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Optimization of Lead Sulfide (PbS) Solar Cell

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***Abstract*— Renewable energy is known as the clean and green energy. Solar energy is one of those in this modern era. Lead Sulfide (PbS) is one of the most suitable semiconductor materials which absorption coefficient is high. It has the most favorable band gap energy and highly stable along with low cost material. Consequently the investigators have great deliberation to observe the ultra-thin PbS solar cell. The optimization of PbS ultra-thin solar cell has been done at 600 nm thickness of PbS absorber and window layer ZnO has also been done at 50 nm thickness. It is shown that the ultra-thin PbS solar cell has given efficiency of 19.40% (J_{sc} = 28.41 mAcm^{-2}, V_{oc} = 0.80 V and FF = 0.85).Hence, it has been investigated the thermal stability of the PbS solar cell. When the temperature is increased from 20^{o}C to 120^{o}C, the TC of the optimization structure is being found at -0.011 %/^{o}C.**

Keywords—PbS; Thin Film Solar Cell; wxAMPS; Thermal Stability.

I. INTRODUCTION

We cannot think the existence of this present era without power. Expenditure of power has not been decreased every day because of the increasing rate of population, the growing section of industry and various expectant through the globe. Up to 2018, quantity of the approximate dealing power throughout the world is around 20 terra watt. Fossil fuels are used 80% [1].Although the conception of the investigators is that the production of fossil fuels would be the last of the period in next generation as well as it has created the greenhouse gasses by the ignition of fossil fuels. Now, we investigate the alternative origin for the energy harvesting concentration mainly on solar energy which is eminently efficient, low price and earth plentiful as well as show the better stability in clean solar cell.

The solar cells which are known as first generation is known as silicon based solar cell. The fabrication technology is costly and greater portion of the energy is misused by generating heat. First generation solar cells restriction is minimized by the solar cells (CIGS) which are second generation also named as thin film solar cells. But its efficiency is inferior. The price of the solar cells generate a little number of cells. So it is needed to search the new materials solar cell that is overcoming this former crisis. Therefore, ultra-thin PbS solar cell is not only feasible but also cost efficient. They are highly effective and also earth plentiful materials for clean and green energy. They assure a peremptory power supply throughout the world .PbS is one of the most abundant materials on earth. Its absorption coefficient is high ($\alpha > 10^4 cm^{-1}$) [2]. The maximum value of absorption coefficient (α) of the film is in the visible region with an average value of 3.25×10^6 cm^{-1} and the minimum value was at 1000 nm near infrared region [3]. It indicates that PbS solar cell is absorbed the higher photon of energy. PbS band gap can be varied in the range of 0.41 – 2.7 eV which is an important material property. It opens the way to a new class of applications [4]. PbS is a plentiful material which is the principal of Pb. PbS is a bulk material which band gap energy is 0.37 eV. This parochial band gap semiconductor has not only conduction but also valence bands at the point of L of the Brillion zone [5].The ultra-thin PbS solar cell is chosen for its Nano crystal material. It is in the extent period which has broad band absorption of tenability [6, 7]. Holes and electrons are uniformly limited [8].They are in incited states which are long lived [7].Value of affinity of electron of PbS increases the feasibility of charge separation. The investigation to explore hidden potentiality of absorber layer is examined and the results are promising for CZTS based solar cells [9-11], SnS solar cell [12] and CdSe based solar cells [13, 14].

In order to find out the potentiality of PbS ultra-thin film solar cells structure, a solar cell simulator wxAMPS (Analysis of Microelectronic and Photonic Structures with wxWidgets) is being used. In this work, the higher performance of PbS solar cell is resolved through the thickness variation of window layer, TCO layer, PbS layer thickness, doping variation, effect of quantum efficiency and the effect of temperature.

