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Purposeful scientific research is a basic pillar for the advancement of Iraq

Numerical analysis of heterojunction AlGaAs/ InP thin film solar cell

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ABSTRACT

High efficiency solar cells are the aim sought by the efforts of researchers due to obtain a clean energy that can face climate changes. In this research a solar cell was designed that contains There are four layers a window layer emitter layer absorber layer and back surface filed layer. The PCID software was used to simulate the solar cell. Where the effect of thickness and the concentration of doping of window layer was studied within the range (0-1) µm, (10^{17}-10^{20}) cm^{-3}, respectively, also the concentration of impurities and value of thickness movables on I-V characteristic of solar cell, and output parameters like Isc, Voc and η. It recorded the best efficiency 30.1 % at thickness and doping concentration,0.02µm and 1.39×10^{20} cm-3, ,respectively. The consequence of both of the thickness value and the impurities concentration of the absorbs layer within the area (0-5) µm and $10^{15}cm^{-3}$ to $10^{20}cm^{-3}$, respectively, was also studied. The best values for thickness and doping level were 1.837µm, and 6.87×10^{15} cm^{-3}, respectively.

Keyword: AlGaAs/InP, Solar cell, heterojunction, thin films, pc1d software

1. Introduction

Our world is facing huge challenge in producing sufficient energy without harming our environment. Scientists, researchers and thinkers came to an agreement that the world needs to cut its carbon dioxide emissions in order to prevent or lessen the impact of global warming [1, 4]. The use of conventional energy sources in powerplants, automobiles and other machineries are the primary cause of huge carbon dioxide deposits in our atmosphere which in turn causes a global rise in temperature which causes an increase in natural disasters around the world. This led to a consensus between various developed nations to promote certain policies which will lead to sustainable developments. One of the most important solution in this global crisis is the use of renewable energy systems [1]. According to the Renewable Energy Statistics published by International Renewable Energy Agency (IRENA), the use of renewable energy systems skyrocketed in the past few decades amounting to a total capacity of more than 2 million megawatts (MW) in 2016 [5].

All This relating to the production of electric current at the junction Photovoltaic technology converts the solar or light energy into electrical energy without any consumption of conventional form of energy and hence the global photovoltaic market is successful over the decades ago [6].The main issue of this technology is low conversion ratio of solar energy into electrical form. Prior optimization of various parameters leading to increase in its efficiency is done [7]. III-V compounds have become the basic materials for modern optoelectronic devices. III-V compounds such as gallium arsenide (GaAs), Aluminum Gallium Arsenide (AlGaAs), and Indium Phosphide (InP) have the characteristics that allow fabrication of high efficiency solar cells. Some of the characteristics of these materials have direct transmission energy gaps , high optical absorption coefficients, and a suitable note values of minority carrier lifetimes and the mobility [7]. The one - junction solar cell has a limitation in being able to efficiently utilize photons of the broad spectrum from (300 nm to 1200 nm).As if we say, in the case of (Si) solar cell, it cannot absorb a photon with a wavelength greater than (1000 nm),which accounts for more than (20%) of the standard terrene normal radiation at air mass (AM1.5) [6], and we must know the wavelengths at the ultraviolet region are not efficiently converted to Si solar because solar cell only converts photons of higher wavelengths than ultraviolet. the stacking solar cells are made by different materials (different power bandgap) together and has proven to be a suitable techneqe to increase the efficiencies of the solar cells, and several researches groups have proposed several devices made from a stack of single junction cells [7].Based on the foregoing , two materials in this research with energy gaps close to AlGaAs (1.817eV) and InP (1.35 eV) were selected to obtain a highly efficient solar cell.

