Effect of defects on the performance of some photovoltaic solar cells: an introduction to research methods to engineering students

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1 INTRODUCTION

Solar energy is the biggest source of energy on Earth, and all other energy sources are either direct or indirect derivatives of it. Harnessing maximum amount of solar energy, storing it in some energy form and utilizing it are important technological issues. Many research groups are dedicated to work on solar energy conversion into electricity that will give a suitable replacement for fossil fuel. As the use of fossil fuel increases harmful gases and other by-products that are extremely unsafe for environment, photovoltaic solar cells that convert solar illumination into electricity is a trending field. Solar cells based on different types of materials have different industrial processes, efficiencies and market shares. Silicon based solar cells, III-V cells (GaAs, InP), CIGS cells, CdTe cells, Dye sensitised cells, Organic cells, Multi-junction devices that can be used as 1-sun or concentrated illumination environment for best possible output. Si-based solar cells dominate the overall market share. In thin film, CIGS based solar cell the research is improving and the experimental results enlightening day by day [1]. The recent experimental result obtained for CIGS based solar cell is above 21 % while the simulated result is around 29% [2, 3].

The analysis of CIGS based solar cells including defects that is due to increasing Ga content, have a drastic effect on the conversion efficiency. Defect states in the solar cell always harm the performance of CIGS solar cells, defects states that or either in interface (CdS/CIGS) or within the absorber layer always have an effect on the overall performance of solar cell. All PV parameters such as V_{OC}, J_{SC}, FF and eta are decreased. Charge carers are trapped or recombined in defects and go waist that do not contribute to transport current to the external load. Unavoidable defect states emerge in solar cell materials, by void, doping, surface or interface.

These defects include, but are not limited to, point defects such as vacancies, interstitials, or substitutional impurities, dislocations, stacking faults and grain boundaries. The defects of interest (1) exist in the semiconductor primarily responsible for electron-hole pair production (CIGS) and (2) have resulted in an allowed energy state in the band-gap which is too deep (i.e. far away from the band edges) to unequivocally be a dopant state. These defects are often referred to as trap states. Unavoidable defect states emerge in solar cell materials, introduced by void, doping, surface or interface, which always decrease Voc and Jsc then deteriorate the cell's performance. Defect states in the band gap of the absorption material or buffer layer material produces discrete Voc values for different solar cells. How defect states affect a cell's performance. The interfaces occur between the different layers, generally play an important role in this film solar cells devices, can cause stresses, defects ,interface states, and surface recombination centres, interface defects, which cause undesirable recombination of carriers.

Defect states (location in the band gap and densities) in absorption layer (as CIGS) and in buffer layer (like CdS) always harm the performance of CIGS solar cells. The performance parameters: photoelectric conversion efficiency, fill factor, open-circuit voltage, and short-circuit current for different defect states were quantitatively analyzed. When defect state density is less than 10^{14} cm^3 in CIGS or less than 10^{18} cm^3 in CdS, defect states have little effect on the performances. Position of the defect states also influence the performance, if located in the middle of the band gap, they are more harmful. The other effects of temperature and thickness are also considered [4].

Engineering and other field related researcher take keen interest in the development of solar technologies. By improving, the performance of PV cells, theoretically as well as experimentally. The aim is to provide best alternatives for energy requirements, by providing cheap alternatives in order to avoid or at least decrease the use of fossil fuel by using renewable and environmental friendly sources.

In order to reach the 'green energy challenge' a large number of professionals and engineers in this field in our educational institutions are required. New laboratories and research centres should be developed and a large number of technical experts capable in solar cells and PV field will be deployed.

