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SIMULATION OF THE FRONT AND REAR SIDE ILLUMINATION OF THE CdS/CIGS THIN FILM SOLAR CELL

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In this study the effect of the rear side illumination on the CdS/CIGS thin film solar cell has been studied. The simulation program SCAPS-1D was used in this study. This program was developed for the simulation properties of the CdS/CdTe and CdS/CIGS thin film solar cells. At the rear side illumination the efficiency of the cell decreased as the thickness of the CIGS absorber layer increased. This was because the light is absorbed far from the junction and near the high recombination back contact region. So that the generated electron-hole pairs are recombined before they reach the junction to separate. The losses in the generated electron-hole pairs increase as the thickness of the CIGS absorber layer increase and this is clearly shown in the variation of the quantum efficiency with the absorber thickness at the rear side illumination

Keywords: cigs, thin film, solar cell, thickness, absorber layer.

В цьому дослідженні було вивчено вплив освітленості тильної сторони на тонкоплівкові сонячні елементи на основі CdS/CIGS. У дослідженні застосовувалася моделююча програма SCAPS-1D. Ця програма була розроблена для моделювання властивостей сонячних елементів на основі CdS/CdTe і CdS/CIGS. При освітленості тильної сторони ККД елементу знижується, оскільки збільшується товщина абсорбуючого шару CIGS. Це відбувається в результаті того, що світло поглинається далеко від переходу, біля області контакту до тильної поверхні. Внаслідок цього, утворені електронно-діркові пари рекомбінуються до того, як досягнуть переходу для розділення. Втрати утворених електронно-діркових пар збільшуються зі збільшенням товщини абсорбуючого шару CIGS, що чітко показано в зміні квантового виходу з товщиною абсорбуючого шару при освітленості тильної сторони.

Ключові слова: CIGS, тонкоплівкові, сонячні елементи, товщина, абсорбуючий шар.

В данном исследовании было изучено влияние освещенности тыльной стороны на тонкопленочные солнечные элементы на основе CdS/CIGS. В исследовании применялась моделирующая программа SCAPS-1D. Эта программа была разработана для моделирования свойств солнечных элементов на основе CdS/CdTe и CdS/CIGS. При освещенности тыльной стороны КПД элемента снижается, так как увеличивается толщина абсорбирующего слоя CIGS. Это происходит в результате того, что свет поглощается вдали от перехода, возле области контакта к тыльной поверхности. Вследствие этого, образованные электронно-дырочные пары рекомбинируются до того, как достигнут перехода для разделения. Потери образованных электронно-дырочных пар увеличиваются с увеличением толщины абсорбирующего слоя CIGS, что четко показано в изменении квантового выхода с толщиной абсорбирующего слоя при освещенности тыльной стороны.

Ключевые слова: CIGS, тонкопленочные, солнечные элементы, толщина, абсорбирующая слоя.

INTRODUCTION

Copper Indium Gallium Selenide Cu(In,Ga)Se_2 (CIGS) is an interesting material for solar cell applications. CIGS is an alloy between Copper Indium Selenide $CuInSe_2$ (CIS) and Copper Gallium Selenide $CuGaSe_2$ (CGS) and is described by the chemical formula $CuIn_1$-*y*GaySe$_2$ where (*y*) is the ratio Ga/(Ga + In).The typical structure of the CIGS solar cell is shown in fig. 1 [1].

CIGS has a direct band gap which is a very desirable in photovoltaic materials. More optimistically, the absorption coefficient (α) of CIGS is high around 105 cm^{-1} for a band gap of 1.4 eV. A polycrystalline CIGS semiconductor has a tunable band gap that varies with the gallium (Ga) content substituted in the CIGS material. The band gap of CIS is around 1.04 eV, whereas by adding Ga into the ternary system of CIS,

