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Optimum Defect Density of Organic–in Organic for High Efficiency Perovskites Solar Cells

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Abstract: In this paper, device modeling of lead-free perovskite solar cells was done using the perovskite absorber layer $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$ with a big bandgap of 1.8 eV, a PCBM layer for the electron transport layer, which is renowned for its anti-hysteresis effect, and a NiO layer for the hole transport layer, which increases stability and boosts the cell's efficiency. The SCAPS-1D, which is highly suited for analyzing photovoltaic design, was used to examine new architecture. Using this software technique, we conducted an analysis the thickness, defect density, operating temperature and work function of the model through modeling under different circumstances. With the optimize the thickness to be (0.3 μm) corresponding best efficiency among several perovskite thicknesses, the defect density of absorber layer (10^{13} cm^{-3}) and maximum power conversion efficiency PCE rose to 35.47%, which is a promising result, the short-circuit current density J_{sc} is 33.498903 (mA/cm^2), and fill factor FF is 78.00% and open-circuit voltage V_{oc} is 1.3584 (V). while, the effect of the working temperature was evaluated, and the outcomes demonstrate that lead-free perovskite cells work quite well increase with increase in temperature then start decrease at 400 K. Finally, study effects for change of the work function on the major parameters of perovskite solar cells.

Keywords: Perovskites, SCAPS-1D, high efficiency, Solar Cells, thickness, work-function.

1. Introduction

In the past few decades, solar PV technology has grown quickly thanks to technological advancements, the search for new, inexpensive materials, and a rise in commercial manufacturing [1]. The efficiency of solar cells must be increased as much as feasible in order to commercialize this technology. One of the limitations of single-junction photovoltaic devices is when the photon energy is uneven with the frequency gap energy because this results in loss of power**.** Energy loss caused by the difference between the photon energy and the material's bandgap energy (Eg) is one of the variables that restrict the performance of single-junction photovoltaic (PV) devices. When the photon energy is equal to the frequency gap energy, the photon energy can be converted into electric energy with high efficiency, but if the photon energy is less than the frequency gap energy, cannot be absorbed, and when the photon energy is greater than the frequency gap energy it does not contribute to thermal conductivity because it loses the additional energy through the pregnant thermal coding [2]. Through this study we were able to analyze and examine the effects of the thickness change of the absorbed layer, HTM and ETL on system output, the SCAPS program was manufactured to simulate the one-dimensional solar cell then this program was developed in Belgium by the University of Gent Department of Electronics and Information Systems. Many researchers were involved in the development SCAPS: Mark Burgelman, Queen Decock, Alex Nemigers, Stefan DeGraff, Johan Verschriegen [3-8].

2. Simulation and Modeling Computer

The use of simulation is essential for gaining a thorough understanding of physical activity, assessing the validity of proposed physical interpretations, and determining the impact of physical alterations on the performance of solar cell devices. In order to simulate solar cells there are a lot of simulation models like (SCAPS, AMPS, SCAP, etc.), SCAPS is a program consisting of 7 input layers for semiconductors [9]. It is impractical and a waste of effort and money to construct a solar cell without stimulation. It can analyze layers and their functions and also increase the ability of solar cells in addition, it reduces risks, shortens time and saves money. Key input parameters must be carefully selected to act as a real counterpart for computer simulation [10-11]. Simulation phases using SCAPS are shown step by step in the flow chart below:

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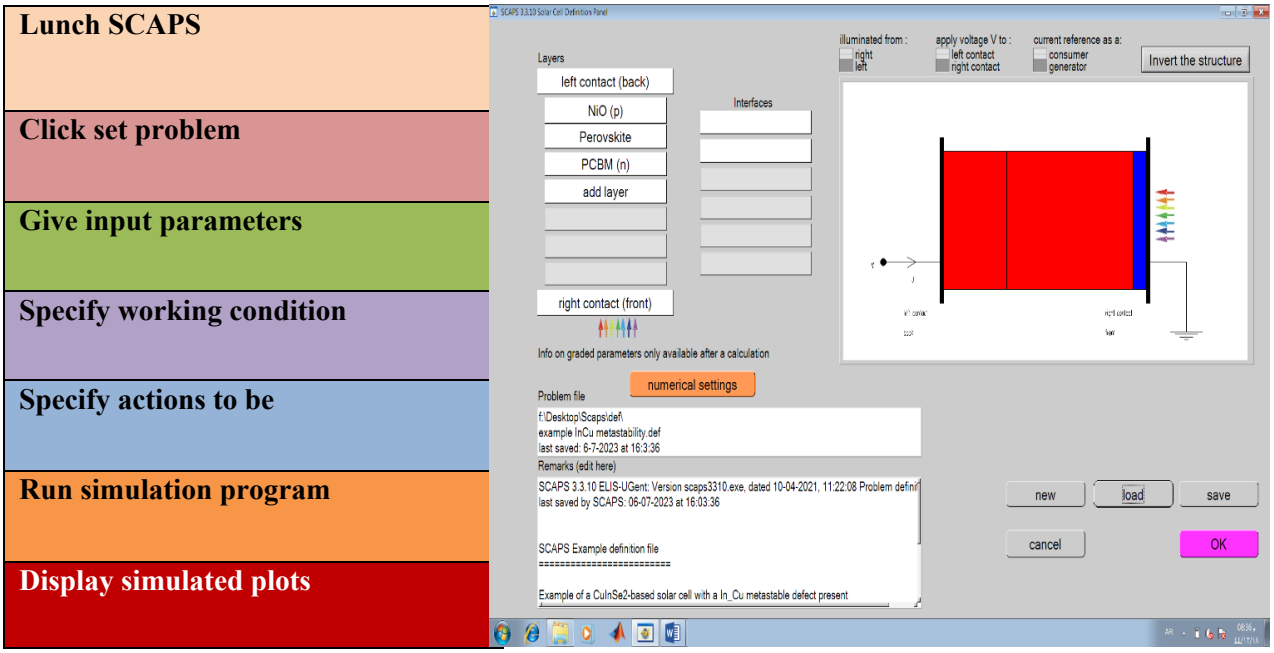


Fig. 1: Explains the simulation process and panel showing the NiO/$C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$/PCBM hetrojunction solar cells definition using SCAPS.

HTM has three main functions: acting as a hole-selective contact, extracting photo-generated holes, and carrying the holes to the metal contact. The ETL reduces charge recombination and enhances total PCE by blocking direct contact between the counter electrode and the perovskite/photoactive layer. Fig 2 shows a comparison of the energy levels of between HTM layer, absorb layer and ETL layer.

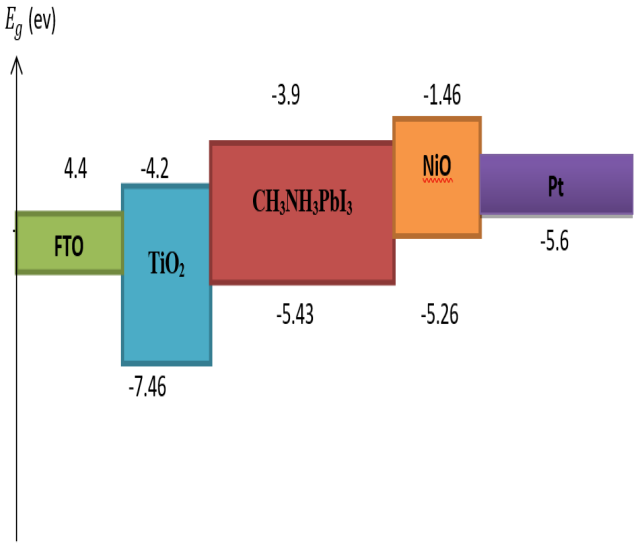


Fig. 2: Energy band alignment.

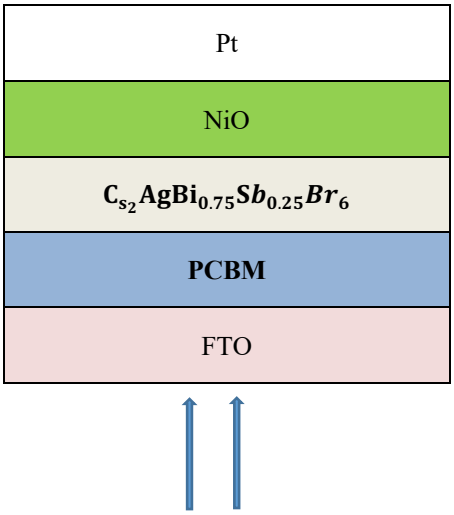


Fig. 3: Schematic representation device architecture (ITO/ NiO / $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$/ PCBM/Pt).