On the other hand, before any practical work and manufacturing of solar cells professionals are required to simulate their work by using adequate software produces thus being crucial that lab practices concerning this topic are developed at universities. In fact there is a number of such software available in market and its introduction and use is mentioned in the literature and specialized software [5], some software are mentioned here,

PC1D (One-dimensional semiconductor device simulator), AMPS (Analysis of Microelectronic and Photonic Structures), SCAPS (a Solar Cell Capacitance Simulator), ASA (Amorphous Semiconductor Analysis), AFORS-HET (Automat For Simulation of Heterostructures), SimWindows, ADEPT-F, ASPIN. Some of these software are dedicated to Si-based solar cells, some to thin-film CIGS solar cells and other for both as well as general electronics and PV devices. In this work we present the results that are performed as a lab session by interested students in solar energy. We use SCAPS for analysing our CIGS cells and the results obtained are stated. SCAPS is a useful tool for teaching the basics of PV devices particularly CIGS, CdTe and other thin film solar cells which provides the students a better understanding of the role of the main parameters that control the behaviour of PV devices.

2 INSIGHT INTO SOLAR CELLS

Here in this analysis the effect of defects on the overall performance of CIGS solar cell has been carried out. The software used for this purposes is Solar Cell Capacitance Simulator software (SCAPS) [6-8]. The band gap of CIGS materials can be tuned as a function of the Ga content that has an effect on the External Quantum Efficiency (EQE) as well as on the other main parameters of the PV device. The simulation results for CGS (with pure Ga) based solar cell was approximately 29%, but the experimental results given in literature is above 21% for 31% Ga content. After introducing defects in the cell, the efficiency to the desired values will are tuned. Defects in the cell will change the simulated values. The analysis of the outputs of the SCAPS model provides a better understanding of thin film PV solar cells.

The advancement of 2nd generation solar cells (thin-film technologies) addresses the gain of better electrical performance. To increase the efficiency from 30-60% while retaining low cost materials and manufacturing techniques (the theoretical solar conversion efficiency limit for a single energy threshold material, calculated by Shockley and Queisser as 31 % under 1-Sun illumination in 1961) [9].

The study of thin-film solar cells and modules is an important goal for the photovoltaic industry. Record-efficiency devices provide a proof of concept for developing products. Dedicated simulation software offer a suitable tool for exploring new concepts.

Numerous simulation and experimental work performed in the photovoltaic field to obtain high conversion efficiency and to increase the stability and durability of the technology. The evolution from 6% efficient crystalline silicon (c-Si) cell is reached to 25.0 %, [10]. The emergence of new materials, and the new concept that boost the efficiency up to 44.7 % for multi-junction (tandem four junction) solar cell, [11]. For chalcopyrite thin-film solar cell, in CIGS the experimental and simulation results for different combination compared in a recent work, [12]. The efficiency for CIGS has obtained an efficiency of 20.8 % for 1-sun but it is 22.8% for concentrated solar cells application, [13].

3 CUINGASE2 (CIGS) SOLAR CELLS

I-III-VI chalcopyrite materials have very desirable properties for PV application. The band gap for CuInGaSe2 is 1.53 eV, an ideal material for PV purposes. Further, the band gap can be controlled by alloying with Ga, Al or S [14]. Moreover $Cu(In,Ga)Se_2$ has gained worthy reputation with high efficiency. The experimental results reported already give the efficiency above 21% [15]. The basic schematic of a thin-film CIGS solar cell is elaborated in Fig. 1. The efficiency for concentrated (multi sun) is 22.8% reported in the latest literature. The CIGS film is consist of a p-CIGS absorber layer with combination of n-CdS layer and ZnO window layer. The band gap here is a function of Gallium and can be varied from 1.0 – 1.72 eV, that would cause the effect in the variation of other solar cell parameters, [16]. Simulation results giving efficiencies above 25% are also published. Though its efficiency is high but still it difficult to commercialize due to the availability of resources and particularly the rare metals Indium (In) and Gallium (Ga) increasing price to CIGS based technology [17].

