Influence of CdS Buffer Layer in CIGS Solar Cell: A Gpvdm Device Simulation

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Abstract

CIGS is one of the leading candidates for solar energy conversion and this technology alone can meet up huge energy requirements. However, CdS is being used as a buffer layer in the mature CIGS technology which is hazardous material for the humans and environment. Hence there is a need to explore CIGS solar cell without any Cd-buffer layer which can offer excellent junction properties with CIGS absorber layer. In this paper, a possibility of very well-known and easy to fabricate buffer layer of ZnO to be used as a buffer layer in CIGS solar cell has been explored by a gpvdm simulation. The proposed solar cell utilizes buffer layer free configuration of CIGS and n:ZnO. The solar cell structure with ZnO/CIGS/Mo/Glass with an active layer (CIGS) thickness of about 1μm is proposed to achieve a competitive efficiency of 17.42% with an excellent fill factor of 88.8%. This study shows that ZnO can be a potential candidate to make an interface directly with CIGS by removing CdS in the present commercially adopted CIGS technology and to develop high efficiency solar cells.

Keywords: ZnO, CIGS, efficiency, buffer layer, IV curves, transmittance

1. Introduction

Over the years CIGS is being used as an active material of solar photovoltaiccell. Due to its ideal material characteristics like band-gap, absorption co-efficientand high bond energy, it has continued to gain attention by industry as well asresearchers. However, CdS has been found to be the best buffer layer to be the part of best performing CIGS based solar cells. Recently, researchers claimed that Cd leaching out of the CIGS and CdTe modules can be hazardous for the environment and we must control this process. In this regard, it is impossible to replace CIGS material with other active layers because of its excellent material properties and exact matching of its band gap with the visible light spectrum. Another alternative has been suggested to replace the buffer layer CdS by any other high band gap material like ZnO, AZO, ZnS or In_2S_3 [1]. However, to think out of the box, none has yet rather reported the influence of complete removal of any buffer layer on the overall performance of the solar modules.

In current study, we have explored the possibility of ZnO with the band gap of 4.03 eV to be used as an active layer directly on to the CIGS solar cell. The current-voltage characteristic has been analysed for the calculation of solar cell merits like open circuit voltage (V_{oc}) short circuit current (J_{sc}) fill factor (FF) and efficiency (η). It will be observed that only 100 nm thick ZnO film can make successful junction with conventional CIGS cell and can work as a power generating device with a little degradation in best performing CIGS based solar modules.

2. The solar cell configuration

For the present simulation, standard CIGSstructure was used once in the present of CdS buffer layer and once without any such layer. Widely accepted CdSbuffer layer of 50 nm thickness was considered to find the best performance out of CIGS based solar cell. Front and back contacts were ZnOand Mo/Glass having thicknesses of 100 nm each. The device structure with and without CdS buffer layer has been presented in Fig.1 (a) and (b), respectively.

3. Device simulation

The given device structure wassimulated with the help of gpvdm software to collect their performance as solar cell. To do that away, an AM 1.5 G light source was used for recording IV spectra of the cell. Applied voltage range was restricted between -0.1and 2.5 V to get the quantitative information about the photogenerated carriers which ultimatelyresulted in photocurrent. Optimal and suggestive parasitic resistances were chosen by default with the help of electrical simulation tool. Resulted output in the form of IV response and images have been recorded and presented to analyse the power conversion efficiencies (PCE) of the proposed solar cell.

4. Results and discussion

The current-voltage characteristic of the proposed cell is presented in Fig.2. It can be seen that the cell successfully works as power generating device with high current density and extraordinary squareness in the curve. The derived solar cell parameters can be found in Table-1. As one can notice that both the solar cells possess very high V_{oc} and J_{sc} irrespective of the presence/absence of CdS buffer layer. At the same time highly squared nature showed ~88% FF in the constructed CIGS solar cells. Importantly, a solar cell without utilizing CdS buffer layer showed an overall PCE of 17.42% compared to a cell utilizing buffer layer 22.24%. In short, one can accept the degradation of about 21.67% to overcome the health hazards issues while using CdS material in large scale installations of CIGS technology. The potential of ZnO alone to be used as an n-type partner layer has been verified from this study. Till date, the studies in this direction show a successful utilization of ZnO layer as a charge transport layer in conventional CdS/CIGS solar cell where CdS is kept as it is [3-6]. New to this in current study, in 90's the researchers have proposed that ZnO can act as a suitable n type partner for CIGS solar cells [7]. In this study, we propose that ZnO is a standalone material both to provide junction as well as efficient transport properties in ZnO/CIGS configuration.Device transmittance profiles have been also recorded analytically and presented in Fig. 3 for comparison purpose. As it can be seen from figure, the influence of CdS layer showed a significant difference in the device's absorption and hence transmittance characteristics. The characteristic of generation rate inside each layer has been depicted in Fig.4. It can be inferred from Fig.4 that the ZnO layer introduces a high potential barrier for holes which are generated in CIGS. In this design, holes can be kept inside CIGS layer and can be easily captured by external contact Mo/Glass which provides an excellent matching in their band edges. In this context, a practical device will be showing the performance on superior side than it has been claimed here.