2. Numerical equation of PC1D program

The PC1D digital simulation way has been use the semiconductor transfer equations as the basic relationships that derived from the (Boltzmann transformation formula).The values of electrons and holes densities J_n and J_p are calculated by the equations (1) and (2). Where (μ_n, μ_p) refers to mobility of electrons and holes respectively and (EFn, Efp) are(quasi-Fermi) energies for electrons and holes [8].

$$J_p = \mu_p . p \nabla E_{FP} \ldots (1)$$

$$J_n = \mu_n . n \nabla E_{Fn} \quad \ldots . (2)$$

$$n = N_c e^{-\frac{(E_c - E_{Fn})}{KT}} \ldots (3)$$

$$P = N_v e^{-\frac{(E_{Fp} - E_v)}{KT}} \ldots (4)$$

In equs (3) and (4), the terms Nc, Nv denote the effective densities of states in both of conduction valence bands. Also the terms E_c, E_v refer to the conduction band energy and valance band energy.

$$\frac{\partial n}{\partial t} = \frac{\nabla J_n}{q} + G_L - U_n \ldots (5)$$

$$\frac{\partial p}{\partial t} = -\frac{\nabla J_p}{q} + G_L - U_p \quad \ldots (6)$$

Also we have been see equats 5and 6 which they uaually the above two determine the number of charge carriers entering a given volume of space. The letter (U_n) refer to net value for the rate of recombination of electrons, And the letter (U_p) refers the net value of recombination rate of holes, (G_L) refers to created electron-hole pairs in a certain size because of photogeneration.

The term of fill factor (FF) can be defined "the ratio between maximum produced power by solar cell and the product of multiplication between open circuit voltage and short circuit current. [9].

$$FF\% = \frac{V_{oc} - \ln(V_{oc} + 0.72)}{V_{oc} + 1} \ldots (7)$$

The value conversion Efficiency can be calculated by equation below [4]

$$\eta = \frac{V_{oc} \times I_{sc} \times FF}{P_{in}} \ldots (8)$$

Where: Voc is open circuit voltage, Isc: short circuit current , Pin incident light power.

the cell Photogeneration proses can be found by applying the equation below

$$G = \alpha N_o e^{-\alpha x} \ldots (9)$$

No: flux of photons on the surface, x: distance of photon way inside the material, : absorption coefficient.

The in-cell model uses the Shockley Read hall formula with different charge carriers life times and a trap energy level that could be adjusted inside the band gap. Shockley Reading Hall's equation appears at the equation (10).

$$R = \frac{pn - n_i^2}{\tau_{n0}\left(p + n_i e^{-\frac{E_t}{KT}}\right) + \tau_{po}\left(n + n_i e^{\frac{E_t}{KT}}\right)} \ldots (10)$$

Where (n_i) is concentrationof effective intrinsic carrier, τ_{n0} eloectron Bulk lifetime, (τ_{po}) holes bulk lifetime, E_t level of trap energy .

3. Methodology

PC1D (One-Dimensional Personal Computer) digital simulation software is widely used in solar cell simulation. This program developed at South Wales University, Sydney, Australia. It simulates the behavior of the structure of semiconductor solar cells by respecting one dimension (axial symmetry) [10]. In fact, we have run many simulations to see the effect of different factors on solar energy efficiency cells. By this research, a four layer solar cell designed , byN- AlGaAs as a matter of fact window layered , N- InP emitter layer, P- InP as a standard layer and P-AlGaAs as a back surface filed (BSF) layer despite shown in figure (1). In order to obtain the highest efficiency of solar cells by studying the effect of thickness and concentration of impurities owing to window and base. Value of window layer thickness was subsequently changed from (0 to1 μm) by icon batch in pcid program, while other parameters were kept constant. Absorber layer thickness was subsequently varied from (0-5) μm while other parameters were kept constant. Background torpidity for overture and base stratum were varied from (10^{17}-10^{20}) cm^{-3} and (10^{15}-10^{20}) cm^{-3}., respectively.

Front Contact
Window layer (N- type AlGaAS)
Emitter layer(N-type InP)
Absorber layer (P-type InP)
Back Surface field BSF (P- type AlGaAs)
Back Contact

Fig. 1: Device structure of solar cell.