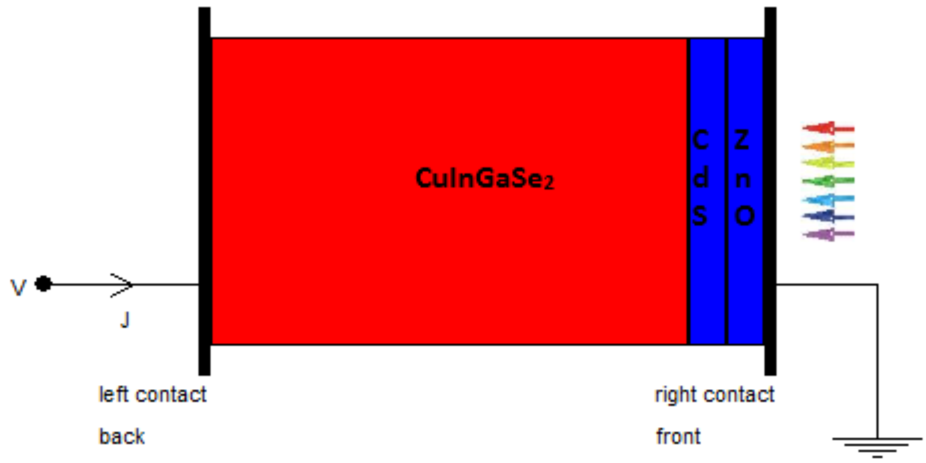

Fig. 1. Schematic of a thin film CIGS solar cell

Table.1 Photovoltaic parameters for CIGS solar cells with different defect concentration

Interface density (1/cm^2)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	eta (%)
1.0 E10	0.95677	40.35444	80.9244	31.245
3.0 E10	0.9553	40.33032	80.2035	30.9005
6.0 E10	0.95132	40.29282	78.8819	30.2364
9.0 E10	0.94349	40.25372	77.4486	29.4143
1.0 E11	0.93971	40.24033	76.9924	29.1142
3.0 E11	0.87308	39.92951	63.2338	22.0443

The defects concentration was changed and the effect of different parameters had been observed in the CIGS thin film solar cell, the summary of results has demonstrated in Tab. 1. The open circuit voltage (Voc) decreases as the defects concentration increases. The short circuit current represented by (J_{SC}) decreases because of the carrier's recombination. Similarly, the Fill-Factor (FF) decreases, the same phenomenon also observed in the case of external quantum efficiency η (%). The results obtained by using SCAPS are given in Table 1.

4 EFFECT OF DEFECTS IN CIGS SOLAR CELLS

Defects reduce solar cell efficiency by providing new recombination pathways (loss), by allowing the light to generate heat rather than electricity. Defects induce deep energy levels in the semiconductor bandgap, which degrade the carrier lifetime and quantum efficiency of solar cells. One of the most reasons is the existence of recombination centres, which trap photogenerated carriers before they reach the solar cell terminals. Defects introduce energy levels in the bandgap, and act as recombination centres, which reduce the free carrier lifetime [18]. In CIGS based thin film devices, while introducing defects in the cell, in absorber layer the location of defects can be anywhere in the cell, will affect the efficiency almost in the same way, but in the interface of CdS/CIGS the deft and location is case sensitive. The PV cell is in the order of ZnO/CdS/CIGS with defects shown in figure 1. CuInGaSe2 of 2.5 µm and CdS of 0.05 µm (optimum thickness), the thickness of n-CdS and i-ZnO layers are 0.05 µm each.

