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Optimization of AlSb Solar Cell to Improve PCE

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***Abstract*—This research work investigates the new prospects in Aluminium Antimonide (AlSb) compound solar cell by numerical analysis. AlSb is a material of binary compound semiconductor group with suitable electrical and optical properties to have a highly efficient and stable solar cell. In this research paper, an optimization of AlSb solar cell is analyzed numerically with simulation software for the analysis of microelectronic and photonic structures named AMPS 1D. It is explored that, the cell conversion efficiency is 18.07% (J_{sc} = 21.342 mA/cm^2, FF = 0.703, Voc = 1.20 V) with a thickness of 1 µm of absorber layer in AlSb solar cell. The proposed cell structure is almost stable with only a small degradation in efficiency with temperature variation. The overall analytical result shows AlSb solar cell as a potential candidate in uprising photovoltaic applications with better efficiency and stability.**

Keywords— ***Solar cell; Cell Optimization; Ultra-thin; Efficient; Thermal stability.***

I. INTRODUCTION

Energy is the mainstay of the world's advancement. But current appraisal shows the crucial condition of energy and the adverse effect on climate. The report made by IEA 2017 shows the uncertainty of energy projection over a year range from 2015-2040 resulting in a different economic growth rate [1]. The supply of energy is 13,690 Mtoe whereas the consumption of energy is 9,425 Mtoe in 2014 [2]. The previous and current data based on energy consumption and demand shows a drastic change in recent years. It has become a prime concern to look for new prospects in renewable energy sources leaving the conventional sources. Solar energy holds the supreme position as the energy source for sustainable development. Considering only the amount of 0.1% of the earth's surface with solar cell modules as a bed with the production of 1 KWh per meter square area per day, the global demand of the energy can be encountered [3]. The future growth scenario is predicted with average cumulative installed global PV capacity of 260 GWp by 2020 [4].

To get rid of this climactic situation, the world needs a significant and concerted transition in its energy sources. Researchers have been prompted to look for numerous developing solar cells are under thought to find out novel scenes. The yearning characteristics of solar cell are efficiency, stability and overall costing. Concentration has been imposed on compound binary and ternary group. The advancement of light-trapping structures combines group III-V materials as absorber layer to form single-junction structure which delivers a high performance supporting various working conditions only at a fractional cost of multi-junction structures. AlSb has suitable electrical and optical properties and the energy band gap is 1.62 eV which is suitable for solar spectrum absorption [5]. In this research work, the ultra-thin and AlSb compound solar cell is observed considering standard AM1.5 illumination which shows the higher cell conversion efficiency and stability.

The present situation remarks it as a great challenge to enhance the cell efficiency with abundant material and better stability in temperature which will contribute to the potential solar cell. In 1976, an observation shows strong photovoltaic response by vacuum electro deposition of AlSb by Francombe [76]. Many processes are observed to prepare AlSb including dc sputtering and the opto-electronic properties are observed [7]. The electrical properties show a favourable response of increasing conductivity with excitation increase. The performance of AlSb was analysed numerically with p-n and p-i-n structure with suitable layer thickness resulting with an efficiency of 14.41% [8]. The analytical outcome results the AlSb as a material of preliminary stage for thin film technology to further improve the conversion efficiency [9]. The optimization technique is observed in CZTS based solar cells [10-12], SnS solar cell [13], and CdSe based solar cells [14, 15].

In this research work, the exploration observes AlSb binary compound semiconductor as an absorber layer to ensure the higher efficiency of the ultra-thin structure. The stability of the cell is also important parameter to ensure it as an uprising candidate. AMPS 1D simulator is used for the analysis of the objectives of the proposed cell effectively.

II. MODELING AND SIMULATION

The numerical analysis on the cell structure attributes to the research by examining it with an optimized cell structure.

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It helps to predict the performance of the cell. The microelectronic parameters with different layer parameters are investigated in this research work with AMPS 1D simulator. Cell optimization is the basement for any dedicated solar cell to improve the cell further. A simple model of basic solar cell structure is proposed for numerical analysis. The suitable TCO and window layer are used for preventing leakage current in the front contact. The front and back contact are the important layers of a cell structure to decrease the impact of reflection, shadowing effect and many losses such as recombination loss. The absorber layer is of p-type where the window layer is of n-type. The wide band gap and transmittance in the visible range allows ZnS as a suitable buffer layer [16].The conductivity of the TCO layer follows the equation as,

$$\sigma = \mu ne \tag{1}$$

Where, the relation of mobility and the density has major impact. The suitable combination of layers parameters shows an efficient result in the proposed structure. The basic structure for cell optimization is shown in Fig. 1.

