

Optimization of a Tandem Solar Cell GaAs / Ge using AMPS-1D

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Abstract

The primary objective of this modeling investigation is to optimize a multi-junction tandem device under the AM1.5G spectrum. Based on previous studies, GaAs and Ge cells, because of their energy band gaps, can be combined together to achieve high-efficiency double-junction devices. In this study, the top cell is made of GaAs (1.42 eV) while the bottom cell is made of Ge (0.66 eV). In order to avoid the losses and design constraints observed in two-terminal and four-terminal devices.

In order to determine the optimal structure of the device, the top and bottom junctions were investigated and optimized with regard to the thicknesses . The optimum configuration of the device shows an efficiency of 32.07% under the AM1.5G spectrum and one sun, which is higher than the efficiency of an optimized single-junction Si cell under the same illumination conditions.

Keywords: AMPS-1D, multi-junction, Ge, GaAs, optimization.

1. Introduction

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 the 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 thermalization effects.

Because solar cells only convert photons with specific wavelengths efficiently, stacking solar cells made of different materials (i.e. different energy band gaps) 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 materials with energy band gaps close to 0.66 eV and 1.42 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.

In the next section, we present the optimization of the structure of the top cells that lead to the best tandem 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 solar cell are shown in the Fig.1. The GaAs layers thickness was varied from 1 μm to 5 μm and the change of performance parameters are observed.

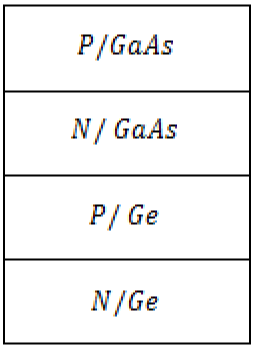

Figure 1.Structure of the solar cell

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

Table1 Parameters used In simulation.

Parameters \ Layers	p/GaAs	n/GaAs	P-Ge	n- Ge
Thickness(μm)	0.1-0.2	0.5-3	1	3
Dielectric constant, ε	13.10	13.10	16.2	16.2
Electron mobility μ_n (cm²/Vs)	8500	8500	3900	3900
Hole mobility μ_p (cm²/Vs)	400	400	1900	1900
Carrier ensity, n or p(cm^{-3})	P:1E17	n:8E16	p:5E17	n:5E17
Optical band gap, E_g(eV)	1.42	1.42	0.66	0.66
Effective density, N_c (cm^{-3})	4.7E+17	4.7E+17	1.1E19	1.1E19
Effective density, N_v (cm^{-3})	7.5E+18	7.5E+18	5.0E018	5.0E018
Electron affinity ,χ(eV)	4.07	4.07	4.38	4.38

3. Results and Discussions

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

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

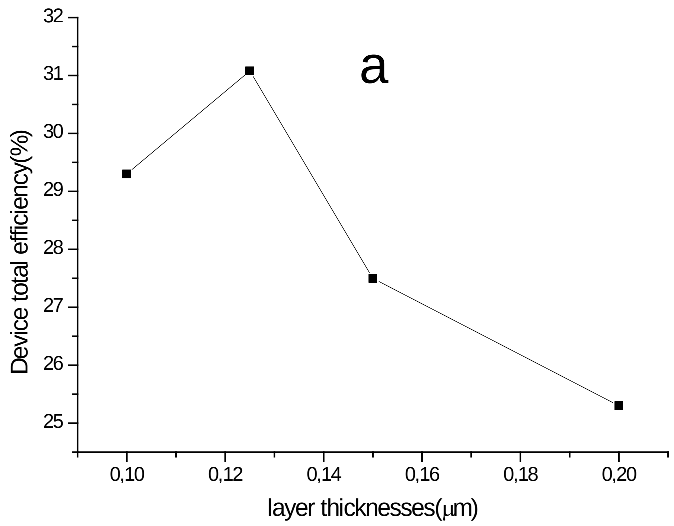

Figure 2.Performance depending on the thickness of the emitting layer of the top cell.

