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Simulation Study of ZAO/CdS/CIGS Structure Solar Cells by SCAPS

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Abstract: In this study, researchers are interested in studying the Copper-Indium-Gallium-Selenium (CIGS) solar cells sandwiched between Cadmiumsulfide (CdS) and ZAO, this TCO consists of heavily Al-doped ZnO (ZAO) as buffer layers and Molybdenum (Mo). Thus, we report the simulation results using the capacitance simulator (SCAPS) in terms of layer thickness, absorber layer band gap and operating temperature to find out the optimum choice. An efficiency of 20.09% (with V_{oc} of 0.633 V, J_{sc} of 42.94 mA cm^{-2} and fill factor of 0.74) has been achieved with CdS used as buffer layer as the reference case. It is also found that the high efficiency of CIGS cells at low temperature were a very high efficiency conversion.

Key words: Thin film solar cells, SCAPS, CIGS, temperature, buffer layers, conversion

INTRODUCTION

Numerical modeling of polycrystalline thin-film solar cells is an important strategy to test the viability of proposed physical explanations and to predict the effect of physical changes on cell performance. In general, this must be done with only partial knowledge of input parameters.

Current solar cell simulation tools typically use discrete components to model one aspect of solar cell operation. These can be very accurate predictors of specific characteristics. This simulation can be done much faster than physical experimentation and can provide solar cell information that is difficult or impossible to measure but lack the breadth of a complete model and are thereby limited in their usefulness as design tools. A good solar cell simulation involves all the best models for each part a manufacturing processes. Ion implantation is one of the 1st step in p-n junction processing that could effect on the final results (Ashworth *et al*., 1990; Lindhard *et al*., 1963). In the single p-n junction of CIGS solar cell, simulation is one of the step used to the short current or short-circuit current of a solar cell is the result of the contribution of the current generated in its different regions. The photon flux in emitter, depletion zone and base generates carriers which are accelerated by the junction electric field and collected in the front and back metal contacts. A percentage of the generated carriers recombines in the bulk and interfaces. The minority carries lifetime or diffusion length in the base and emitter are the global parameters which governs the recombination losses. The Spectral Response (SR) is the parameter that determines the ratio of collected carriers with respect to the incoming photon flux at a given wavelength (Green, 1987). The internal spectral response or quantum efficiency is given by:

$$SR_{int}(\lambda) = \frac{J_{Ph}(\lambda)}{q\varphi(\lambda)(1 - R(\lambda))} \quad (1)$$

The short-circuit current can be calculated by the integration of Eq. 1:

$$J_{SC} = q\int_0^{\lambda n} \varphi(\lambda)[1 - R(\lambda)]SR_{int}(\lambda)d\lambda \quad (2)$$

The DICE analysis permits the calculation of short-circuit current by the following equation (Takahama *et al*., 1986):

$$J_{SC} = q\int_0^{W} \delta(x)D(x)dx \quad (3)$$

Where, D(x) is the DICE parameter and ø(x) is given by:

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$$\varphi(x) = \int_0^{\lambda_n} x(\lambda)\delta(\lambda)\left[1 - R(\lambda)\right]\exp(-x\alpha(\lambda))d\lambda \tag{4}$$

The cell generates the maximum power P_{max} at a voltage V_m and current I_m and it is convenient to define the Fill Factor (FF) by:

$$FF = \frac{I_m.V_m}{I_{sc}.V_{oc}} = \frac{P_{MAX}}{I_{sc}V_{oc}} \tag{5}$$

At Air Mass 1.5 (AM 1.5), the efficiency of solar cell, η_s is given by where, $P_m = 1000\ Wm^{-2}$ in AM 1.5:

$$\eta_s = \frac{I_{sc}.V_{oc}FF}{P_m} \tag{6}$$

RESULTS AND DISCUSSION

Optimization of CIGS absorber thickness

Solar cells: It is developed, especially for CdTe and CIGS solar cells. SCAPS is used to replicate and investigate all the available research-level CIGS solar cells with various buffer layers. From the solution provided by an SCAPS (Gloeckler *et al*., 2003) simulation, output such as current voltage characteristics in the dark and under illumination can be obtained. These may be computed as a function of temperature. For solar cell and detector structures, collection efficiencies as a function of voltage, light bias and temperature can also be obtained. By incorporating the various material parameters into SCAPS for all of the analysis aspects, changes in the values for efficiency, V_{oc}, J_{sc} and FF as well as the effect of operating temperature are observed. Table 1 shows the description of the parameters in the simulation and the base parameters that have been used in this study (Gloeckler *et al*., 2003). SCAPS is a one dimensional computer software to simulate the AC and DC electrical characteristics of thin film. To justify the simulation, the conventional CIGS structure with CdS buffer layer has been verified in terms of CIGS absorber and CdS buffer layer. At first, the CIGS absorber thickness has been varied to find out the optimum thickness for the conventional CIGS structure with CdS as the window layer. Electrons will be captured easily by the back contact for the recombination process. Therefore, fewer electrons will contribute to the quantum efficiency of the solar cell and the value for Voc and Jsc will be low. The J-V characteristics of the solar cells are shown in Fig. 1.

