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Effect of Different Back Surface Field Layers on Performance of CuO Solar Cell Using SCAPS-1D: Numerical Investigation

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***Abstract*—The current global shortage of electrical power, among other types of energy, is creating immense suffering among the world's human population, according to this study. An analysis was conducted numerically using the Solar Cell Capacitance Simulator (SCAPS-1D) on thin-film solar cells based on copper oxide (CuO). Therefore, this state of affairs has evolved into the core concept of the ongoing investigation into improving photovoltaic power generation. Investigations on the effects of different Back Surface field (BSF) layers on photovoltaic system performance included a wide range of BSF layers, including as CuSbS2, ZnTe, CuTe, and SnS. To examine specific characteristics, the selected absorber and its associated back surface field (BSF) layers were modified by varying their thicknesses. Voltage open-circuit (VOC), current density in a short circuit (J SC), fill factor (FF), and total power conversion efficiency (η) were the variables that were used. Because of this, we were able to look at these crucial parts. Upon examining the results and configurations achieved, the ZnTe BSF layer was found to have the highest efficiency at 32.68%. There has also been an investigation into how the device's performance is affected by its operating temperature, which is an extra interesting topic. The results show that efficiency generally decreases as temperature increases. This situation has arisen because of an increased reverse saturation current and a higher recombination rate.**

***Keywords*— Solar cell; CuO; BSF layers; efficiency; SCAPS-1D; numerical simulation.**

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I. INTRODUCTION

Solar cells are one of the most effective ways to harness solar energy and convert it into electricity [1]. A solar cell is one type of device that can capture sunlight. [2] Silicon has been the ideal material for solar systems for a very long time. One possible reason for all of this is that it's simple to obtain a lot of silicon, and the process of producing silicon has grown a lot better over time. As a result, extensive research has been conducted on various materials that can absorb light, are inexpensive, operate efficiently, and are easy to manufacture. On the other hand, silicon-based solar cells are more expensive and less efficient than other types of solar cells. CuO, or copper oxide, is a kind of semiconductor that belongs to the p-type group. Copper oxide is a kind of semiconductor. The band gap in copper oxide is a straight line and can range between 1.3 and 1.51 electron volts. This makes it an excellent material for absorbing the solar spectrum [3]. It is a suitable choice for absorber layers in thin-film solar cells because it can be created at low temperatures, is safe for humans and the environment, is affordable, and can be stretched during fabrication [4].

Solar light is a reliable form of sustainable energy that doesn't use up the Earth's resources and doesn't generate noise or pollution. Solar light is a source of energy that is always available. It can provide us with more energy than the fossil fuels and oil supplies already available on Earth. These are two kinds of energy that cannot be replenished. Using renewable energy, which utilizes many solar cells, is a more effective solution to address this problem. The development of solar cells has progressed significantly from one generation to the next. The two most significant drawbacks of solar cells are that they are costly and have limited efficiency [5].

Researchers have been working diligently on a range of materials over the past few decades to meet the ongoing demand for the three most crucial factors: affordability, efficiency, and lifespan.

Thin film solar cells have performed very nicely historically [6]. Affordable, very stable, with a high conversion efficiency, Cu(In,Ga)Se2 (CIGS) has a band gap that one may change. Given its high absorption coefficient of about 107 m–1 [7], CIGS is a useful and interesting material for solar applications. It can accommodate enough of light. In the laboratory, authors [8] found that regular baseline structured CIGS solar cells had greatest efficiency now at 22.67%. Their knowledge came from the lab. Whereas the letter x (x = Ga/Ga + In) speaks for the amount of Ga in the CIGS sample, the symbol Eg denotes for the band gap in electron volts. By reducing the absorber layer size in CIGS samples, researchers have been trying to lower the cost of these materials. Hard to obtain and expensive, the Ga (Gallium) and In (Indium) components used in CIGS experiments [9].

