variation of the window layer, emitter, base layer and back surface field layer was investigated to explore the higher performance single junction GaInP solar cell.

II. DEVICE STRUCTURE OF THE SIMULATED SOLAR CELL

Fig. 1 illustrated the structure of single junction GaInP solar cell with optimized the each functional layer in GaInP solar cell. The overall cell performance was numerically analysed by wxAMPS (Analysis of Microelectronic and Photonic Structures with wxWidgets) simulation software.

For the numerical analysis on the cell performance of a solar cell, Poisson's equation can be expressed by the following equation:

$$\frac{d}{d_x}\left(\varepsilon(X)\frac{d\psi}{dx}\right)=q^*\left[p(X)-n(X)+N_D^{\ +}(X)-N_A^{\ -}(X)+p_t(X)-n_t(X)\right]$$

Where, ψ = electrostatic potential; n,p= free electron and hole and n_t,p_t= are the trapped electron and hole. All are the function are co-ordinate of *X.* The continuity equation for electron and hole given as follows:

$$\frac{1}{q}\left(\frac{dJn}{dx}\right)=-G_{op}(X)+R(X) \qquad \text{For electron}$$

$$\frac{1}{q}\left(\frac{dJp}{dx}\right)=G_{op}(X)-R(X) \qquad \text{For hole}$$

In this simulation work a top GaInP solar cell was modelled where 0.01μm ZnO as TCO layer is placed on the AlInP window layer which is 0.025 μm thick and 0.03 μm thick GaInP BSF layer is inserted between GaInP absorber layer and molybdenum (Mo) has been selected as a back contact metal in the single junction GaInP solar cell. The conversion efficiency of single junction GaInP solar cells was developed by including a ZnO TCO layer and AlInP window layer, thinning the thickness of emitter layer up to 30 nm with suitable GaInP absorber layer thickness.

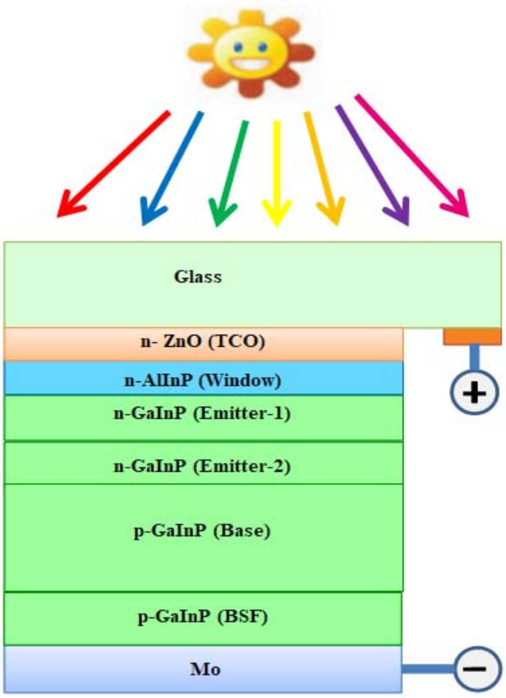

Fig. 1: Schematic structure of single junction GaInP solar cell

The values of material parameters of every layer and for this single junction GaInP solar cell junction solar cell used in simulation work which were based literature review and investigational data that are described in Table I [18-20].

TABLE I MATERIAL PARAMETERS VALUES AS USED IN THE SIMULATION

Parameter	ZnO	AlInP	GaInP
Band gap, E_g (ev)	3.37	2.4	1.9
Affinity, χ (eV)	4.35	4.2	4.16
Relative permittivity, ε_r	10	11.7	11.80
Density of states in conduction band, N_C (cm^{-3})	2.2×10^{18}	1.08×10^{20}	1.54×10^{19}
Density of states in valance band, N_V (cm^{-3})	1.78×10^{19}	1.28×10^{19}	1.45×10^{19}
Electron mobility, μ_c (cm^2/Vs)	100	2291	1945
Hole mobility, μ_p (cm^2/Vs)	25	142	141
Doping concentration (cm^{-3})	1.00×10^{20}	1.00×10^{20}	1.00×10^{19}

III. RESULTS AND DISCUSSION

A. Effect of the presence of n-ZnO layer

In order to investigate the presence of TCO layer on cell performance of single junction GaInP solar cell as first, simulations has been done by incorporating n-ZnO layer and without n-ZnO layer. It is shows in Table II that the better efficiency is found 29.47% where open circuit voltage is 1.14 V, current density is of 24.57 (mA/cm^2) and fill factor is of 0.813 for incorporated n-ZnO layer in the single junction GaInP solar cell.

TABLE I I EFFECT OF N-ZNO LAYER IN SINGLE JUNCTION GAINP SOLAR CELL MEASURED UNDER 1SUN CONDITIONS

Device Structure / Parameter	V_{oc} (V)	J_{sc} (mA/cm^2)	FF	η (%)
Without ZnO	1.03	21.42	0.852	27.82
With ZnO	1.14	24.57	0.813	29.47

B. *Effect of n-AlInP window layer thickness*

The impact of AlInP window layer of first cell on cell performance has been investigated numerically by varying the thickness from 19 nm to 29 nm. The thickness of AlInP window layer is fixed at 25 nm because the efficiency is not increased further with increment of AlInP layer thickness. The simulated result is showed in Fig. 2.