Effects of operating temperature on CIGS solar cells with various buffer layers: Operating temperature plays a vital role in the performance of the solar cells. The optimum operating temperature that has been used for most of the simulation in this study is 300 K or 27°C (Fig. 2). From Fig. 3, it has been found that the overall efficiency in case of CDs buffered cells is severely affected by the operating

Table 1: Base parameters for ZAO/CdS/CIGS

Quantities	ZAO	CdS	CIGS
Layer thickness (nm)	100	50	3000
EPS	9	10	13.6
CHI (eV)	4	3.8	4.1
Eg (eV)	3.3	2.4	1.15
MUN (cm^2/V_s)	100	100	100
MUP (cm^2/V_s)	25	25	25
N_c ($1\ cm^{-3}$)	2.22E18	2.22E18	2.22E18
N_v ($1\ cm^{-3}$)	1.18E19	1.7E19	1.78E19
NA ($1\ cm^{-3}$)	0	0	3.5E16
ND ($1\ cm^{-3}$)	1E5	3.5E17	0
ve ($cm\ sec^{-1}$)	1E7	1E7	1E7
vh ($cm\ sec^{-1}$)	1E7	1E7	1E7

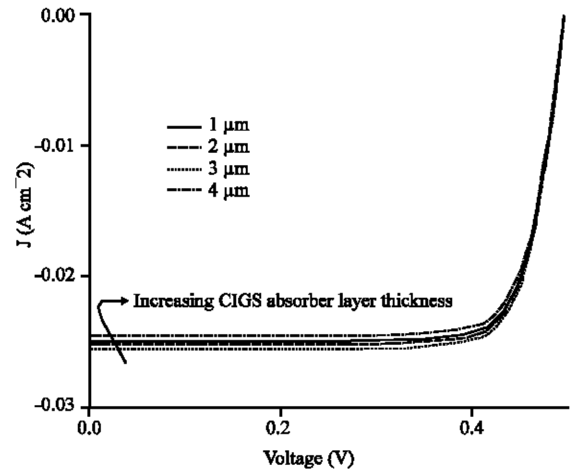

Fig. 1: J-V characteristics of solar cell with variable thickness of CIGS absorber layer

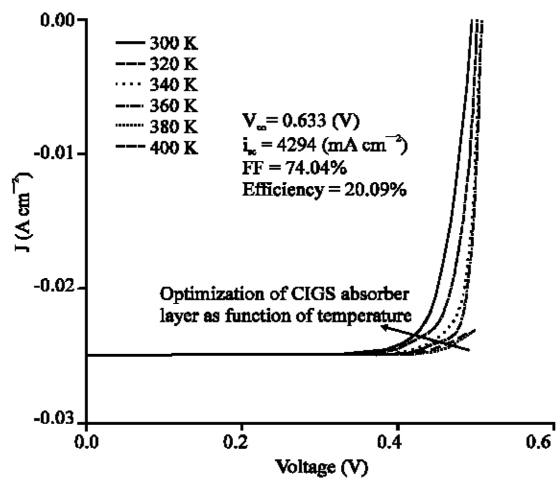

Fig. 2: J-V characteristics of solar cell with variable temperature of CIGS absorber layer

