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Simulation analysis of the CIGS based thin film solar cells

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ABSTRACT

This paper indicated a theoretical investigation of a CIGS based solar cells. An optimum value of the thickness of this structure has been calculated and it is shown that by optimizing the thickness of the cell efficiency has been increased and cost of production can be reduced. Numerical optimizations have been done by adjusting parameters such as the combination of band gap and mismatch as well as the specific structure of the cell. It is shown that by optimization of the considered structure, open circuit voltage increases and an improvement of conversion efficiency has been observed in comparison to the conventional CIGS system.

1. Introduction

Thin film solar cells are large area diodes tailored to enable and maximize the absorption of light within a short distance from the space charge region of solar cells and offer a number of interesting advantages compared to the bulk silicon devices, which are fairly complicated and expensive to produce [1–3]. Chalcopyrite Cu(In,Ga)Se (CIGS) is a very promising material for thin film photovoltaics and also, chalcopyrite based solar modules uniquely combine advantages of thin film technology with the efficiency and stability of conventional crystalline silicon cells [3–8].

Highest efficiencies for CIGS solar cells are commonly obtained by the vacuum evaporation method using sophisticated multistage growth processes that induce favorable growth of large and smooth grains in CIGS [5]. Cu(InGa)Se_2 (CIGS)-based thin film solar cells have up to now yielded efficiencies of up to 19.9% [3,9]. CIGS absorbers today have a typical thickness of about 1.5–2 μm. However, on the way towards mass production, it will be necessary to reduce the thickness even further [6].

The main reasons for this are material costs, the fact that indium and gallium resources are limited, and the need to cut the process duration in order to achieve a higher output of the production [8]. So far, absorbers down to a thickness of about 0.5 μm have already been achieved with no or only little reduction of the open-circuit voltage and the fill factor [10]. But, the short-circuit current density is decreased significantly in those devices, as the absorber thickness is no longer much larger than the absorption. CIGS devices are typically fabricated in a substrate configuration by sequentially depositing metal and semiconductor layers on a suitable base substrate (Fig. 1). In order to attain cost efficient fabrication of solar cells, materials capable of low-cost production are required [8,11]. Furthermore, to optimize the full efficiency potential from low-quality wafers, the effects of the higher impurity contents on the cell performance should be studied. In order to increase the efficiency of the cell toward the ideal one, it is necessary to reduce the sum to losses in the cell [11,12].

In this paper, in order to investigate the effects of cell composed layers' thickness on the performance of the cell, a typical CIGS solar cell structure which it is composed of six layers, namely a transparent conductive oxide (TCO) contact which composed of ZnO:Al, an n-doped ZnO layer, an n-doped CdS buffer layer, an p-doped $Cu(In_{1-x}Ga_x)Se_2$ layer, and a molybden metal contacts, and a glass substrate, as shown in Fig. 1, were simulated by SCAPS simulation software [12,13]. This paper indicated a simulation study to optimize the CGIS based thin film solar cells. An optimum value of the thickness of this structure has been calculated and it is shown that by optimizing the thickness of the cell efficiency has been increases and cost of production can be reduces.

2. Numerical simulation

We have modeled the *J*–*V* characteristics, fill factor (FF) of graded $Cu(In_{1-x}Ga_x)Se_2$ solar cells with the numerical simulation package SCAPS [11–14]. Electron and hole mobilities of 100 cm^2/V s and 25 cm^2/V s were selected [13,14]. Recombination in deep bulk

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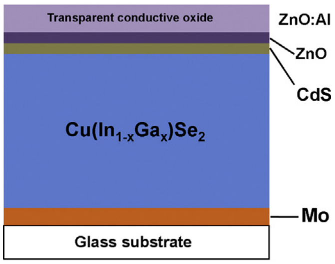

Fig. 1. Schematic structure of typical CIGS based thin film solar cells.

levels and their occupation is described by the Shockley–Read–Hall (SRH) formalism. The current transport mechanism of our model can be explained in general terms by considering the effect of light on the band diagram [13]. This gap state distribution does not completely account for correlation effects but it has been shown [13]. In SCAPS program, the interface states can be distributed in energy, in the same way as are the bulk states. At the metal–semiconductor interfaces (contacts), transport of majority carriers is described by thermionic emission (Bethe theory) [9]. Transport of minority carriers is described by their surface recombination velocity S_n or S_p at the contact. Tunneling at interfaces or at contacts is not implemented in SCAPS. The recombination rate in defects also depends on the capture cross section and on the thermal velocity. We have assumed a capture cross section of 10^{-16} cm^{-2} for neutral traps [11–15].