3. Modeling and simulation

A model of perovskite solar cell involving $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$ is proposed. Device simulations for the ITO/NiO/$C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$/PCBM/Pt structure have been performed using SCAPS1D. From I-V characteristics of structure, it was evident that the highest efficiency can be namely, Poisson's equation (1), continuity equation for holes (2) and continuity equation for electrons (3) as follows:

$$\frac{d}{dx}(-\varepsilon(x)\frac{d\psi}{dx}=q[p(x)-n(x)+N_d^+(x)-N_a^-(x)+p_t(x)-n_t(x)] \quad (1)$$

$$\frac{dp_n}{dx}=G_P-\frac{P_n-p_{n0}}{\tau_p}-p_n\mu_p\frac{d\xi}{dx}-\mu_p\xi\frac{dp_n}{dx}+D_p\frac{d^2p_n}{dx}, \quad (2)$$

$$\frac{dn_p}{dx}=G_n-\frac{n_p-n_{p0}}{\tau_p}+n_p\mu_n\frac{d\xi}{dx}+\mu_n\xi\frac{dn_p}{dx}+D_n\frac{d^2p_n}{dx^2} \quad (3)$$

Where, D is the diffusion factor, ψ represent the electrostatic voltage. The value of q represents the amount of the electron charge while G represents the rate of generation and ξ is permittivity. n represents free electrons either p free hole, n_t represents trapped electrons and p_t represents trapped holes. N_a^- refers to ionized acceptor-like doping concentration while N_d^+ stands for ionized donor-like doping concentration [12].

Table 1: Basic parameters used in modeling [13-20].

parameters	NiO	$C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$	PCBM
Band gap (ev)	3.600	1.800	2.000
Electron effinity (ev)	1.800	3.580	3.900
Dielectric permittivity	11.700	6.500	4.000
CB effective density of states (1/cm^2)	2.500E+20	2.200E+18	1.000E+21
VB effective density of states (1/cm^2)	2.500E+20	1.800E+19	2.000E+20
Electron mobility (cm^2/v.s)	2.800E+0	2.000E+0	1.000E-2
Hole mobility (cm^2/v.s)	2.800E+0	2.000E+0	1.000E-2
Donor Concentration N_D/cm^{-3}	0.000E+0	1.000E+13	5.000+14
Acceptor Concentration N_A/cm^{-3}	3.000E+8	1.000E+17	0.000E+0

Table 2: Parameters used to simulate SCAPS.

Left contact electrical properties(Pt)	
Thermionic emission /surface recombination velocity electron and hole (cm/s)	10^7
Metal (Pt) work function (ev)	5.6
Right contact electrical properties	
Thermionic emission /surface recombination velocity electron and hole (cm/s)	10^7
work function of ITO (ev)	4.4

4. Result and Discussion

Effect of layer thickness, Defects, Temperatures and Work function change on the NiO/ $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$ /PCBM solar cells devices

4.1. Effect of the NiO (HTM) layer thickness change on solar cells

The thickness of NiO as the (HTM) must be carefully controlled, to thoroughly a full cover the perovskite layer, absorb the most photons possible, and create electron-hole pairs. Layer thickness NiO has been range from (0.1 to 0.7) µm. A thin HTM layer does not completely cover the absorber layer, as a result, at thickness 0.1µm, the efficiency is low. At thickness of the absorber layer $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$ increases from 0.2 to 0.5µm, chances of recombination are rises because an increase in the path length of charge carrier and the electric resistance of the device, which boosts efficiency. Figure 4 sketches the change in the PV parameters of perovskite solar cell with thickness NiO as the HTM, the graph show an efficiency, voltage, and current density decreases with increasing thickness, while the filling factor stays constant. when the thickness is increased from 0.2µm to 0.5µm, we note efficiency stay constant 0.57 then decrease at thickness 0.6µm, while voltage is constant at the thickness 0.1µm and 0.2µm then increase at thickness 0.3µm Then it starts to decrease in thickness 0.5µm as illustrated in Figure (4). As a result, the best efficiency is obtained at a thickness of 0.2 m, where the efficiency hits 0.57%. The resistance rise with the layer thickness increases from 0.6 to 0.7µm, further lowering the cell's performance. The drawing data is shown in table number three.

