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EFFECT OF SERIES AND SHUNT RESISTANCE ON THE PERFORMANCE OF KESTERITE SOLAR CELLS

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ABSTRACT:

Kesterite devices are created from cheap, readily available, non-toxic basic components. Due to their p-type conductivity, direct band-gap shifts, comparatively high absorption coefficient, and adjustable band-gap, kesterite semiconductors have attracted a lot of attention from scientists for use in solar cells.The efficiency and overall performance of kesterite solar cells are influenced by various factors, including the incorporation of series and shunt resistances. In the present communication, we report the effect of series and shunt resistance on the photovoltaic performance of CZTSe kesterite solar cells. The relationship between series resistance and device parameters, such as fill factor, the open-circuit voltage, the short-circuit current density and the efficiency, is explored, providing valuable insights into device optimization. The efficiency was found to decrease with increase in the series resistance and *vice-versa*.

Keywords: Kesterite, CZTSe, Series Resistance, Shunt Resistance, SCAPS-1D

1. INTRODUCTION:

Thin-film photovoltaic materials [1] as Cu(In,Ga)Se_2 (CIGS) and Cadmium Teluride (CdTe) have drawn a lot of attention for decades of research due to their capacity to produce inexpensive and high performance with large-area solar cells made of thin films. Cu_2ZnSnS_4, $Cu_2ZnSnSe_4$, and $Cu_2ZnSn(S,Se)_4$ (CZTSSe) stand out as promising alternatives under intense research as potential replacement absorber materials for thin-film solar cells. This pursuit is driven by the substantial material consumption and costs associated with CIGS materials [7–10]. Structurally akin to Chalcopyrite (Cu(In,Ga)Se_2) solar cells, they boast bandgap values that closely approach the ideal single junction value of 1.5 eV and feature a Kesterite-type structure [11]. Furthermore, the bandgap of CZTS can be effectively reduced by incorporating its Se equivalent, offering the potential to enhance solar cell efficiency through the integration of $Cu_2ZnSnSe_4$ (CZTSe) and $Cu_2ZnSn(S,Se)_4$ (CZTSSe) absorber layers [11]. Notably, in 2013, Wang et al. [12] achieved a groundbreaking record cell efficiency of approximately 12.6% with $Cu_2ZnSnSSe_4$-based solar cells, employing a hydrazine pure-solution technique. Leveraging the abundant and promising nature of kesterite-based materials, they are emerging as formidable contenders against the matured Cu(In,Ga)Se_2 technology

[7,13-17]. Kesterite-based absorber layers, characterized by higher band gaps (E_g > 1.5 eV), not only enhance light absorption and the buffer layer at p/i interfaces but also bolster the overall performance of the solar cell, encompassing charge carrier extraction, open-circuit voltage, and the fill factor [15]. A down-shifting material, the transparent conductive oxide layer (i-ZnO) on the front side of the solar cell can produce one low-energy photon for each high-energy photon that is incident [18].

Solar cells exhibit parasitic characteristics known as series and shunt resistances, which significantly influence the illuminated I-V characteristics and overall efficiency of an otherwise well-performing cell. In the case of an n+-p or n+-p-p+ silicon solar cell, the series resistance (R_s) primarily comprises the resistances originating from the bulk material, the uppermost n+ diffused layer, and the contact resistance encountered on the front and rear surfaces. Conversely, the shunt resistance (R_{sh}) represents a high-conductivity pathway that runs in parallel to the p-n junction or along the cell edges. This shunt resistance has the effect of reducing the open-circuit voltage (V_{oc}), the curve factor (CF), and the maximum output power (P_m) of the cells by facilitating leakage current [19,20]. It's worth noting that low shunt resistance can also influence the short-circuit current density when series resistance is present. The performance of photovoltaic (PV) systems hinges significantly on R_{sh}, particularly under conditions of low irradiance. The challenge posed by low Rsh becomes more pronounced during instances of reduced light intensity, such as on overcast days or when the sun is positioned lower in the sky [21]. Therefore, to accurately assess cell efficiency, it becomes imperative to understand and address both R_s and R_{sh}.