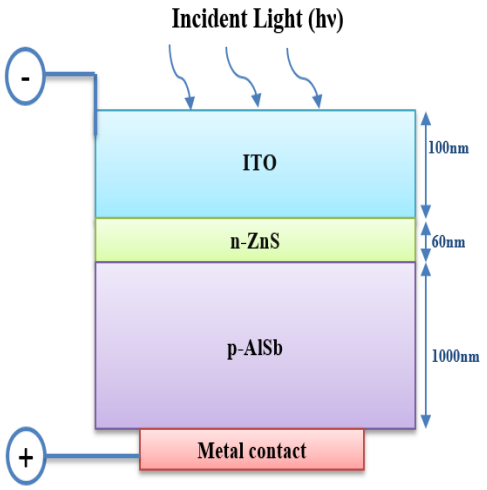

Fig. 1 The Proposed structure of the AlSb solar cell

The application of the numerical analysis through AMPS-1D simulator is to optimize the cell structure ensuring the objectives of a thin film solar cell. The structure of AlSb solar cell is analysed to obtain the highest cell conversion efficiency of the proposed ITO/ZnS/AlSb solar cell. The AMPS 1D simulator follows Poisson's distribution, continuity equations of electron and hole to examine the structure.

$$\frac{d}{dx}(\varepsilon(x)\frac{d\psi}{dx}) = q[p(x) - n(x) + N_D^{+}(x) - N_A^{-}(x) + P_t(x) - N_t(x)] \tag{2}$$

$$\frac{\partial n}{\partial t} = \frac{1}{q}\frac{\delta Jn}{\delta x} + G_n - U_n \tag{3}$$

$$\frac{\partial n}{\partial t} = \frac{1}{q}\frac{\delta Jp}{\delta x} + G_p - U_p \tag{4}$$

where ε is the permittivity, ψ is the electrostatic potential, p and q are the charge of hole and electron, n the free electron, N_A and N_D are the acceptor and donor concentration, P_t and N_t are the trapped hole and electron, G_n and G_p shows the generation rate for holes and electrons, J_n and J_p are the density of current for electron and hole. The incident sunlight on the ITO passes it to absorber layer through the buffer layer. The buffer layer between the TCO and the absorber layer improves the FF and V_{oc} by smoothing the surface of the junction. The thickness of the TCO layer is considered 0.1µm and thickness of ZnS is considered 0.06 µm for optimization. The absorber layer is the main carrier absorber and its absorption capacity increases with thickness of the absorber layer. It works as the photoactive layer for the power conversion of the cell. So, the absorber layer thickness affects the cell performance but for optimization its variation is observed over a wide range starting from 0.1 µm. Table I represents the basic parameters for different layers that are used in numerical analysis [17].

TABLE I PROPERTIES OF DIFFERENT LAYERS FOR NUMERICAL ANALYSIS

Parameters	ITO	n-ZnS	p-AlSb
Thickness (µm)	0.1	0.06	0.1-5
Permittivity, (ε/ε0)	9	10	9.4
Electron mobility, µe (cm^2/Vs)	100	100	80
Hole Mobility, µp (cm^2/Vs)	25	25	420
Concentration of Acceptor or Donor (cm^{-3})	1×10^{18}	1×10^{17}	1×10^{17}
Electron Affinity, χ (eV)	4.50	4.5	3.6
Bandgap, *Eg* (eV)	3.6	3.72	1.62
Density of electrons on conduction band, Nc (cm^{-3})	2.22×10^{18}	1.5×10^{18}	7.8×10^{17}
Density of holes on valance band, Nv (cm^{-3})	1.8×10^{19}	1.8×10^{18}	1.8×10^{19}

Considering the difference between the work function and the electron affinity in the front and back contact the value of PHIBO and PHIBL is taken for simulation. The numerical analysis is done to predict the cell performance where different layer thickness may be considered within acceptable ranges. All the parameters are remained same except the variable one to check the effect on performance parameters.