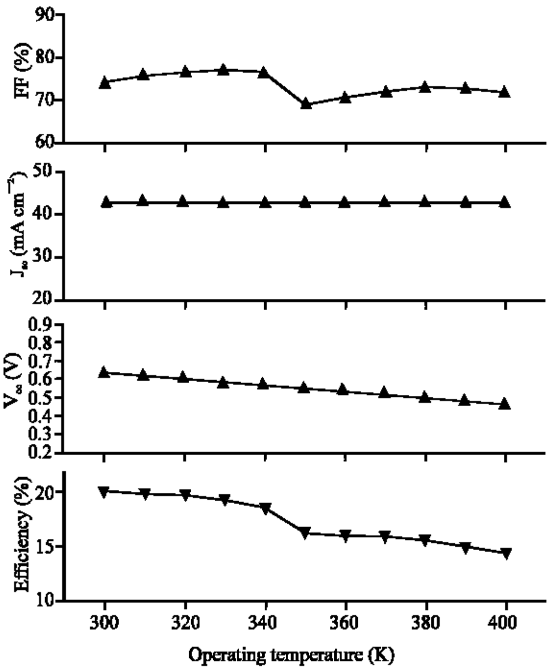

Fig. 3: Solar cell performance of the CIGS cells with different buffer layers

temperature. At higher temperature, parameters such as the electron and hole mobility, carrier concentrations and band gaps of the materials would be affected that result in lower efficiency of the cells (Nakada and Mizutani, 2002). The efficiency is decreasing when the temperature is increased with a declination trend of 0.32% K^{-1}. At higher temperature, the band gap energy has been slightly narrowed and this may accelerate the recombination of EHP between valence band and the conduction band.

Although, more free electrons are produced into the conduction band but the band gap energy at higher temperature is unstable which may lead to recombination of electrons and holes while traveling across the regions. For the simulation, there were used the same structural parameters for all the operating temperatures to simplify (Chelvanathan *et al*., 2010).

Open circuit Voltage (V_{oc}) and short circuit current density (J_{sc}) of the CIGS solar cells are also shown in Fig. 4. Both values are increasing with the thickness of the absorber layer. This may mainly due to the increase of the absorber layer which is the p-type region in solar cell. This allows the longer wavelengths of the illumination to be collected which in turn contribute to electron-hole pair

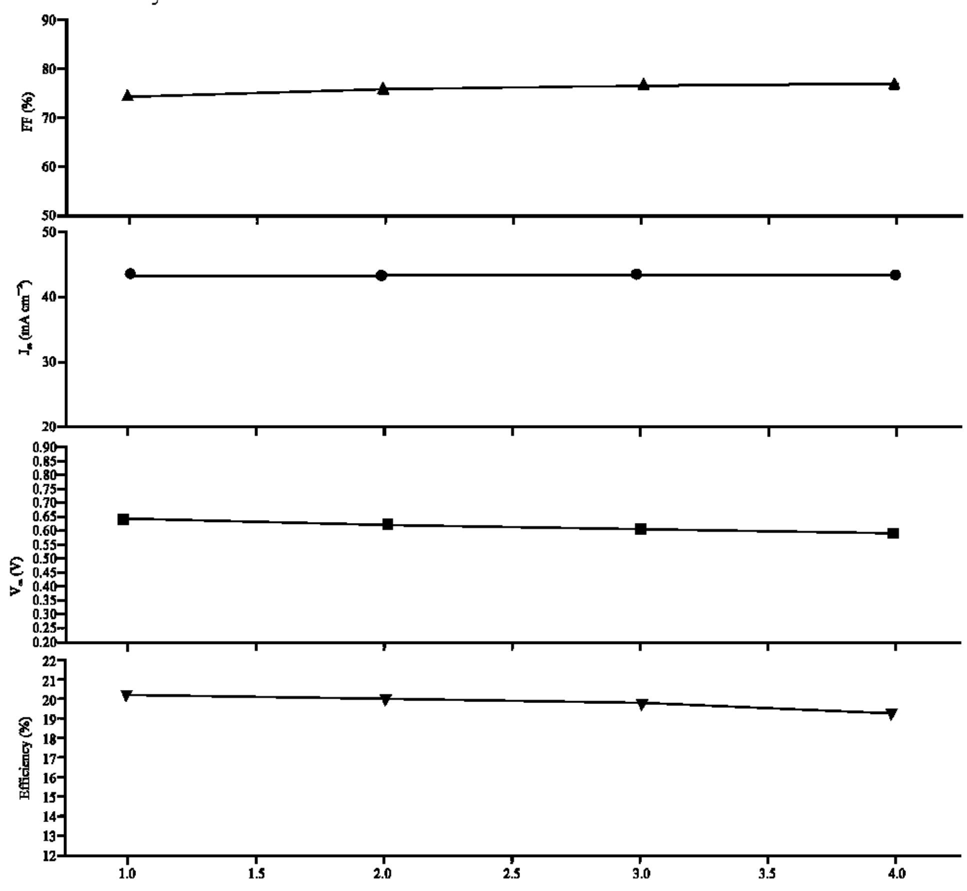

Fig. 4: Cell performances with variable thickness of CIGS absorber layer

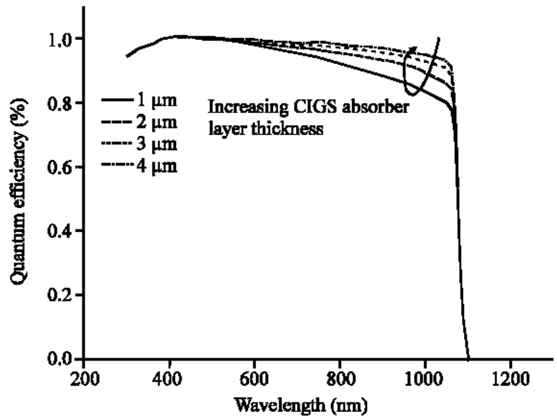

Fig. 5: Spectral response of solar cells with variable thickness of CIGS absorber layers

