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Numerical Analysis of Single junction InGaP/GaAs Solar Cell with BSF layer

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Abstract- *This paper represents the feasibility & potentiality of GaAs heterojunction solar cell with InGaP as buffer layer. GaAs is an important III-V compound semiconductor material used in solar cells for high bandwidth of 1.42eV which allows it for high photon absorption & high power conversion efficiency. Moreover, it has a direct bandgap which means that transition between valance band and conduction band requires only a change in energy. In this research work only numerical investigation was done. By simulating the proposed heterojunction cell with BSF layer an power conversion efficiency of 27.684%, short circuit current density of 28.078mA/cm^2, open circuit voltage of 1.15V and fill factor of 85.6% was obtained under optimization which is higher than the duel junction InGaP/GaAs hetero structure reported before. At the end, the effect of temperature and lifetime parameter variation on the optimised heterojunction solar cell has been investigated and it is found that the cell performance degrades with operating temperature at a gradient of -0.036/^{o} C which indicates that the cell is thermally stable.*

Keywords: GaAs solar cell, InGaP buffer layer, BSF layer, Heterojunction , Optimization, Thermal stability.

1. INTRODUCTION

Energy crisis has become one of the most burning question today. With increased population of the world increases the demand and usage of energy. Conventional sources are running out of reserves because of their excessive usage to fulfil the demand of the people. As a result global coal production decreased by 6.2% whereas renewable power grew by 14.1% [1]. Other conventional energy resources are also diminishing day by day because of their limited reserves. So to say there is an immediate emergency to shift our interest of energy consumption towards the renewable resources to meet our energy demand and to make the environment pollution free. Solar cell is most promising source of energy as sunlight is abundant in nature and it doesn't run out with time. Moreover it is environment friendly and can convert the energy in photon into electricity in most efficient way. Semiconductor materials are most well suited for fabricating solar cell devices. For modelling solar cells we must choose material that is efficient, non-toxic, cost effective and stable in nature.

There has been a large interest on development of thin film technology where GaAs is a top contender for it's higher light absorption, thermal stability and direct band gap of 1.42eV. It's higher band-gap makes it highly resistive in combination with high dielectric constant. GaAs has a higher saturated electron velocity and higher electron mobility. Moreover, its' direct band-gap gives it advantage over silicon in absorbing light more efficiently [2].

The single junction GaAs solar cells have been investigated by photovoltaics lab since 1994 [3]. Previously GaAs solar cell was first developed in 1970[4]. Alta Device produces most efficient GaAs single junction solar cell having efficiency about 28% by a unique method called photon recycling [5, 6]. However, several researches has been carried out to improve the efficiency of GaAs solar cell and development of new technique of fabrication has been evaluated. A research on GaAs based solar cell using AlGaAs as window and BSF layer optimized the characteristic curve using MATLAB and found an effective efficiency of 16.02%[7]. Another research work explored the photonic crystal structure of GaAs rods surrounding SiO_2 and found high efficiency of 27.69%[8] . However based on recent research on 2016 a metal combination of AuBe/Pt/Au is employed as a new p-type metal contact with which an n-on-p single-junction GaAs thin-film solar cell on flexible substrate was successfully fabricated and an efficiency of 22.08% was achieved [9].

Various InGaP/GaAs heterojunction and multijunction cell have been fabricated and simulated to increase the PCE because it is a proven structure for solar application. Paper thin InGaP/GaAs solar cell has been fabricated by introducing a tunnel junction between top and bottom cell and achieved efficiency of about 22% [10]. Another GaAs single junction solar cell was fabricated by LPE with n-AlGaAs BSF and p-AlGaAs window layer and measured efficiency was 26.2% at 1000 sun and 25.0% at 2000 sun [11]. A recent study shows a numerical simulation based comparison between duel junction InGaP/GaAs and triple junction InGaP/GaAs/Ge with BSF and window layer. Tunnelling was done in between the junctions to increase the number of photons absorbed. The maximum power conversion efficiency for duel junction is 23.33% and for triple junction is 32.11% [12].

In this research work numerical simulation was done for n-InGaP/ p-GaAs with p doped InGaP back surface field layer because highly doped InGaP BSF layers are proven to reduce resistive loss when InGaP is used as a top cell [13]. The BSF layer was kept fixed at 100nm at a doping concentration of 1×1019 cm-3. And the thickness and doping concentration of GaAs absorber layer was varied. The back contact of the cell was also optimised. Finally, the thermal stability and effect of lifetime was investigated.

