TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol.12, No.7, July 2014, pp. 4924 ~ 4927
DOI: 10.11591/telkomnika.v12i7.5827

Modeling of Tunnel Junction (GaAs) in the Cascade Solar Cell

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Abstract

In this paper describes a simple model for tunnel junction (GaAs) between the top cell (GaAs) and bottom cell (Ge) of cascade solar cells. We theoretically studied the electrical characteristics (IV) of GaAs tunnel diode with the accounting program MATLAB for doping concentration of the junction after Using this model between two cascaded solar cell (GaAs / Ge) and we calculate the electrical characteristics and performance using AMPS-1D software. The conduction properties of this tunnel diode show good ohmic behavior and low contact resistance.

Keywords: *tunnel junction, cascade solar cell, current–voltage (I–V), modeling, AMPS-1D.*

1. Introduction

Multijunction solar cells offer higher efficiencies than those of single-junction solar cells at the cost of a more complex device structure. To act as a single power- producing unit, the component subcells must be interconnected to form two-terminal units which produce a single current at a single voltage.

The individual sub cells of a multijunction cell are inter-connected via Esaki interband tunnel diodes [1]. They feature both low electrical resistivity and high optical transmissivity.These are the key issues for connecting the cells monolithically [2-3].

The tunnel diode has been applied as an interconnector in monolithic devices such as tandem solar cells which have a predicted conversion efficiency of about 35%. One of the major problems in achieving high-efficiency and stable tandem solar cells is thermal degradation of the tunnel junction interconnection during fabrication. This degradation is caused by the impurity diffusion from highly doped tunnel junctions and results in a decrease in the tunnel peak current. Thus, high doping for obtaining a large peak current density is ineffective for GaAs tunnel diodes when they are annealed above about 600"C.

For the interconnection of a tandem solar cell, the thickness of the tunnel junction should be less than 100 nm in order to minimize optical loss; the peak current density after annealing at 700'C should be greater than the short-circuit density in order to minimize electrical loss.

In this article, we evaluate the effect of doping in the tunnel junction and we are simulated cascade solar cell (GaAs/Ge) by using AMPS-1D software, including I-V characteristic, conversion efficiency:

2. Tunnel Junction Model

The growth condition of tunnel junction is a key parameter for tandem solar cell and a poor design of tunnel junction will remarkably decrease efficiency . of solar cell. The I-V characteristic of tunnel diode is the sum of the three current components Tables and Figures are presented center, as shown below and cited in the manuscript [4] (Figure 1).

$$J = J_{t} + J_{x} + J_{th} \quad (1)$$

Received January 12, 2014; Revised February 23, 2014; Accepted March 7, 2014

$$J = J_P\left(\frac{V}{V_P}\right) exp\left(1-\frac{V}{V_p}\right) + J_V\ exp[A_2(V-V_v)] + J_0 exp\left(\frac{qV}{KT}\right) \quad (2)$$

The tunneling current's contribution to the total current is significant for $V < V_v$, the excess current's contribution is significant for $V \approx V_v$ and contribution of the thermal current is significant for $V > V_v$.

In Equation (2), Jp is the peak current density of the tunnel current and J_V is the valley current density of the tunnel current. Since the tandem solar cell is in series connection, the total output current must be limited the minimum current presented by some subcell. Therefore, if J_{SC} is lower than J_V ($J_{SC} < J_V$).

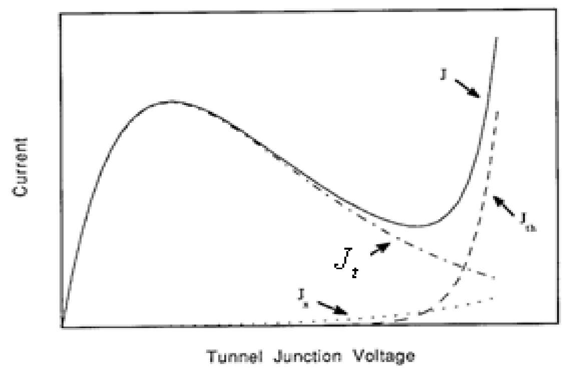

Figure 1. Current Components in a Tunnel Junction

3. 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 modeling 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 Figure 2. The tunnel junction GaAs layers electron doping concentration was varied from 10^{18} to 10^{20}(cm^{-2}) and the change of performance parameters are observed.

