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Numerical simulation of CZTS solar cell with silicon back surface field

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Abstract

Formation of back surface field has an important impact on the solar cell performances. In this work, a numerical simulation of CdS/CZTS based solar cell is performed using the solar cell capacitance Simulator (SCAPS). The simulation was run in order to study the effect of silicon back surface field (BSF) layer in the rear side. The thickness and carrier density impact on the performances of the cell were predicted. From the simulation results, the cell with BSF layer exhibited better characteristics and an improving in conversion efficiency from 7.72 % to 10.69% has been reached.

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Keywords: Solar cell; CZTS; Silicon BSF.

1. Introduction

In photovoltaic domain, the main goal of researchers is the realization of new structures to improve the power/cost ratio [1]. In other words, compounds with high efficiencies and low cost. For this reason, different materials such as CdTe, CIS and CIGS have been employed for the fabrication of solar cells. However, some of these materials are expensive or toxic [2]. Consequently, researcher are actually motivated to use new environmentally and friendly materials [3]. Cu2ZnSnS4 (CZTS) is one of these materials. It is an excellent semiconductor and a promising absorber material for thin-film solar cells. It has excellent material properties such as absorption coefficient exceeding $10^4 cm^{-1}$ [4, 5]. It possesses suitable direct nature band gap [6,5] of 1.5 eV that well matches to the solar spectrum and acquires most of the intensity photons from the solar radiation[7] . Moreover, all the elements of CZTS absorber are abundant in earth crust and nontoxic [4, 7, 8] which is an advantage as compared to other semiconductors. The investigation of this new and cheap material is thus necessary to improve efficiency of such eco-friendly cells. In this work, we propose a CZTS based solar cell with a silicon BSF layer. The study was performed to predict the existence of back surface field (BSF) layer and its effect on the performances of the cell.

2. Numerical simulation

The fabrication of quaternary semiconductors is complicated and involves long and expensive technical steps [9]. On the other hand, it is not possible to avoid experimental methods to validate theoretical assumptions which are necessary in research [10]. To economize these two parameters (*i.e.* time and money), the use of Computer-based simulations tools (such as PC1D, AMPS, COMSOL, SCAPS) plays a critical role in the design, development and optimization of electronics and physics device. It is an important way to test and predict the effects of various models parameters (as well as materials characteristics) on the output performances of the cell [4]. In this paper, we use the SCAPS software which was developed by Marc Bargeman and colleagues at the University of Gent [11]. It is one dimensional solar cell simulation program which may be used for large variety of semiconductors.

In the first time, we have studied the existence of silicon back surface field (BSF) layer effect on the performances of CdS/CZTS based solar cell. Afterwards, numerical simulations were run to study the BSF parameters (thickness and carrier density) effects on the performance of the thin film solar cell. We note that, the absorber layer can be reduced in the cell by the presence of Silicon BSF layer.

3. Device structure

The physical device used in this study is represented by figure 1. We considered this structure of solar cells using SCAPS software. This multilayer is composed by n type ZnO (zinc oxide) which was chosen as window layer. CdS was used as a buffer on the CZTS absorber layer. Molybdenum (Mo) was inserted as back contact between the soda lime glass substrate and silicon back surface field.

The solar cells parameters used in the simulation were selected from literature, theories or experiment results of some researcher (see table 1). The illumination spectrum and the operation temperature are set to the global Am 1.5 and 300 K respectively.

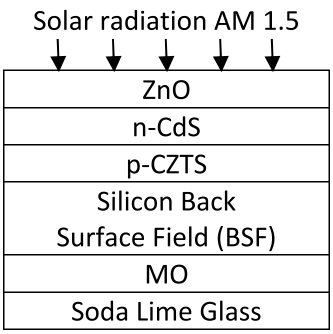

Fig. 1. Representation of the physical device used in the simulation.

