

Simulation of Tunnel Junction in Cascade Solar Cell (GaAs/Ge) Using AMPS-1D

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The development of the tunnel junction interconnect was key the first two-terminal monolithic, multi-junction solar cell development. This paper describes simulation for the tunnel junction (GaAs) between top cell (GaAs) and bottom cell (Ge). This solar cell cascade was simulated when using one dimensional simulation program called analysis of microelectronic and photonic structures (AMPS-1D). In the simulation, the thickness of the tunnel junction layer was varied from 10 to 50 nm. By varying thickness of tunnel junction layer the simulated device performance was demonstrate in the form of current-voltage(I-V) characteristics and quantum efficiency (QE).

Keywords: AMPS-1D, Multi-junction, GaAs, Tunnel junction.

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1. INTRODUCTION

The Single-junction photovoltaic devices have limitations in the ability to utilize efficiently the photons of the broad solar spectrum ranging from 300 nm to 2500 nm. For instance, in case of Si solar cells, they cannot absorb photons with wavelengths longer than 1100 nm, which represents more than 20 % of the standard terrestrial normal radiation at AM1.5 [1]. Short wavelengths in the ultraviolet region also are not converted efficiently by Si solar cells because of thermalisation effects. Because solar cells convert only photons with specific wavelengths efficiently, stacking solar cells made of different materials (i.e. different energy bandgaps) together proved to be a good approach to increase the efficiency of photovoltaic devices, and many devices made of a stack of single-junction cells have been proposed by many research groups [2].

Indeed, efficiencies as high as 41.3 % and 32.6 % have been reported for triple-junction and double-junction devices under 343 and 1026 suns, respectively, using the AM1.5 spectrum [3].

The vertical multi-junctions (VMJs) cell consists of a number of non-monolithic edge-illuminated junctions connected together in parallel or in series. The series VMJs cell is fabricated by metalizing, stacking and alloying a number of silicon wafers together. Then, cutting and sizing processes take place. The series VMJs cell has the property of high voltage at a low current. The light is incident on the VMJs cell parallel to the junctions rather than perpendicular to them and the carriers generated by the long wavelength part of the light spectrum have the same probability to be collected by the junction as those generated by short wavelength part. Thus, these VMJs cells have uniformly wide spectral responses. The output current of the series connected VMJs cell is limited by the lowest current of a certain junction. The parameters of top illuminated monolithic series connected multi-junctions such as the energy gap, the thickness, the doping concentration and others have to be carefully designed to ensure current matching between junctions. How-ever, since all the wafers are similar for edge-illuminated series VMJs, the use of

uniform light ensures similar currents in each unit cell. The important benefit of the series VMJs solar cell lies in its capability of operation at very high intensities [4].

The application of such high light intensities requires good cooling techniques for these solar cells and good design to the concentrators.

Based on the above, we expect a tandem device with tunnel junction and sub-cells made of materials with energy bandgaps close to 1.42 eV and 0.66 eV to be highly efficient.

In this paper, we propose a two-junction solar cell device having GaAs (1.42 eV) as a top cell and Ge (0.66 eV) as a bottom cell. The two cells are connected back to back and separated by tunnel junction GaAs.

In the next section, we present the modeling of the thickness of junction tunnel GaAs lead to the best cascade solar cell GaAs/Ge device.

2. OPTIMAL DEVICE STRUCTURE

The major objectives of numerical modeling and simulation in solar cell research are testing the validity of proposed physical structures, geometry on cell performance and fitting of modelling output to experimental results. Any numerical program capable of solving the basic semiconductor equations could be used for modeling thin film solar cells. The fundamental equations for such numerical programs are (i) Poisson's equation for the distributions of electric field (φ) inside the device and (ii) the equation of continuity for conservation of electrons and holes currents. [5]

The AMPS-1D program has been developed for pragmatically simulate the electrical characteristics of multi-junction solar cells. It has been proven to be a very powerful tool in understanding device operation and physics for single crystal, poly-crystal and amorphous structures. To date, more than 200 groups worldwide have been using AMPS-1D for solar cell design [6]. One-dimensional AMPS-1D simulator has been used to investigate the effect of different top cell layers. The structure of conventional GaAs/Ge solar cell is shown in Fig. 1.

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Table 1 – Description of the special paragraph styles

Layers	n/GaAs	P/GaAs	P + -GaAs	N + -GaAs	p/Ge	n/Ge
Parameters						
Thickness (μm)	0.1	3.5	0.005-0.025	0.005-0.025	0.5-5	0-0.3
Dielectric constant, ϵ	12.90	12.90	12.90	12.90	16.2	16.2
Electron mobility μ_n (cm^2/Vs)	8500	8500	8500	8500	4000	4000
Hole mobility μ_p (cm^2/Vs)	1900	1900	1900	1900	1200	1200
Carrier density, n or p (cm^{-3})	N:1E18	P:8E16	P:5E19	N:5E19	p:1E17	n:5E16
Optical band gap, E_g (eV)	1.42	1.42	1.42	1.42	0.66	0.66
Effective density, N_c (cm^{-3})	4.7E17	4.7E17	4.7E17	4.7E17	1E19	1E19
Effective density, N_v (cm^{-3})	9.0E018	9.0E018	9.0E18	9.0E018	5E18	5E18
Electron affinity, χ (eV)	4.07	4.07	4.07	4.07	4	4

N – GaAs
P – GaAs
P + –GaAs
N + –GaAs
N – Ge
P – Ge

Fig. 1 – Cascade solar cell GaAs/Ge structure used for the modeling

The tunnel junction GaAs layers thickness was varied from 0.01 μm to 0.05 μm and the change of performance parameters are observed.