We now understand that the efficiency of solar cells is influenced by three components. According to a past work [10], the process consists of three steps: breaking up excitons, eliminating charges, and either transporting or collecting the produced charge carriers. When recombination happens at the rear surface and the contact interface between the semiconductor and the metal substrate [11], solar cells perform less as well. Selecting a back contact metal with a suitable work function is crucial if one wants to create a solar cell as effective as feasible. [12] a Schottky-barrier contact develops between the metal electrode and the CIGS absorber layer. Center of the other is this interaction. This is so as most metals lack high enough work capabilities to be regarded as outstanding. The Schottky barrier can greatly affect the I-V characteristics of CIGS cells [13]. It makes an ohmic contact with the CIGS absorber layer by selecting a metal of great quality with a high work function, therefore preventing migration of holes. This is thus true as the layer of CIGS absorbers is semiconductor. One often used approach to solve this is heavy doping. As seen in [14], it offers an extra layer of back surface field (BSF) depending on the suitable material. This layer either makes the barrier less wide or shorter [15]. Another aim of this layer is to separate the CIGS and final metal back contact. The circuit runs from the CIGS to the final metal back contact. This stratum straddles the two. Research on how to improve CIGS solar cells by including a rear surface field layer [16], [17] both theoretically and experimentally.

This work mixed theoretical and experimental methods. According to [18], [19], [20], [21] theoretical efficiency for CIGS thin-film solar cells is 21.3 percent, 22.0 percent, 22.1 percent, and 22.6 percent. Still, these cells have been demonstrated to be just 19.2 to 19 percent efficient. Costly, the absorber layer must be three meters thick if the solar cell is to operate as it should. Just 22.67% of the time does the solar cell operate. Rising from 9% to 14.5% [22], the efficiency of CIGS solar cells with a molybdenum selenide (MoSe2) BSF layer improved The solar cells performed better, hence this was correct. We also considered both in principle and in fact the prospective use of SnS as BSF layers in CIGS solar battery cells. One performed research on this kind of application. Their research showed that the thin CIGS layer may increase performance in an affordable and low-cost manner.

The back-surface field (BSF) layer in CIGS solar cells might find usage for the recently identified semiconducting lead sulfide (PbS). Simultaneously, this would also make the CIGS absorber layer smaller [23]. One of the most important structural elements that would let solar cells run more effectively [24] would be Among the most important structural details would be an efficient back surface field (BSF) layer. Among the several layers, this one is very probably the most crucial one. It is well known since the 1980s that BSF layers reduce surface recombination by bouncing minority carriers back toward the p-n junction. This is so as BSF levels are known to reject minority carriers. This may be accomplished by raising the carrier collecting of the device without appreciable change in its series resistance [25].

BSF layers also assist to retain light in, therefore facilitating the photon absorption. Their efforts have produced a variety of modeling tools showing thin-film solar cell functioning. Among these were SCAPS, AMPS, wxAMPS, and COMSOL. Thin-film solar cells may be modeled simpler because to these technology. Conversely, SCAPS-1D is more well-liked as the simulation results almost match the test data and its user interface is more easy to understand [26]. The basic semiconductor equations upon which this theory is based are the Poisson equation and the continuity equations for electrons and holes [27], [28]. These equations support this idea.

This study mimics a completely new CuO-based inorganic heterojunction thin-film solar cell fabrication [29], [30]. This is accomplished with the SCAPS-1D program and additional many more BSF layers. It is necessary to use a rigorous approach to investigate how the thickness of the BSF and absorber layers affects things. This is carried out with the system's running temperature. To improve the running of the solar cell construction, researchers have also looked at and changed certain important performance factors. This was carried out in order to get the best results available. Measures falling under this group of criteria include the fill factor (FF), the open-circuit voltage (VOC), the short-circuit current density (SF), and the general efficiency (Þ).

II. Materials and Methods

The first table shows the results of the physical and electrical characteristics of the layers; the second table lists the most important simulation settings and parameters that have to be satisfied to obtain accurate results that are representative of the normal working conditions of solar cell.

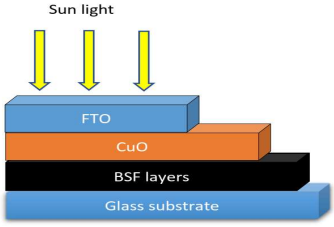

Fig. 1 Schematic diagram of CuO solar cell.

The choice of the structural elements and material properties of the layers was made with considerable attention

to reach the highest potential performance from the solar cells. While the second table describes the most important simulation settings and parameters that must be satisfied to obtain accurate results indicative of the normal operating circumstances of solar cells [31], [32]. Table 1 offers a description of the physical and electrical characteristics of the layers.