2. Device Structure and Simulation

Fig. 1 shows the device structure of the proposed heterojunction InGap/GaAs solar cell with back surface field layer and optimized back contact. The overall numerical analysis was done by using computer programmed simulation software AMPS-1D. In this research work Lifetime model was chosen instead of DOS model.

For numerical analysis, poisson's equation can be written as follows for one dimension:

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

Where ψ is the electrostatic potential, n is free electron, p is free hole, n_t is the trapped electron and p_t is the trapped hole all are the function of co-ordinate *X*.

Continuity equation for free electron and free hole in valance band and conduction band is given as follows:

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

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

In this simulation process a top layer n-InGaP buffer was modelled beneath which a p-GaAs absorber layer is situated to form a p-n hetero structure. The p-n single junction is modelled on top of a InGaP BSF layer to reduce the resistive loss. P-GaAs absorber layer was varied from .5 µm to 5µm and n-GaAs buffer layer was varied from 10nm to 100nm keeping all other parameters fixed. The doping concentration and back contact was also optimized.

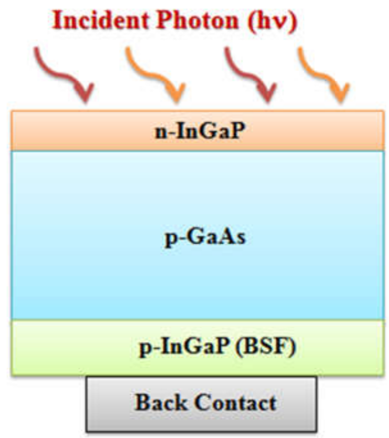

Fig.1 Device structure of simulated cell

Material parameters of GaAs used in this research work are given below in Table I. The thickness of n layer was optimized at 60nm and BSF layer thickness was kept fixed at 100nm. The numerical simulation was carried out on the basis of this material parameter which is found by literature review to observe the effect of cell performance [14].

TABLE I PARAMETERS USED FOR NUMERICAL ANALYSIS OF GALLIUM ARSENIDE SOLAR CELL

Material Parameters	n-InGaP	p-GaAs	p-InGaP (BSF)
Thickness, D (µm)	.06	0.5- 5	0.1
Band gap, Eg (eV)	1.74	1.42	1.74
Electron mobility, µn (cm^2/Vs)	1000	8500	1000
Hole mobility, µp (cm^2/Vs)	35	400	35
Free carrier concentration n,p(cm^{-3})	$1E10^{19}$	$1E10^{17}$	$1E10^{19}$
Density of state in conduction band, Nc (cm^{-3})	$1.54E10^{19}$	$4.77E10^{17}$	$1.54E10^{19}$
Density of state in valence band, Nv (cm^{-3})	$1.45E10^{19}$	$7.5E10^{18}$	$1.45E10^{19}$
Dielectric constant, ε_r	11.80	13.10	11.80
Electron affinity, χ (eV)	4.09	4.07	4.09

From the simulated cell 27.684% power conversion efficiency, 1.15V open circuit voltage (Voc) , 28.078 mA cm-2 short circuit current density (Jsc), 0.856 fill factor (FF) are achieved

3. RESULT AND DISCUSSION

3.1 Absorber Layer Thickness Variation of the Solar Cell

Effect of p-GaAs layer thickness was observed by varying the layer thickness from 0.5µm to 5µm while keeping the other parameters constant. Fig. 2 shows the variation of all the output performance parameter with respect to absorber layer thickness variation. The performance of the proposed cell improves with increasing thickness as more and more photons are absorbed.