In this communication, we present a simulation study that investigates the impact of series and shunt resistance on the photovoltaic performance of CZTSe solar cells. To conduct this study, we employed SCAPS-1D simulation software for the purpose of simulating CZTSe kesterite solar cells.

2. METHODS AND MATERIAL

The configuration of the solar cell device investigated in our study is illustrated in Figure 1. This setup comprises a p-type CZTSe absorber layer, an n-type wide band gap buffer layer made of CdS, a window layer that serves both as a passivation layer and is composed of ZnO, and a transparent conducting oxide (TCO) layer consisting of Al-doped ZnO (Al:ZnO). The material properties of the various materials utilized in our simulations are outlined in Table 1, and were obtained from previous studies [22-26]. We used these material properties to simulate the photovoltaic response of the device structure proposed in our study.

To simulate the proposed solar cell device structures, we employed SCAPS software which is a one-dimensional numerical simulator [27]. With the aid of this simulator, we were able to computationally solve the coupled Poisson and continuity equations for electrons and holes. This was achieved while taking into account the appropriate boundary conditions as defined at the contacts and interfaces [28-31]. It has been extensively utilized for simulating various types of solar cells in prior studies [32-37].

The following structure was considered for the simulation of CZTSe single junction solar cells,: Al:ZnO /ZnO /CdS /absorber layer /back contact. The Al:ZnO layer was used to provide the electrical contact at front and to remain transparent for the solar radiation incident on it. The ZnO was used as the window layer, while the n-CdS was utilized as the buffer, forming a p-n junction which is heterostructure with the p-CZTSe light absorbing layer. The defects were presented at 0.6 eV above the valence band maximum (Ev) in the light absorbing layer, with a single energetic distribution to ascertain mid-gap defect. For the back contact, we considered a flat band with surface recombination velocities of around 1 x 10^5 cm s^{-1} for electrons and 1 x 10^7 cm s^{-1} for holes. It's important to note that all simulations were conducted under AM1.5 G 1SUN illumination conditions.

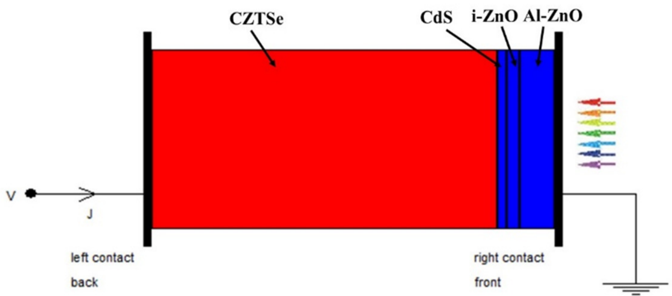

Figure 1: Schematic of ***"Al-ZnO/i-ZnO/CdS/CZTSe/Back contact"*** solar cell used in present simulation.

Table 1: Material parameters used for simulating solar cell structures [22-26]

	CZTSe	**CdS**	**i-ZnO**	**Al-ZnO**
Thickness (µm)	2	0.05	0.080	0.2
Electron Affinity (eV)	4.46	4.5	4.6	4.6
Bandgap (eV)	1	2.42	3.37	3.37
Dielectric Permittivity	9.1	9	9	9
CB Effective DOS (cm^{-3})	2.2×10^{18}	1.8×10^{19}	2.2×10^{18}	2.2×10^{18}
VB Effective DOS (cm^{-3})	1.8×10^{19}	2.4×10^{18}	1.8×10^{19}	1.8×10^{19}
Hole Thermal Velocity (m/s)	1×10^7	1×10^7	1×10^7	1×10^7
Electron Thermal Velocity (m/s)	1×10^7	1×10^7	1×10^7	1×10^7
Hole Mobility (cm^2/Vs)	40	50	25	25
Electron Mobility (cm^2/Vs)	145	160	150	150
Shallow Uniform Acceptor Density NA (cm^{-3})	5×10^{16}	0	0	0
Shallow Uniform Donor Density ND (cm^{-3})	0	1×10^{17}	1×10^{17}	1×10^{20}

