DESIGN AND MODELING OF GAAS/ INGAP/ INGAAS/ GE III –V TRIPLE-JUNCTION SOLAR CELL

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ABSTRACT

The solar cell efficiency is the most important parameter, in the research area of solar cell. The researchers concentrate their work in multidimensional for better efficiency, better performance. In this work, the Tandem solar cell is considered with III-V compound materials, to improve the efficiency of Tandem solar cell. One Triple-Junction Tandem solar cell with III-V compound material, made of GaAs/InGaP/InGaAs/Ge has been modeled and simulated in Virtual Fabrication Lab of Silvaco TCAD (ATLAS). The newly modeled TJ tandem solar cell made of GaAs/InGaP/InGaAs/Ge gives promising results and has achieved the conversion efficiency of 32.848% and the Fill Factor (FF) of this solar cell is 89.71% under the AM1.5 illumination (1000 suns).

Keywords: Tandem Solar Cell, TCAD, Efficiency (H), Absorption Coefficient(A), Band-Gap Energy(E_g)

I. INTRODUCTION

The proposed triple junction tandem solar cell is made of III-V compound optical semiconductor materials. This type of devices has very high potential of converting solar irradiation to electrical energy. Now a day, solar cells are very useful in every area like solar-powered building to solar power satellite and vehicles [1]. Solar cell is necessary to use for saving the natural sources of energies like coal, petroleum etc. as because the fossil fuels are prime source of conventional energy production. The burning of fossil fuel discharges huge amount of green house gases and carbon dioxide. When photon of appropriate energy strikes this combination of materials an electron by acquiring energy from photon moves from one layer to another and consequently generates electricity. Modern technologies are using this phenomenon for production of solar cells but less efficiency and high cost are major setback for them.

The solar cells receive photons in the form of solar irradiation and convert the light energy in to electrical energy. Depending upon the absorption of light the efficiency will vary. The absorption of photon depends on the band gap suitable of wave length of light. As the solar irradiation is consists of different wave length of radiation, and apart from the visible spectrum, the ultra violet and infrared wave are also there. The visual spectrum of light also consists of different wave length of light. Keeping in mind of different wave length, the different layer of tandem solar cells are developed which can arrest more spectrums and ultimately increases the efficiency of the cell.

In this work, a Triple junction (TJ) tandem solar cell is designed using of III –V compound material [2] GaAs/InGaP/InGaAs/Ge using Silvaco ATLAS. The software ATLAS tool is a virtual fabrication and simulation tool, which are considered the different mathematical models and solved them and gives the simulated structural design and the I-V curve of output result. The materials are chosen on the basis of their band gap. The mobility and concentration of doping are the other parameters which causes the output current. After these entire process cell factors are calculated from general equations. The efficiency of the proposed TJ solar cell is 32.848 % presence of AM1.5 illumination (1000 suns) [2].

II. DEVICE STRUCRURE AND MODELS OF TJ CELL

Structure of Triple Junction tandem solar cell designed on the basis of materials' band gap. Schematic diagram of TJ solar cell structure shown below in figure1 and also net doping profile is given in figure 3.

2.1 Cell Simulation

Three individual cells shown in figure-1 that is top cell, middle cell and bottom cell. Top cell made by three layers the first layer is n-type GaAs (0.001 um), second layer is n-type GaInP (0.001 um), and the third layer is made by p-type GaInP (0.005 um). Top cell materials have largest band gap. The middle cell materials have a lower band gap than top cell. It made by two layers of GaAs. InGaAs (0.002 um) and another p-type InGaAs (0.005 um) are used. The bottom cell has least band gap compare of top cell and middle cell. The bottom cell made by three layers. The first layer is n-type acceptors InGaAs (0.005 um), second layer may by n-type Ge (0.005 um) and the third layer is p-type Ge (0.015 um).