3. Results and discussion

Several research groups have an attempt to improve the efficiency of CIGS based solar cells [12]. Also, replacing toxic CdS buffer layer with other materials has been reported. One of the man challenges in CIGS based solar cell is the cost of materials which it is limited the mass production of these devices. Typical thickness of CIGS absorber is about 1.5–2 μm but it is not cost efficient and thickness of the cell should be reduce. This paper indicates a study to optimize the CIGS based solar cell by considering the effects of layer thickness on the performance of the cell. In this respect, a typical structure of CIGS based thin film solar cell, as shown in Fig. 1, has been selected. Fig. 2 shown variation of transparent conductive oxide thickness, ZnO:Al, versus FF and efficiency. It is shown that by decreasing the thickness of TCO, cell efficiency increases. It is due to this fact that TCO is not fully transparent for light and always this layer absorbs and reflects the sunlight. As it shown in Fig. 2, by increasing the TCO thickness, light absorption increases and leads to lower efficiency. By decreasing the TCO layer from 100 nm to 10 nm, cell efficiency increases from about 17.65% to 18.4%. Also, FF curve has same increasing rate as it shown in η. Calculation shown that variation of the TCO thickness has no effects on the current density.

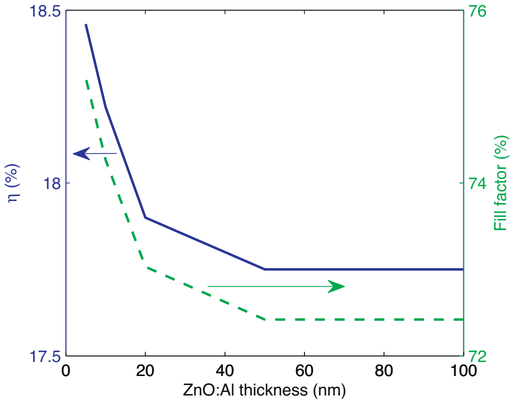

Fig. 2. Variation efficiency and FF as a function of ZnO:Al thickness.

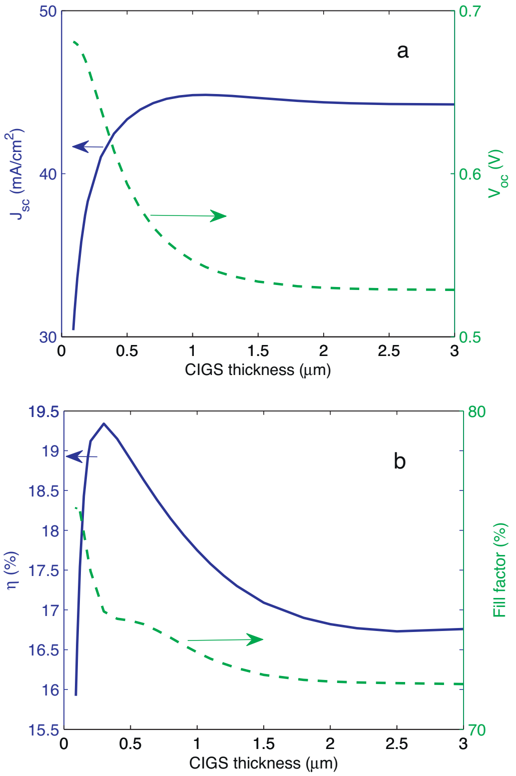

Fig. 3. (a) Variation of J_{sc} and V_{oc} and (b) FF as a function of CIGS layer thickness.

In the CIGS structure, CdS and ZnO have a very thin thickness and optimized values of these layers are 10 nm. CIGS layer is so important in cell efficiency. CIGS absorbers today have a typical thickness of about 1.5–2 μm. However, on the way towards mass production, it will be necessary to reduce the thickness even further. The main reasons for this are material costs, the fact that indium and gallium resources are limited, and the need to cut the process duration in order to achieve a higher output of the production. To optimize the cell thickness it is necessary to determine best value of CIGS layer thickness. Fig. 3 shows the variation of cell parameters in terms of the CIGS thickness. It is a conservative assessment since it assumes the absorption follows the Beer–Lambert law.

In Fig. 3(a) shows the variation of short circuit current (J_{sc}) and open circuit voltage (V_{oc}) in terms of the CIGS thickness. It is shown that by increasing the thickness from 5 nm to 1 μm, J_{sc} increases and after 1 μm, J_{sc} is constant. Also Fig. 3(a) demonstrates that by decreasing the CIGS thickness, V_{oc} increases near exponentially. Fig. 3(b) shows the variation of η and FF versus CIGS thickness. It is shown that by increasing the thickness from 10 nm to 0.3 μm, efficiency increases from about 16% to its' maximum value, 19.34%, and after 0.3 μm η falls down. From the simulation results it was found that optimized value of CIGS thickness is 0.3 μm, which leads to a thinner and cheaper solar cell. Simulation results shown optimized value of CIGS and TCO thickness is 0.3 μm and 20 nm, respectively. By choosing this parameters and simulate the cell with optimized values, it was found that cell efficiency increasing more than pick efficiency with seen optimized value only in CIGS layer thickness. By choosing the optimized value, J_{sc}, V_{oc} and η are 41.1 mA/cm^2, 0.64 V and 20.34%, respectively.