II. MODELING AND SIMULATION

A solar cell simulator wxAMPS (Analysis of Microelectronic and Photonic Structures with wx Widgets) is being used in order to intention of not only numerical modelling but also simulation. For finding out the of ultra-thin PbS solar cells potentiality, several layers which has various parameters of cells to be inlay included proposed model of single during simulation work .A theoretical study constructed of CdS/PbS structure was given by H.A. Mohamed et al. on 18 July 2014 [15]. PbS solar cells baseline modeling was described by Jaymin Ray et al. [16]. In this paper, he reported the theoretical investigation into the use of Nano crystalline PbS in place of QDs as solar cell absorber. A structure of

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(SLG/ITO/CdS or ZnO/PbS/Al) solar cell was simulated using SCAPS software. Most of the researchers had used ITO as the best TCO of this conventional structure and most of the solar cell structure of the simulation and theatrical investigation based work [16, 17].In this work ITO is also being used.

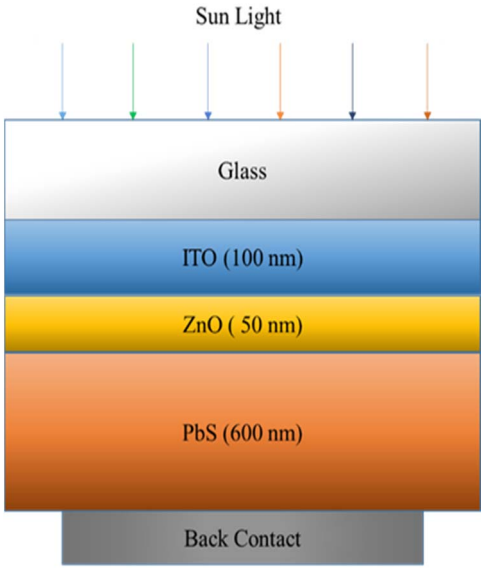

Fig. 1. Optimization structure of PbS Solar cell.

In 2015, Deuk Ho Yeon et al. reported about the good stability and highest conversion efficiency of depletion heterojunction solar cells based PbS thin film. It was not quantum dot based PbS solar cell. Chemical bath deposition (CBD) is a process which is being applied to grow PbS thin film. It is relatively low temperatures and low cost. By using double absorber layer of PbS, efficiency can be increased as much as 30% [18]. Back contact metal, nickel is being used in this work. In this optimization cell, ITO is being used as TCO and ZnO is being used as window in this structure. ZnO is the best used window layer in PbS single junction solar cell of thin film based [17, 18]. Mostly used TCO, ITO has two important properties of optical transparency and electrical conductivity [19].Optical transparency of ITO has not only (T>85% at 550 nm) but also conductivity of electrical (ρ~10-4Ω.cm).Its transmittance is about 88% and lower resistivity of (2.6×10-3) Ω.cm [20].In order to get conducting, doping should be reached in higher level. After that level in order to reach Fermi level of the conduction band, free carrier density is also needed to increase [23]. Absorber layers little bit thickness causes the transmission losses (incomplete absorption) and for this result consideration of the metallic back contact will not be taken. Optical losses are the absorption losses in TCO and window as well as the reflection from all interfaces [15]. N-type one dimensional nanowires are known as ZnO which one with a large energy gap. Its surface area is large. It has visibility to transparency and light of IR [17]. Different fabrication techniques are applied to fabricate thin film based solar cell of PbS such as electro deposition, chemical bath deposition CBD [21]. Basic equations related to semiconductors are being solved like the continuity equations, Poisson equation. They are needed to observe numerical simulation which are for not only free holes but also free electrons. Band-alignment of two junctions are needed to stack. Without intervening any layers, the enhancement of conversion efficiency has caused in order to absorb the solar spectrum in wider range [17].

In this research work, it is shown from Table I that the cell performance parameters value was taken for inserting the different layer materials in a PbS solar cell into the literature values [16, 22, 23].