TABLE I
PARAMETERS OF ALL DIFFERENT MATERIALS

Parameters	FTO	CuO	$CuSbS_2$	ZnTe	CU_2Te	SnS
W (μm)	0.05	0.700	0.05	0.05	0.05	0.05
Eg (eV)	3.6	1.510	1.58	2.26	1.18	1.31
χ(eV)	4.0	4.300	4.2	3.65	4.20	4.3
ϵ_r	9.0	18.1	14.6	14	10	13
N_C (cm^{-3})	2.2×10^{18}	2.2×10^{19}	2.0×10^{18}	7.5×10^{17}	7.8×10^{17}	1.18×10^{18}
N_V (cm^{-3})	1.8×10^{19}	5.5×10^{20}	2.0×10^{19}	1.5×10^{19}	1.6×10^{19}	4.76×10^{18}
V_n (cm/s)	10^7	10^7	10^7	10^7	10^7	10^7
V_p (cm/s)	10^7	10^7	10^7	10^7	10^7	10^7
μ_n (cm^2/V s)	100	100	49	70	500	130
μ_p (cm^2/V s)	25	0.1	49	50	100	4.3
N_D (cm^{-3})	5×10^{18}	0	0	0	0	0
N_A (cm^{-3})	0	10^{18}	10^{18}	2.16×10^{19}	10^{19}	10^{15}
N_t (cm^{-3})	10^{14}	10^{12}	10^{14}	10^{14}	10^{14}	10^{14}

TABLE II
SIMULATION PARAMETERS USED IN SCAPS-1D

Parameter	Value
Temperature (K)	300
Frequency (Hz)	1×10^6
Light power (W/m²)	1000
Number of points	5
solar spectrum	AM1.5G
Transmission	100%
I-V Scan range (V1-V2)	0.00V-2.00V

III. RESULTS AND DISCUSSION

A. Performance Comparison of Different BSF Layers in CuO-Based Solar Cells

We used the SCAPS-1D program to do a comparison simulation study to find out which back surface field (BSF) material works best to improve the performance and stability of CuO-based solar cells. The goal of this study was to find out which BSF material works best. Four distinct semiconductor materials made up the BSF layers in the cell structure: CuSbS2, ZnTe, CuTe, and SnS. Each of these materials added to the construction in its way. We conducted tests to determine the impact of these materials on key photovoltaic properties. Table 3 shows the results of the simulations. They demonstrate that the structure based on ZnTe exhibits the highest power conversion efficiency (PCE), at 32.68%. Next are the structures that are based on CuSbS2 (26.84%), SnS (17.37%), and CuTe (17.17%). This indicates that ZnTe is the most suitable BSF option among all the materials examined. ZnTe works better because it has a wider bandgap [33], which stops carriers from recombining at the back contact. This is one reason why ZnTe works better. This results in both the open-circuit voltage (VOC) and the short-circuit current density (Jsc) increasing, which is beneficial. Adding the right BSF layer not only helps gather carriers more effectively, but it also allows you to make the absorber layer thinner without sacrificing efficiency. The BSF layer helps capture carriers more effectively, which is why this occurs.

TABLE III
ASSOCIATED PERFORMANCE FOR SOLAR CELL WITH DIFFERENT BSF LAYERS

Layers	Voc (V)	Jsc (mA/cm^2)	FF%	(η) %
CU_2Te / CuO / FTO	0.9363	21.369587	85.79	17.17
ZnTe / CuO / FTO	1.4313	26.556045	85.99	32.68
SnS / CuO / FTO	0.9403	21.535469	85.76	17.37
$CuSbS_2$ / CuO / FTO	1.1300	26.620318	89.21	26.84

B. Impact of BSF Layer Thickness on Solar Cells Performance

Researchers examined the impact of layer thickness on the performance of CuO-based solar cells. In this experiment, the BSF layer's thickness changed from 0.05 μm to 0.55 μm in steps of 0.1 μm. The thickness of the CuO absorber layer remained constant at 1.5 μm throughout the experiment. At the same time, the temperature was maintained at 300 K. Figure 2 presents the simulation results, illustrating the changes in the main photovoltaic parameters. Open-circuit voltage (VOC), short-circuit current density (JSC), fill factor (FF), and power conversion efficiency (η) are among these key metrics. Four different BSF materials, $CuSbS_2$, SnS, ZnTe, and Cu_2Te, show these differences.

The figures 2 show that the electrical performance characteristics don't change significantly when the thickness of the BSF layer varies for all the materials studied. From this, we can conclude that once the BSF layer reaches a particular thickness, any further increases have little effect on the device's performance [34]. ZnTe was shown to be a suitable BSF layer, as it consistently exhibited better performance metrics across all thicknesses. For this scenario, the best thickness for all BSF layers is 0.05 μm. The optimization findings show that the optimal efficiency for ZnTe, $CuSbS_2$, SnS, and Cu_2Te BSF layers is 32.68%, 26.84%, 17.37%, and 17.17%, respectively.

