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Computational Study of the Photovoltaic Performance of CdS/Si Solar Cells: Anti-reflective Layers Effect

O. Boultif[1], B. Zaidi[1,*], S. Roguai[2], A. Mehdaoui[1], F. Diab[1], T. Bouarroudj[3], K. Kamli[4], Z. Hadef[4], C. Shekhar[5]

[1] *Department of Physics, Faculty of Material Sciences, University of Batna 1, Batna, Algeria*
[2] *LaSP2A Laboratory of Structures Properties and Interatomic Interactions, Science of Matter Department, Abbes Laghrour University, Khenchela 40000, Algeria*
[3] *Scientific and Technical Research Center in Physico-Chemical Analyses (CRAPC), Bouismail, Tipaza, Algeria*
[4] *Department of Physics, Faculty of Sciences, University 20 Août 1955, BP 26, 21000 Skikda, Algeria*
[5] *Department of Applied Physics, Amity University Gurgaon, 122413 Haryana, India*

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Photovoltaic conversion is a photo-electronic process that involves the interaction between a photo and an electron. The subject is to present a study on the physical principle of operation of a photovoltaic cell based on silicon. The external parameters that we have determined from a photovoltaic model are the short-circuit current (J_{sc}), the open-circuit voltage (V_{oc}) and the photovoltaic conversion efficiency (η), we simulate the photovoltaic parameters by the Solar Cell Capacitance Simulator structures (SCAPS-1D) software whose mathematical model is based on solving the equations of Poisson and continuity of electrons and holes. We used two structures to carry out this study, the first ITO/CdS/Si and the second ZnO/Si/CdS, after having noted their current-voltage characteristic (*J-V*). In this paper we studied the effect of the temperature and the doping concentration on the two structures of heterojunction solar cell. The highest performance value for the ZnO/CdS/Si heterojunction solar cell was simulated as 29.3 %. The performance value for the ITO/CdS/Si structure was increased to 29.7 % with the impact of the ITO antireflective layer.

Keywords: Si, CdS, ITO, ZnO, Solar cells, SCAPS-1D.

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1. INTRODUCTION

Solar energy is a clean and renewable source of power that has gained significant attention in recent years as a way to reduce dependence on fossil fuels and combat climate change [1-6]. Among the various types of solar cells available, CdS/Si (cadmium sulfide/silicon) heterojunction solar cells have emerged as a promising option due to their efficiency, cost-effectiveness, and stability [7-10]. A CdS/Si heterojunction solar cell is a type of heterojunction solar cell that utilizes a thin layer of CdS as the light-absorbing material and a layer of silicon as the semiconductor [11]. CdS based solar cells have been used as moisture based electricity generators, photo detector [12], highly sensitive detector for the solar light, dopant free solar cells [12]. The CdS and silicon layers are carefully engineered to form a p-n junction, which allows for efficient conversion of sunlight into electrical energy. The CdS layer absorbs the sunlight and generates electron-hole pairs, which are then separated by the *p-n* junction and collected by the electrodes to generate an electrical current. CdS/Si heterojunction solar cells have achieved efficiencies of up to 12.29 % in laboratory conditions and are relatively low-cost to produce[13]. They also have a good stability. However, CdS is toxic and therefore CdS/Si solar cells are not widely used as compare to other solar cells like CIGS [14-16] or CdTe [17].

In this work, it is provided an in depth acquaintance to the new technological advancement in the field of solar cells. The use of a possible combination of CdS/Si heterojunction with ITO or ZnO is proposed as a probable step to increase the solar cell efficiency above the theoretical limit.

2. NUMERICAL MODELING AND MATERIAL PARAMETERS

The composition of solar cells from right to left, the CdS/Si cells are composed of transparent conductive film (ZnO) or (ITO); absorber layer of s silicon; *n*-type layer of CdS; a substrate made of Mo/glass as shown in the Fig. 1 below. The initial physical parameters of ITO, ZnO, CdS and Si layers simulation are summarized in Table 1.