TABLE I PROPERTIES OF MATERIALS USED IN NUMERICAL SIMULATION

Parameters	**ITO**	**n-ZnO**	**p-PbS**
Thickness,(μm)	0.1	0.05	Variable
Dielectric constant, ϵ/ϵ_o	9	9	10
Band gap, E_g(eV)	3.72	3	1.4
Conduction band Density of States, $N_c(cm^{-3})$	4.0×10^{18}	2.0×10^{18}	2.0×10^{18}
Valence band Density of States, N_v (cm^{-3})	1.0×10^{19}	1.5×10^{19}	2.0×10^{18}
Mobility of Electrons, μ_n $(cm^2/v/s)$	100	100	50
Mobility of Holes, $\mu_p(cm^2/v/s)$	25	25	20
Density of Electrons and Holes, N_A, N_D (cm^{-3})	1.0×10^{20}	1.0×10^{19}	5.5×10^{16}
Affinity of Electrons, χ (eV)	3.6	4.50	4.35

Without simulation numerically it is quite impossible to justify the results before expensive fabrication. In this work, the different materials property which are being inserted such as band gap, electron affinity, hole mobility, dielectric constant and others are taken from literature review. Insertion of this property is needed to take carefully. Because without it, appropriate justification cannot be observed.

III. RESULTS AND DISCUSSION

A. Thickness Variation Result of ZnO

In this PbS absorber layer based solar cell, ZnO works as a heterojunction partner in order to get the optimum value. It must be maintained as well as it works as a protection layer at the time of sputtering of TCO.

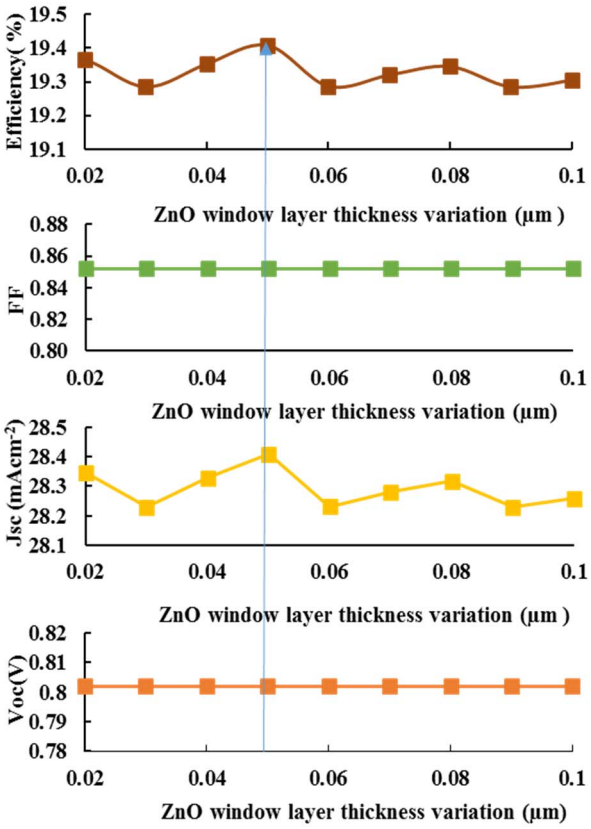

Fig. 2. Result of thickness variation of ZnO for the optimization cell.

If a minimum window layer thickness is not taken, it can damage the overall cell by creating short path between the absorber layer and TCO layer. Thickness is varied between 20 nm to 100 nm. The efficiency is being found varied for the variation of thickness. Then increasing thickness V_{oc} and FF all are remaining also constant but J_{sc} is being varied.

B. Result of TCO Layer Thickness Variation

Transparent conducting oxide (TCO) layers are used to absorb the photon energy from sunlight. It has also offered not only electrical but also optical contact. Prevention of the hole creation in window layer materials is caused by it. Indium tin oxide (ITO) layer is responsible for transparency and conductivity. In this work, TCO layer thickness is caused variation between 20 nm to 100 nm. Fig.3 has shown that conversion efficiency of the cell is increasing with decreasing of TCO layer thickness. Performance parameters of such as V_{oc}, FF and J_{sc} are almost remain constant. Reflectivity at front is chosen as 0.15 and back is chosen as 0.9 for these material systems limitation and other consideration.

