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Review of Prospective Aluminium Antimonide Compound Solar Cells in Photovoltaics

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Abstract- *The uprising trend towards renewable energy sources has promising impact on sustainable development of the world. Solar is the most prospective one considering it the ultimate source of energy. The semiconductor compound of group III-V has the suitable optical and electrical properties to have higher efficient solar cell. Aluminium Antimonide (AlSb) is a binary compound semiconductor material of group III-V having suitable criteria in properties to have high efficient and stable solar cell. In this paper, the prospects and technological impacts are observed to find out its contribution in the advancement of solar cell technologies.*

Keywords: Renewable energy; Solar cell; Compound Material; Efficient; AlSb Solar Cell.

1. INTRODUCTION

The technological advancement and revolution in the industries have risen up the demand for energy. With the ever increasing demand, it is predicted that the consumption of energy would be 30 TW in 2050 to ensure the sustainability in development [1]. The supply and consumption of energy in 2014 is 13690 Mtoe and 9425 Mtoe respectively [2].The ever increasing consumption has causes a climactic situation as the demand is many times larger than the reproduction of the conventional energy sources. This causes rapid diminishing of the conventional energy sources at an alarming rate. So it is high time to move to renewable energy sources to mitigate the problem ensuring the objectives of clean energy sources. Among all the renewable sources, solar is the ultimate source of energy. If only 0.1% of the earth's surface can be covered with module of solar cell producing 1KWh per day in one meter square area, the global energy demand can be met [3]. Solar cell can be considered as the most promising clean source of energy for a green world.

Researchers are endeavouring to look for many emerging solar cells with various material observation. High efficient, low cost, abundant solar cell with stability are main desired characteristics of solar cell. To find out new prospects the immediate concern can be imposed on binary and ternary compound of group III-V and II-VI. With advanced light-trapping structures, the combination of III-V absorber structures with single-junction can deliver a high efficient performance based on many operating conditions at a fractional cost of multi-junction structures [4]. Aluminium Antimonide (AlSb) is a compound material of group III-V having a band gap is 1.62 eV which is suitable for solar spectrum absorption [5]. The suitable optical and electrical properties of AlSb marks it as a prominent candidate.

2. LITERATURE REVIEW

To select any suitable material for solar cell, abundance of material is relative to ensure cost effectiveness. Al and Sb has abundance and low cost too which creates interest to research about this material. In 1965, AlSb was prepared by co- evaporation method having conduction energy of 0.17 and 0.29 eV [6]. For the first time, the strong photovoltaic response in vacuum deposited AlSb was observed by Francombe in 1976 [7]. Czochralski process is used to prepare single crystal AlSb. AlSb also can be deposited on a number of insulating substrate and it was done by MOCVD technique in 1979 [8]. AlSb was deposited by MBE process and oxidation was studied in 1991 [9]. AlSb thin film was prepared by dc magnetron sputtering and its electrical and optical properties were studied in 2007 [10].

At room temperature, the free energy for the formation of AlSb compound is -68.71 kJ/mol. The negative value for formation indicates the electro-deposition process as favourable. Electro-deposition of AlSb on TiO_2 substrate was done by Dhakal et al. in 2009 [11]. Due to corrosive nature of the Al and Sb ions causes Vacuum deposition technique to be used to prepare AlSb. In 2011, Toda observed deposition of different layer thickness of AlSb thin films onto amorphous glass substrate using thermal evaporation techniques [12]. The relation between bandgap and transmittance was observed considering the Al: Sb. To get the ideal bandgap for fabrication of AlSb thin film, the ratio of Al and Sb is considered 3:7. This results in nearly 1.44 eV [13]. If the ratio is reversed it will result in an unclear transmittance spectra. The band gap of AlSb shows that it is nearly equal to the optimum band gap required to get the maximum power. The observation shows the relationship between conductivity with the temperature. The activation energy is estimated 0.68 eV ensuring AlSb has an increasing conductivity with the increase in excitation.

3. DEVELOPMENT OF ALUMINIUM ANTIMONOIDE SOLAR CELLS

3.1 Electrodeposition of AlSb for Thin Film Solar Cell

In this proposed cell structure electro-deposition of AlSb is done on TiO_2. The structure shows that ITO is used as TCO layer, TiO_2 is the n-type material and p-type AlSb is the absorber layer. Here AlSb is considered as intrinsic absorber layer depositing a p-type CuSCN layer below the absorber layer and above the back contact. The insertion of intrinsic layer increases the concentration of the structure to minimize the losses at the contacts. This structure was observed by Dhakal et al. in 2009 [11]. The ITO/ TiO_2/AlSb/CuSCN structure is shown in Fig. 1.