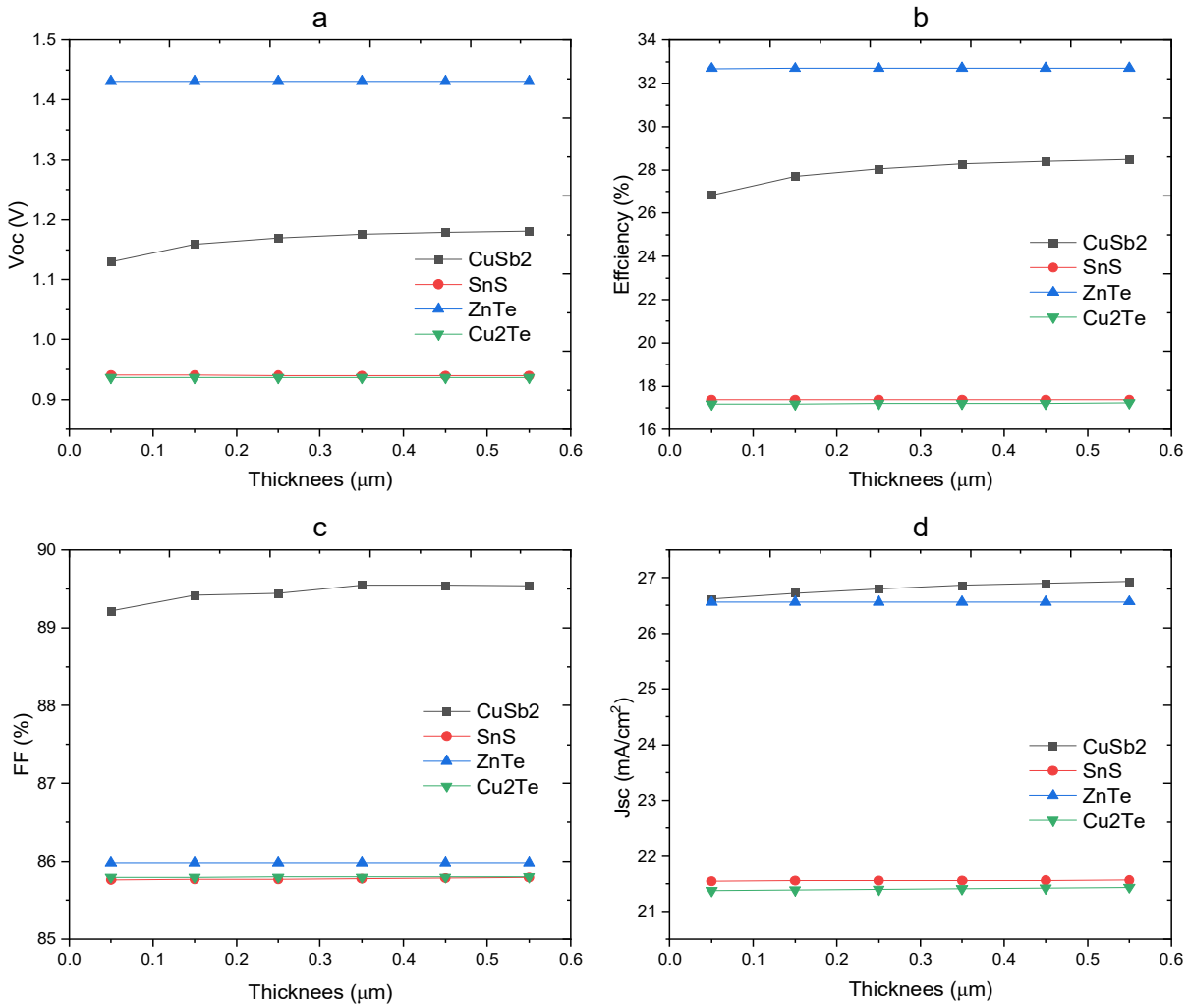

Fig. 2 (a) VOC vs. BSF layer thickness; (b) JSC vs. BSF layer thickness; (c) Fill factor vs. BSF layer thickness; (d) Efficiency vs. BSF layer thickness