Table 3: Variation of Thickness for NiO with device parameters.

Thickness(µm)	V_{oc}(V)	J_{sc}(mA /cm^2)	F.F (%)	η (%)
0.1	1.2295	1.488065	30.88	0.56
0.2	1.2295	1.488097	30.88	0.57
0.3	1.2296	1.488135	30.88	0.57
0.4	1.2296	1.488134	30.88	0.57
0.5	1.2295	1.488056	30.88	0.57
0.6	1.2294	1.487893	30.88	0.56
0.7	1.2292	1.487655	30.88	0.56

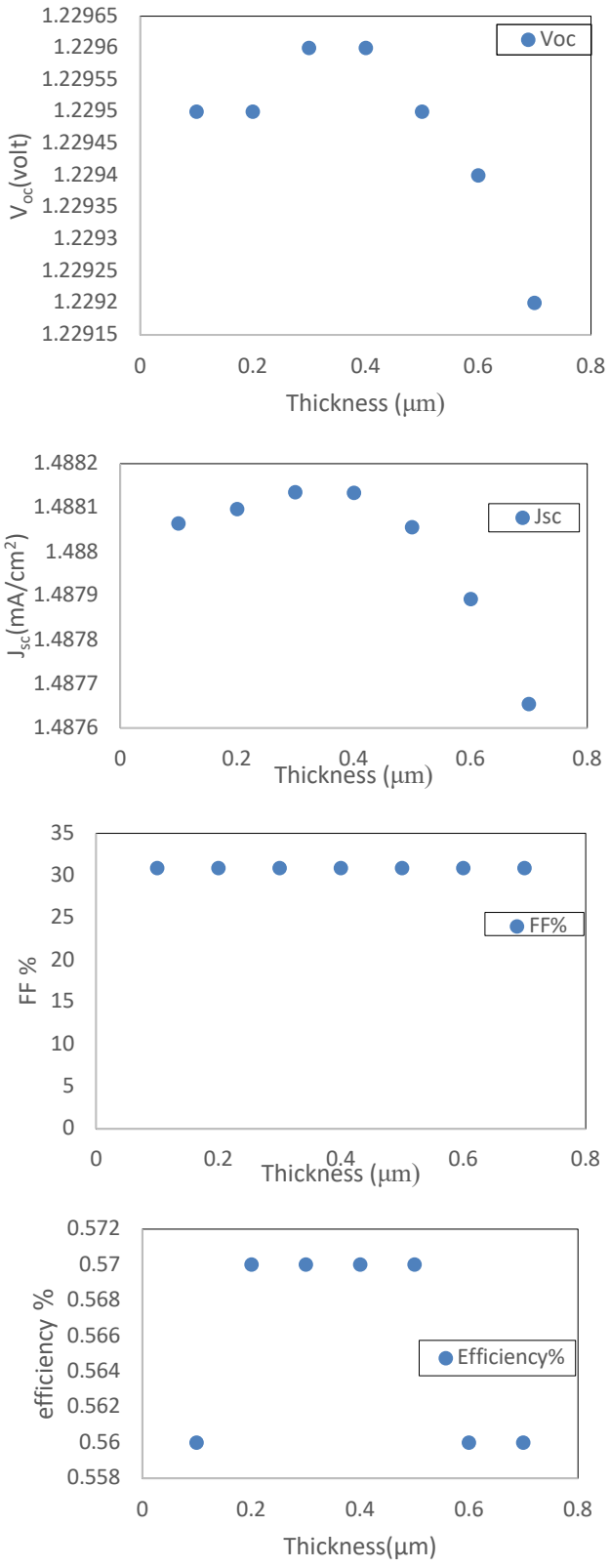


Fig. 4: Photoelectric parameters change by NiO thickness change.

