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Simulation and Design of CIGS thin Film Solar Cell using Distributed Bragg Reflector

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Abstract— CIGS is a better replacement of Si solar cell having low possibility of damage different layers is used for CIGS cell which decreases short current losses. CIGS solar cell technology is a very highly competitive and also need less raw material as well as low cost of fabrication. As compared to C-Si (~11000C) thermal budge is very low for the production of CIGS modules about (~550 0C approximately). The comparison of weight C-Si solar panels have lesser weight than CIGS because in CIGS solar panels there are two glass panes and in C-Si there is only one pane of glass are used. The absorption coefficient of CIGS is high as compare to C-Si because CIGS solar cells using direct band gap materials and C-Si included in indirect band gap material and having lower absorption coefficient property (104/cm) that's why CIGS solar cell thickness is 100 times lesser than as compare to C-Si solar cells. There are a lot of techniques to increase the efficiency and decrease transmission losses but the scope of this work covers how to use DBR (Distributed Bragg Reflector) as a back reflector and also examining its effect on decreasing thickness of the absorber layer. In real world it is not possible to reduce the transmission losses approximately equal to zero because some part of the light is absorbed and lost in metal used at the rear surface of the cell in the form of heat but reflection losses can be reduced up to zero. It is seen that mostly in conventional thin film solar cells thick metal plate is used at the rear surface of the solar cell for increasing reflection and decreasing transmission losses at the back surface of the cell. A huge proportion of heat is lost due to the collision of incident photons with metallic surfaces. However, DBR is tested in CIGS solar cell for increasing back surface reflection and increasing light trapping by this research work.

Keywords: Buffer layer, window layer, Independent Spectroscopy, Distributed Bragg Reflector, Soda lime glass.

I. Introduction

Direct solar energy is a type of renewable energy in which electrical energy generated based on utilizing solar irradiance in the form of light or heat. Some green and clean energy technologies are indirectly dependent on sunlight and solar irradiance for generation of electric power such as tidal and wind energy technologies. Different amount of thermal energy absorbed by several materials on earth's surface such as water, oceans, ground, etc. which has the capability to cause variation in thermal potential. Thus when wind blows it is important for normalize the temperature variance. Solar PV technology uses solar irradiance and changes it to Electrical power using photovoltaic (PV) [1]. However there are several technologies of solar cells but amongst them thin film is the most active option because they are flexible nature and light weight. Among thin film solar cells CIGS (copper indium gallium Selenide) is the leading technology in the market thin film solar cells are the leading thin film due to its mechanical flexibility and durability cost effective and reliable fabrication process. It is a compound related to the quaternary Selenide semiconductor alloy.

However the efficiency and performance of CIGS solar cell is not larger than much advanced multijunction cells or C-Si based solar cell but research work is in progress to reduce this efficiency gap. Many methods have been examined to increase the efficiency of CIGS solar cell the performance parameter of cell on depends on thickness, band gap and doping each portion of the cell. Word direct solar means those renewable energy technologies which based on solar energy from sun directly. Among all other technologies of solar cells thin film is the most attractive option because they are flexible nature and light weight. CIGS (copper indium gallium Selenide) thin film solar cells are the leading thin film technology in market it is a compound similar to quaternary semiconductor alloy. The properties like durability and mechanical flexibility presents attractive features for both military and civilian these properties are because of material properties used in CIGS solar cells [2].