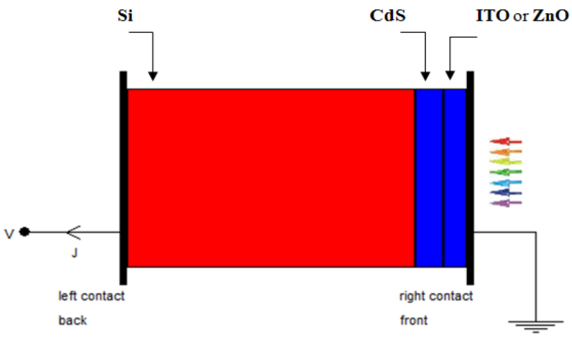

Fig. 1– Structure of Solar cell used for the numerical

* beddiaf.zaidi@univ-batna.dz

Table 1 – Physics Parameters used in our simulation

Parameters	Si	CdS	ITO	ZnO
Thickness(nm)	950	150	80	150
Relative permittivity	11.9	11.9	8.9	9
Electron affinity (eV)	4.05	3.9	4,5	4.1
E_g (eV)	1.12	2.44	3.65	3.3
BC (N_c (cm^{-3}))	2.8×10^{19}	1×10^{20}	2×10^{18}	4×10^{18}
BV (N_v (cm^{-3}))	1.04×10^{19}	1×10^{20}	2×10^{19}	1×10^{19}
μ_n (cm^2/V·s)	1.5×10^{3}	1×10^{2}	1×10^{2}	1×10^{2}
μ_p (cm^2/V·s)	450	20	25	25
N_d (cm^{-3})	1×10^{18}	1×10^{20}	1×10^{20}	1×10^{12}
N_a (cm^{-3})	1×10^{5}	1×10^{14}	1×10^{14}	1×10^{20}

In this paper, the Solar Cell Capacitance Simulator structures (SCAPS-1D) has been used to analyses the CdS/Si solar cells for both the configurations as stated above. SCAPS is Windows application software. It was developed to simulate the electrical characteristics of heterojunction solar cells and thin film. It has been extensively tested in solar cells by M. Burgelman et al [16-18].

The numerical computation of the small signal solution of this system is performed through the use of SCAPS. The first step in this calculation is to create a mesh. The system's primary algorithm is designed to provide a large number of locations in the region that experience significant fluctuations, such as interfaces and contacts, while providing only a few locations where attributes do not vary significantly, such as in the bulk.

One-dimensional simulation tool SCAPS-1D employs the Poisson equation to determine a cell's band diagram, carrier transit, and recombination profile, along with the continuity equations for electrons and holes [9].

To simplify the numerical analysis by SCAPS-1D simulator, thermal velocity of for electrons and holes has been assumed to be 10^7 cm/s in each layer. The Surface recombination velocity (SRV) has also been fixed at 10^7 cm/s for electrons and holes at front and back contacts. The interface parameters for (ZnO or ITO)/CdS/Si solar cell device study are shown in Table 2 below.

Table 2 – Defect parameters at interfaces used in the (ZnO or ITO)/CdS/Si solar cell

Parameters (Unit)	CdS/Si interface
Type of defect	Neutral
Electrons capture cross-section [cm^{-2}]	1×10^{18}
Holes capture cross-section [cm^{-2}]	1×10^{18}
Reference for defect energy level [eV]	Above the highest eV
Energy with respect to reference [eV]	0.6
Total defect density [cm^{-2}]	1×10^{12}

3. RESULTS AND DISCUSSION

Since the solar cell faces different climatic conditions, it is necessary to study the stability of the cell at different operating temperatures. Fig. 2 presents the influence of temperature on cell performance in temperatures ranging from 270 to 330 K for the ITO/CdS/Si solar cell.

It has been observed that the increase in temperature leads to a decrease in the Voc under constant illumination. It is noted that the values of the open circuit voltage and efficiency decrease with the increase in temperature.

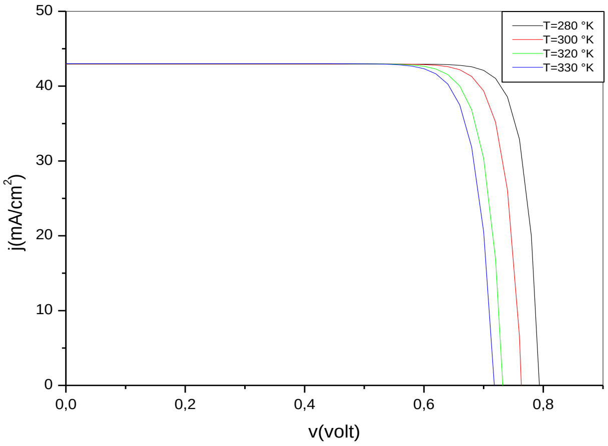

Fig. 2 – Effect of temperature on electrical characteristics (*J-V*) of ITO/CdS/Si