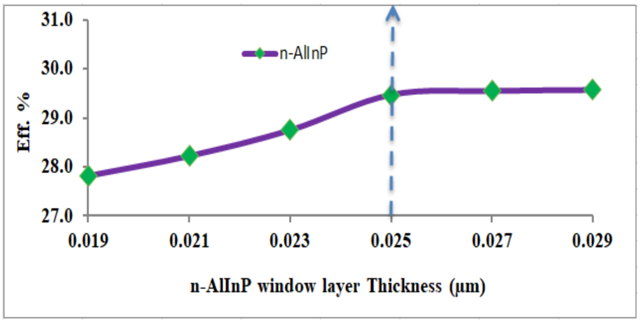

Fig. 2: Effect of AlInP window layer thickness on cell performance

C. *Effect of n-GaInP emitter layer thickness*

In order to optimize the GaInP emitter 1 and emitter 2 layer thickness of cell numerically investigated by varying their layer thickness from 10 nm to 35 nm. The thickness of both emitter1 and 2 layers are set at 30 nm. Fig. 3 and 4 presented the simulated result for GaInP emitter 1 and emitter 2 layers. Both figure shows that the efficiency of the cell has been increased with the increment of emitter layers thickness but the cell efficiency is sharply increases in emitter 2 rather than emitter 1.

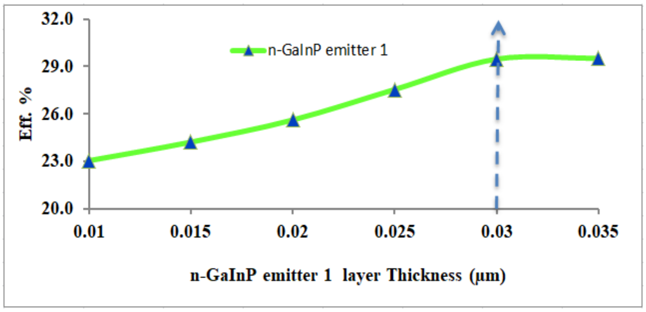

Fig. 3: Effect of GaInP emitter 1 layer thickness on cell performance

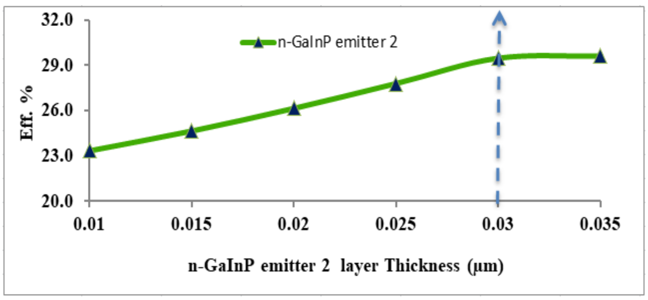

Fig. 4: Effect of GaInP emitter 2 layer thickness on cell performance

D. *Effect of GaInP BSF layer thickness*

The GaInP BSF layer is inserted in between the GaInP absorber layer and back contact. Fig. 5 describes the impact of GaInP BSF layer thickness with GaInP absorber layer on cell performance parameters. The BSF layer is varied from 10 nm to 60 nm.

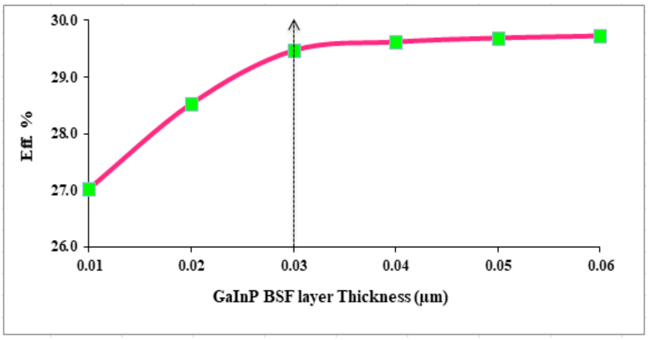

Fig. 5: Effect of GaInP BSF layer thickness on cell performance

It is seen from the figure above that the cell conversion efficiency is increased sharply with increases of the GaInP BSF layer thickness at 30 nm then the efficiency is increased with slowly.

E. *Effect of GaInP absorber layer thickness*

The cell performance characteristic of single junction GaInP solar cell is investigated by varying the GaInP absorber thickness from 400 nm to 650 nm. The simulated result is presented in Fig. 6.