4.2. Effect of the $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$ layer thickness change on solar cells

The thickness of the absorber layer significantly affects the efficiency of the solar cell. The absorber layer thickness of $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$ has varied between 0.1 μm and 1.6μm. Fig. 5 Reflects the change of the photovoltaic characteristics with perovskite where is value the efficiency 0.56 at thickness 0.1μm and 0.2μm then thickness the efficiency of the solar cell increase at thickness 0.3μm to value 0.57 then stay constant same the value to thickness 1.6μm, 0.3μm is considered to be the ideal thickness for the solar cell, where the value of efficiency 0.57%. By increasing the thickness of the absorber layer $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$, the depletion layer becomes extremely similar to the back contact, and more electrons are gathered for recombination Through the back contact. by looking at the (F.F/ thickness), (V_{oc}/thickness) and (J_{sc}/thickness) graphs, we can be noted that FF value increase at thickness 0.2 mm then stay constant to thickness 1.6 mm, while V_{oc} stay constant, finally the value of J_{sc} increases and then decrease with increasing thickness. The drawing data are shown in table number four.

Table 4: Photoelectric parameters change by $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$ thickness change.

Thickness (μm)	V_{oc}(V)	J_{sc}(mA /cm^2)	F.F (%)	η (%)
0.1	1.2295	1.488562	30.86	0.56
0.2	1.2295	1.488002	30.88	0.56
0.3	1.2295	1.488079	30.88	0.57
0.4	1.2295	1.488097	30.88	0.57
0.5	1.2295	1.488105	30.88	0.57
0.6	1.2295	1.488127	30.88	0.57
0.7	1.2295	1.488184	30.88	0.57
0.8	1.2295	1.488118	30.88	0.57
0.9	1.2295	1.488202	30.88	0.57
1	1.2295	1.488163	30.88	0.57
1.1	1.2295	1.488255	30.88	0.57
1.2	1.2295	1.488211	30.88	0.57
1.3	1.2295	1.488171	30.88	0.57
1.4	1.2295	1.488142	30.88	0.57
1.5	1.2295	1.488309	30.88	0.57
1.6	1.2295	1.488233	30.88	0.57