Table 1. The solar cells parameters used in the simulation.

parameters	ZnO	CdS	CZTS	Si	References
thickness (µm)	0.200	0.05	2.0	0.6	[4,8,9,12,13]
Band gap (eV)	3.300	2.40	1.5	1.12	[4,8,9,14]
electron affinity (eV)	4.400	4.2	4.4	4.01	[8,13]
dielectric permittivity (relative)	9.00	10.0	10.0	11.9	[4,8,12,13,14,15]
electron thermal velocity (cm/s)	1.0E+7	1.0E+7	1.0E+7	1.0E+7	[4]
hole thermal velocity (cm/s)	191.0E+7	1.0E+7	1.0E+7	1.0E+7	[4]
electron mobility (cm^2/Vs)	1.0E+2	1.0E+2	1.0E+2	1450	[4,8,15]
hole mobility (cm^2/Vs)	2.5E+1	2.5E+1	2.5E+1	370	[8,12,13,14]
shallow uniform donor density ND ($1/cm^3$)	1.0E+18	1.1E+18	1.0E+1	1.0E+1	[4,8]
shallow uniform acceptor density NA ($1/cm^3$)	1.0E+1	1.00E+0	1.0E+16	4.0E+14	[13]
absorption coefficient cm^{-1}	By SCAPS	By SCAPS	5.0e4	By SCAPS	[4,7]

4. Results and Discussion

In this section, the main results obtained in our work are presented. In figure 2, the simulation results are displayed for conventional solar cell and solar cell with BSF layer. According to simulation results, the cell with BSF layer exhibited better I(V) characteristics. Indeed, from this plot, it is clear that BSF cell possesses better performances with regards to the reference (*i.e.* conventional). In table (1), the main results namely voltage in open circuit (Vco), current in short circuit (Isc), efficiency (η) and Fill Factor (FF) are displayed. According to this table, it is evident that all these parameters are improved by BSF insertion in the cell. In particular, it is noteworthy that the conversion efficiency has jumped from 7.72 % to 10.69%.

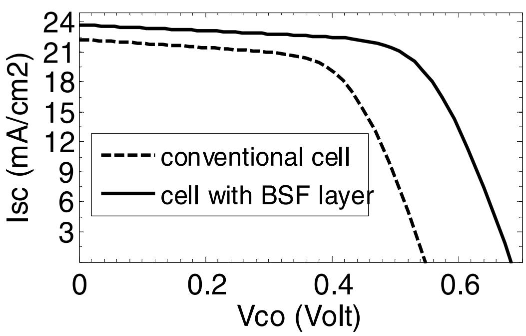

Fig. 2. SCAPS simulation of I (V) characteristics for conventional (---) and BSF (—) solar cells.

Table 2. Output characteristics of the tow solar cells.

	V_{co} (volt)	I_{sc} (mA/cm^2)	η (%)	FF (%)
Conventional cell	0.55	22.11	7.72	63.21
Cell with BSF	0.68	23.71	10.69	65.97

In figures 3 (a-c), we display the effect of BSF doping level on the output characteristics of the BSF cell (*i.e.* voltage in open circuit, current in short circuit and efficiency) for different values of BSF thicknesses. We observe arising in the open circuit voltage which leads to an increase in the conversion efficiency with the increase of BSF doping level. This is due to the electrical field distribution which prevents minority carrier recombination at the rear contact. In addition, the short circuit current almost remains stable with large BSF area which is probably caused by the recombination effect at Si/CZTS interface and in the BSF layer.

