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Simulation Study of CuO-Based Solar Cell with Different Buffer Layers Using SCAPS-1D

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Abstract

In copper oxide (CuO) based solar cells, various buffer layers such as CdS, In_2S_3, WS_2 and IGZO have been investigated by solar cell capacitance simulator (SCAPS) in this work. By varying absorber and buffer layer thickness, photovoltaic parameters (open circuit voltage, fill factor, short-circuit current density and efficiency) are determined. The highest efficiency achieved is 19.6% with WS_2 buffer layer. The impact of temperature on all CuO-based solar cells is also investigated.

Keywords

Solar cell, Buffer Layer, Efficiency, Hetero-Junction, Scaps-1D

1. Introduction

Solar cell is considered the finest method that uses solar energy to generate electric power [1] [2] [3] [4]. Silicon is the most used material for solar cells due to its feasibility and available in plenty [5]. But silicon-based solar cell is not cost-effective and highly efficient. So photovoltaic researchers are focused on finding alternative materials to be used as absorber layers that can be easily fabricated, low cost and highly efficient. Copper oxide (CuO) is p-type semiconductor with a band gap of 1.3 - 1.51 eV which is suitable for absorption of good solar spectrum [6] [7] [8] [9] [10]. It is non-toxic, cost-effective and has an easy fabrication process.

The purpose of the research work is to simulate and investigate the electrical parameters of CuO-based hetero-junction thin film solar cells with different buffer layers using the SCAPS-1D software. Moreover, the effect of various operating temperatures along with various buffer layers has also been evaluated on CuO-based solar cells.

2. Simulation Methodology and Device Structure

Various softwares such as SCAPS (26), AMPS (27), wxAMPS and COMSOL [11] [12] [13] [14] are used to simulate thin-film solar cells. Due to results being compatible with experimental results, SCAPS is used widely by researchers [15] [16] [17]. It provides results based on semiconductor basic equations which are and continuity equations of electrons and holes and Poisson's equation [18] [19] [20] [21].

In this research work, the CuO-based solar cells with different buffer layers such as CdS, In_2S_3, WS_2 and IGZO were simulated using SCAPS-1D software. The solar cell electrical parameters such as open circuit voltage (V_{oc}), short circuit current density (J_{sc}), fill factor (FF) and efficiency (η) were analyzed. CuO-based solar cell's electrical parameters with different buffer layers at different working temperatures were also evaluated.

Figure 1 shows the device structure of the solar cell where ITO acts as a window layer, different materials such as CdS, In_2S_3, WS_2 and IGZO as the buffer layer, CuO as the absorber layer and the Mo plays the role of back contact in the simulation. The parameters used in the simulations are summarized in **Table 1**. Here, an illumination of 1000 W/m^2, a temperature of 300 K and a global spectrum Air Mass of 1.5 G have been considered for all simulations.

3. Results and Discussion

3.1. Effect of CuO Absorber Layer's Thickness

The impact of CuO layer thickness on solar cell performance was observed through simulation in CuO solar cell structure with CdS, In_2S_3, WS_2 and IGZO buffer layer. For simulation, the thickness of CuO was varied from 0.5 to 3 μm with a step size of 0.5 μm with a fixed buffer layer thickness of 0.05 μm. The simulation was done at a fixed temperature of 300 K. The influence of CuO absorber layer on solar cell performance is shown in **Figure 2**.

It is found that in all structures when absorber layer thickness increases from

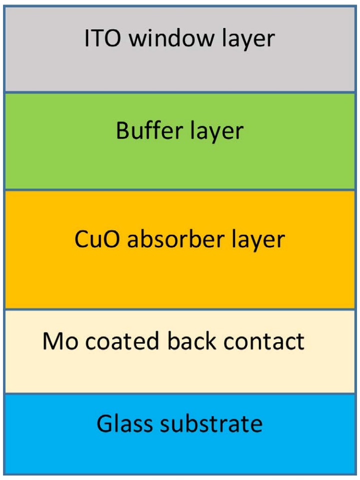

Figure 1. Schematic diagram of CuO solar cell.

Table 1. Material parameters of different layers were used for the simulation.