Top Cell	GaAs 2e20cm-3 N 0.001um Window	
	GaInP 2e18cm-3 N 0.001um Emitter	
	GaInP 7e20cm-3 P 0.005um Base	
First Tunnel	GaAs 2e21cm-3 P 0.0005um	
	GaInP 2e17cm-3 N 0.0005um	
Middle Cell	InGaAs 2e17cm-3 N 0.002um Emitter	
	InGaAs 2e20cm-3 P 0.005um Base	
Second Tunnel	GaAs 2e21cm-3 P 0.0005um	
	GaAs 2e17cm-3 N 0.0005um	
Bottom Cell	InGaAs 2e17cm-3 N 0.005um	
	Ge 2e17cm-3 N 0.005um Emitter	
	Ge 7e20cm-3 P 0.015um Base-substrate	

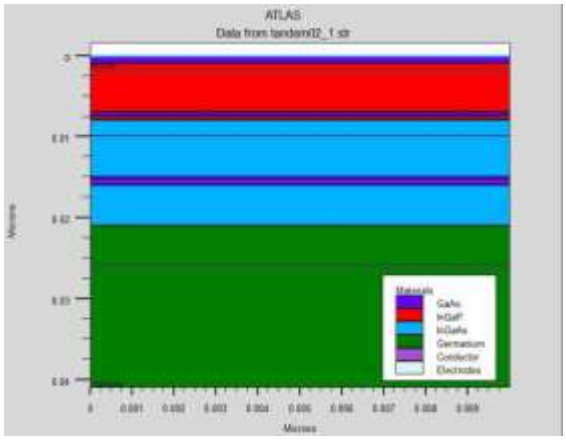

Figure-2. Schematic Diagram of Triple Junction Solar Cell

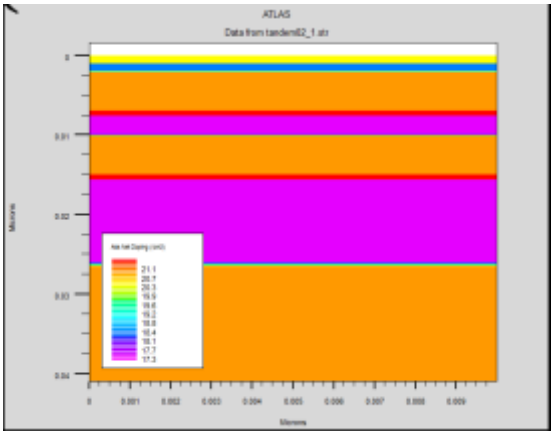

Figure-3. Net Doping Profile of Triple Junction Solar Cell

2.2 Tunnel Junction Simulation

Tunnel junction is a very important layer, essential in vertical stacking of more than one cell, in order to construct a multi-junction configuration. It should be optically transparent and connect the component cells in the multijunction structure with the minimum of electrical resistance [3]. Dissimilar layers regions of Triple Junction solar cell reducing the current flow for this cause using tunnel junction because tunnel junction reduce this type of factors from the junction. In this Triple junction solar cell have two tunnel junctions. First tunnel junction made of two layers one is p-type donors GaAs (0.0005 um) and other is n-type GaInP (0.0005 um) and Second tunnel made of two layers of GaAs of thickness of 0.0005um.

Simulation of this structure is done through ATLAS (SILVACO). ATLAS virtually generates a photocurrent in the device which is generated by a beam of user defined wavelength. We have used wavelength of 300nm for this study. ATLAS then mathematically solves the structure to get the cathode current using different user defined mathematical models. In this study, we have used the models namely, SRH, CONMOB, OPTR, AUGER, BGN [3].

2.3 Srh Recombination

It specifies Shockley Red Hall recombination using fixed lifetimes.

$$R_{SRH} = \frac{Pn - nie\text{^}2}{TAUPo[P + nie\ \exp\left(\frac{ETRAP}{kTL}\right)] + TAUNo[P + nie\ \exp\left(\frac{-ETRAP}{kTL}\right)]}$$

where, ETRAP is the difference between trap energy and intrinsic Fermi level, TL: is the lattice temperature in Kelvin, TAUN0 and TAUP0 are electron and hole lifetimes, p and n are hole and electron densities and nie is intrinsic carrier density[4].This model is activated by using the SRH parameter of the MODELS statement. The electron and hole lifetime parameters, TAUN0 and TAUP0, are user-definable in the MATERIAL statement.

2.4 Auger Recombination

Auger recombination technique, is given by the equation

$$U\text{auger} = \Gamma n\ (\text{np} - ni\text{^}2) + \Gamma p\ (\text{p} - ni\text{^}2)$$

here again, n and p are hole and electron densities and ni is the intrinsic carrier density [5].