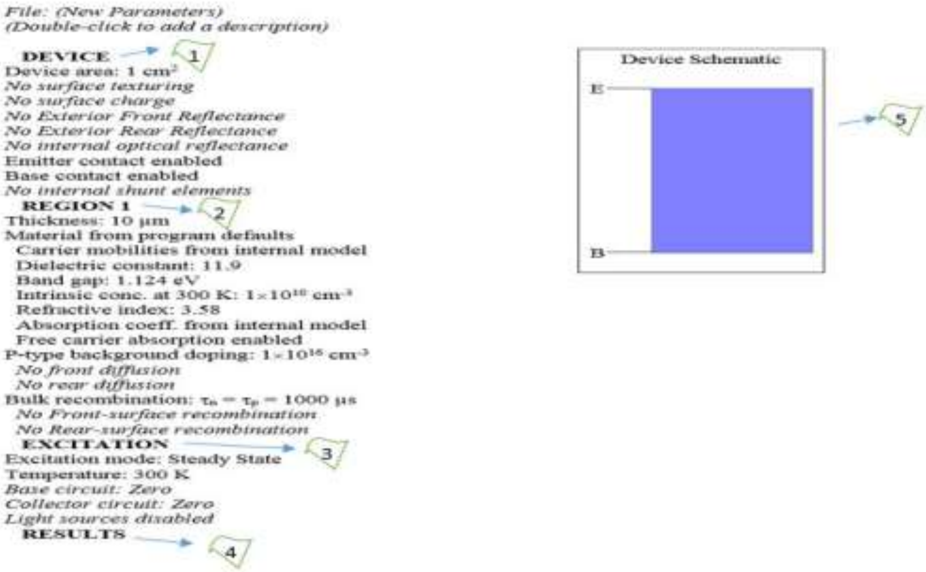

Fig. 2: Main Window of PC1D

After simulation for AlGaAs/InP solar cell, by parameters as shown in table (1), using PC1D program, where to obtained on the optimizing of thickness and doping concentration level.

Table 1: parameters of solar cell.

Parameters	Value
Device area	1cm^2
Thickness window layer N-AlGaAs	0.020 μm
Thickness emitter layer N- InP	0.102 μm
Thickness absorber layer P- InP	1.837μm
Thickness BSF layer P- AlGaAs	0.04 μm
Back ground doping N- AlGaAs	1.39 ×10^{19}cm^{-3}
Back ground doping N- InP	1×10^{14} cm^{-3}
Back ground doping P- InP	6.87×10^{15} cm^{-3}
Back ground doping P- AlGaAs	3.91×10^{15} cm^{-3}
Band gap of AlGaAs	1.817 eV
Band gap of InP	1.35 eV
fundamental concentration at T=300K of AlGaAs	1754 cm^{-3}
Intrinsic concentration at T=300K of InP	8×10^6 cm^{-3}
Refractive indicator of AlGaAs	3.81
Refractive indicator of InP	3.45
Bulk the process of combining things	$\tau_n = \tau_p$=1000μs
Temperature of device	25 C^0
Primary light exporter	AM 1.5g spectrum
excitement Mode	Transient
Base loop	Sweep from -8 to 5 V

4. Results and Discussion

4. 1. I-V curve Characteristic

After inserting the input parameters of the structure n-AlGaAs/ n-InP/p-InP/p-AlGaAs. The obtained results I-V curve is represented in figure (3). The turn loop voltage (V_{OC}), low loop current (I_{SC}), and utmost power (Pmax) in simulation are used to calculate the fill factor and solar cell efficiency. Photovoltaic simulation result under standard test conditions, temperature 25 °C, radiation 0.1 m W/cm^2, and AM1.5G, as shown in Figure 3. With this condition, the current (I_{SC}) is 32.8 mA, voltage (V_{OC}) 1.038V, maximum power 0.0301W with fill factor (FF) 88.5% and efficiency 30.1%.