As declare by the world energy council the total energy reaching on the earth is 7500 times' excess than the total world energy consumption [3]. Copper indium gallium di-seleniod (CIGS) based thin film cells are drawing worldwide attention and focus they are efficient for solar based power generation and has achieved 20.7% quantum Efficiency as associated to crystalline carbon silicon wafer based solar cell. CIGS is good absorber material which have attracted a good attention because of its band gap (~1.0-1.12ev) and having appropriate absorption coefficient (105/cm) and after usage very minor material wastage Unit cell of CIGS has tetragonal geometry [4, 5]. Focus was given to its efficiency the modern of these with using a few years of research behind them changed 22% of incoming solar power to electrical power [6]. When thickness of the absorber layer decreases from 1500m to 600nm and the use of In2O3: H (IOH) both as back and front TCO, combined with a unique 2-D grating structure, led to increase and shows improvement up to 25% optical performance as compared to equally thick flat device [7]. Optoelectronic nano patterning path to reduce material consumption and increase efficiency of the cells [8]. Transparent conductive oxide (TCO) used as a front electrode for thin film solar cells and plays a major role in defining the maximum efficiency. Doped ZnO is a prominent TCO material which is extensively used in (a-Si) and CIGS thin film solar cells [9]. Combining nano-sized local point's contacts and rear surface passivation layer is one of them. For generation point contact openings atomic layer deposition (ALD) of Al2O3 is used for CIGS surface passivation and generate nano-sphere precipitates. The nano-sized local rear point contacts with Al2O3 rear surface passivated CIGS cell shows a significant development in open circuit voltage (Voc) as compared to an unpassivated reference cells [10]. The cost of CuInGeSe2 (CIGS) have already arrived in to the market having cost almost equal or lower than the conventional Si based solar cells [11].

The cells performance has been considering impact changes in hole or electron minority carrier life time and carrier density and efficiency record [12]. Now the first company of solar cell has stated recently maximum cell efficiency by 20.4% and a module efficiency reaching by 13.9% noted in laboratory conditions [13]. Explicitly metallic back reflectors would also act as electrodes for a cell, metals damage and suffer from intrinsic absorption losses incurred at the interface and surface. This absorption would be reduced by adding and inserting an optical spacing layer [14]. For all conductive webs would be used for both a- Si and CuInSe2, so a single cell is designed by edging and cutting the web then put on a metal grid manufacturing structure for developing the front contact to the cell and then assembling in group series manner to C- Si module [15]. That time it was the first thin film company which expresses "reliability and performance of thin film PV" which assist large scale PV modules and significantly decrease PV module cost and has attained the smallest manufacturing and power generation cost particularly for industry about 1$ per watt [16].

CIGS is one of the three mainstreamed thin film technology the other two technologies are CdTe and amorphous Silicon (a-Si). CIGS layer is flexible, thin and would be able to be deposited on a very flexible material. Earth receives huge amount of energy from sun for millions of years. The sun is just like of a fusion reactor and provides incredible amount of energy to earth. The evaluation and history of the cell is very dramatic [17]. CIGS has maximum absorption coefficient material of 105/cm so a film of thickness 1-2 µm very suitable for absorption most of the light which is altered from Si solar cell having cell thickness 200-300 µm. The required layer of CIGS is so thin, flexible and confirmed as a stable device outside, inside testing and is more trustworthy to high energy radiation as match to other thin film solar cell devices [18].

II. Methodology

The research work explains numerous methods unified to reflection losses in photovoltaic solar cell. At the very first stage we have explained some old methods then in second stage we associate new methods and techniques to the existing ones and have used PV Light house online software for consistent and advance results. PV light house software most possibly used for simulation and designing purposes to find optical and electrical properties of solar cell devices. The university of New South Wales (UNSW) PV light house and have officially publicized major free access solar cell fabrication simulator online. PV factory have said that all physics processes integrate in to a software package which is easy to understand, practice and which has been treated by over 500000 virtual cells throughout data testing. Improvements are likely to include more recording process steps and adding production lines.

The main resolve of the research is to minimize reflection losses by a special technique introducing Distributed Bragg Reflector (DBR) with different materials and then examined its efficiency for solar cells. This work also explains the variation of size and its effect on active region of thin film solar cell. However, we have used different software in this research work such as (originpro, SunSolve, webplot digitilizer) mostly concentrated on solar cell simulation processes, so we would associate new materials for DBR as a back reflector and at last relate these results for a specific range of DBR. The paper has given information about electrical properties of the materials so one can extent current and voltage (I-V) curve, short circuit current density (Jsc) and fill factor (FF) from (I-V) curve also can extent open circuit voltage (Voc), then at the end External quantum efficiency (EQE) of the solar cell was noted.