3. RESULTS AND DISCUSSION

3.1 Effect of Series Resistance

In this study, we investigated the influence of series resistance on the photovoltaic performance of CZTSe Kesterite solar cells. We systematically varied the series resistance within the range of 1 Ω cm^2 to 10 Ω cm^2 and recorded the corresponding changes in V_{oc} (open-circuit voltage), J_{sc} (short-circuit current), FF (fill factor), and η (efficiency), as summarized in Table 2. Our findings clearly indicate that as the series resistance increases, the efficiency of the solar cell experiences a notable decrease. It's noteworthy that V_{oc} remains nearly unaffected by changes in series resistance. This outcome aligns with the fact that in the open-circuit condition, series resistance has negligible influence over the voltage across the device. However, J_{sc} exhibits a decline due to the impedance introduced by the elevated series resistance, which hinders the carrier flow. As a result, there is a simultaneous reduction in both the fill factor (FF) and the power conversion efficiency (PCE) owing to the decreased maximum output power.

Table 2: Variation of photovoltaic parameters with series resistance

PV Parameters	**Series Resistance** (Ω cm^2)									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
V_{oc} (V)	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
J_{sc} (mA/cm^2)	25.84	25.82	25.81	25.79	25.77	25.75	25.73	25.71	25.69	25.67
FF (%)	78.47	74.56	70.73	66.98	63.31	59.73	56.27	52.91	49.71	46.68
Efficiency (%)	11.89	11.3	10.72	10.14	9.58	9.03	8.51	7.99	7.5	7.04

3.2 Effect of Shunt Resistance

Photovoltaic performance of CZTSe kesterite solar cells was investigated against the variation of the shunt resistance. Table 3 depicts the variation in photovoltaic parameters with the increase in shunt resistance. It can be clearly seen from the Table 3 that on increasing the shunt resistance from 100 to 1000 (Ω cm^2) FF and efficiency increase rapidly. This phenomenon can be explained as the shunt resistance increases, the unintended current leakage paths that bypass the photovoltaic junction and create shunt currents diminish. Lower leakage currents mean that a larger portion of the generated current flows through the intended photovoltaic pathway. This reduced leakage results in a higher effective current, leading to an increase in the fill factor. Also, Shunt resistance plays a role in compensating for the adverse effects of series resistance. Series resistance, which arises due to the resistive losses in the conductive elements of the solar cell, can cause a drop in the fill factor and efficiency. A higher shunt resistance can partially offset the impact of series resistance, allowing more efficient charge carrier collection and mitigating the losses incurred.

Table 3: Variation of photovoltaic parameters with shunt resistance

PV Parameters	Shunt Resistance (Ω cm^2)									
	100	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**
V_{oc} (V)	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
J_{sc} (mA/cm^2)	25.86	25.86	25.86	25.86	25.86	25.86	25.86	25.86	25.86	25.86
FF (%)	65.94	73.96	76.68	78.04	78.87	79.74	80.13	80.42	80.65	80.84
Efficiency (%)	9.89	11.15	11.58	11.79	11.92	12.06	12.12	12.17	12.2	12.23

4. CONCLUSION

In the current study, CZTSe kesterite solar cells were subject to simulation using SCAPS-1D simulation software. The primary objective was to investigate the impact of varying series and shunt resistances on the photovoltaic performance of these simulated solar cells. Our results reveal a clear trend: as series resistance increases, the efficiency of the solar cell decreases. Conversely, when shunt resistance is increased, the efficiency of the simulated solar cell demonstrates improvement. This outcome underscores the significant influence exerted by both series and shunt resistances on the power outputs of CZTSe Kesterite solar cells. It is imperative to recognize and comprehend these parasitic resistances, as they play a critical role in the analysis of PV module performance degradation and potential failures under real operating conditions. In summation, this research underscores the paramount importance of series and shunt resistances in shaping the performance of kesterite solar cells. By gaining a deep understanding of and optimizing these resistive parameters, we can make substantial strides in enhancing the efficiency and stability of kesterite solar cells. This, in turn, contributes significantly to the advancement of renewable energy technologies and accelerates our transition toward a more sustainable energy future.

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