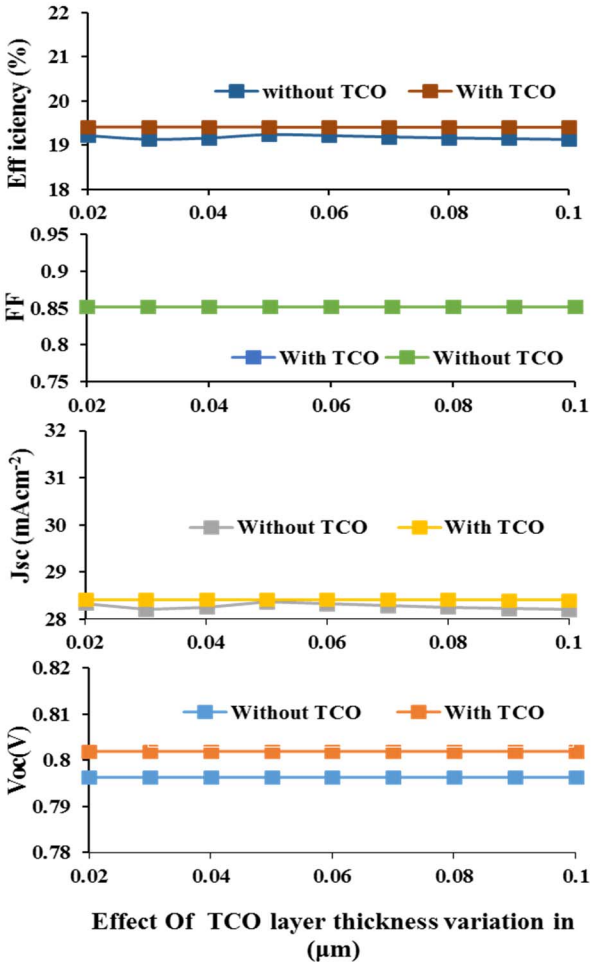

Fig. 3. Result of with and without TCO layer thickness variation.

TABLE II. TCO EFFECT COMPARISON

Parameters	*Voc* (V)	Jsc (mAcm^{-2})	FF (%)	η(%)
Without TCO	0.79	28.20	0.85	19.13
With TCO	0.80	28.41	0.85	19.40

Conversion efficiency is increasing by adding TCO layer which is playing a very important role to make it transparency and more conductive.

C. Result of Thickness Variation of Absorber Layer

Investigation is done through the PbS absorber layer thickness variation in the range between 0.1 µm to 5 µm. Numerical analysis is done after calculation. Variation of thickness of ultra-thin PbS solar cell are given in Fig. 4.

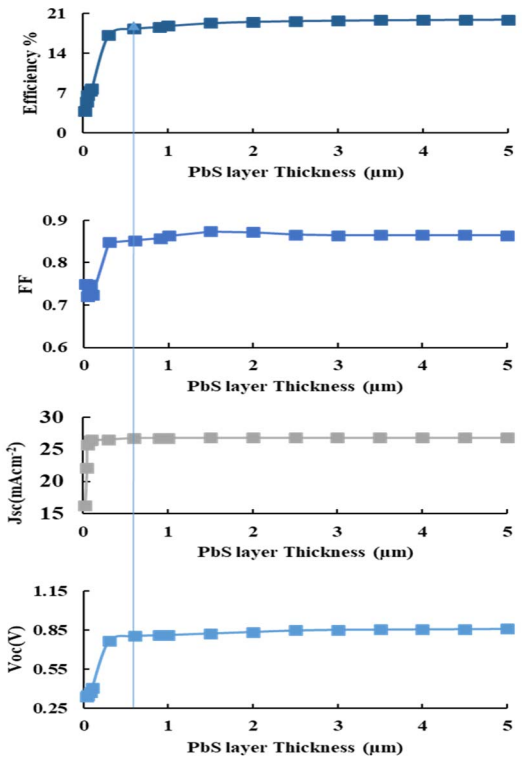

Fig. 4. Result of absorber layer variation of thickness for the optimization cell.