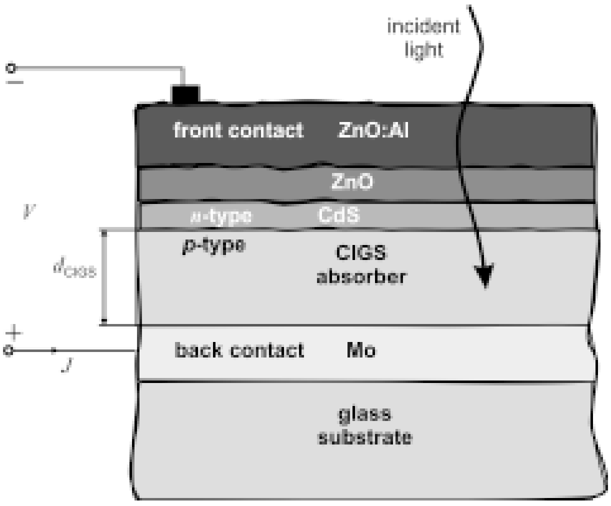


Fig. 1. Structure of the CIGS solar cell.

the band gap energy of the CIGS quaternary system can be varied over a range of 1.04 to 1.68 eV. This property can be used to engineer the band gap of the CIGS when it is used as absorber layer in the solar cell and to make a cell with a graded band gap [2].

CIGS based solar cells have shown record efficiency (~20%) for thin film devices in testing. This places CIGS solar cells at the forefront of the thin film solar cell industry [3]. A wide variety of techniques has been used to fabricate CIGS. These include Evaporation, Solemnization, Electro deposition, Sputtering, Vapor Transport, Spray Pyrolysis, Electrophoretic Deposition, Liquid Phase Epitaxial, Flash Evaporation, Laser-Induced Synthesis and Molecular Beam Epitaxial [4]. One of the methods that have been used in increasing the efficiency of the thin film solar cells is the illumination of the cell from both sides simultaneously. In this study we will shows the effect of the rear side illumination on the performance of the CdS/CIGS thin film solar cell.

DEVICE SIMULATION

Simulation of the structure (front contact/ZnO/CdS/CIGS/back contact) thin film solar cell was carried out using the simulation program SCAPS-1D. This program was developed at the University of Gent for the simulation of the photonic devices. For the front side illumination the back contact was the Molybdenum. In the rear side illumination the Molybdenum was replaced with a transparent conducting oxide (TCO), such as Indium Tin Oxide (ITO). ITO has 85% transparency at 550 nm incident wavelength [5].

RESULT AND DISCUSION

– The optical generation in the CdS/CIGS thin film solar cell.

Generation due to monochromatic light source describe by the following equation

$$G(y) = \frac{\alpha P_0}{Ahv} \exp(-\alpha y) . \quad (1)$$

The spectrum of the light used in the simulation results is the standard one-sun illumination also called AM1.5. The total generation is the sum of wavelengths generation.

Fig. 2 illustrates the total generation due to AM1.5. The generation by short and long wave-

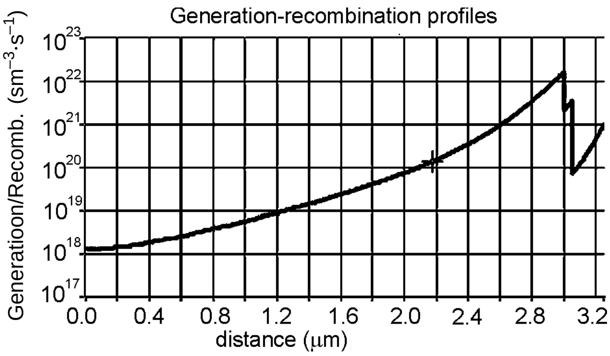
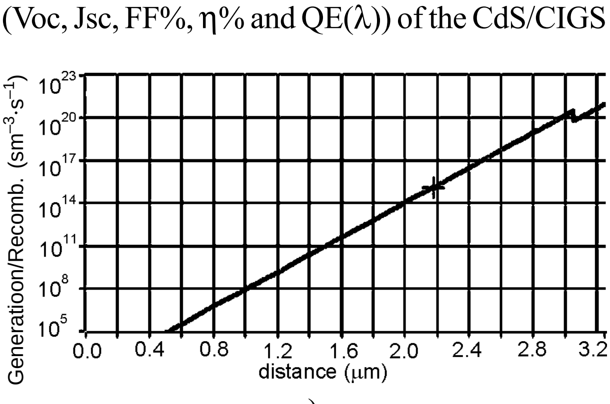