C. Impact of CuO Layer Thickness on Solar Cells Performance

SCAPS-1D simulations for four distinct BSF configurations—$CuSbS_2$, SnS, ZnTe, and Cu_2Te—were used to assess the photovoltaic performance impact of CuO absorber layer thickness. At 300 K, with a constant buffer layer thickness of 0.05 µm, the CuO thickness was changed from 0.5 µm to 4.0 µm in 0.5 µm increments. Figure 3 shows the outcomes. As the CuO thickness increases from 0.5 µm to 1.5 µm, a notable improvement is observed in all key performance criteria (Vco, Jsc, FF, and efficiency). Increased photon absorption and production of additional electron-hole pairs account for this enhancement, hence improving the photo-produced VOC and JSC [35]. Beyond 1.5 µm, nevertheless, the rate of improvement in these factors becomes negligible. This saturation behavior is likely caused by the CuO layer extending beyond the minority carrier diffusion length, resulting in recombination losses that limit further performance improvements. From both performance and cost angles, a CuO thickness of 1.5 m is shown to be ideal for attaining high efficiency without superfluous material use [36]. Among the BSF configurations examined, the ZnTe-based cell regularly outperformed others at all thicknesses, hence presenting the most attractive choice for integration with the CuO absorber.

D. Effects of Working Temperature with Various BSF Layers

A study examined the impact of temperature on the performance of CuO-based solar cells, which featured multiple buffer layers. The study looked at temperatures between 300 K and 400 K. The thickness of the buffer layer was set at 0.05 H 5 m in all of the simulated configurations, while the thickness of the CuO absorber layer was fixed to 1.5 H 5 m. Figure 4 shows the results. When the temperature of the solar cell goes up, the bandgap of the absorber material goes down because the lattice vibrations get stronger. The cell can now absorb longer wavelengths of the sun's spectrum because of this decrease. This causes a slight rise in the current short-circuit density (Jsc). The open-circuit voltage (VOC) clearly decreases with the bandgap shrinking. This is thus because the reverse saturation current [37] increases with increasing intrinsic carrier concentration. Since the VOC value depends on the increasing saturation current, it lowers. The efficiency of the cell falls with temperature. These findings show that CuO-based devices are susceptible to temperature and stress, therefore stressing the need of good thermal management especially in choosing BSF layers to guarantee the devices stay as stable as feasible in practical environments.