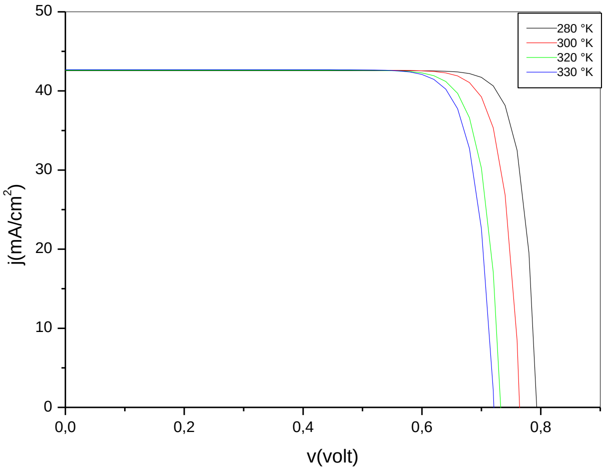

Fig. 3 – Effect of temperature on the electrical characteristics (*J-V*) of ZnO/CdS/Si

Fig. 3 represents the variation of the *J-V* for several temperatures in the range 280-330 K for ZnO/CdS/Si solar cell. With the increase in temperature *Voc* decreases. A decrease in the maximum power is observed with increasing temperature. On the other hand, the increase in temperature leads to the decrease in *V* decreases, direct effect, perhaps due to the dependence of the voltage with the reverse saturation current.

Similar effect of the increase in the temperature on the (*J-V*) characteristic has been observed in the literature [14]. We observe that the efficiency decreases with the increase in temperature, the open-circuit voltage decrease almost linearly with the rise in temperature.

Fig. 4 reports the variation of efficiency as a function of acceptor concentration for the ITO/CdS/Si solar cell. With the increase in the acceptor concentration, the efficiency of the solar cell increases linearly from 21 % to 29 %.

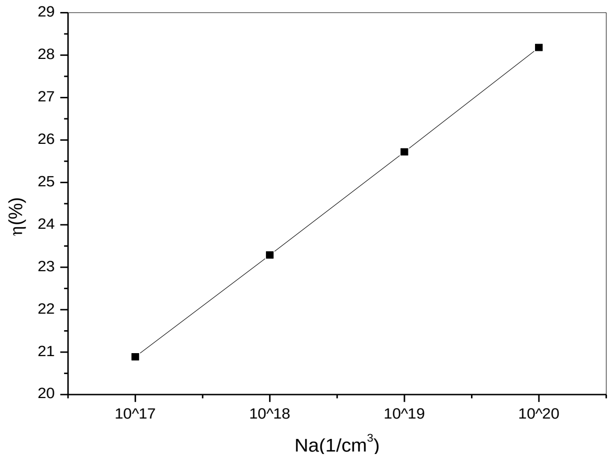

Fig. 4 – Effect of acceptor concentration N_a on efficiency of ITO/CdS/Si

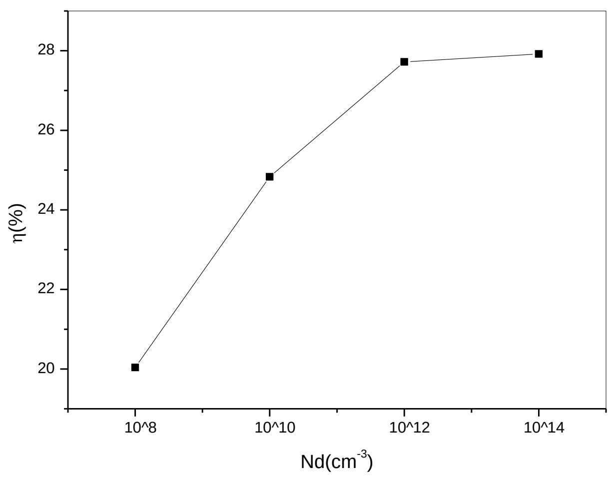

Fig. 5 – Effect of donor concentration N_d on the performance of ITO/CdS/Si

The effect of donor doping on the ITO/CdS/Si solar cell is presented in Fig. 5. Fig. 5 shows that the increase in N_d doping from 10^8 to 10^{12} cm^{-3} led to an almost linear increase in efficiency from 20 % to 27.8 %. The further increase in the defect concentration from 10^{12} to 10^{14} cm^{-3} increases the efficiency marginally to 28 %. The increase in efficiency is linked to the improvement of the electrical characteristics of silicon-based solar cells and leads to increases the collection of generated carriers and finally resulting to increases the current.