Parameter	CuO	CdS	WS_2	In_2S_3	IGZO	ITO
Thickness (μm)	0.5 - 4	0.050 - 0.12	0.050 - 0.12	0.050 - 0.12	0.050 - 0.12	0.200
Band gap (eV)	1.51	2.4	1.8	2.8	3.05	3.5
Electron affinity (eV)	4.07	4.4	3.95	4.5	4.16	4
Dielectric permittivity	18.1	10	13.6	13.5	10	9
CB effective density of states (cm^{-3})	2.2×10^{19}	2.2×10^{18}	1×10^{18}	2.2×10^{17}	5×10^{18}	2.2×10^{18}
VB effective density of states (cm^{-3})	5.5×10^{20}	1.8×10^{19}	2.4×10^{19}	1.8×10^{19}	5×10^{18}	1.8×10^{19}
Electron thermal velocity (cms^{-1})	1×10^{7}	1×10^{7}	1×10^{7}	1×10^{7}	1×10^{7}	1×10^{7}
Hole thermal velocity (cm^{-1})	1×10^{7}	1×10^{7}	1×10^{7}	1×10^{7}	1×10^{7}	1×10^{7}
Electron mobility (cm^2/Vs)	100	100	100	100	15	20
Hole mobility (cm^2/Vs)	0.1	25	100	25	0.1	10
Shallow uniform donor density, N_D (cm^{-3})	0	1×10^{18}	1×10^{18}	1×10^{18}	1×10^{18}	1×10^{19}
Shallow uniform acceptor density, N_A (cm^{-3})	1×10^{16}	0	0	0	0	0