Fig. 2. Total generation due to one-sun illumination in the baseline cell.

lengths light in the CdS/CIGS cell is illustrated in fig. 3a and fig. 3b respectively. Short wavelengths light ($\lambda \leq 400$ nm) are strongly absorbed and hence there is no significant deep generation and most of generation processes will occur in the CdS buffer layer and ZnO widow layer. Long wavelengths light ($\lambda \geq 600$ nm) which have smaller absorption coefficient (α) shows absorption and generation rate rather deep in the cell and most of the absorption will occur in the CIGS absorber layer.

– B. The output parameters.

The dependence of the output parameters (Voc, Jsc, FF%, η% and QE(λ)) of the CdS/CIGS



a)

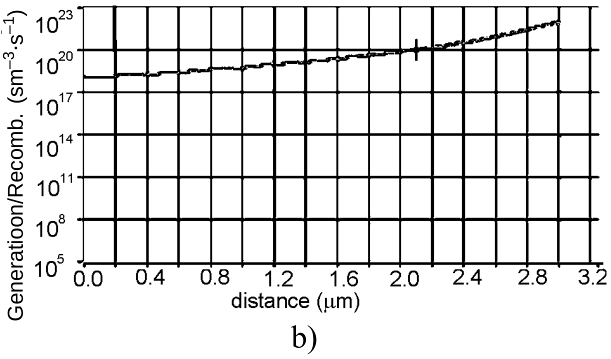


Fig. 3. Generation due to (a) short wavelengths ($\lambda \leq 400$ nm) and (b) long wavelengths ($\lambda \geq 600$ nm) in the CdS/CIGS solar cell.

cell on the absorber layer thickness for both front and rear side illumination is shown in fig. 4. For front side illumination both the open circuit voltage (Voc) and the short circuit current density (Jsc) of the cell was increased when the thickness of the absorber layer increased from 200 nm to 3000 nm. Voc remains high unless the absorber layer thickness is less than 500 nm. When the thickness of the CIGS increased this will allow the longer wavelengths of the illumination to be absorbed (as shown in fig. 3b) which in turn contribute in the electron-holes pair generation. Thus Voc and Jsc increased as the absorber layer thickness increased. This will result in increasing in the fill factor (FF%) and the efficiency (η%) of the cell. If the absorber layer thickness reduced, the high recombination back contact region will be very close from the depletion region. Thus the electrons will be captured easily by the back contact for the recombination process. Therefore, fewer electrons will contribute in the generation process. The result was reduction in the output parameters for thin absorber. For the rear side illumination it is required most of the light to be absorbed in the bulk part of the CIGS absorber layer. For the rear side illumination and thick absorber the absorbed light generate carriers in the bulk part of the absorber and often far from the electric field of the junction and near the high recombination back contact region so that and at the same absorber thickness Voc and Jsc for the rear side illumination will be less than what found in the front side illumination as shown in fig. 4.

Also at the rear side illumination Voc increased as the thickness of the absorber layer increased from 200 nm to 600 nm because the photons