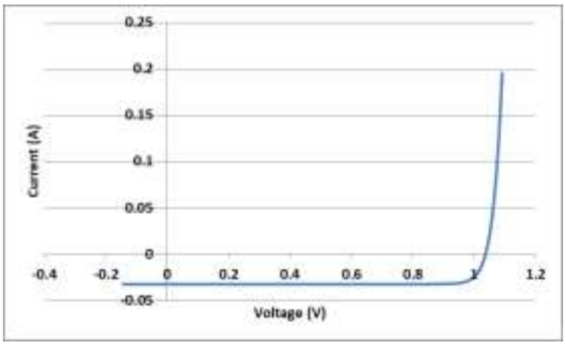

Fig. 3: Current- Voltage curve of a typical solar cell.

4.2 Influence of window layer thickness and doping concentration

To investigate the influence that can have the light layer AlGaAs on the overall solar cell performance, some factors, like thickness and doping concentration levels have been changed from 0 µm to 1 µm and from2.02× 10^{17} to 10^{20} cm^{-3}, respectively. Figures (4) show the relationship between the short circuit current and the open circuit voltage with the window layer thickness. where we note that the short circuit current gradually decrease from32.76mA to 18.74mA with increase coalescence of the window stratum of 0 µm to 1 µm and was the highest value of the Isc is 32.76mA at thickness 0.02 µm. Open circuit voltage was 1.0379 V and then decreased slightly to 1.023 V with increase of the light layer. As for the conversion efficiency the highest value was 30.1% at window thickness 0.02 µm, then it gradually decreased with increasing thickness of window layer. As shown in figure (5 Because of the increase in thickness, more photons are digested into the cell. Which leads to an increase in the optical generation rate at the window layer? Moreover, the increase in window layer thickness would lead to a decrease in the number of photons that have reached the base layer and give a share into the photovoltaic conversion. Genuine sin can further the process of recombining things. The rate of charge carriers reduces the solar cell electrical parameters values, because of high recombination at the surface, the thickness of the window layer should be narrow. Therefore, both the short circuit current and transference efficiency of the solar cell decrease with an increase in the value of the light thickness of the window layer should be narrow. Therefore, both short circuit current and conversion effectiveness of the solar cell decrease with an increase in the value of window thickness [11]. figure (6) the effect of doping concentration in the window layer by conversion efficiency is represented. we observed that the conversion efficiency starts to increase after doping level $10^{18}cm^{-3}$ and then almost stabilizes upon doping level $10^{19}cm^{-3}$.

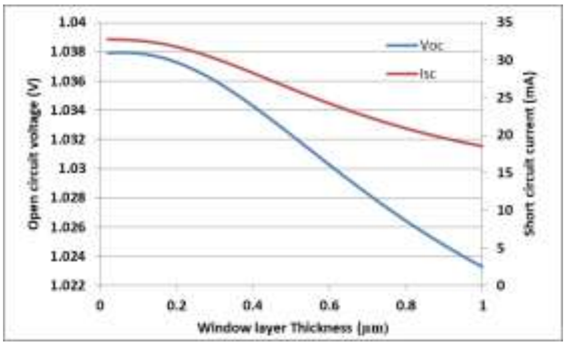

Fig. 4: Open circuit voltage and short circuit current as a function of window layer thickness