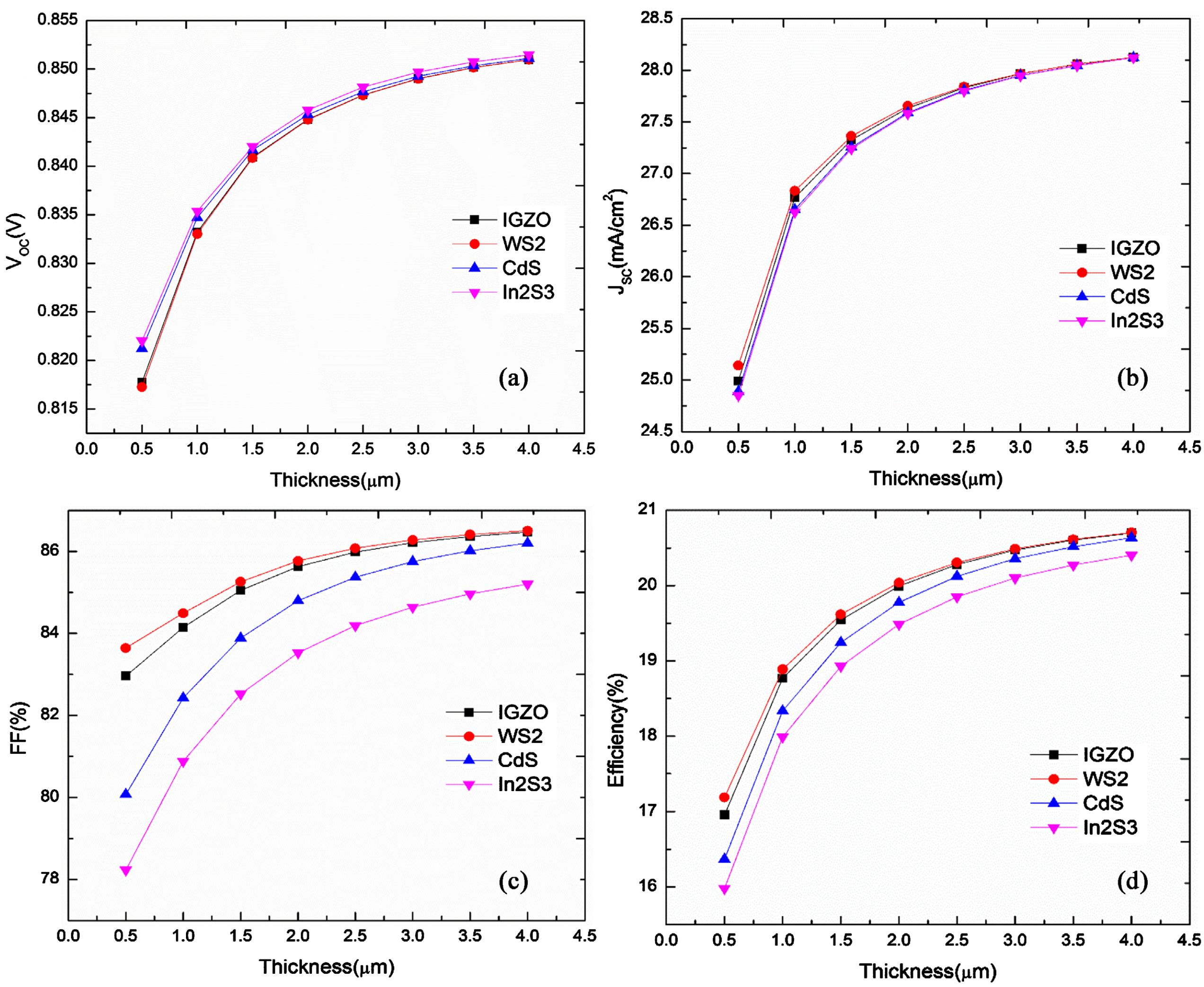

Figure 2. (a) V_{oc} vs. absorber layer thickness; (b) J_{sc} vs. absorber layer thickness; (c) Fill factor vs. absorber layer thickness; (d) Efficiency vs. absorber layer thickness.

0.5 μm to 1.5 μm, all electrical parameters (V_{oc}, J_{sc}, FF and η) increase at a sharp rate. After that, the evaluated parameters increase at a slow rate. At 0.5 μm of absorber layer thickness due to high recombination, all electrical parameters have low values. For an increase of absorber layer thickness up to 1.5 μm, the CuO layer will absorb more photons and generate more electron-hole pairs which causes an increase in V_{oc} and J_{sc} [22]. As the thickness of the CuO layer is increased beyond minority carrier diffusion length, due to recombination all parameters increase at a slow rate. To make production at a low cost, the optimal thickness of CuO layer is chosen 1.5 μm for this simulation.

3.2. Effect of Buffer Layer's Thickness

The thickness of buffer layer was varied from 0.05 to 0.12 μm with a CuO absorber layer thickness of 1.5 μm at a temperature of 300 K in this simulation. Figure 3 shows the impact of varying thicknesses of buffer layer. It is found that the impact of buffer layer thickness on electrical parameters V_{oc}, J_{sc}, FF and η is negligible in all structures.