III. RESULTS

A. Effect of AlSb absorber layer

In any proposed solar cell, the higher cell conversion efficiency was attained by the enhancing the cell performance parameters such as FF, V_{oc} and J_{sc}. The overall efficiency varies with these cell performance parameters values. The main objective to be accomplished in this research work is to optimize the solar cell with a higher efficiency compared to the previous research works [17, 18].

Therefore, by varying the thickness at a range from 0.1 µm to 5 µm the cell performance is observed in Fig. 2.

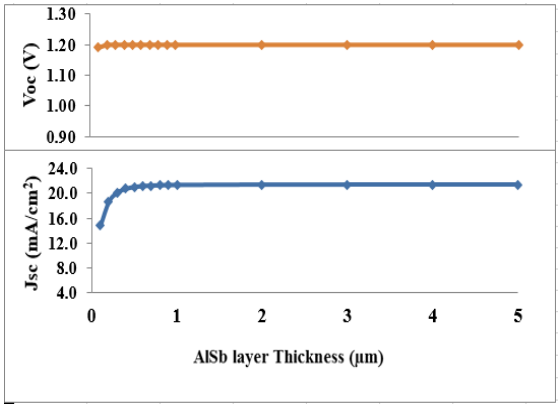

Fig. 2 Effect on open circuit voltage and short circuit current due to the AlSb thickness variation

The illustration shows that the increase in absorber layer thickness increases the voltage slightly but almost same over a wide range. But the short circuit voltage changes drastically within 1 µm. As the thickness of the absorber layer is increased, the absorption capacity of the layer is increased with an improved performance. Reduction in thickness of the photoactive layer may cause to a decrease of photo generated current by increasing the series resistance.

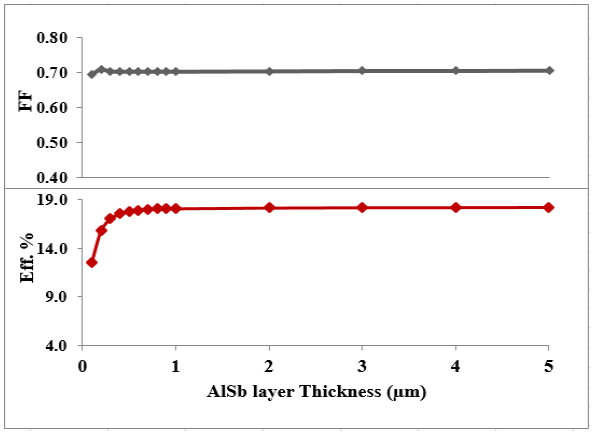

Fig. 3 Effect on fill factor and efficiency due to the AlSb thickness variation

Fig. 3 shows the fill factor and efficiency changes with the absorber layer thickness. The fill factor has significant relation with open circuit voltage. The recombination occurring in the depletion region may reduce the FF. Besides, the effect of parasitic resistance is also significant in the performance parameters. The graphical presentation of efficiency shows that it is increasing in a very slow trend which is almost in saturated level after 1µm and the increase is shown up to 5 µm.

The overall performance parameters of the base cell significantly results in overall increase in cell conversion efficiency. The cell conversion efficiency is 18.07 % achieved from the entire research work at only 1 µm thickness of AlSb absorber layer along.

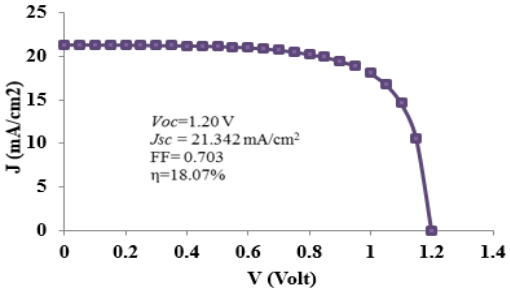

Fig. 4 J-V characteristics curve of proposed cell

The figure above shows the *J-V* curve of the cell which shows the relation between current density and open circuit voltage of the simulated cell.The current and voltage of solar cell follow the equations (5) and (6) respectively,

$$J = J_0[\exp(\frac{qV}{nKT}) - 1] - J_{SC} \quad (5)$$

$$V_0 = \frac{nKT}{q}\ln(\frac{I_{SC}}{I_0}) + 1 \quad (6)$$

It is clear from Fig. 4 that the highest short circuit current is attainable when the open circuit voltage is zero and the highest voltage is found for zero short circuit current density. Considering both cases, the highest efficiency is found at the maximum power point. The overall power conversion efficiency of a solar cell relates the open circuit voltage, short circuit current resulting in efficiency as,

Power conversion efficiency,

$$\eta = \frac{V_0 I_{SC} FF}{P_{in}} \quad (7)$$

The following the basic equations the simulated output is explored to find out the optimized structure with better efficiency range. Fig. 5 shows the quantum efficiency with respect to wavelength change for the absorber layer thickness of 1000 nm.