2.5 Optical Recombination (Optr)

The optical recombination model which can be stated as

$$R\text{auger}=\text{AUGN (pn^2 - } nnie\text{^2) + AUGP (}np\text{^2 } - nie\text{^2)}$$

Where, p, n, nie are as described earlier. AUGN and AUGP are user definable whose default values are 8.3e-32 cm6/s and 1.8e-31 cm6/s respectively. Here, neither Klaassens temperature dependent model nor the narrow bandgap model is incorporated, as the BGN model is used [6].

2.6 Band Gap Narrowing (BGN)

Specifies band gap narrowing models which is expressed as an analytical model relating to variation in bandgap to doping concentration given by

$$\Delta Eg = BGN.N\{ln\frac{N}{BGN.N} + \left[\left(ln\frac{N}{BGN.N}\right)^2 + BGN.C\right]^{\frac{1}{2}}\}$$

We can specify BGN.E, BGN.N, BGN.C parameters according to Klaassens model. The default values for BGN.E, BGN.N, and BGN.C are 9.0e-3 V, 1.3e7 cm-3 and 0.5 respectively. Variation of bandgap models are not introduced here as our material band-gap is not variable [7].

2.7 Concentration Dependent Mobility (Conmob)

Specifies that a concentration dependent mobility model be used for silicon and gallium arsenide. This model is a doping versus mobility table valid for 300K only. This model is used to solve the top layer and substrate.

In addition to all these equations, Fermi level and models for fixed Fermi are solved for the final current calculation. The simulator solves basic Poisson equation and continuity equation for holes and electrons separately which fall under the drift diffusion model. All important generation and recombination mechanisms are taken into account. The spontaneous recombination and optical absorption can be calculated with quantum mechanics using Fermi's golden rule, which may be important for novel solar cells using quantum well and quantum dot materials. For optical simulation relating to electron and hole generation due to incident light, simulator takes into account Fresnel's reflection, refraction and transmission. The optical and electrical properties of the materials are taken from the sopra database [8].

III. RESULTS AND DISCUSSIONS

The triple junction solar cell shown in figure-2 all cell are modeling and simulate the program very well from that graph is plotted on the basis of Open-circuit voltage (V_{oc}), Short circuit current density (J_{sc}), Maximum power (P_m), maximum voltage (V_m) and the Current (I_m) using all these formulae calculated Fill Factor (FF) and Efficiency all these values shows in Table-1.On these basis plotted the graph of Cathode current vs. Anode voltage shows in figure-3

Table -1

Jsc	1.387e-10 Amp/m^2
Voc	1.20021 Volt
Pm	1.494e-10 Watt/m^2
Vm	1.1 Volt
Jmin	-7.212e-10 Amp/m^2
FF	89.71%
Eff	32.848%

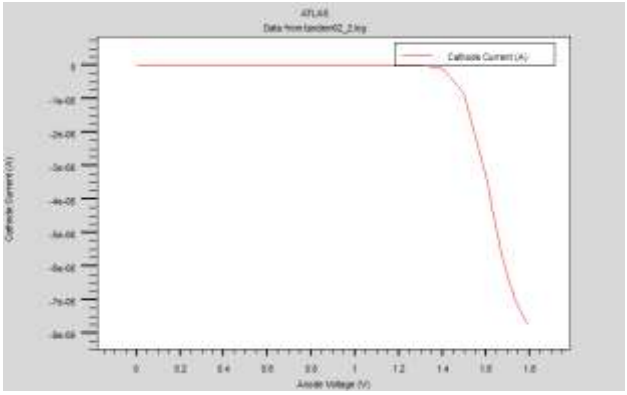

Figure-4. The graph of Cathode Current vs. Anode Voltage

IV. CONCLUSION

In this work we have designed and modeled triple junction solar cell with the III-V compound semiconductor material (**GaAs/InGaP/InGaAs/Ge**). This work has been done in Silvaco ATLAS. This Triple junction solar cell has achieved an efficiency of 32.84% and the fill factor of 89.71%. Short-circuit current (Isc) 0.01388mA and the open-circuit voltage (Voc) 1.20021v have been observed .This paper is completely done by computer aided design Silvaco ATLAS tools. More exploration is required in selecting of materials and the modeled solar cell is to be fabricated in physical lab and the efficiency of that physical lab should match with the simulated one as the virtual environment considered all the physical parameters, then only the validation of this cell will over.

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