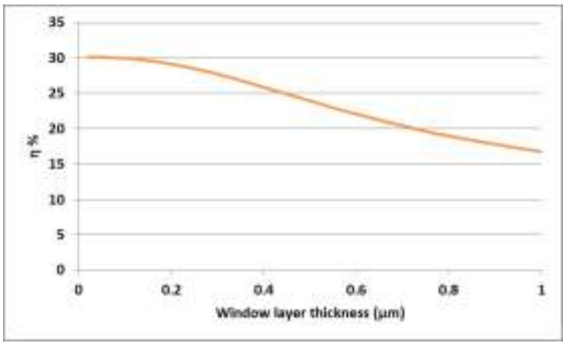

Fig. 5: changing of solar cell efficiency with the window layer thickness

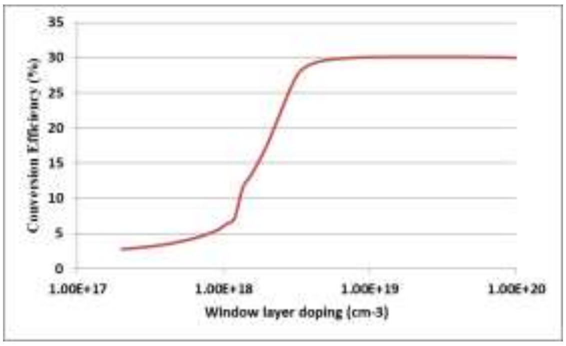

Fig. 6: changing of solar cell efficiency with doping concentration

4.3 Influence of absorber layer thickness and doping concentration

Figure (7) shown the changing of short circuit current and open circuit voltage when the thickness of the window layer changes. As the concentration of the absorber layer increased from the domain (0-5)µm the open circuit voltage decreased slightly from 1.087 V to 1.013 V and the short-circuit current increased from 23.27m A to 33.51m A, the cause for this increase in the short circuit current is due to the increase in the concentration of the absorber layer, which leads to the absorption of the largest amount of photons falling on the solar cell, which contributes to the process of generating electron-hole pairs and thus increases the photocurrent [12]. Figure (8) shows the connection between solar cell AlGaAs/InP efficiency and the thickness of the absorber layer. The value thickness of the absorber layer increases from (0 µm to 5 µm). The increase in the thickness of the absorber layer leads to an increase in AlGaAs/InP solar cell efficiency d the increase in effectiveness is spotted up to the concentration of 1.837µm. Thus, thicknesses of 1.837µm and conversion efficiency of 30.1% are in the best taken. The increase in the solar cell effectiveness is due to the increase in the value of shortened circuit current and a very few decrease in the value of open circuit voltage, instituted on equation (8) conversion efficiency increase with increasing concentration [12]. Open loop voltage a bit decrease from 1.038V to 1.017 V with increase doping level from $10^{14}cm^{-3}$ to $10^{20}cm^{-3}$ as shown in figure(9). While the short circuit current almost did not change in the doping region from $10^{14}cm^{-3}$ to $10^{18}cm^{-3}$and after this region it decreases with the increase of doping level. image (10) offers the relationship between of doping concentricity level and adequacy of the AlGaAs/InP solar cell. The conversion efficiency maximum value was 30.01% and it reached a better torpidity level is 6.87×10^{15} cm^{-3}. the density of impurities causes harm to the crystalline shell from the AlGaAs/InP solar energy cell, which leads to down transference efficienctiveness for increasing doping level at the absorbent layer. [13].

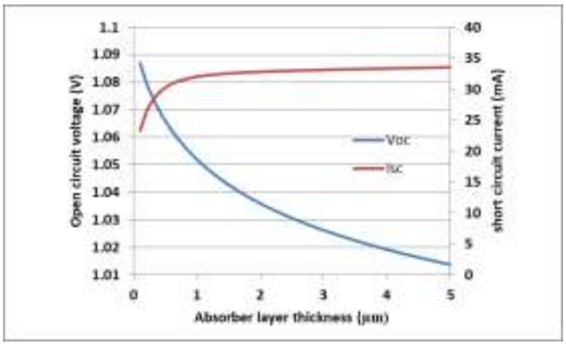

Fig. 7: Open circuit voltage and short circuit current as a function of absorber layer thickness