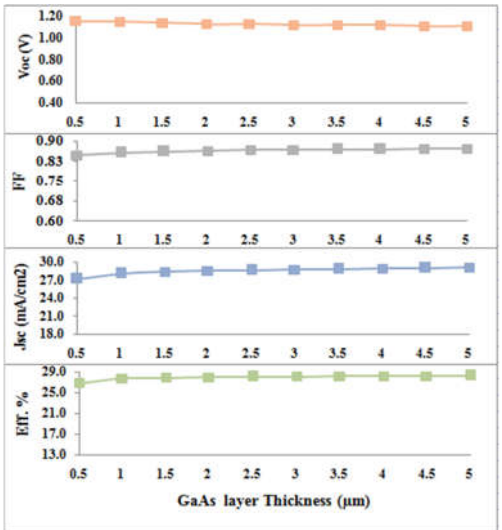

Fig. 2 Variation of absorber layer thickness of the proposed model

From fig. 2 it has been found that short circuit current density (J_{sc}) and efficiency rises with increasing p layer thickness and reaches saturation after certain variation of thickness. Short circuit current density increases more sharply than efficiency. Fill factor (FF) remains almost constant throughout the entire variation. Open circuit voltage (Voc) decreases linearly with the increasing thickness. As our main motive is to maximize the power conversion efficiency, increased thickness of p-layer is necessary. But material preservation specially a costly material like GaAs is also an important consideration. It is seen from the curve that the power conversion efficiency of the modelled cell reaches saturation after 3µm of absorber layer thickness. After this certain limit increase in efficiency of the cell is not prominent. So, as a requirement of the thin film solar cell and ease of fabrication the layer thickness was optimized at 1µm.

2.2 Doping Concentration of the Solar Cell

In this research work to investigate the effect of doping concentration on the performance parameter and PCE simulation process was done by varying the doping concentration of both p and n layer form 1×10^{11} to 1×10^{17}.

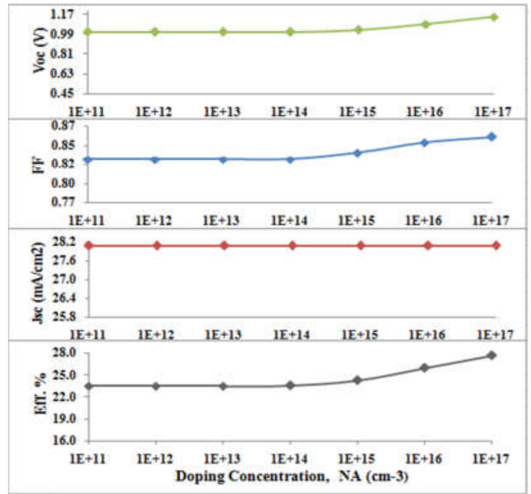

Fig.3 Effect of the GaAs doping concentration on cell performance

Fig. 3 shows that efficiency of the proposed cell remains constant upto 1×10^{14} cm^{-3} then it starts to increase with doping concentration and it is highest at -1×10^{17} $cm^{-3.}$ J_{sc} remains constant throughout the entire variation. Fill factor follows similar trend as efficiency and is highest at 1×10^{17} cm^{-3}. In this case open circuit voltage (V_{oc}) increases with doping concentration upto 1×10^{14} cm^{-3}. Then it starts to increase further. However, considering power conversion efficiency and all other performance parameters, the doping concentration of the absorber layer was optimized at 1×10^{17} cm^{-3}.

2.3 Temperature Variation of the Solar Cell

Fig. 4 describes the effect of temperature on the performance parameter of the solar cell. The operating temperature was varied from 20°C to 100°C. The temperature variation of the solar cell is necessary to find out the thermal stability and how the performance of the cell degrades with ageing. If it is limited to a definite value then the cell is stable. The variation of cell performance parameter indicates the stability of the solar cell.

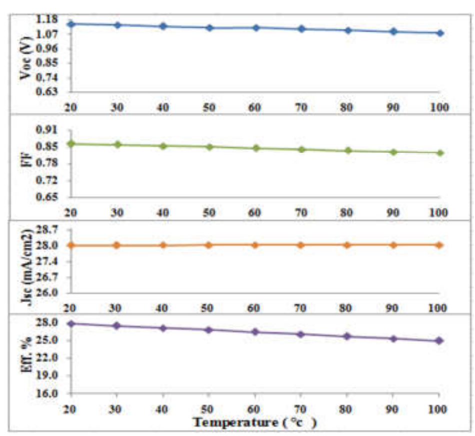

Fig.4 Effect of temperature variation on cell performances

The graphs shows that efficiency, open circuit voltage(Voc) and fill factor of the cell decays with increasing temperature but short circuit current density remains almost constant throughout the entire variation. So the cell performance shows an inverse relationship with the increasing operating temperature. From figure it can be said maximum efficiency of the cell occurs at low temperature. Here, the cell works efficiently at 20°C. But by considering the overall atmospheric condition that the cell has to tolerate, it is kept at 25°C. The normalized efficiency variation with respect to temperature is also investigated.