This research described various means associated to optical and reflection losses in photovoltaic. In the beginning we explained some old methods then in second stages we correlate new approaches and results to the current ones and have used PV Light house online software for reliable results. During simulation of various materials the optical and electrical properties of materials must kept in record so that it would be easily recognized that how efficiently photons or light energy transmuted in to electrical energy. Sun-Solve simulator contains both electrical and optical prototypes to produce extrapolative and precise device simulation. The model solves and processes the equation in 2D or1D this may be in time domain or steady state. The model described the transfer of charge within the device by solve hole and drift –diffusion and carrier continuity equations exactly in position space. Using Sun-Solve simulator we fabricated a design of CIGS solar cell involving DBR (distributed Bragg reflector) Fig.1 shows a solar cell in Sun-Solve simulator.

Figure 1. Sun-Solve simulator window

After getting access to the software and login to the software and then further select C-Si HJ cell so we could see a prototype solar cell. We have to select explicitly the upper most layer and then introducing films according to the desire and exact model of CIGS thin film solar cell and enlarge thickness of each film by giving electrical and optical details of layer, in second layer we add-on glass which act as a transparent layer and after this layer we add-on reflectors that in Ag (silver) or inserting DBR (distributed Bragg reflector), DBR contain alternate layers of Si and SiO2layer.

III. Discussion and Results

This Paper have publicized that PV lighthouse software has been used for simulation and designing of CIGS solar cell. After officially login to the Sun-Solve ray tracer module of sun solve simulator to process and simulate our CIGS model. There are various kinds of cells but for CIGS thin film select c-Si HJ solar cell and it generates a new model with different layers. Modern commercially and industrially formed CIGS cells containing six specific layers and hence each layer has specific function and parameters first of all substrate is essential then various layers are placed through various commercial methods. The model of CIGS cell is shown in Fig.2.

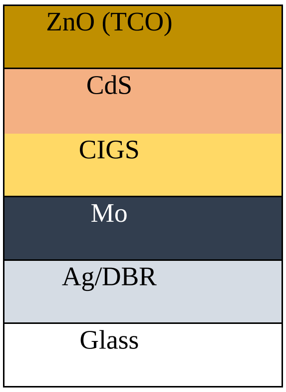

Figure 2. Sun-Solve model of CIGS thin film cell during Simulation

Several techniques have been recognized for fabrication CIGS solar cell. However, we have deliberated several layers and its optimization and fabrication for different layers. The first layer of CIGS solar cell is substrate which shows that the solar cell is may be rigid and flexible. Glass are the most frankly and commonly available substrate because of resist to corrosion and low cost. Commonly soda lime glass (SLG) usedfor increasing manufacturing and performance. However, we have used Glass in Sun-Solve CIGS model having thickness of 1000 nm. Which is to be found just beneath the ITO layer? It is thin and light weight. Generally back contact of the CIGS cell is reserved below the active layer and above the back reflector. It is fabricated especially for the collecting of carriers which are generated in the absorber layer. Typically Back contact is a metal serves as anode or positive lead having low resistivity. Though, in CIGS cells, most of the situations molybdenum (Mo) is used because of its compatibility and flexibility in the fabrication process. As long as during optimization deviation in the thickness of back contact current density in the absorber layer also varies shown in the Table I.

TABLE I. VARIATION OF JSC IN THE ACTIVE LAYER BY CHANGING THICKNESS OF BACK CONTACT (MO) THICKNESS

Back Contact (Mo) Thickness	**Current density in the absorber layer (J_{sc}) mA/cm^2**
10m	335
20m	336
30m	336
40m	337
50m	337
60m	338
70m	338

Hence in 10 nm thickness is chosen for the model so at this thickness average current density (Jsc) is 33.5 mA/cm2 which is appropriate for the absorber layer. Active layer is the key layer where majority of carrier generation occur. Though, CIGS also documented as chalcopyrite is an I-III-VI semiconductor. Essentially CIGS (copper indium gallium di-Seleniod) also an alloy consist of CuInSe2 (CIS) &CuGaSe2 (CGS) having direct band gap materials and excessive absorption coefficient with band gap having range of 1.07eV to 1.75 eV. However, values of the band gap has mostly covered the higher energies and infrared range of the solar spectrum so that most of the incoming light being entranced close to the P-n hetero junction molded with the CdS film. Hence, this characteristic permits the active layer CIGS with more thickness than traditional C-Si solar cells. The thickness of the active layer changes from 200 nm to 800 nm and current density (Jsc) also varies from 23.7 to 30.4mA/cm2 as we can see from the Table II.