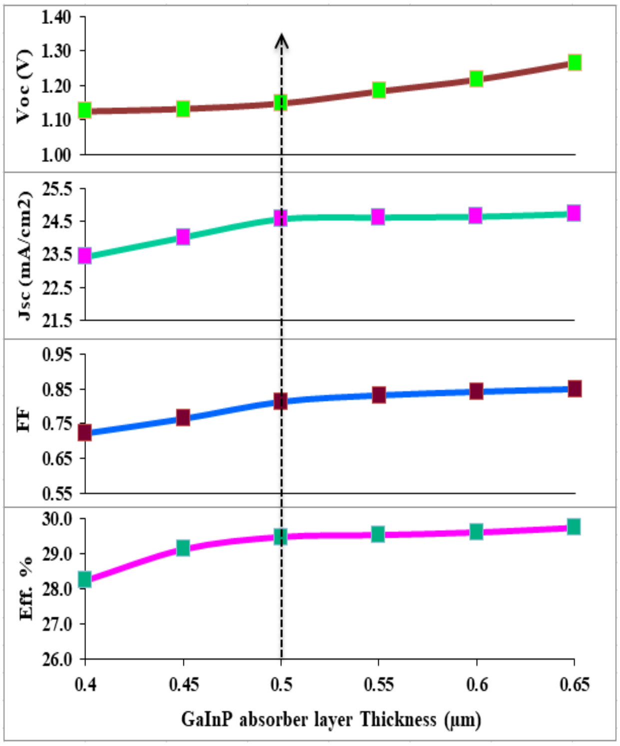

Fig. 6: Effect of GaInP absorber layer thickness on cell performance

From Fig. 6 it is observed that the cell conversion efficiency and current density is increased at a same trend with the increment of GaInP absorber layer thickness up to 500 nm thickness then almost same. The Open circuit voltage and FF both increased sharply with increase in thickness. It is evident that the overall cell conversion efficiency of 29.47% has obtained at 500 nm GaInP absorber layer with 30 nm GaInP BSF layer.

The J-V characteristics curve of the top GaInP solar cell is shown in Fig.7 where the simulated results on the cell performance 29.47% showed good agreement to the related published work [17]. The cell performance optimized at 500 nm GaAs absorber layer and 0.01µm of ZnO layer with 0.03 µm of BSF. The modelled cell also requires the less material to fulfil the requirement of thin film technology.

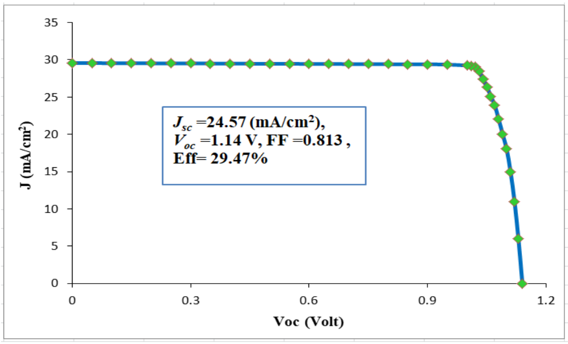

Fig. 7: J-V characteristics curve of single junction GaInP solar cell

F. *Effect of Operating temperature*

The thermal stability of the single junction GaInP solar cell has been investigated numerically by varying different operating temperature in the range of 20°C to 100°C where other using parameters kept in constant. The operating temperature was kept at 25°C in the simulation. The performance of this solar cell with different operating temperature is shown in Fig. 6. From this figure it is shown that the normalized efficiency of the single junction GaInP solar cell decreased a little amount at a -0.03%/°C of temperature coefficient (TC) with increased of the operating temperature.

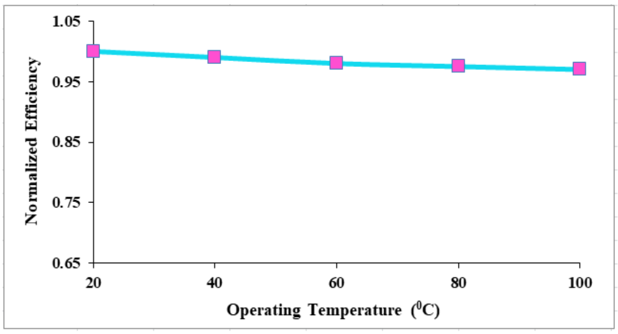

Fig. 8: Effect of the operating temperature on the cell performance of single junction GaInP solar cell

IV. Conclusions

GaInP is the most promising material for the solar photovoltaic application due to its material availability, cost effectiveness, thermally stable. This research work evaluate the hidden potentiality of single junction GaInP where the higher cell conversion efficiency was attained 29.47% (J_{sc} = 24.57mA/cm^2, FF = 0.813, V_{oc} = 1.14 V) with ZnO as TCO layer. In this case for optimized the cell performance with material preservation 500nm of absorber layer and 25 nm of AlInp window layer was taken. It also showed that the cell conversion efficiency was better with ZnO TCO layer that the without TCO layer. The thermal stability of the optimized single junction GaInP solar cell showed the better performance in the higher operating temperature with a gradient of -0.03%/°C. It has been showed that the single junction showed the better performance with absorbs a part of solar spectrum whereas the double junction or triple or four junction may be utilized a maximum spectrum than the single junction.

Acknowledgments

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