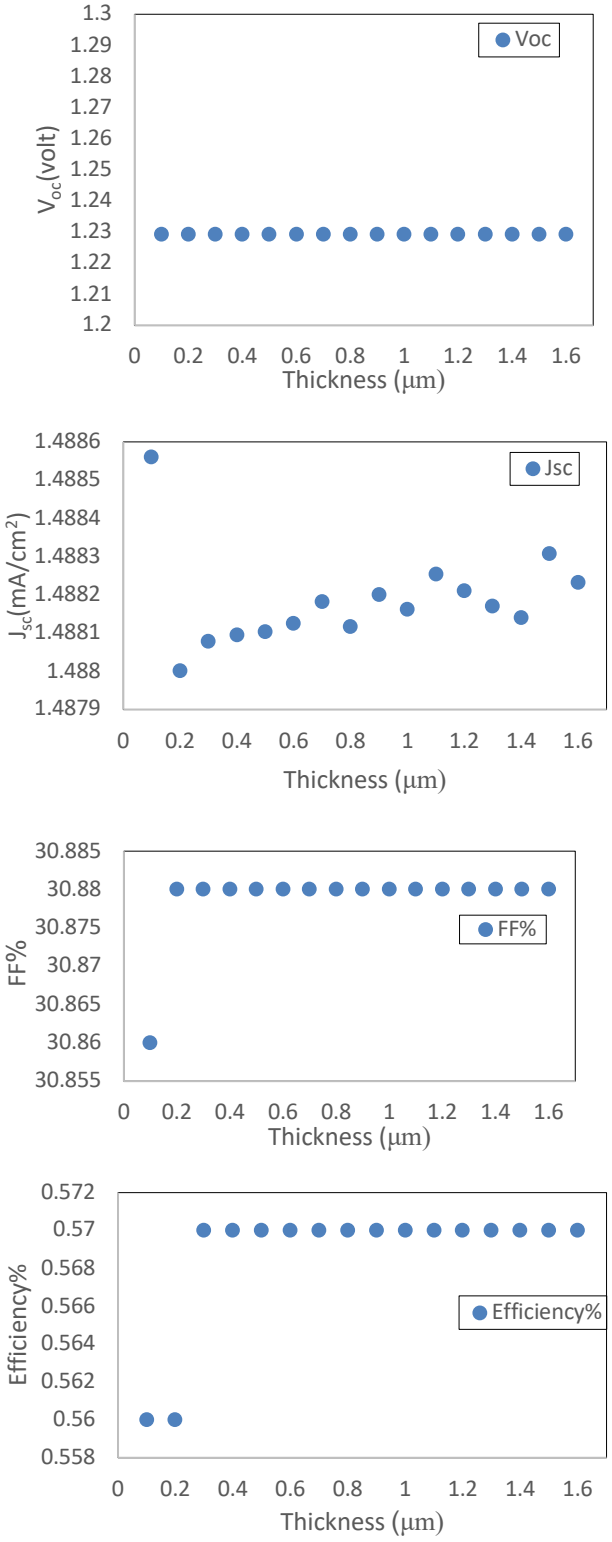


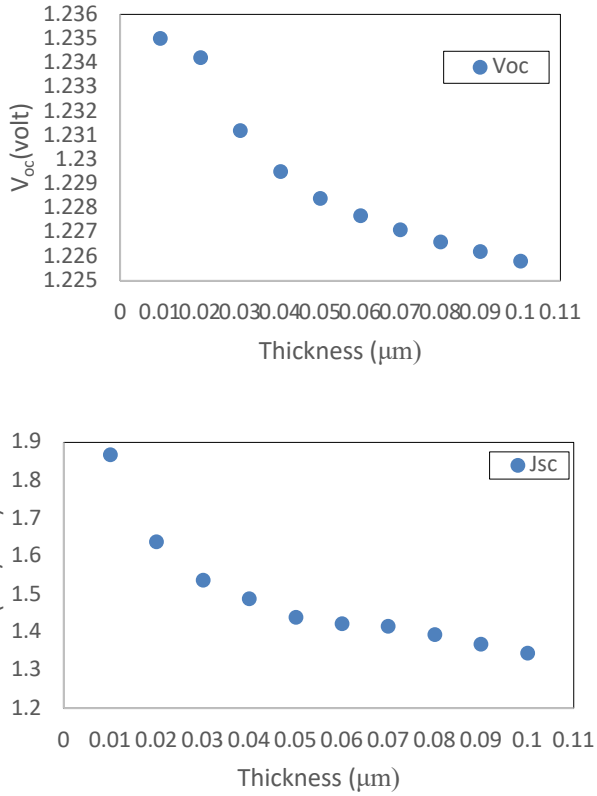
Fig. 5: Photoelectric parameters change by PCBM thickness change.

4.3. Effect of the PCBM (ETL) layer thickness change on solar cells

The value of the thickness of the (PCBM) layer has been changed from (0.01 to 0.1) µm. When the thickness of the (PCBM) layer increases from 0.01 µm to 0.05µm, the PCE exhibit a steady state behavior till the thickness 0.05 where (PCE) reached to 0.57 then declined efficiency gradually to 0.53 at thickness 0.1 µm ,while the Jsc decrease gradually with increase the thickness due to increase the resistivity with thickness, where highest value of Jsc at thickness 0.01µm reached to 1.868658 (mA/cm^2), as well V_{oc} decreases gradually with increase the thickness, afterwards, at increases thickness from 0.06 µm to 0.1µm, decreases PCE, J_{sc}, and V_{oc}, while the FF increase from (24.74) to (32.36) in all interval from thickness (0.01 to 0.1)µm, which can be noticed in Fig 6. Additionally, increasing the PCBM thickness results in the creation of bigger pinholes and an uneven surface, which lowers the J_{sc} and V_{oc} and also decreases the PSC's overall effectiveness. The drawing data are shown in Table five.

Table 5: Change of Thickness for PCBM with device parameters.