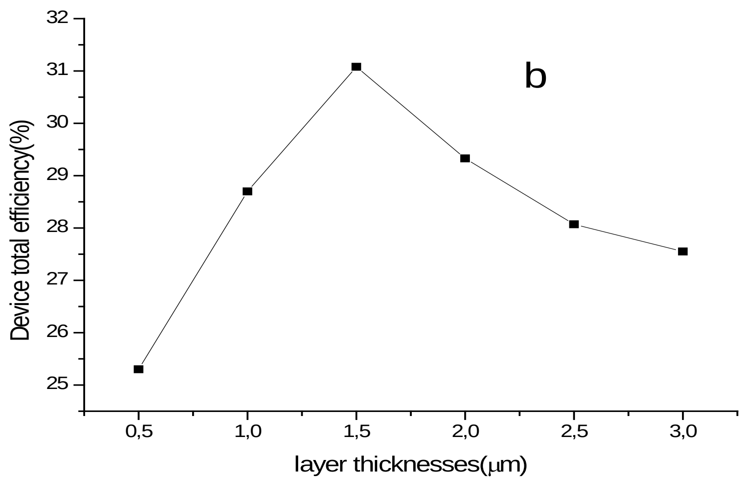

Figure 3. Performance depending on the thickness of the base layer of the top cell.

Figure 2 shows the device total efficiency (i.e. the sum of the efficiency of top and bottom cells) versus the thickness of the emitter layer of the top cell. The results on the figure show that the optimum thickness is 0.1 microns. Figure 3shows the device total efficiency versus the thickness of the base layer of the top cell.

The results indicate that the optimum thickness is about 1.7microns as for the bottom cell.

Device Operation

From the above results are obtained using the AMPS-1D software we can determine the solar cell which has the best performance while giving the thickness of each layer o Table 2.

Table 2.Thickness of each layer

p/GaAs	n/GaAs	p/Ge	n/Ge
0.125	1.5 µm	3 µm	2 µm

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 figure 3 for multijunction solar cell. The corresponding PV parameters (open-circuit voltage Voc, short-circuit current Isc, fill-factor FF and efficiency (η) are all summarized in Table 3.

Table 3. PV parameters of the optimized GaAs / Ge device.

Grandeurs photovoltaïc	$V_{co}(V)$	$J_{sc}(A)$	FF	$\tau(\%)$
	1.10	32.74	0.89	32.07

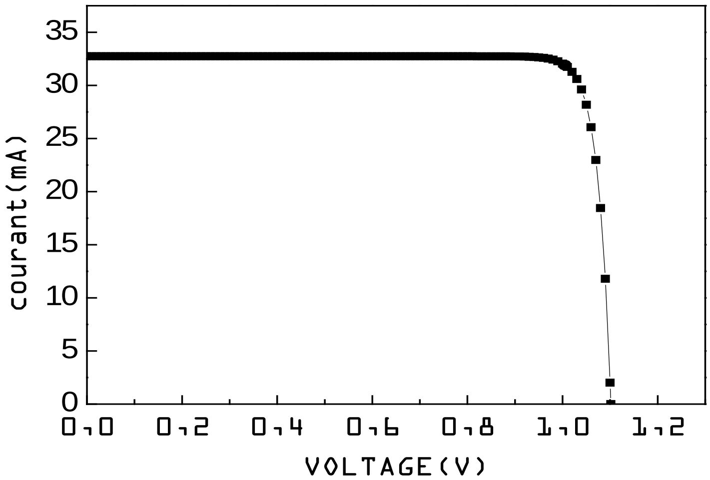

Figure 4. Current-voltage characteristics GaAs /Ge device

4. Conclusions

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 tendem device. Under the standard solar spectrum and one sun, the efficiency of the device is 36.4%, which is much higher than the efficiency of an optimized single-junction Ge based device under the same illumination conditions.

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