The quantum efficiency of solar cell is the measure of output with the incident sunlight. Furthermore the wavelength depends on the band gap of the absorber layer as,

$$\lambda = \frac{hc}{E_g} \tag{8}$$

Where, the relation between wavelength and the band gap is inverse considering the others as constant.

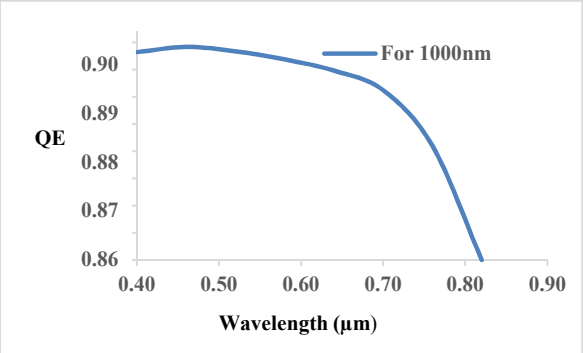

Fig.5 Change in Quantum Efficiency with Wavelength

Following the equation, the observation in the illustration shows that the response is highest for the wavelength between 400 nm and 500 nm. Efficiency is in moderate range for medium wavelength range with only a small degradation in quantum efficiency. The wavelength out of the visible range shows a rapid degradation in efficiency leading to zero. It ensures that the optimum band gap of the absorber layer material shows a tremendous response in the visible wavelength range. The resultant outcomes of numerical analysis is shown in Table II.

TABLE II OPTIMIZED RESULT OF PROPOSED CELL

Performance Parameters	Optimized Outputs
Open Circuit Voltage, (V_{oc})	1.20 V
Short Circuit Current, (J_{sc})	21.342 mA/cm^2
Fill Factor , (FF)	0.703
Cell Conversion Efficiency, (η)	18.07 %

The overview of the simulation result shows an improvement than the previous numerical analysis claiming the AlSb solar cell as prospective cell.

B. Effect of Doping Concentration on Cell Performance

In this cell, p-type layer (AlSb) is the main solar radiation absorber. The n-type materials (ITO and ZnS) have high electron concentration that have insignificant change with doping. This obligates the the p-type Alumimium Antimonide layer to observe the variation of the cell parameters with doping concentration. In Fig. 5 the variation in doping concentration varying from 1×10^{14} cm^{-3} to 1×10^{18} cm^{-3} for analysis and cell performance parameters with this variation is represented graphically.

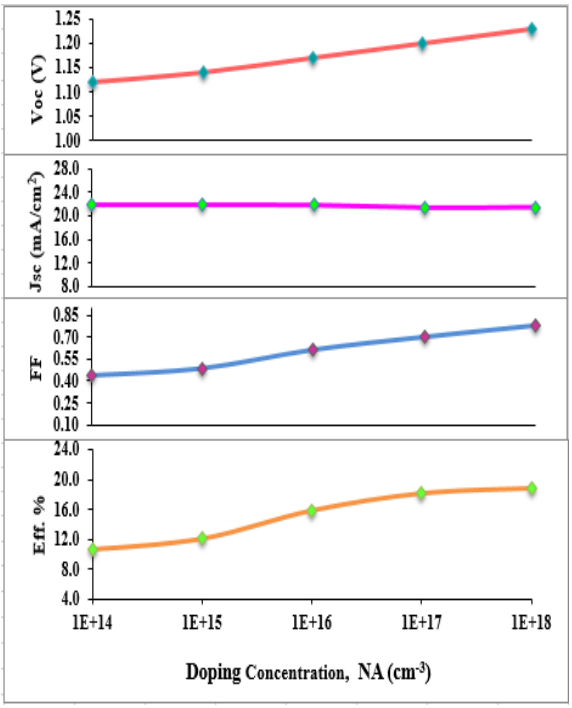

Fig.5 Cell performance with the variation in Doping concentration

The doping of the p-type absorber layer increases its conductivity by increasing the majority carrier by trapping them in a bond. In this case the holes are the majority carrier with electron as minority carrier. The doping effect results in the reduction in band gap and the recombination loss is reduced inversely with minority carrier lifetime. The illustration in Fig. 5 shows that the maximization is attainable with an increasing doping concentration. For optimization doping concentration=1×10^{17}cm^{-3}is considered.