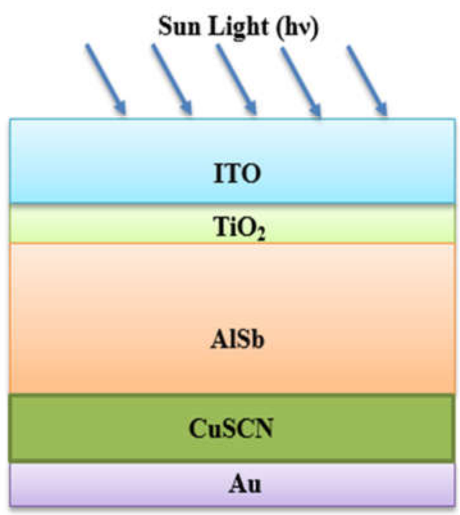

Fig. 1: p-i-n junction structure of AlSb Solar cell

The structure was investigated considering the standard AM 1.5 illumination. AMPS 1D (Analysis of Microelectronic and Photonic Structures) software is used to investigate the simulation result. For simulation, the thickness of TiO_2 is 50 nm and absorber layer thickness is 500 nm. The boundary condition between the valance and conduction band determines the back contact material. The barrier height value is the main factor in this case. Here, gold contact of 20 nm is used as the back contact estimating the value of barrier height approx. 1.35 eV.

The simulated result of this structure has efficiency 14.41 % where the short circuit current (*Jsc*) value is 21.7 mA/cm^2, open circuit voltage (*Voc*) is 1.19 V, fill factor (FF) is 0.55.

With the same process of electrodeposition a p-n structure is also observed. In this structure only p-type AlSb absorber layer is used. This hetero-junction structure ITO/ TiO_2/AlSb is simulated using AMPS 1D in this case estimating the same thickness (500 nm) for absorber layer. The structure is shown in Fig. 2.

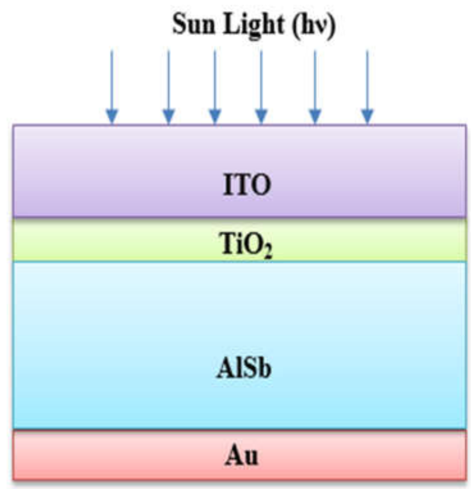

Fig. 2: p-n hetero-junction structure of the AlSb Solar cell

This structure has an improvement in efficiency of approx. 19%. In spite of these, p-i-n shows better photovoltaics responses. Many factors such as stability in temperature, different losses is to be considered for the characterization of a cell structure.

3.2 Variation in the n-type Window layer in AlSb Solar Cells

The n-type window layer is one of the most important parameter in solar cell structure. It must have enough band gap to pass the incident light to the absorber layer without absorbing it. The absence of this layer causes non-uniformity in the absorber layer degrading the cell performance. Different losses minimization with least series resistance is an important object of this layer. In this case, the Al and Sb were co-sputtered varying the power to have efficient absorber layer for solar cell. Dc Magnetron sputtering process was used to fabricate the thin film of AlSb. The active layers are annealed at different temperatures.

For fabrication the thin film is annealed at different temperatures where the ratio of Al and Sb has a great impact. If the ratio of Al and Sb is 7:3 then it becomes more metallic showing an absorbed visible spectrum. The different ratio of Al and Sb are chosen for investigation such as 1:3, 2:5, 1:1 and 3:7 [13, 14]. Among this the ratio 3:7 is the most efficient one having $Eg = 1.44$ eV which is nearly the ideal band gap value for

AlSb. The different deposition parameters are also observed showing Table 1.