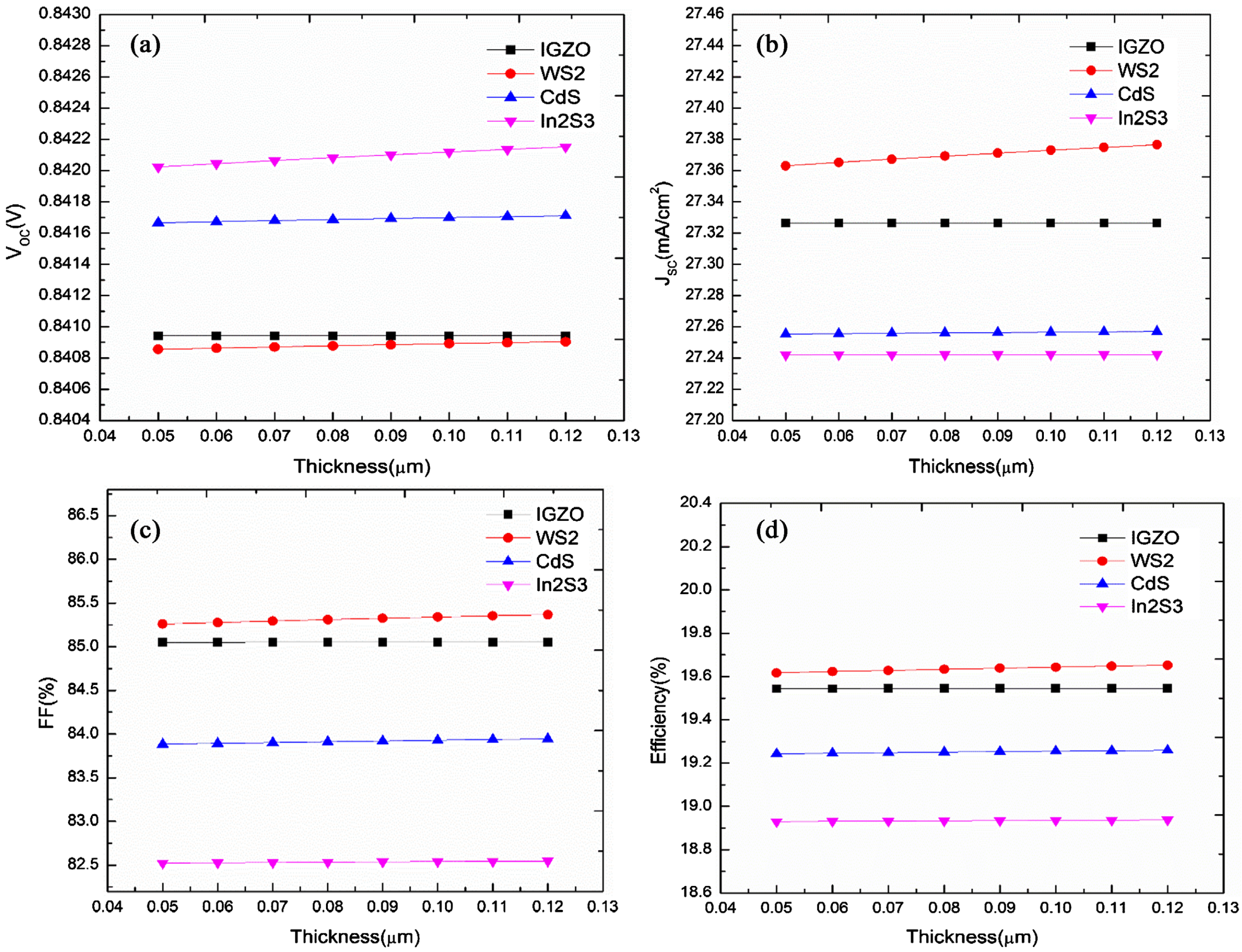

Figure 3. (a) V_{oc} vs. buffer layer thickness; (b) J_{sc} vs. buffer layer thickness; (c) Fill factor vs. buffer layer thickness; (d) Efficiency vs. buffer layer thickness.

With the increase in thickness of the buffer layer, buffer layers' minority carriers' low diffusion length results in higher recombination rate. As a result, efficiency is reduced [23]. It is found that the impact of buffer layer thickness on electrical parameters V_{oc}, J_{sc}, FF and η is negligible in all structures in the simulation. The optimal thickness of all buffer layers is chosen 0.05 µm in this simulation. The obtained optimal efficiency of CdS, In_2S_3, IGZO and WS_2 buffer layers is 19.2%, 18.9%, 19.5% and 19.6% respectively. So IGZO and WS_2 is a potential alternative to toxic CdS buffer layers due to their higher value of efficiency.

3.3. Effects of Working Temperature with Various Buffer Layer

To evaluate the temperature effect, the temperature was varied from 300 K to 400 K for CuO-based solar cells with various buffer layers. For all structures the CuO absorber layer's thickness was kept fixed at 1.5 µm, while the buffer layer's thickness was fixed at 0.05 µm value. Effect of temperature on CuO solar cells with different buffer layers is shown in Figure 4. With increase in temperature, the