Thickness (µm)	V_{oc}(V)	J_{sc}(mA /cm^2)	F.F (%)	η (%)
0.01	1.2350	1.868658	24.74	0.57
0.02	1.2342	1.638597	28.39	0.57
0.03	1.2312	1.537761	29.86	0.57
0.04	1.2295	1.488097	30.88	0.57
0.05	1.2284	1.440060	32.10	0.57
0.06	1.2277	1.423482	32.20	0.56
0.07	1.2271	1.415616	31.95	0.56
0.08	1.2266	1.393949	32.02	0.55
0.09	1.2262	1.369400	32.18	0.54
0.1	1.2258	1.346208	32.36	0.53



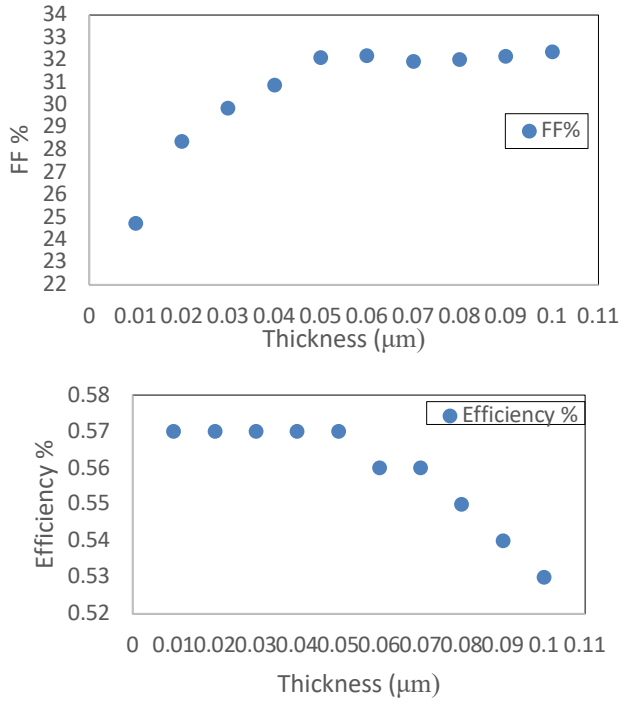


Fig. 6: Photoelectric parameters change by PCBM thickness change**.**

4.4. Effects of the Defect State of the Interface Defect Layer NiO /$C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$/ PCBM

Recombination and generation take place in the absorber layer of the proposed $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$, where the parameters of the defects have a substantial impact on the device's effectiveness. According to Fig 7, the difference of parameters for solar cell, versus the defect density. The proposed defect density values in this simulation range from $10^{13}\ cm^{-3}$ to $10^{21}\ cm^{-3}$, where we note that the defect density value for the absorber layer when increases from $10^{13}\ cm^{-3}$ to $10^{21}\ cm^{-3}$, the efficiency decrease significantly from (35.47 to 0.10) %, as for filling factor also decrease from (74.83 to 27.94)%, while current density of the photovoltaic parameters and open circuit voltage decrease at increasing defect, which indicates that the increasing defects serve as a recombination hub that shorten of carrier lifetime. We get it optimal defect efficiency through results obtained at $10^{13}\ cm^{-3}$, where is the efficiency value 35.47 %, F.F =74.84%, J_{sc} =32.810481 (mA/cm^2) and V_{oc}=1.4444 (Volt).

Table 6: Change of defect for NiO/$C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$/ PCBM with device parameters.

Defect Nt(1/cm^3)	V_{oc}(V)	Jsc (mA/cm^2)	F.F (%)	η (%)
1*10^{13}	1.4444	32.810481	74.83	35.47
1*10^{14}	1.3794	16.181453	59.89	13.37
1*10^{15}	1.3141	4.668733	48.31	2.96
1*10^{16}	1.2729	3.044798	37.52	1.45
1*10^{17}	1.2295	1.488097	30.88	0.57
1*10^{18}	1.1699	0.615897992	27.56	0.20
1*10^{19}	1.0944	0.428778448	26.12	0.12
1*10^{20}	1.0161	0.389453702	26.81	0.11
1*10^{21}	0.9606	0.379571926	27.94	0.10