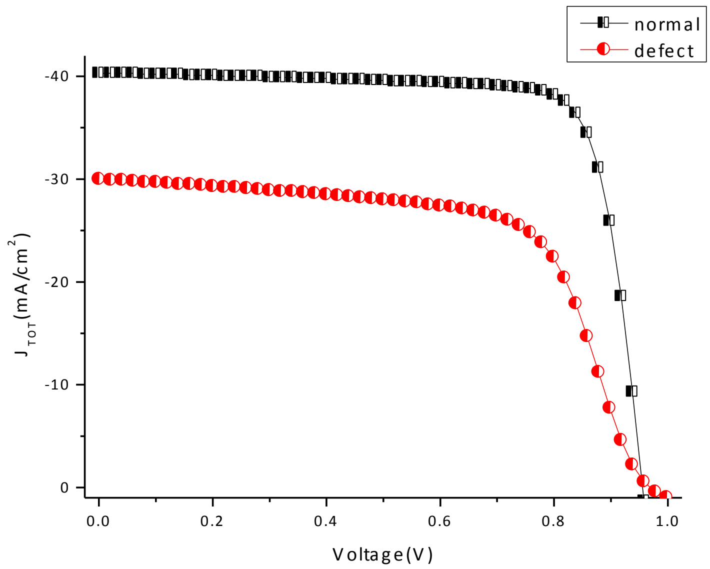

Fig. 2. J-V characteristic curve for CdS/CIGS interface

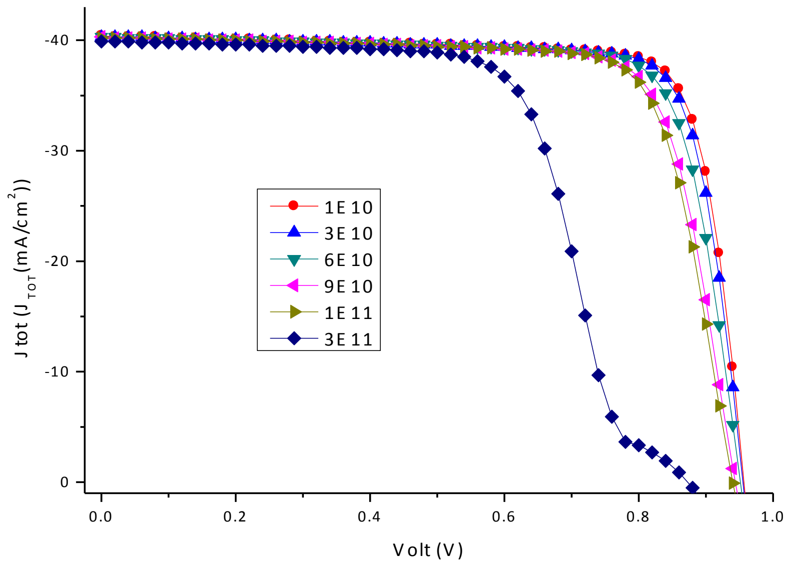

Fig. 3. J-V characteristic curve for CdS/CIGS interface with different defect values

Fig. 2 and *Fig. 3* give the J-V curve for the cell, with changing the value of defect concentration, Fig*. 2* gives the extreme result, and *Fig. 3.* gives the variation of J-V curve with different value of defects.

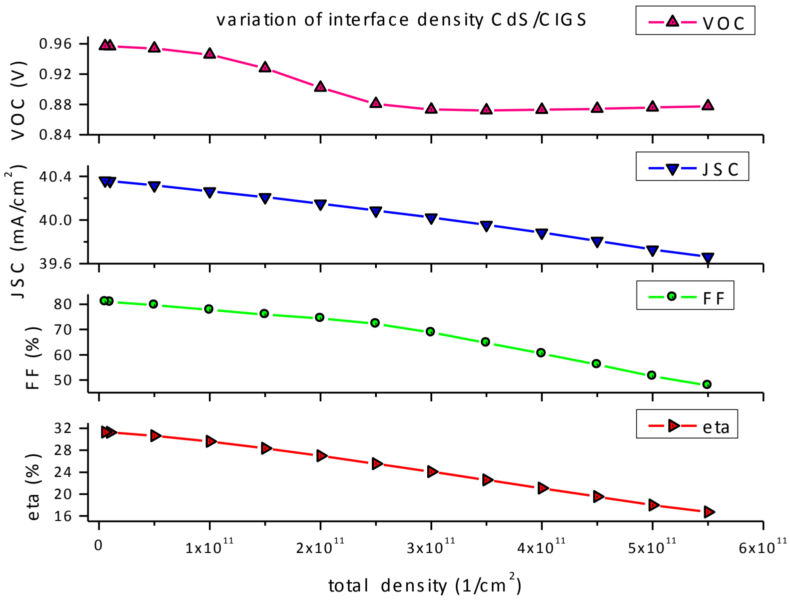

Fig. 4. Influence of interface defects CdS/CIGS on PV parameters

5 RESULTS AND DISCUSSION

The simulation results for both cells (CIGS single layer, and CIS/CGS multi-layer) were obtained from a chain of simulation experiments and tabulated. In Table 1, the simulated results are for the first case, giving maximum efficiency of 30.0% for Ga contents of 0.66, and a layer thickness of 2.5 µm. The experimental result giving maximum efficiency of above 20% and similar results that obtained from simulations in a recent work [18]. Our simulation gives better results.