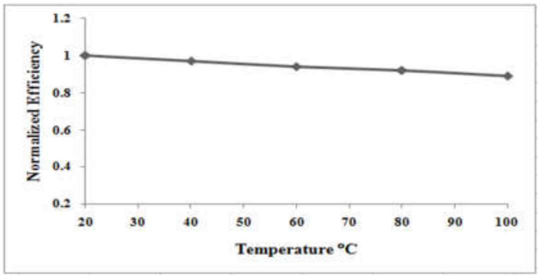

Fig.5 Effect of operating temperature on normalized efficiency

Fig.5 shows the effect of variation of temperature from 20°C to 100°C on normalized efficiency. From the above mentioned graph and calculation of overall simulation result it has been found that the cell performance parameter degrades with operating temperature with a gradient of -3.6%/°C.

2.4 Lifetime Variation of the Solar Cell

Majority carrier lifetime of GaAs layer in nanoseconds is varied to observe the effect of carrier lifetime on cell performance. Lifetime was varied from 10ns to 100ns to observe the effect. The cell shows a low performance at 10ns carrier lifetime and better performance at 100ns. Fig. 6 shows the effect of carrier lifetime on cell performance.

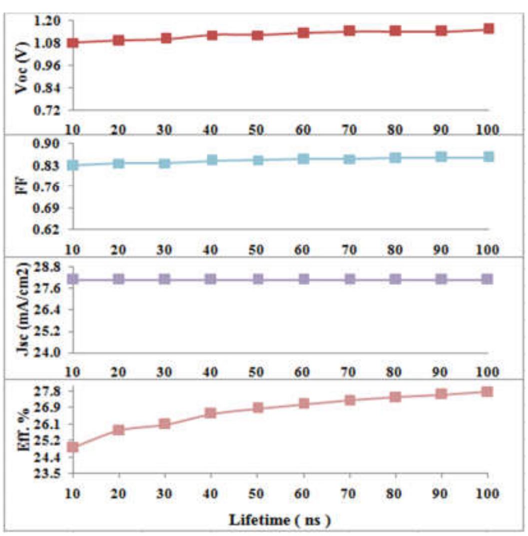

Fig. 6 Effect of lifetime variation on cell performances

From the figure, it can be observed that efficiency shows a linear relationship with lifetime parameter. J_{sc} and fill factor remains unchanged with increasing lifetime. But V_{oc} increases upto 50ns of increasing lifetime and becomes constant. By considering all the parameters the cell was optimized at carrier lifetime of 100ns.

4. Optimized Results

This research work was aimed at optimizing the hetero junction InGaP/GaAs solar cell. Simulation work was carried out with back surface field layer to reduce the resistive loss. BSF of p doped InGaP acts as an outstanding mirror for minority carrier. In this research work a high performance of modelled solar cell has been achieved with 100nm of BSF layer. The absorber p-GaAs layer was optimized at 1000nm and the buffer n-GaAs was optimized at 60nm which ensures material preservation. Table II shows optimized performance of the solar cell under all the optimization mentioned above.

TABLE II OPTIMIZED OUTPUT PARAMETERS OF THE PROPOSED CELL

Output parameters	Value of the parameters with BSF layer
Jsc mA/cm^{-2}	28.078
Voc volt	1.15
FF	0.856
Eff. (%)	27.684

The J-V characteristics curve of the solar cell with is shown in Fig. 7 which shows 27.684% efficiency which is higher than the InGaP/GaAs duel junction solar cell reported before. The cell optimizes at 1000nm of absorber GaAs layer and 60nm of InGaP layer with 100nm of BSF. The modelled cell also requires less material to fulfil the requirement of thin film technology.

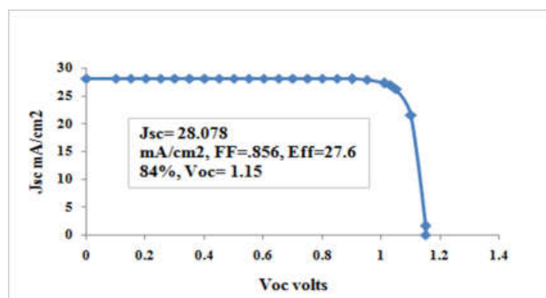

Fig. 7 J-V curve of 27.684% InGap/GaAs single junction solar cell

4. CONCLUSION

This research work explores the potentiality of InGaP/ GaAs single hetero junction solar cell with BSF layer. The power conversion efficiency is 27.684% (Jsc=28.078mA/cm^{-2}, Voc=1.15V, FF=0.856). In this case for optimization and material preservation 1000nm of absorber p layer and 60nm of n buffer layer has been taken. p-doped InGaP is used as back surface field layer which is kept at a fixed thickness of 100nm. The optimized cell also shows a better thermal stability at a gradient of -3.6%/°C.

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