5. Conclusion

In conclusion, through the present analytical simulation study, the acceptable degradation in the power conversion efficiency of conventional CIGS technology has been discussed. The proposed Cd free device structure showed ~ 21% degradation in solar cell performance by eliminating hazardous CdS buffer layer. In this manner, it is thus concluded that the large scale installations of CIGS technology can be achieved by overcoming the health hazard issues with CdS layer which was conventionally used till date for CIGS technology. The role of ZnO layer as buffer medium and efficient hole blocking region has been claimed. In addition, without using any CdS layer, the device made up of CIGS/ZnO heterojunction showed an overall efficiency of 17.42%. Such theoretical investigation will enlighten a pathway for research community to design and fabricate highly efficient CdSbuffer layers free CIGS and CZTS.

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Table 1 Solar cell parameters derived from illuminated IV curves

Parameter (unit)	Solar cell w/o CdS buffer layer	Solar cell with CdS buffer layer
$J_{sc}(A/m^2)$	0.845	1.075
$V_{oc}(V)$	2.32	2.34
$P_{max}(W/m^2)$	1.742	2.223
J_m (A/m^2)	0.792	0.101
$V_m(V)$	2.20	2.20
FF (%)	88.8	88.4
η (%)	17.42	22.24

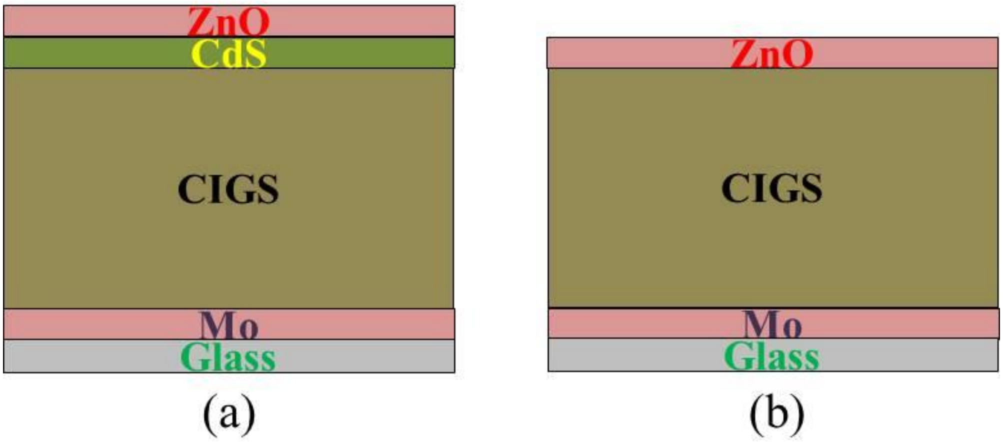

Figure 1 Proposed CIGS solar cell (a) with CdS and (b) without CdSbuffer layer

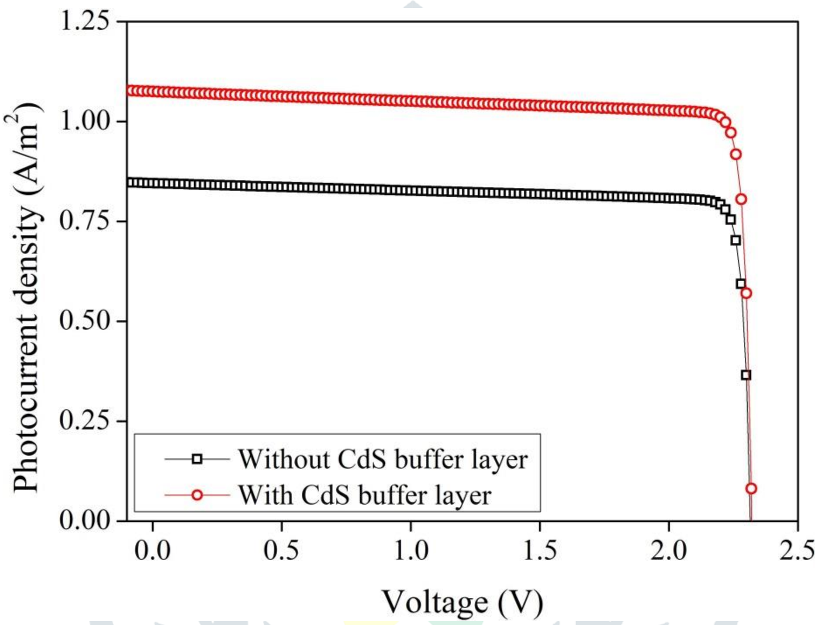

Figure 2 Photocurrent densityvs. Voltage characteristic of proposed CIGS solar cell