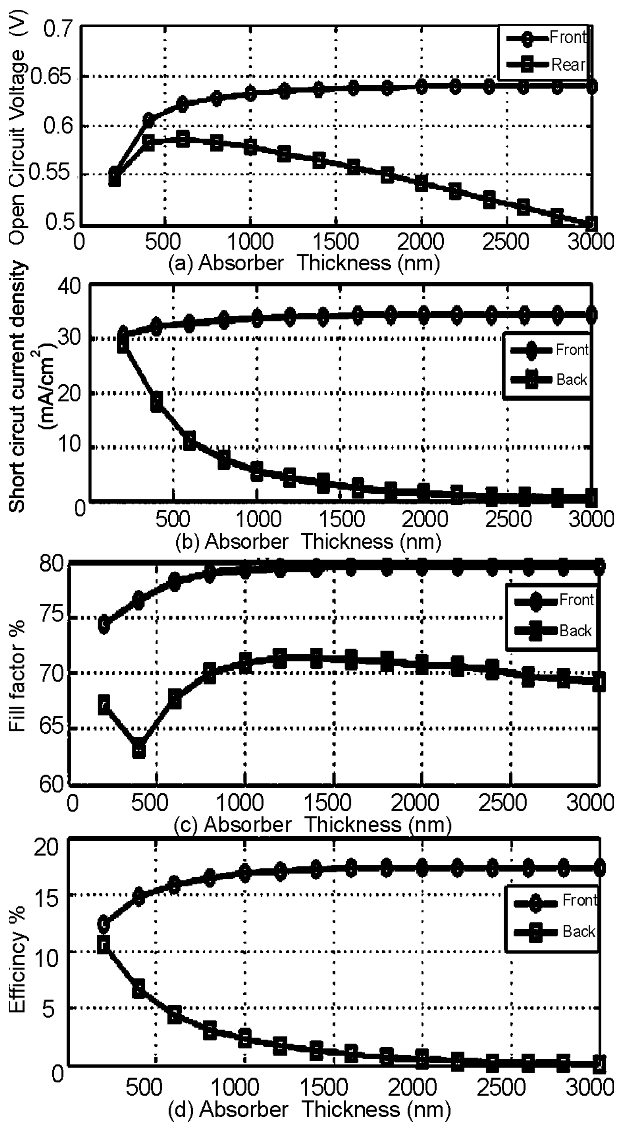


Fig. 4. The dependence of the output parameters of on the absorber layer thickness for front and back side illumination.

will be absorbed near the junction, and the generated electron-hole pairs will have strong probability to be separated. For absorber thickness above 600 nm the photons absorbed far from the electric field so that Voc decreased when the absorber thickness increased to 3000 nm. Jsc decreased when the absorber layer thickness increased for rear side illumination because the photons will be absorbed near the high recombination back contact region and far from the space charge region. The reduction in Voc and Jsc will causes a reduction in FF% and η%. As shown in fig. 4. For front side illumination the longer wavelengths photons will be absorbed deeper within the CIGS layer (as shown in fig. 3b). So that the effect of the CIGS absorber layer thickness on the quantum efficiency (QE(λ)) has been occurred in the region extended from λ = 520 nm to λ = 1200 nm as shown in fig. 5. For thick absorber layer the generation process has been occurred far from the back contact region so that the quantum efficiency will increase when the absorber layer thickness increase.

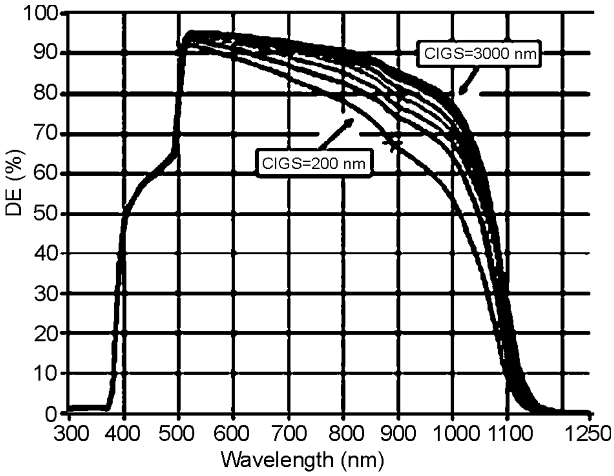


Fig. 5. Variation of the quantum efficiency of the baseline cell with the thickness of the absorber layer.