TABLE II. VARIATION OF (JSC) IN THE ABSORBER LAYER BY CHANGING THICKNESS OF THE CIGS.

Absorber Thickness (CIGS)	Current density(J_{sc})mA/cm^2
200 nm	23.6
250 nm	24.7
300 nm	25.2
350 nm	26.4
400 nm	27.5
500 nm	28.1
550 nm	28.4
600 nm	28.6
650 nm	29.1
700 nm	29.4

Hence, from the above argument it is clear that after optimization we fixed thickness of the absorber layer on 670 nm having current density (Jsc) of 29.5mA/cm2. Definitely, Buffer layer provide n-type hetero junction of CIGS solar cell. However, thin film of CdS having most possibly band gap of 2.4 eV may allow maximum amount of the usable photons to conduct through. Though Cd is toxic but there is no suitable alternative that has same level of performance so here, varying the thickness of CdS buffer layer and tested for performance and current density at the absorber layer as shown in the Table III.

TABLE III. VARIATION OF JSC IN ACTIVE LAYER BY CHANGING THICKNESS OF CDS

CdS Buffer layer	Current density J_{sc} in absorber layer
5 nm	33.6
10 nm	33.7
20 nm	32.9
30 nm	32.1
40 nm	32.2

However, by changing the thickness of buffer layer current density and efficiency varies that's why buffer layer thickness has been fixed at 10 nm thickness. Window layer is fabricated with a comparable function as the back contact. This window layer collects the carriers which are basically generated in the active layer and transmit it to the load. This layer is the upper layer of the so it should be transparent to the maximum range of light spectrum so that is essential for generation of carriers and photoelectric effect. Mostly transparent conductive oxide (TCO) has used as a window layer an effective TCO having broad band gap and permits large number of photons to go in to the active layer. This is also essential that the TCO layer has low resistivity and low recombination losses. Normally CIGScells use ZnO for TCO layer having range of band gap 3.3 eV. However, ZnO is experienced for a series of its thickness as shown in the Table IV.

TABLE IV. DEVIATION OF (JSC) IN ABSORBER LAYER BY CHANGING THICKNESS OF WINDOW LAYER.

TCO (ZnO) Thickness	current Density (J_{sc}) of Active layer
10 nm	27.8
20 nm	27.8
30 nm	27.9
40 nm	28.2
50 nm	28.3
60 nm	28.8
70 nm	29.1
80 nm	29.3
90 nm	29.9
100 nm	30.1
110 nm	30.1

Hence, 90 nm thickness of ZnO is secure in the window layer having current density is 29.9 nm which is a very competent value.

Results with using (Ag) as a Back reflector:

As mentioned above different results of the simulated model it is essential to check absorption of photons when using silver (Ag) as a back contact then examine the efficiency and absorption using DBR as a back reflector in term of absorption and reflection loss. Hence using Ag as a back reflector the number of the photons are captivated by the Silver and losses occurs that's why current density (Jsc) comes to 29.6 mA/cm2 as we can see in Fig. 3 external quantum efficiency (%EQE) goes decreasing after 400nm wavelength, because some of photons are absorbed by the Silver and eventually produce heat.

