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High Efficiency AlAs/GaAs/Ge Lattice Matched Multijunction Solar Cells

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Abstracts - This paper reports on the theoretical design and performance analysis of the AlAs/GaAs/Ge based triple junction solar cells. The efficiency of the lattice matched solar cells has been evaluated considering the effect of reflection coefficient. The efficiency is also compared with the lattice mismatched triple junction solar cells. The current matching is done by varying the thickness. The effect of depletion width has been taken into account in order for accuracy. However, no significant change has been observed between the results without and with considering the depletion width. The efficiency of the proposed solar cells has been found to be ~ 43.5%. The effect of reflection coefficient has also been considered. The efficiency is found to be 23% to 37% considering reflection loss. This simulated model shows that the proposed model can improve the efficiency with increasing the number of junctions.

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HIGH EFFICIENCY ALASGAASGE LATTICE MATCHED MULTIJUNCTION SOLAR CELLS

Strictly as per the compliance and regulations of:

High Efficiency AlAs/GaAs/Ge Lattice Matched Multijunction Solar Cells

Md. Jahirul Islam[α], Md. Habibullah[Ω], Sk. Hasan Hafizul Haque[β], Md. Mottaleb Hossain[ψ], Md. Rejvi Kaysir[¥]

Abstract - This paper reports on the theoretical design and performance analysis of the AlAs/GaAs/Ge based triple junction solar cells. The efficiency of the lattice matched solar cells has been evaluated considering the effect of reflection coefficient. The efficiency is also compared with the lattice mismatched triple junction solar cells. The current matching is done by varying the thickness. The effect of depletion width has been taken into account in order for accuracy. However, no significant change has been observed between the results without and with considering the depletion width. The efficiency of the proposed solar cells has been found to be ~ 43.5%. The effect of reflection coefficient has also been considered. The efficiency is found to be 23% to 37% considering reflection loss. This simulated model shows that the proposed model can improve the efficiency with increasing the number of junctions.

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I. Introduction

The photovoltaic solar cell is becoming widespread and very important as a clean and gentle energy source for the earth [1]. However, the efficiency of conventional and commercially available solar cells is still very low. To be competitive with the conventional energy source the efficiency of photovoltaic cell must be improved. Researchers are looking for the highly efficient photovoltaic cells from the beginning of this decade. Attempts have been made to fabricate photovoltaic cells with materials other than silicon and with no lattice mismatch. At the same time modifications in design are being carried out to reduce the reflected component of solar energy due to lattice mismatch.

Limitations of efficient use of broad solar spectrum of one junction solar cell have led to carry out much more theoretical and experimental works on the multijunction (MJ) solar cells. MJ solar cells are being being widely investigated by the researchers to increase the efficiency.

It has been shown that the theoretical Efficiency of the MJ solar cells increases as it incorporates more and more junctions [2]. However, practically there is a very little range of material that could be used to make these cells. A major challenge in achieving widespread use of solar cells lies in the identification of suitable materials with appropriate lattice and band gap matching. Besides lattice and band gap mismatches, recombination before drift, and reflection at top surface contact obstruction associated with MJ solar cells restricted the achievement of higher efficiency [3]. Due to lattice mismatch, generated carrier will be recombined in the defect of the lattice. After considering the effect of lattice mismatch the efficiency of the proposed solar cell has been found approximately 43.5% and the approach targeting 50% efficiency is proceeding using the invert lattice mismatch quantum well solar cells [4]. In this paper, the effect of antireflection on MJ solar efficiency is also studied.

II. Device Structure

Improved efficiency is the most important factor in designing the MJ solar cells. Currently used MJ solar cells are based on two or three layers of different material which are usually III-V semiconductors [5]. But lattice constants of different junctions are not same. The efficiency decreases due to the lattice mismatch. The AlAs/GaAs/Ge based solar cells have been proposed for higher efficiency.