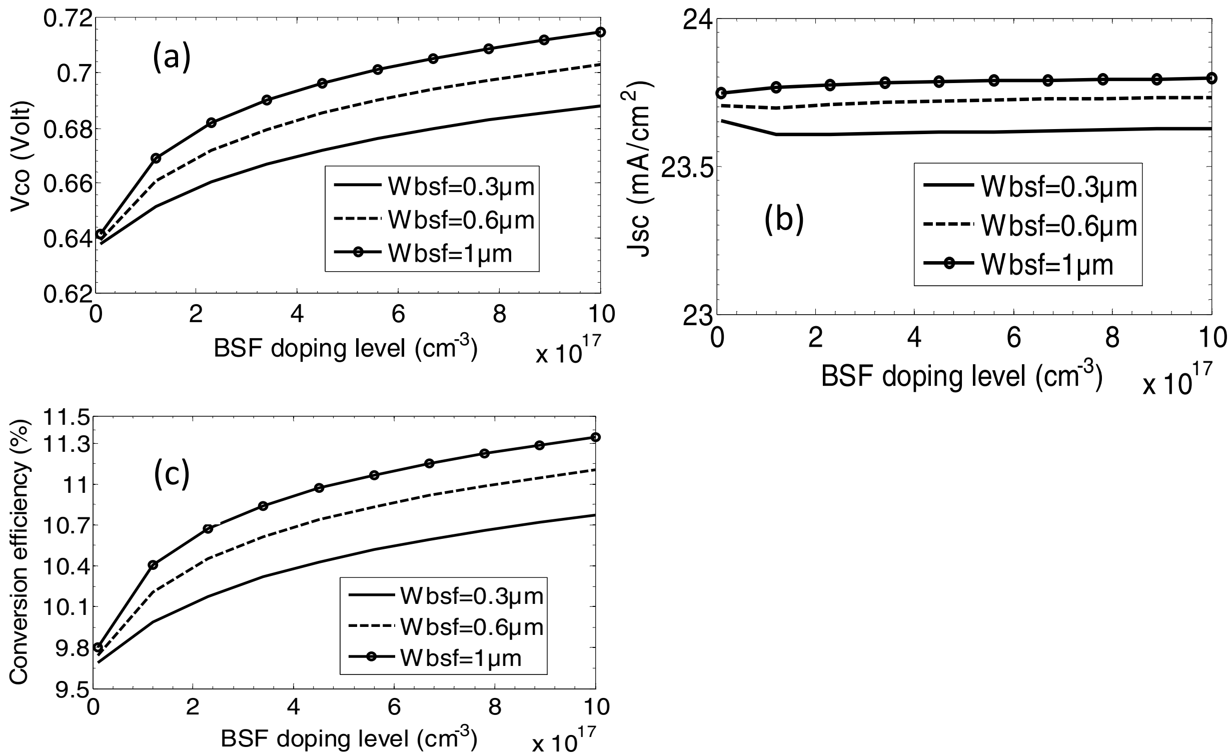

Fig. 3. Output characteristics of the solar cells versus BSF doping level for different BSF layer thicknesses: (a) Open circuit voltage, Vco; (b) Short circuit current, Isc; (c) conversion efficiency, eta (%).

The absorber layer is affected by the insertion of silicon BSF. Indeed, if we introduce BSF layer between absorber and MO back conductor layers, the thickness of absorber is reduced. Consequently, this reduction may influence the output characteristics of the BSF solar cell. In figure 4, we display the output of the solar cell as a function of CZTS thickness. The variations of these curves are negligible over a thickness of 1.3 μm. Hence, we assume that (by the proposed structure), we are able to improve the conversion efficiency by diminution of absorber layer which means reduction in cost. This is, obviously, an important step in the development of solar cells.

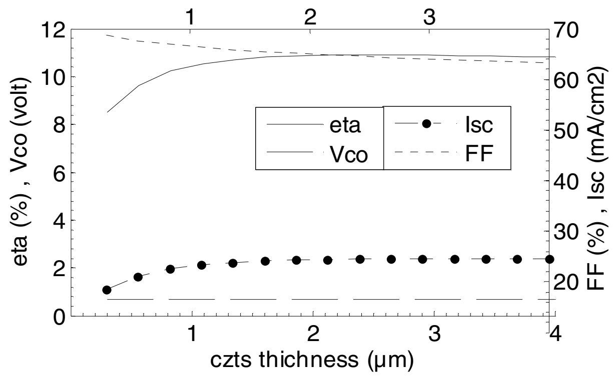

Fig. 4. BSF solar cell output characteristics as a function of absorber layer thickness.

5. Conclusion

The simulation by SCAPS was helpful to predict the main characteristics of the cells. The obtained results were important. It was established that BSF insertion provided an improvement in all parameters. Moreover, by reduction in the absorber thickness, it is possible to improve all output characteristics of the cell which is an advantage since this lead to reduction in time and money in the fabrication of the compound.

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