From this figure it has been seen that the efficiency is being increased as the thickness of absorber layer is increased. At 600 nm thickness of PbS absorber layer, the efficiency is 19.40% of the optimization cell. At 1000 nm of absorber layer thickness of the optimization cell, the efficiency is 19.92% with 50 nm ZnO window layer. A solar cell structure of (SLG/ITO/CdS or ZnO/PbS/Al) was described by Jaymin Ray et al [16] .In his paper he has investigated on PbS thin-film solar cell in the place of quantum dot. He has claimed that around 16.80% power conversion can be gained by SLG/ITO/CdS/PbS/Al solar cell structure .And 18.50% power conversion can be gained by SLG/ITO/ZnO/PbS/Al solar cell structure which is not involving quantum dot. Our investigation has given better conversion efficiency.

D. Results of Doping Variation of Absorber Layer

For calculating the conversion efficiency of the cell with numerical simulation, PbS absorber layer doping concentration is varied. Doping concentration variation is caused between 5.5×10^{13} cm^{-3} to 5.5×10^{19} cm^{-3} and it is provided in Fig. 5. Conversion efficiency of the cell of PbS is increased because of doping concentration is increased. It is almost proportional in this type of solar cell because of the three of the parameter which are playing a vital role to increase the efficiency of the typical type. Hence J_{sc} is in decreasing trend but other two parameters are in increasing trend. The overall efficiency is also increasing trend for this reason. But appropriate doping concentration is needed to optimize the ultra-thin film solar cell. So doping concentration is playing a vital role in this regard. Investigation is done through the PbS absorber layer thickness reduction.

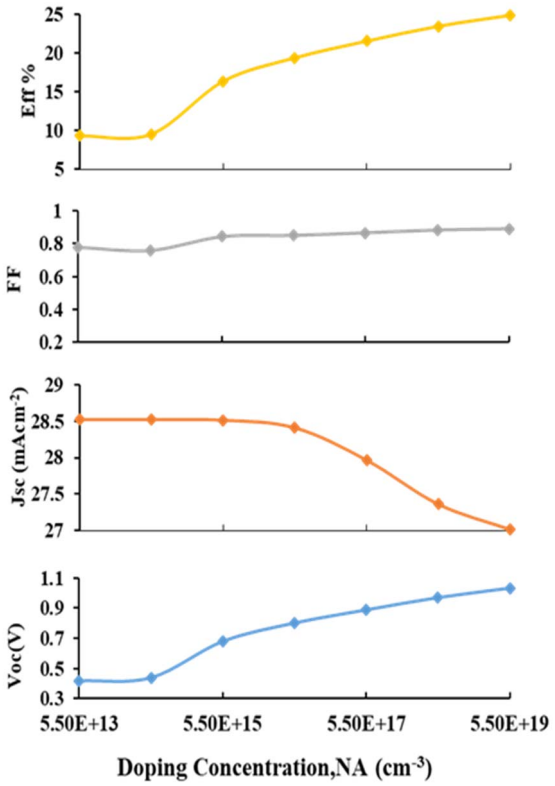

Fig. 5. Results of doping variation of absorber layer.

The result of I-V curve is provided in Fig.5.In order to compare a solar cell with other; the most used parameter is efficiency. Efficiency is the ratio of energy coming output from the solar cell to the input of the energy coming from the sun. Solar cell efficiency lies on different criteria including band spectrum, incident photon and cells temperature. Without I-V curve, performance of solar cell can't be observed. So justification is badly needed in here.

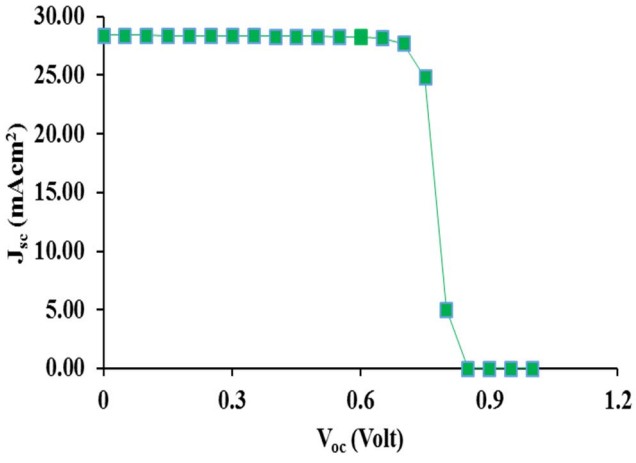

Fig. 6. I-V characteristics curve of the optimization structure.