For designing this solar cell, the materials are used in buffer layer and tunnel junction having nearly the same lattice constant and this helps to improve the efficiency [6]. These layers act as antireflection coating which reduces the refection of incident light. The schematic illustration of the proposed AlAs/GaAs/Ge MJ solar cells is shown in Fig. 1. The sub cells are arranged from bottom to top with lower to higher the band gap. Tunnel junctions are placed between the layers of a MJ to avoid the formation of junction as well as potential barrier between the layers. However dislocations at the interference of the GaAs and Ge are limiting the cell efficiency. This propagation often causes Shockly-Read-Hall recombination in the active cell regions.

To reduce the number of dislocations and cease their propagation through the upper layers of the junction cell, step graded buffer layers of InGaAs are used. Thus the constant remains the same due to small composition of In.

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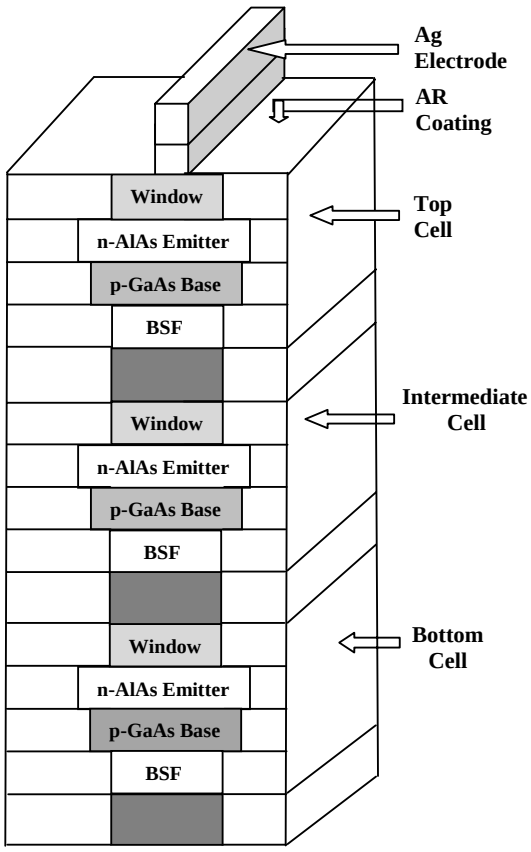

Fig. 1 : Schematic illustration of the proposed lattice matched solar cells.

III. Performance Analysis

The performance of solar cells depends on the choice of material used, the direction of light energy incident into the p-n junction, the number of junctions between the cells, the matching of the lattice of the used compound alloys, and carrier concentration. The amount of light energy absorbed by the p-n junction of solar cell is one of the important issues in performance evaluation. The less the reflection of incident light, the more efficient the solar cell is. The values of different parameters for the materials of Ge, GaAs, and AlAs which are used in the theoretical design and performance evaluation of the lattice matched multifunction solar cells are shown in Table I.

Fig. 2 shows the graphical representation of reflectance or reflection coefficient and efficiency of lattice matched AlAs/GaAs/Ge-based MJ solar cells. Efficiency of the solar cells decreases with the increasing percentage of reflectance.

The current densities for electrons and holes are expressed as [7],

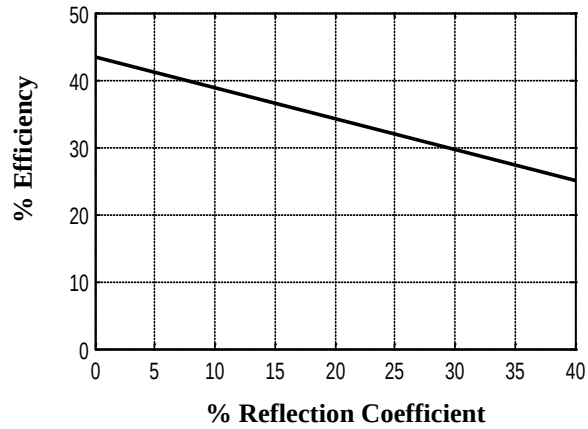

Fig. 2 : Efficiency variation of solar cell with respect to reflection coefficient.

$$J_n = q\mu_n n_p \xi + qD_n \frac{dn_p}{dx'} \quad (1)$$

and

$$J_P = q\mu_P p_n \xi - qD_p \frac{dp_n}{dx'} \quad (2)$$

where q is the electron charge, μ_n and μ_p are the mobility of electrons and holes respectively, p is the electron concentration in p region, p_n is hole concentration in n region, ξ is electric field, and $D_{n,p}$ is the minority carrier diffusion coefficients in n and p regions respectively.