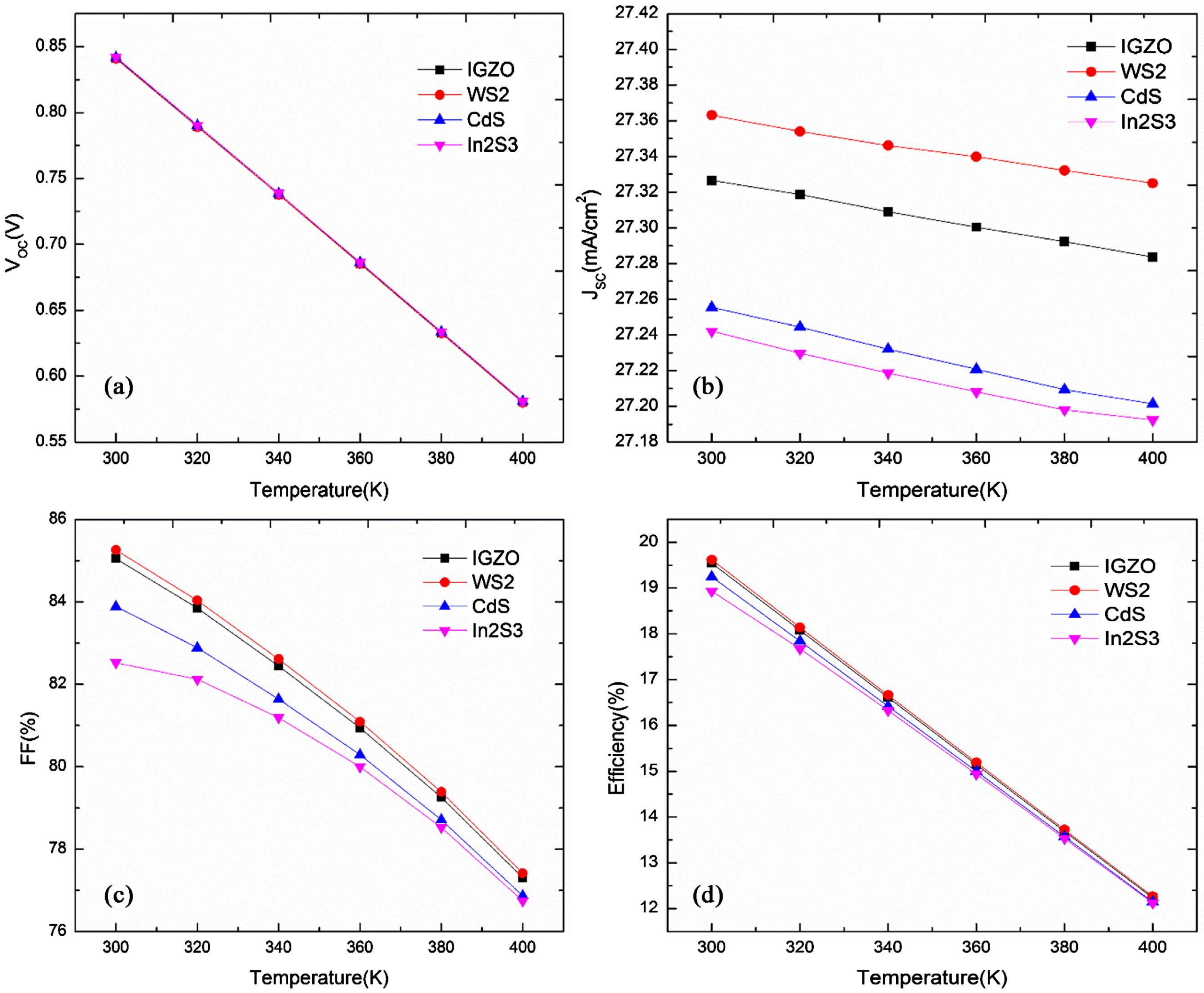

Figure 4. Effect of temperature on photovoltaic parameters of CuO-based solar cell with different buffer layers.

band gap decreases. The number of free carriers decreases as the recombination rate increases which dominates the creation of photons. An increase in temperature raises reverse saturation current. So J_{sc}, fill factor and V_{oc} decrease with an increase in temperature and hence the efficiency of all CuO-based solar cells.

4. Conclusions

In this work, SCAPS was used to simulate CuO-based solar cells using different buffer layers such as CdS, In_2S_3, WS_2 and IGZO. The optimum thickness of CuO absorber layer is found to be 1.5 μm and for all buffer layers optimum thickness is found to be 0.05 μm. CuO-based solar cells with WS_2 and IGZO buffer layer achieved the efficiency of 19.6% and 19.5% respectively. It is found that with increase in temperature, the solar cell performance is degraded. WS_2 and IGZO is a promising alternative to replace toxic CdS as their efficiency is higher than 19.2%.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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