(EHP) generation. Therefore, the value for V_{oc} and J_{sc} are increased. It is also understood that both the V_{oc} and J_{sc} value will be reduced if the thickness of the absorber layer is reduced. This may be caused by the recombination process at the back contact of the solar cell. If the absorber layer thickness is reduced, the back contact will be very near to the depletion region. The increasing trend in V_{oc} and J_{sc} can be seen when the absorber layers are increased. Spectral responses of the solar cell with varying thickness of absorber layers are shown in Fig. 5. It has been found that the quantum efficiency of the solar cell is increasing with the increase of absorber layer thicknesses. As mentioned before when the absorber layer thickness is increased more photons are absorbed, especially the long wavelength of the illumination.

Thus, a greater percentage of electron-hole pairs would be produced from the absorbed photons. Therefore, the quantum efficiency would be increasing with the increase of the absorber layer thickness (Chelvanathan *et al*., 2010). With the spectral response of the cell, it is possible to estimate where carriers are generated and how they are collected. For instance, absorption in the CdS buffer layer that does not lead to collected carriers cause a depression of the QE curve in the UV region (region I, Fig. 5). Interference in the window layers leads to QE maxima and minima depending on the thickness of these layers (region II). As this reflects the transmittance of the window layers, these features are not present in the internal QE. In the IR region (III), poor QE collection is often present due to the fact that photons at these wavelengths are to a large extent absorbed deep down in the absorber layer far from the depletion region. The electron-hole pairs generated here run an increased risk of recombining at the back contact as well. The short circuit current of the cell can be calculated through:

$$J_{SC} = \int_{\lambda=0}^{\infty} G_{\lambda}(\lambda)QE(\lambda)d\lambda \qquad (7)$$

Where, Gλ is the spectral irradiance according to a reference distribution like the most commonly used AM 1.5. This short circuit current value should coincide with the one obtained from a J-V curve if the spectrum for the lamp in the J-V set up is used and if the cell is irradiated using a similar light source as bias illumination in the QE measurement.

CONCLUSION

Various buffer layers for a possible replacement of CdS have been investigated in terms overall cell performance at various operating temperature. For an optimum thickness of around 2-3 Im of high-efficiency CIS or CIGS absorbers, the optimum thickness of buffer layers is found to be in the range of 40-60 nm. Among all kinds of buffer layers studied, cells with ZAO buffer layer revealed the best efficiency of 20.09%. Moreover, simulation results show that the solar cell performances are affected by the increase in operating temperature for all buffer layers with differences in the temperature gradients.

REFERENCES

Ashworth, D.G., R. Oven and B. Mundin, 1990. Representation of ion implantation profiles by pearson frequency distribution curves. J. Phys. D: Applied Phys., 23: 870-876.

Chelvanathan, P., M.I. Hossain and N. Amin, 2010. Performance analysis of Copper Indium Gallium Diselenide (CIGS) solar cells with various buffer layers by SCAPS. Curr. Applied Phys., 10: S387-S391.

Gloeckler, M., A.L. Fahrenbruch and J.R. Sites, 2003. Numerical modeling of CIGS and CdTe solar cells: Setting the baseline. Procedings of the 3rd World Conference on Photovoltaic Energy Conversion, May 11-18, Osaka, pp: 491-494.

Green, M.A., 1987. High Efficiency Silicon Solar Cells. Trans Tech Publications, Switzerland.

Lindhard, J., M. Scharff and H.E. Schiott, 1963. Range concepts and heavy ion ranges (notes on atomic collisions, II). Danske Videnskab. Selskab. Mat. Fys. Medd, 33: 1-42.

Nakada, T. and M. Mizutani, 2002. 18% efficiency Cd-free Cu (In, Ga)Se_2 thin-film solar cells fabricated using Chemical Bath Deposition (CBD)-ZnS buffer layers. Jap. J. Applied Phys., 41: L165-L167.

Takahama, T., M. Isomura, S. Tsuda, H. Tarui and Y. Hishikawa *et al*., 1986. A new analytical method of amorphous silicon solar cells. Jap. J. Applied Phys., 25: 1538-1541.