In the case of an n on p junction with an n-type emitter and p-type base the expression for p on the top side of the junction is given by

$$D_P \frac{d^2 p_n}{dx'^2} + \alpha F(1-R)e^{-ax'} - \frac{p_n - p_{no}}{\tau_p} = 0 \quad (3)$$

where F is the number of incident photon per cm^2 per second per unit band width, α is the absorption coefficient, R is the number of reflected photon from surface, p_{n0} is the equilibrium minority carrier density in the dark, and τ_p is the minority carrier lifetime.

The Open circuit voltage is expressed as [8],

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{J_{sc}}{J_0} + 1\right) \quad (4)$$

and

$$J_0 = qn_i^2 \left(\frac{D_{nj}}{L_{nj} N_A} + \frac{D_{Pj}}{L_{Pj} N_D} \right), j = 1,2,3....n \quad (5)$$

where J_{sc} is the short circuit current density, J_0 dark saturation current density, n_i be the intrinsic carrier concentration, N_A and N_D are the acceptor and

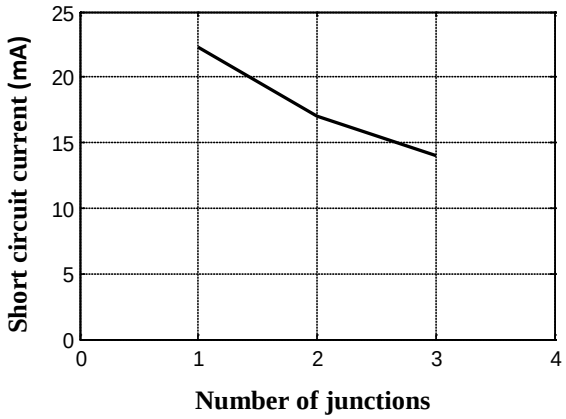

Fig. 3 : Variation of shot circuit current with number of junctions.

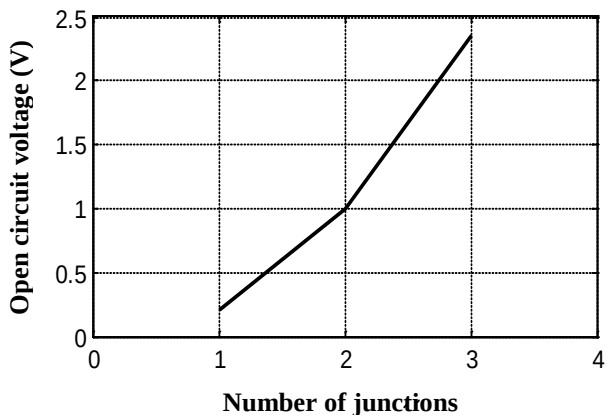

Fig. 4 : Variation of open circuit voltage with number of junctions.

Donor impurities respectively, and $L_{n,p}$ is minority carrier diffusion length in *p* and *n* regions respectively.

Short circuit current decreases as the number of junction increases. Simulation result shows that with the increase of number of junctions from single to triple short circuit current decreases about 35%. The result is shown in Fig. 3.

Fig. 4 shows the variation of open circuit voltage with the number of junctions. Open circuit voltage increases with increasing the number of junctions. For choosing of a new junction material, care has been taken about lattice constant so that lattice mismatch does not create in designing of MJ solar cells.

As the number of junctions i.e. the number of cells increases, short circuit current decreases and open circuit voltage increases which consequently causes the increase of solar cell efficiency. Fig. 5 shows the variation of efficiency with the number of junctions. Simulation result shows that efficiency increases about 30% as the junction number increases from single to triple.