Table 1: Parameters of Deposition for Different Film Ratio

Al : Sb	Deposition rate of Al (A°/s)	Deposition rate of Sb (A°/s)	Sputtering Power of Al (W)	Sputtering Power of Sb (W)
1:3	2	6	104	37
2:5	2	5	104	33
3:7	3	7	150	42
1:1	1	1	150	24
7:3	7	3	261	24

Different opto-electrical properties are observed from this parameters. The transmittance spectra shows the ratio 3:7 suitable to characterize the thin film for fabrication of solar cells. Besides better doping is required to increase the built in field. So, the comparison between ZnO and TiO_2 as suitable n-type material is shown in Table 2.

Table 2: Voltage-current Characteristics of p-n junction Structure

Structure	*Voc* (mV)	*Jsc* (mA/cm^2)	FF	Efficiency (%)
ITO/AlSb/TiO_2	80	12×10^{-3}	0.23	0.001
ITO/AlSb/ZnO	120	76×10^{-3}	0.24	0.009

The above table shows a better performance in ZnO as n-type material. In this experiment, the n-type layer ZnO is used instead of TiO_2. Many technical difficulties for synthesis make it less known absorber layer material. So, it is to be analysed with different structure to ensure the efficient result.

The observation of p-i-n structure using ZnO as n-type attributes to more efficiency than p-n structure. The p-i-n structure having more strong built in field contributes to efficiency increment. The ITO/ZnO/AlSb/CuSCN structure is shown in the Fig. 3 and Fig. 4. The structure in Fig. 3 and Fig. 4 show that different back contact material. The Mo and Au back contact has a value of PHIBL 0.85 and 1.35 respectively. It mainly depends on the material optimization considering the concentration, band gap and mobility.

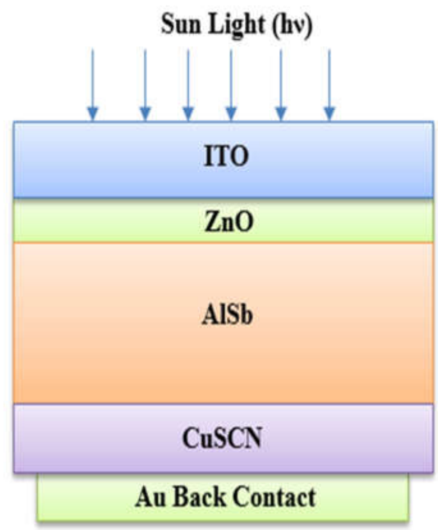

Fig. 3: Structure of the AlSb Solar cell with Au Back Contact

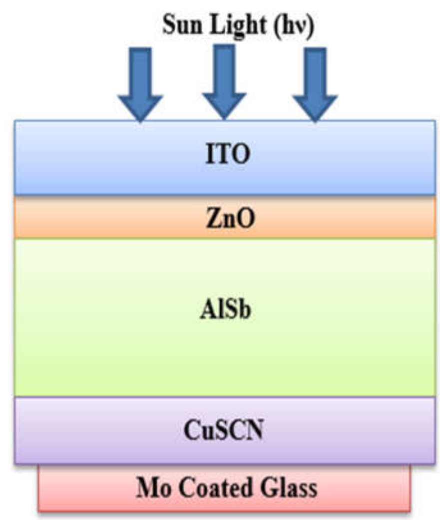

Fig.4: Structure of the AlSb Solar cell with Mo Coated Glass

The CuSCN is used as p-type material that can be considered as a prerequisite material for charge extraction. Considering the NREL calibrated standard the I-V response of the both structure was observed. For different barrier height the back contact is varied here.

The AMPS 1D simulation shows efficiency approx. 14.41% where the FF is 55.5%, short circuit current is 21.7 mA/cm^2, open circuit voltage is 1.19 V. The efficiency is increased to 19% for 2 micron of absorber layer thickness. Many factors are to be considered in the interfaces of the junction to increase the efficiency keeping other factors optimum.

4. CONCLUSION

In this review paper, many deposition processes are focused for AlSb absorber layer. The structures are observed to have suitable structure for simulation. The Numerical analysis using AMPS 1D software shows efficiency 14.41% (FF = 55.5%, I_{sc}= 21.7 mA/cm^2, V_{oc} = 1.19 V) for absorber layer thickness 1000 nm. The p-i-n structure shows more prominent result than p-n structure. All the observations show AlSb as an uprising one for contributing photovoltaic material. Experiments are to be carried out on this material for further improvement in efficiency and other performance parameters.

5. ACKNOWLEDGEMENT

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