Fig. 6 shows QE(λ) of the cell for the rear side illumination (red) as compared with QE(λ) for the front side illumination for 500 nm absorber thickness. In this figure the losses in the absorbed photons due to the absorption far from the electric field and near the high recombination back contact region for the rear side illumination is evident. The losses are high for the photons which have large absorption coefficient (small wavelengths).

The dependence of the quantum efficiency for the rear side illumination on the CIGS absorber

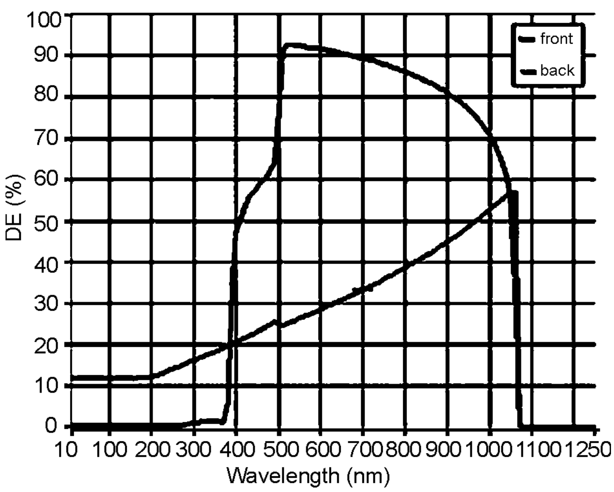


Fig. 6. Quantum efficiency at front and rear side illumination for 500 nm CIGS absorber thickness.

thickness is shown in fig. 7. The thickness was 0.25 μm, 0.5 μm and 1μm. The photons which have a large absorption coefficient (low wavelength) have a high generation probability in a thiabsorber (below 0.5 nm) because it will generate electron-hole pairs near the electric field. The quantum efficiency at low wavelength is high for the rear side illumination as compared with front side illumination because the high-energy photons will be absorbed by CdS buffer layer at front side illumination. The effect of the rear-side illumination on the Light/Dark J-V curves and the quantum efficiency (QE(λ)) of the CdS/CIGS thin film solar cell has been studied practically by T. Nakada et. al. [5]. He took the effect of the CIGS absorber layer thickness and the concentration of Gallium (Ga) at the rear-side illumination on the output parameters and the quantum efficiency into consideration. A good agreement between these practical results and the found simulation results.

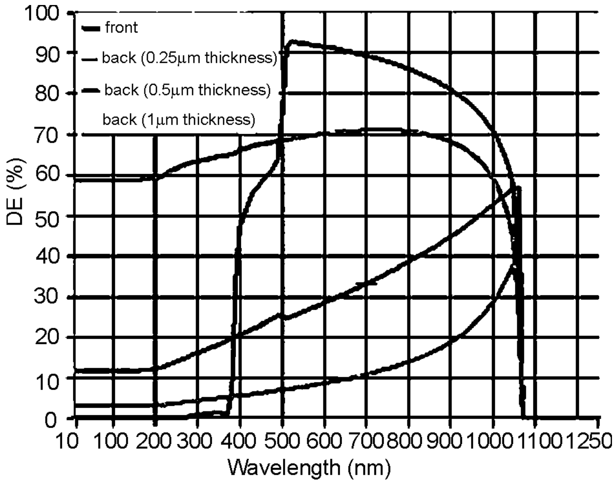


Fig. 7. The dependence of the quantum efficiency on the absorber thickness for the rear-side illumination as compared with the front side illumination.

CONCLUSION

At the front side illumination the light needed to pass through the window and buffer layer and this will results in a losses in the number of the photons in the absorber layer. When the thickness of the CIGS absorber layer increased the efficiency of the cell increased due to the high probability of absorption for the long wavelength photons. While at the rear side illumination the incident light will absorbed in the bulk part of the absorber layer but near the high recombination back contact region.

So that when the thickness of the CIGS absorber layer increase the electron-hole pairs will generate far from the electric field of the junction and near the high recombination back contact region. Therefore the generated electron-hole pairs will recombine by the back contact before they separated by the electric field of the junction.

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