C. Effect of Temperature

The observance of the cell structure results in a change with the temperature variation. The cell performance may decrease due to increase in temperature or with durability. Limit of degradation in the cell performance must be considered for cell optimization. The increase in temperature causes tp decrease the mobility of the charge carrier. This study shows the numerical analysis to explore the cell stability at a variable temperature range for proposed AlSb solar cell structure. Fig. 6 shows the performance parameters of ultra-thin AlSb solar cell which

shows degradation with the increase of operating temperature.

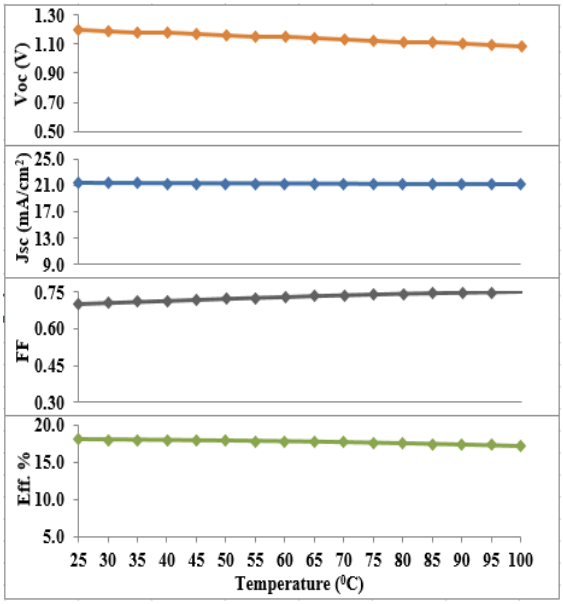

Fig.6 Effects of operating temperature variation on the cells performance

Thermal stability ensures the performance parameters to track the optimized efficiency with increase in temperature.

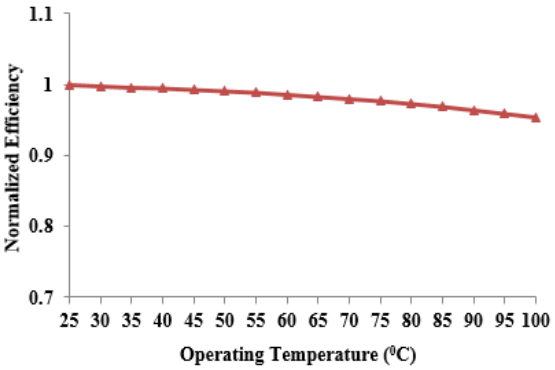

Fig.7 Normalized efficiency with Temperature Change

Observation shows an outcome of operating temperature variation from 25°C to 100°C maintaining thermal stability. The Fig. 7 illustrates normalized efficiency with a temperature range 25°C to 100°C. In this observation, the stability of optimized AlSb solar cell by a TC of -0.06%/°C. The illustration shows that the normalized efficiency of the cell decreases with the increase in temperature but the temperature co-efficient (TC) has lower degradation within allowable range. The consequence of TC for AlSb solar cell evinces better stability even at higher temperature.

IV. CONCLUSION

The conversion efficiency obtained from the numerical analysis of ultra-thin AlSb solar cell is 18.07% with *Voc*=1.20 V, *Jsc* = 21.342 mA/cm^2, FF= 0.703. The ultra-thin structure (1μm) of the absorber layer with better efficiency ensures the material preservation. Further increases in absorber layer thickness gives higher output following the agreement of theoretical observation. The cell is also thermally stable with a TC (Temperature Coefficient) of -0.06%/°C. The numerical analysis of the optimized AlSb solar cell substantiates that the power conversion efficiency has been improved with better thermal stability.

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