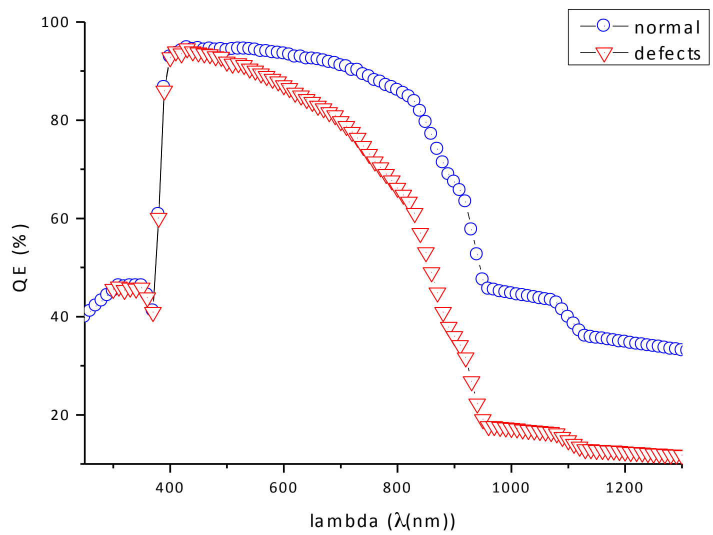

Fig. 5. QE for CdS/CIGS interface

The PV parameters of a ZnO/CdS/CIGS solar cell with defects value 10^{10} to $3.0x10^{11}$ (cm^{-2}) are specified in detail in Figure 4. The maximum values obtained here are eta 31.2 %, FF 80.9 %, JSC 0.0403 (A/cm2) and open circuit voltage VOC 0.9567 (V) for the lower defects values.

Fig. 4 gives the overall performance of the solar cell. For each value of the defects, the corresponding value of the output parameters is given in Table 1.

Fig. 5 explains some facts about the quantum efficiency (QE) of the solar cell, increasing the defects concentration in the cell, cause to decrease the QE value of the cell. The same phenomenon can be observed if we increase the band-gap of the CIGS cell by increasing the Ga content. Defect values influence highly the parameters beyond the 10^{11} (cm^{-2}) values.

6 CONCLUSIONS

The work developed is a laboratory practice of electrical engineering and students interested in photovoltaic energy so that they can understand the details concerning the physical operation of a thin-film solar cell structure by means of its numerical simulation. In PV cell structure there are many parameters influencing the efficiency and performance. Only the I-V characteristic measure is not enough to fully describe a PV cell because of the physical mechanisms taken place inside. To get confidence in a solar cell model, the student must consider different characteristics as well as different possible conditions to be simulated and compared.

In this work the effect of defects in the interface of CdS/CIGS and within absorber layer CIGS are discussed. The simulation results prove that defect states in the solar cell always harm the performance of CIGS solar cells. All PV parameters such as V_{OC}, J_{SC}, FF and eta are decreased. Charge carers are trapped or recombined in defects and go waist that do not contribute to transport current to the external load. Unavoidable defect states emerge in solar cell materials, by void, doping, surface or interface. Defects reduce solar cell efficiency by providing new recombination pathways. Simplicity of manufacturing and the cost per reliable watt are a result to be considered by future professionals. A conclusion of the work developed by making the experiments explained throughout this paper is that there are many parameters that influence the efficiency and performance in PV cell structure and in many simulation processes numerical modelling alone does not guarantee obtaining better photovoltaic solar cells.

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