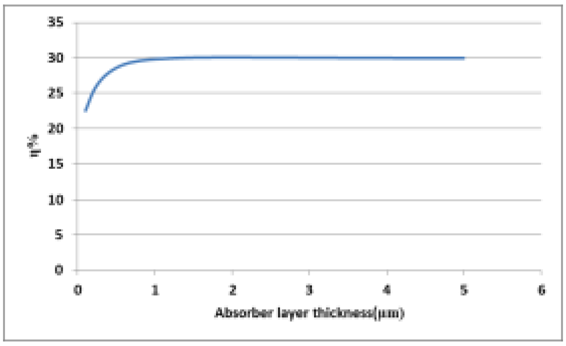

Fig. 8: Conversion efficiency as a function of absorber layer thickness

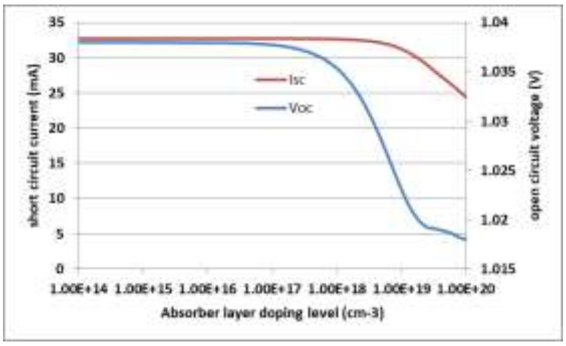

Fig. 9: Open circuit voltage and short circuit current as a function of absorber layer doping

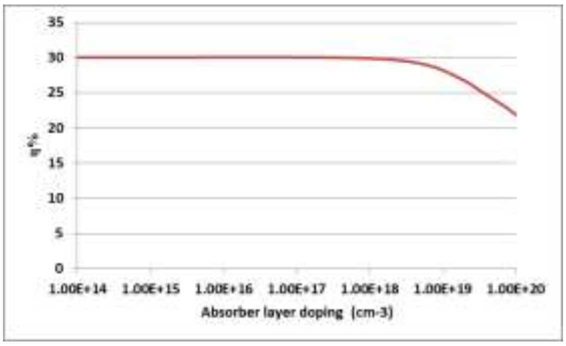

Fig. 10: Conversion efficiency as a function of absorber layer doping.

5. Quantum Efficiency

The results of Quantum efficiency express a great value for assembling analysis losses in summing the absorption and optical losses in the structure of window layer. It is easy to define the (Quantum efficiency) defind the ratio between number of carriers and the number of energy photons that hit the solar cell... The value EQE is calculated by equation below:[14]

$$EQE(\lambda) = \frac{hc}{q\lambda} SR(\lambda) = \left(\frac{hc}{q\lambda}\right)\left(\frac{J(\lambda)}{E_{e,\lambda}}\right) \quad ....(11)$$

hence c refers to light velocity and $E_{e,\lambda}$ means the irradiance spectral [$W.m^{-2}.nm^{-1}$].J(λ) is the Diversion qualification as a duty. Figure (11) It depicts the quantum versus wavelength efficiency for different absorption thicknesses ranging from 0.1 µm to 2 µm. It can be seen that a decrease in the absorption thickness serves to reduce the absorption of a photon with a longer wavelength. This is due to the small number of photogenerated electron-hole pairs within the absorbent layer. Moreover, when the wavelength is greater than 930 nm, the quantum efficiency drops to zero due to no light absorption under bandgaps, at longer wavelengths and at lower energy [15].

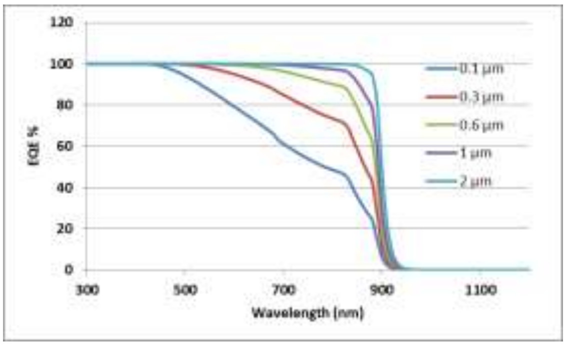

Fig. 11: Quantum efficiency as a function of the wavelength

6. Conclusion

in this way work, a four-layer solar cell is prepared by pc1d program, n-AlGaAs Window layer , n-InP emitter layer , p-InP absorbed stratum and p evidence surface domain layer. The thickness and doping level in the window and absorber layer were changed and their effect on solar cell output parameters.

After conducting simulation and determining optimal parameters for each layer , a conclusion was reached, Isc=32.8 mA, Voc=1.038 V, F.F=88.5% and η=30.1%.

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