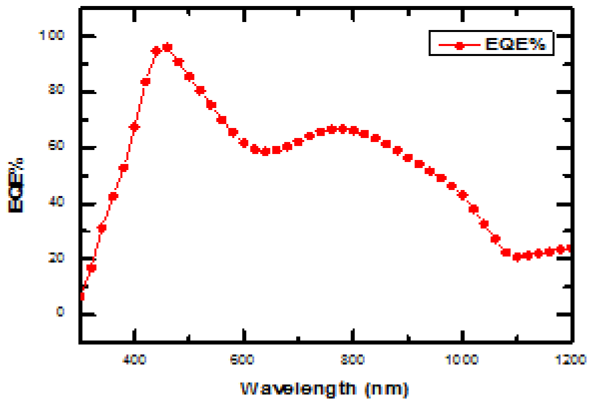

Figure 3. External quantum efficiency (%EQE) with silver as back reflector.

After using silver (Ag) as a back reflector replacing (Ag) with 1 DBR (distributed Bragg Reflector) as a back surface reflector in model. DBR consist of synchronized SiO2 and Si layers. DBR is a material containing of alternate high and low refractive index in the subsequent graph it is exposed that the overall performance of the cell has been upgraded, and photons captivation also have altered across the wavelength. Therefore, current density has upraised up to 30.3mA/cm2 as shown in Fig 4.

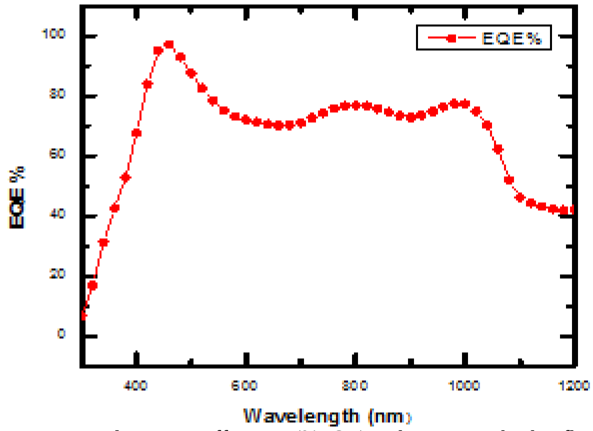

Figure 4. External quantum efficiency (%EQE) with 1 DBR as back reflector.

Hence, after using 1 DBR act as a back reflector replacing it with 2 DBR and it has seen that the cell performance and external quantum efficiency (EQE%) also changed, and definitely current density of the absorber layer amplified up to 32.2 mA/cm2 as shown in Fig 5.

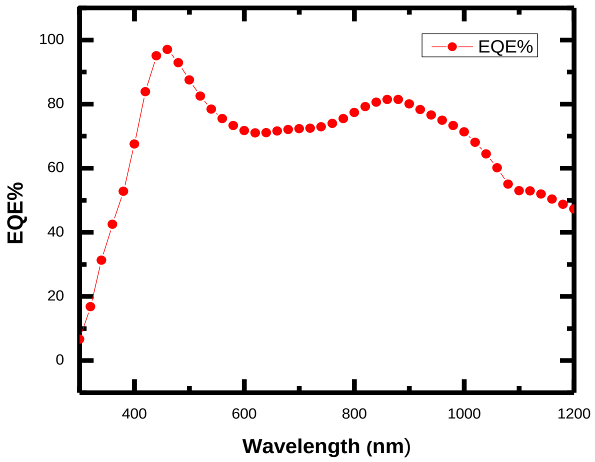

Figure 5. Variation in External quantum efficiency (%EQE) with 2 DBRs as back reflector.

After all for further simulations replacing back reflector 2 DBR with 3 DBR it is has shown from the following graph that the performance and external quantum efficiency upgraded overall the spectrum and the current density (Jsc) also varies to 33.4 mA/cm2 as shown in the Fig 6.

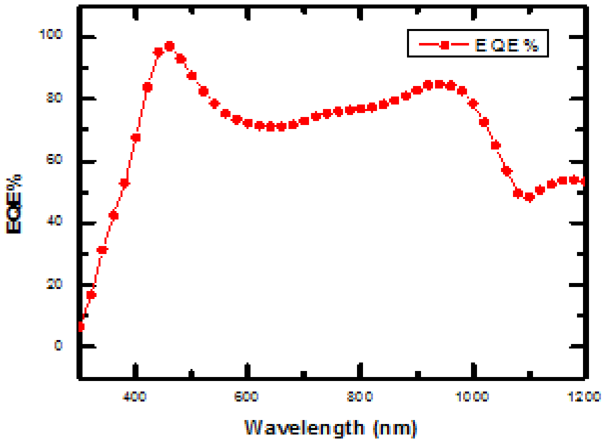

Figure 6. Variation in External quantum efficiency with 3 DBRs as back reflector.