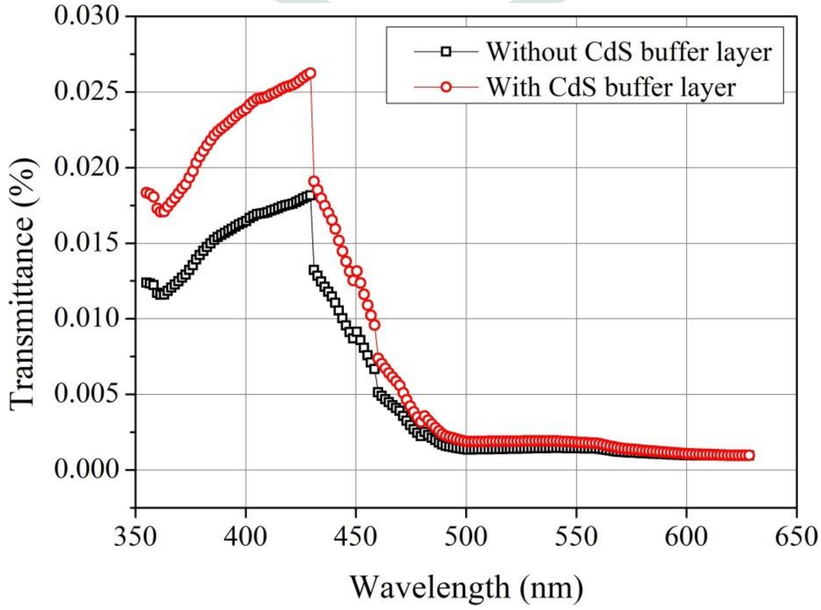

Figure 3Transmittance profiles of proposed CIGS solar cells

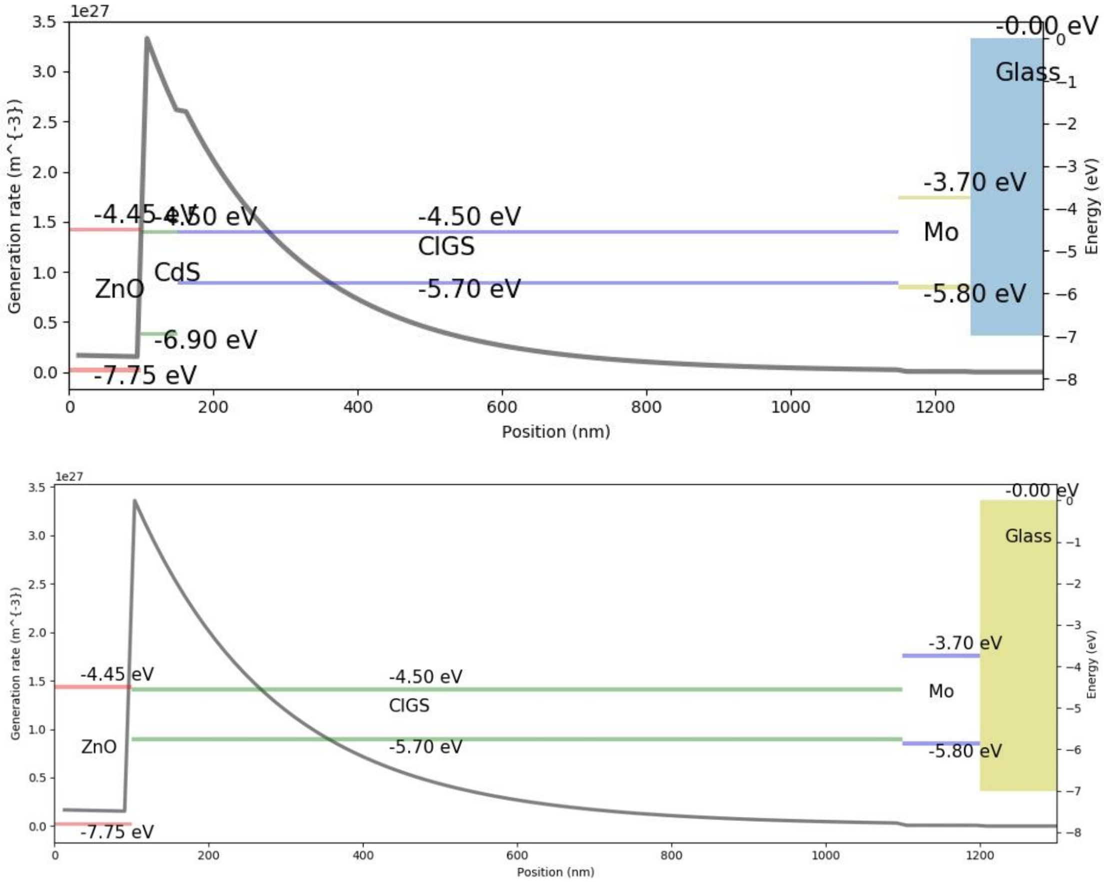

Figure-4: Generation rate profiles in individual layers of proposed solar cell along with its thicknesses