E. *QUUANTUM EFFICIENCY EFFECT*

The optimization cells quantum efficiency has simulated by wxAMPS software and it is shown in Fig.7.

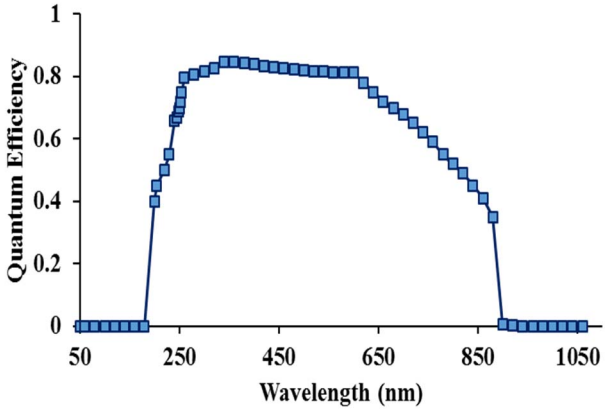

Fig. 7. Quantum efficiency of the optimization structure.

Whether a certain wavelengths photons energy are being fallen and the carriers of minority are being preserved in end, so at that wavelength, quantum efficiency is shown unity. Below band gap energy, quantum efficiency is shown zero.

F. *Temperature effect on the cell*

In this work, cell stability has been investigated at higher operating temperature. Temperature affects the concentration of carrier, states of density. It also affects not only hole and electron mobility but also band gap energy. The cells operating temperature is caused variation between 20°C to 120°C.

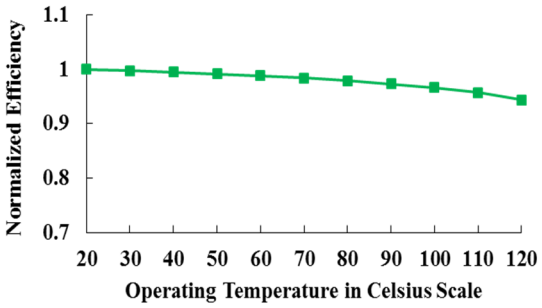

Fig. 8. Variation of operating temperature effect.

From Fig. 8, it is being proved that at the range of high temperature, the optimization cells temperature co-efficient is -0.011 %/°C. It is caused for the temperature between 20°C to 120°C.

G. *Results of the Optimization Cell Structure*

By investigating this simulation work, stable ultra-thin PbS solar cells hidden potentiality is being observed where inserting the potential window layer material of 50 nm ZnO. In addition, a layer of TCO which is ITO is taken. Its thickness is 100 nm. Conversion efficiency of the optimized cell is up to 18.26% is possible with 600 nm PbS absorber and 18.76% power conversion efficiency can be gained with 50 nm thickness of ZnO window layer and 1 μm PbS absorber. Optimized cells output parameter is shown in Table III.

TABLE III

THE OUTPUT RESULT OF THE OPTIMIZATION STRUCTURE

Parameters	**Optimization Structure (Simulated)**
Jsc (mAcm^{-2})	28.41
Voc (V)	0.80
Fill Factor	0.85
Efficiency (%)	19.40
Temperature co-efficient(%/^{O}C)	-0.011

IV. CONCLUSION

The optimization of PbS solar cell is being done by taking ZnO as a window layer and ITO as TCO. The optimization structure shows the efficiency of 19.40% with J_{sc} = 28.41 mA/cm^2, V_{oc} = 0.80 V and fill factor = 0.85. It has shown a better thermal stability which has TC of -0.011%/^{o}C. The possibility of further research to develop ultra-thin PbS absorber layer and ZnO window layer for efficiency improvement is opened by optimization of this structure.

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