The base parameters used for different structures adopted from some standard references are shown in Table 1

3. RESULTS AND DISCUSSION

3.1 Total efficiency versus tunnel junction layer thicknesses

The simulation work has been performed aiming to compare the different types of cell structure made by changing thickness of The tunnel junction emitter layers GaAs-N and base layers GaAs-P to find out best structure for higher efficiency and more stable GaAs/Ge solar cells.

The effect of tunnel junction on performance such as effect on general performance parameters, quantum efficiency (QE), shunt and series resistance, light and dark I-V characteristics.

Figure 2 (a) shows the device total efficiency. The sum of the efficiency of top and bottom cells) versus the thickness of the emitter layer of the tunnel junction. The results on the Figure 2 show that the optimum thickness is 0.02 microns. Figure 2 (b) shows the device total efficiency versus the thickness of the base layer of the tunnel junction cell.

The results indicate that the optimum thickness is about 0.040 microns for the tunnel junction.

3.2 Device Operation

The current-voltage and power-voltage characteristics generated by the GaAs/Ge optimized device under the AM1.5G spectrum and one sun are displayed in Fig. 3 for multi-junction solar cell. The corresponding PV parameters (open-circuit voltage V_{oc} , short-circuit current I_{sc} , fill-factor FF and efficiency (η) are all summarized in Table 2.

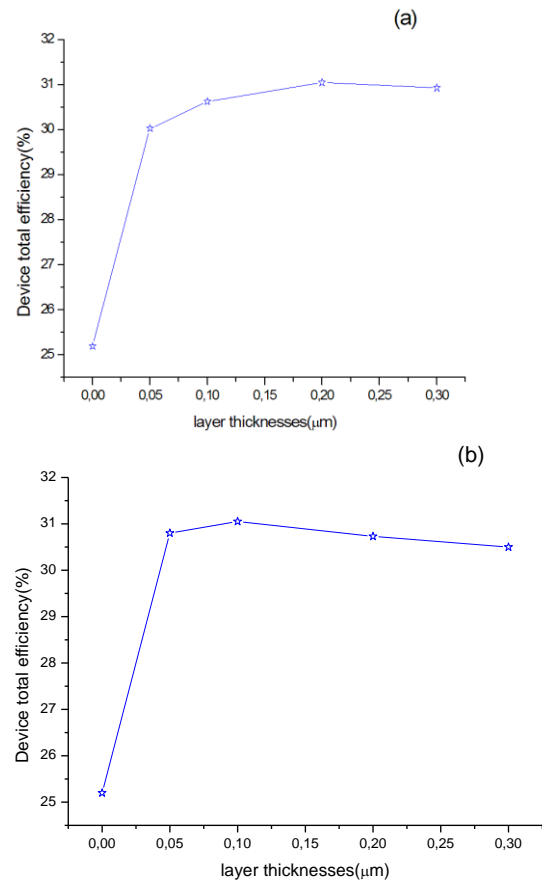


Fig. 2 – Device total efficiency versus tunnel junction layer thicknesses: (a) emitter layer n , (b) base layer p

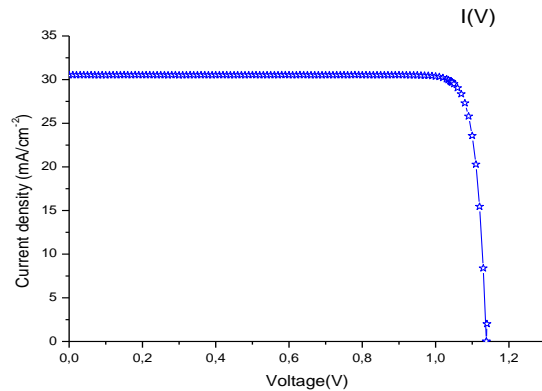


Fig. 3 – Current density-voltage characteristics GaAs/Ge device

Table 2 – Parameters PV of the optimized GaAs / Ge device

Parameters photovoltaic	$V_{oc}(V)$	$J_{sc}(A)$	FF	$\tau(\%)$
	1.13	0.030	0.89	33.5

4. CONCLUSION

In this investigation, we have shown that a relatively thin double-junction GaAs / Ge device can achieve a remarkably high power output. An extended spectral coverage due to a careful choice of the materials and optimization of the thickness and doping levels of each

layer led to an enhanced overall power output from the GaAs / Ge cascade device. Under the standard solar spectrum and one sun, the efficiency of the device is 31.05 %, which is much higher than the efficiency of an optimized single-junction GaAs based device under the same illumination conditions.

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REFERENCES

1. A. Duffie, W.A. Beckman, *Solar Engineering of Thermal Processes, 3rd Edition* (John Wiley & Sons: 2006).
2. J.M. Olson, D.J. Friedman, S. Kutz, *Handbook of Photovoltaic Science and engineering* (Ed by A. Luque, S. Hegedus) (John Wiley & Sons: 2002).
3. M.A. Green, K. Emery, Y. Hishikawa, W. Warta, *Prog. Photovolt: Res. Appl.* **18**, 346 (2010).
4. G.L. Araujo, A. Marti, *Sol. Energy Mater. Sol. C.* **33**, 213 (2002).
5. M. Burgelman, John Verschraegen, Stefaan Degraeve, Peter Nollet, *Prog. Photovolt: Res. Appl.* **12**, 143 (2004).
6. Hong Zhu, Ali Kaan Kalkan, Jingya Hou, Stephen J. Fonash, *AIP Conf. Proc.* (Osaka, Japan, March 5, 1999).