The effect of the temperature on the performance of the solar cells has been presented in Fig. 6 with the presence of ITO or ZnO anti-reflective thin films. As expected, the efficiency of CdS/Si solar cell increases more than 0.5 % with the presence of ITO compared to ZnO in the temperature range of 280-320 K. The efficiency decreases linearly with the temperature in the range studied indicating the suitability of lower temperature for the efficient usage of these solar cells. The interface between CdS and anti-reflective layers enhances the photocurrent by reducing the recombination of excess carriers generated by photons, thereby prolonging their [19-20].

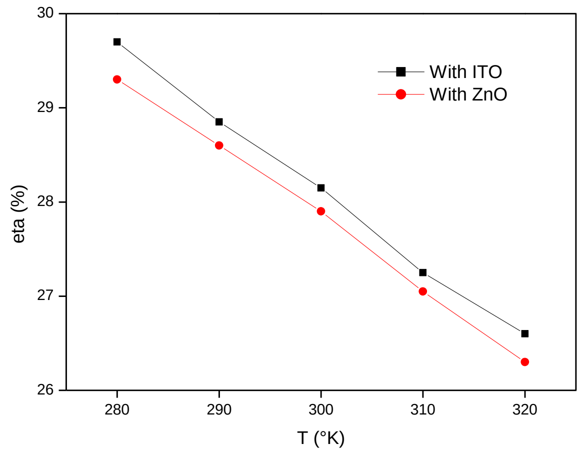

Fig. 6 – Effect of temperature on the performance of CdS/Si solar cells

4. CONCLUSIONS

In this paper, a study of the effect of temperature on the electrical characteristics of the cell such as: the open circuit voltage (V_{oc}) and the efficiency (η) have been studied. The effect of ITO as anti-reflective layer on the photovoltaic parameters of the solar cell has been analyzed. This simulation approach will be useful for development of CdS/Si thin film solar cells. The simulation results revealed that a performance value of 29.3 % is obtained from ZnO/CdS/Si structure which is pulled up to 29.7 % for ITO/CdS/Si heterojunction solar cell.

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Обчислювання фотоелектричних характеристик сонячних елементів CdS/Si: ефект антиблікових шарів

O. Boultif[1], B. Zaidi[1], S. Roguai[2], A. Mehdaoui[1], F. Diab[1], T. Bouarroudj[3], K. Kamli[4], Z. Hadef[4], C. Shekhar[5]

[1] *Department of Physics, Faculty of Material Sciences, University of Batna 1, Batna, Algeria*
[2] *LaSP2A Laboratory of Structures Properties and Interatomic Interactions, Science of Matter Department, Abbes Laghrour University, Khenchela 40000, Algeria*
[3] *Scientific and Technical Research Center in Physico-Chemical Analyses (CRAPC), Bouismail, Tipaza, Algeria*
[4] *Department of Physics, Faculty of Sciences, University 20 Août 1955, BP 26, 21000 Skikda, Algeria*
[5] *Department of Applied Physics, Amity University Gurgaon, 122413 Haryana, India*

Фотоелектричне перетворення - це фотоелектронний процес, який передбачає взаємодію між фотоном та електроном. Мета полягає в дослідженні фізичного принципу роботи фотоелектричного елемента на основі кремнію. Зовнішніми параметрами, які ми визначили на основі фотоелектричної моделі, є струм короткого замикання, напруга холостого ходу і ефективність фотоелектричного перетворення. Проведено моделювання фотоелектричних параметрів за допомогою програмного забезпечення симулятора ємності сонячних батарей SCAPS-1D, математична модель якого базується на розв'язуванні рівнянь Пуассона для електронів і дірок. Для досліджень були використані ITO/CdS/Si та ZnO/Si/CdS. У даній роботі вивчено вплив температури та концентрації легування на дві структури сонячного елемента з гетеропереходом. Найвище значення ефективності для сонячної батареї з гетеропереходом ZnO/CdS/Si мало величину 29,3%, для структури ITO/CdS/Si - 29,7 % завдяки впливу поглинаючого шару ITO.

Keywords: Si, CdS, ITO, ZnO, Сонячна батарея, Програмне забезпечення SCAPS-1D.