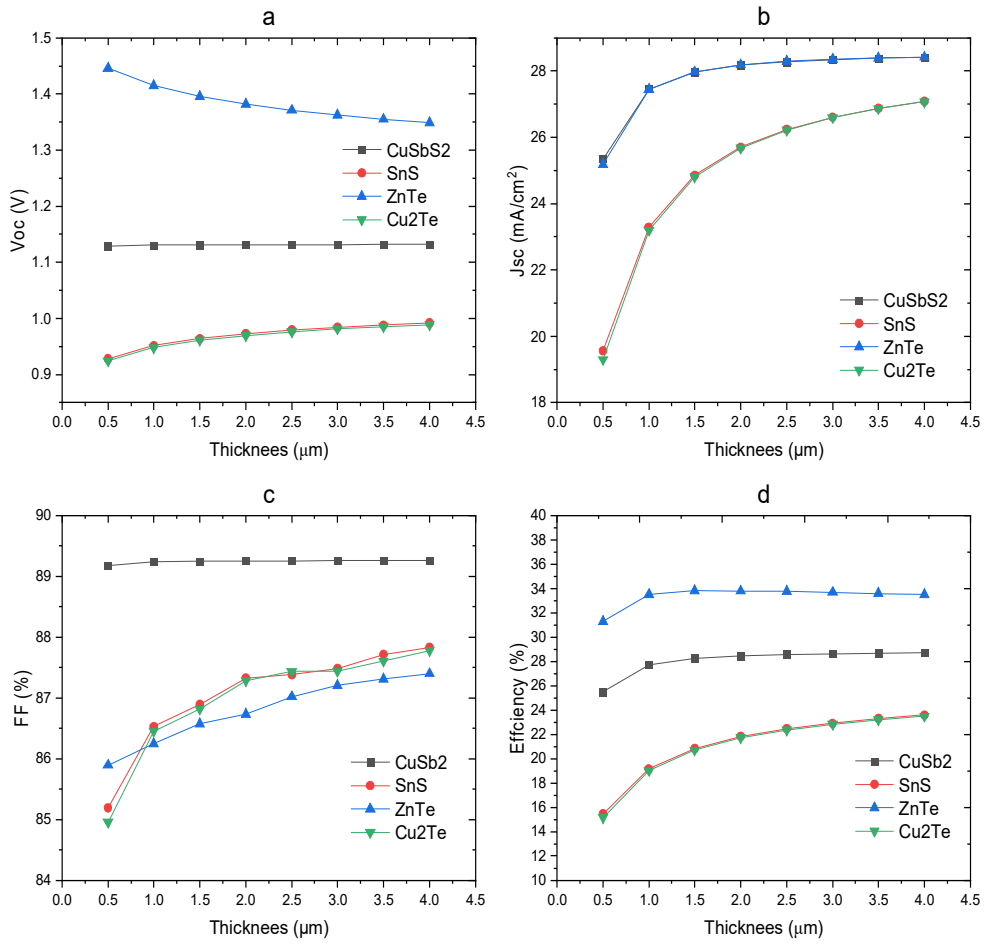

Fig. 3 (a) VOC vs. absorber layer thickness; (b) JSC vs. absorber layer thickness; (c) Fill factor vs. absorber layer thickness; (d) Efficiency vs. absorber layer thickness.

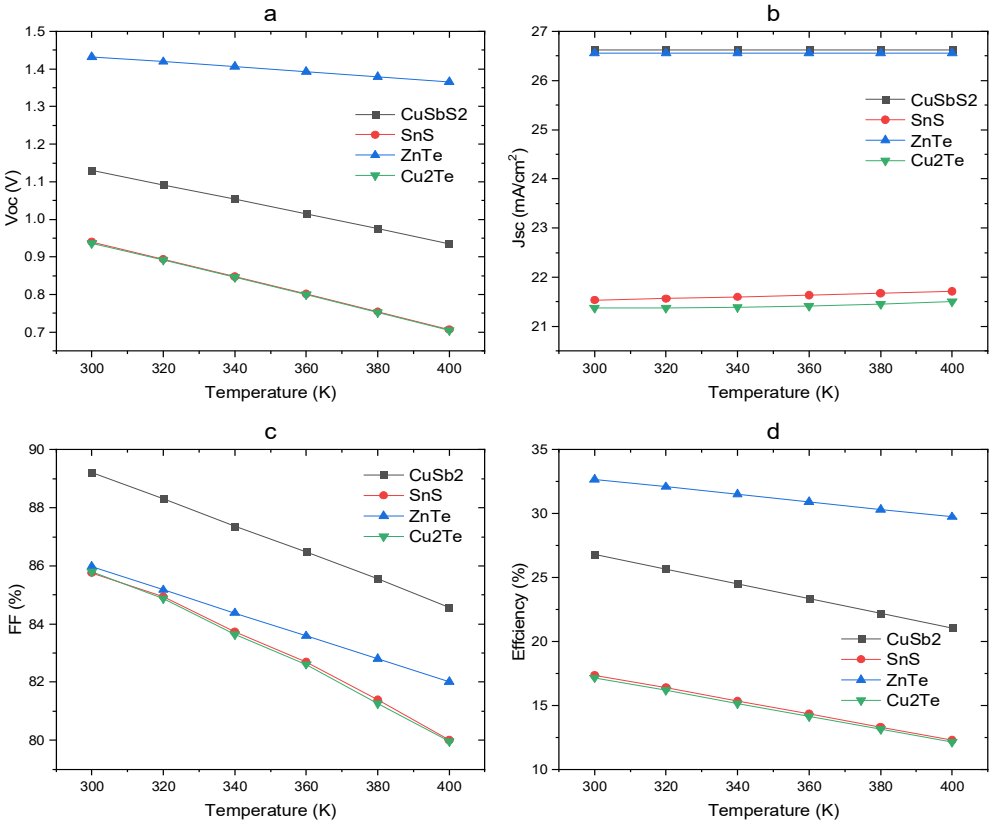

Fig. 4 (a) VOC vs. temperature; (b) JSC vs. temperature; (c) Fill factor vs. temperature; (d) Efficiency vs. temperature.

IV. Conclusion

This paper investigated the performance of CuO-based solar cells with many back surface field (BSF) layers: CuSbS2, ZnTe, Cu_2Te, and SnS utilizing the SCAPS-1D simulator. Although the buffer layer thickness was optimized at 0.05 m across all designs, 1.5 m turned out to be the optimal absorber layer thickness. With respective efficiencies of 32.68% and 26.84%, ZnTe and CuSbS2 shown the greatest solar performance among the BSF materials investigated. The results of the simulation also showed that device performance declines with rising operation temperature. These findings highlight the prospect of ZnTe and $CuSbS_2$ as effective BSF materials for high-efficiency CuO-based solar cells.

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