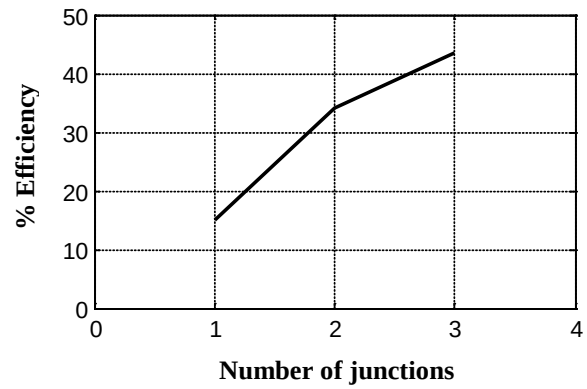

Fig. 5 : Efficiency variation of solar cell with respect to number of Junction.

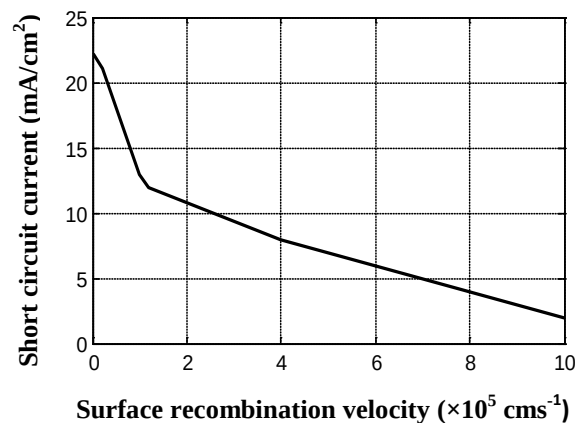

Fig.6. Effect of surface recombination velocity on short circuit current

The influence of surface recombination velocity on the short circuit current is shown in Fig. 6. Higher the recombination velocity, lower the short circuit current. Lattice matched solar cells reduce short circuit current (Fig. 3) which in turn increase the efficiency of the solar cells.

The comparison between lattice matched and mismatched triple junction solar cells considering the values of open circuit voltage, short circuit current, and efficiency is shown in Table II.

Table I: The Simulation Results of Lattice Matched MJ Solar Cells

Parameters	Ge	GaAs	AlAs
N_A (cm^{-3})	10^{16}	10^{16}	10^{16}
N_D (cm^{-3})	10^{18}	10^{18}	10^{18}
n_i (cm^{-3})	2.33×10^{13}	1.84×10^{6}	$8{\cdot}5\times10^{17}$
N_C (cm^{-3})	1.04×10^{19}	6.0×10^{18}	1.2×10^{19}
N_V (cm^{-3})	4.45×10^{19}	7.72×10^{18}	4.62×10^{19}
J_o (A)	7.2×10^{-3}	1.1×10	8.9×10^{-5}
V_{oc}(V)	0.20	0.7928	1.33
V_T(V)	2.3228		

Table II: Comparison Table Between Lattice Matched and Mismatched Triple Junction Solar Cells

Parameters	Lattice matched (AlAs/GaAs/Ge)	Lattice mismatched (AlAs/GaAs/Ge)
Open circuit voltage, V_{oc} (V)	2.3228	2.683
Short circuit current J_{sc} (mA/cm$_2$)	22	15.94
Efficiency (η)	43.5%	37.73%

IV. Conclusions

The theoretical design of the lattice matched AlAs/GaAs/Ge-based multi junction solar cells has been proposed and performances have been evaluated. The performances are evaluated by developing a simulation model which optimizes the design of the lattice matched AlAs/GaAs/Ge MJ solar cells for high efficiency. The efficiency of the proposed device structure has been obtained to be ~ 43.5%. The lattice mismatch is made to about nil. This increases surface recombination velocity and decreases short circuit current. The currents of each junction are made equal by adjusting the thickness of the emitter. Some major challenges including tunnel junction, buffer layer, and anti reflection coating in designing the effective MJ solar cells have been overcome. All these results show that the proposed AlAs/GaAs/Ge based multijunction solar cells are promising candidates to achieve high efficiency.

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