$N - GaAs$
$P - GaAs$
$P + -GaAs$
$N + -GaAs$
$N - Ge$
$P - Ge$

Figure 2. Cascade Solar Cell GaAs/Ge Structure used for the Modeling

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

Table 1. AMPS-1D Parameters GaAs/Ge Solar Cell

Layers / Parameters	n/GaAs	P/GaAs	P + −GaAs	N + −GaAs	p/Ge	n/Ge
Thickness (μm)	0.1	3.5	0.020	0.05	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 (cm²/Vs)	8500	8500	8500	8500	4000	4000
Hole mobility μ_p(cm²/Vs)	1900	1900	1900	1900	1200	1200
Carrier density,n or p (cm^{-3})	N:1E18	P:8E16	P:1E19	N:1E18-1E20	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	9.0E018	9.0E018	5E18	5E18
Electron affinity, χ (eV)	4.07	4.07	4.07	4.07	4	4

4. Results and Analysis

For that presented simulation, we have chosen a range of electron doping concentration between 5×10^{18} to$5 \times 10^{19}(\mathrm{cm}^{-3})$ for tunnel junction N+ layer. The Figure 3 schematizes the illuminated characteristics J-V of GaAs tunnel junction and the Figure 4 schematizes the illuminated characteristics J-V cascade solar cell GaAS/Ge. According to these results, we notice a maximal density of current (30.52mA/cm2) and a maximal voltage (1.104V) for a value of the doping of the tunnel junction layer N+ $5 \times 10^{19}(\mathrm{cm}^{-3})$).

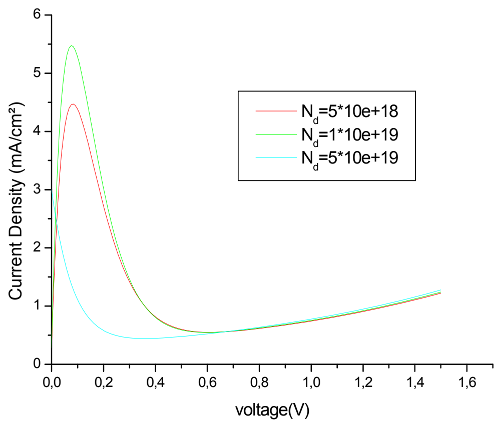

Figure 3. J-V Characteristics with Different Doping Concentration of GaAs

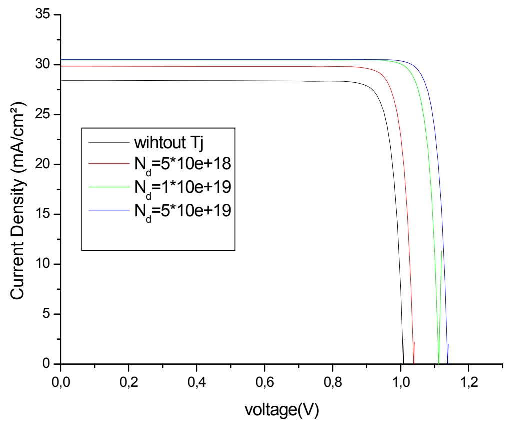

Figure 4. The Effect of Doping of the Tunnel Junction in Cascade Solar Cell on the Characteristics J-V

The effect of the doping tunnel junction N+ layer on cell performance such as effect on general performance parameters, quantum efficiency (QE), shunt and series resistance, light and dark I-V characteristics. Characteristics of each cell with tunnel junction N+ layer a doping are shown in the Table 2.

Table 2. Characteristics of each Cell Cascade

doping of T j N+layer	$J_{sc}(mA/cm^2)$	$V_{oc}(V)$	$E_{ff}\%$
Without T J	28.84	1.00	25.20
Na=5*10e+18	29.84	1.03	27.37
Na=1e+19	30.49	1.11	30.21
Na=5e+19	30.52	1.13	31.03

5. Conclusion

We used AMPS-1D to investigate the dependence of electron doping concentration of junction tunnel GaAs for GaAs/Ge cascade solar cells. We demonstrated the effect of doping in tunnel junction N+ layer on the parameters of solar cells as open-circuit voltage (Voc), the short-circuit current density (Jsc), the conversion the quantum efficiency (QE). The conversion efficiency increased until electron doping concentration of tunnel junction GaAs reaches around $5 \times 10^{19}(\mathrm{cm}^{-3})$ Further increase of doping shows no improvement in efficiency. Similarly QE responseis almost overlapping after the $5 \times 10^{19}(\mathrm{cm}^{-3})$toping layer N+ tunnel junction. These observations led to the conclusion that for the optimal performance of the solar cell device the electron doping concentration of layer plays a role.

Acknowledgements

We would like to acknowledge the use of AMPS-1D program that was developed by Dr. Fonash’s group at Pennsylvania State University (PSU).

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