Hence, by changing 3 DBR with 4 DBR act as a back reflector it is clear that the cell (EQE %) has enhanced performance and current density of the cell also promoted to 34.7 mA/cm2 so attraction of the active layer increases as shown in the Fig. 7.

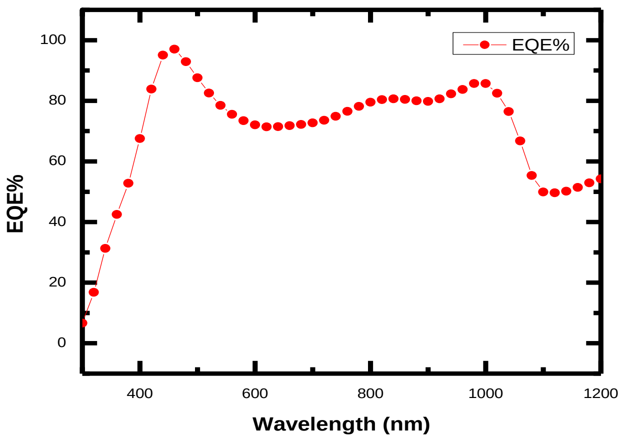

Figure 7. Variation in External quantum efficiency 4 DBRs as back reflector.

However, comparing both the graphs of 4 DBR and Ag the curve shows 4 DBR improved EQE% and performance however, black curve shows Ag EQE% and performance of the absorber layer at larger wavelengths while keeping thickness of the active layer constant. It shows that the cell performance and EQE% has improved at higher wavelengths with 4 DBR as compare to Silver (Ag) as a back reflector in case of 4 DBR more absorption of photons have occurred as shown in Fig.8 .

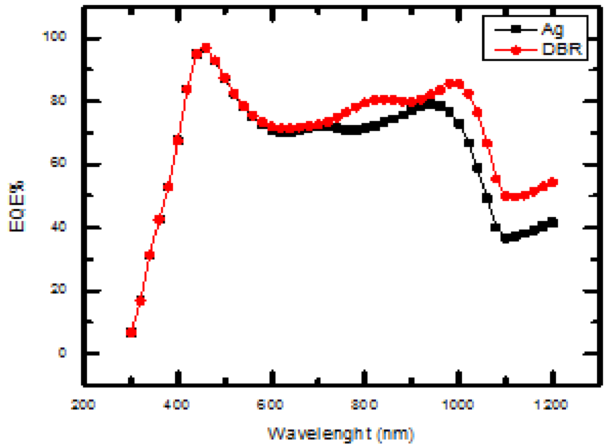

Figure 8. External quantum efficiency comparison using silver and four DBRs as a back reflector.

CONCLUSION

This paper, have revealed work on fabrication and designing of CIGS thin film solar cell though, its illustrations exposed the potential of improved efficiency among the thin film solar cells. As long as the efficiency of the CIGS increases becoming better and near to the C-Si based solar cell. However, there is need to carry out a lot of research work for future to rise its EQE % value close to Shockley queisser limit. This work shows high current density in the active layer that is 34.7 mA/cm2as compared to ideal calculation which is of 37mA/cm2 when all incoming photons transformed in to electron-hole pair generation. However, by inserting several DBR films as a back reflector in place of silver (Ag) therefore can potentially enhance its current density Jsc and EQE % value. This paper mainly focused on optimizing thickness of the CIGS, ZnO and CdS semiconductor layers. CIGS would diverge in band gap so several models would be tested to achieve higher efficiency. An effort would be done by insertion of higher band gap CIGS material above a lower band gap one and generate a dual junction CIGS solar cell.

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