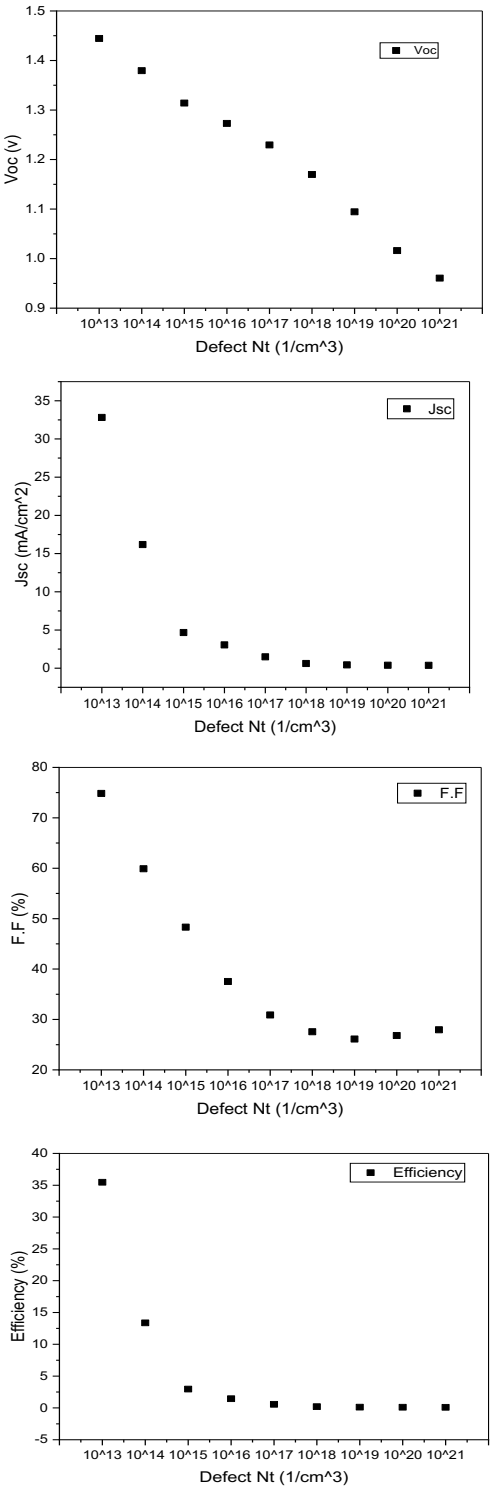


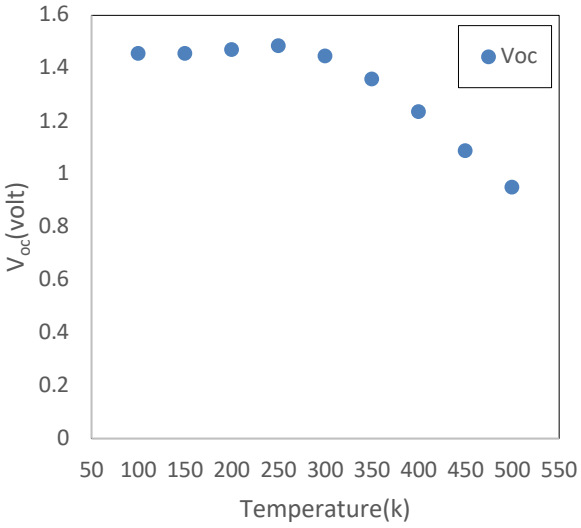
Fig 7: Defect density of the HTM /$C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$ / ETL layer.

4.5. Effect of annealing Temperatures for $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$

In this model we note when the temperature achieved to 300 K, get greatest value of efficiency is 35.47% with J_{sc} = 32.810481 (mA/cm^2), FF = 74.83% and V_{oc} = 1.4449 , therefore the best result at the standard temperature. The temperature of the surrounding environment has a significant impact on productivity. For example, when the temperature rises from 100 K to 350 K, the PCE, FF, and J_{sc} increase due to an increase in the generation of electron-hole pairs in the perovskite materials, while the V_{oc} value decreases from 1.4545 to 1.3584 as shown in Fig 8, then decrease PCE, V_{oc} , FF at increase temperature from 400 k to 500 k. As shown in Fig 8, the open-circuit voltage reduces gradually generally with rising temperatures, and the device performance can be changed with temperature changed because the ability to of controlling recombination, create, and a collecting charge carriers, so the appropriateness temperature for the use of perovskites solar cells with $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$ as PVSC is 300 k.

Table 7: The parameter of the for NiO/$C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$/ PCBM heterojunction solar cells.

Temperature (K)	V_{oc}(V)	J_{sc} (mA/cm^2)	F.F (%)	η (%)
100	1.4545	29.145484	65.78	27.89
150	1.4545	29.145484	65.78	27.89
200	1.4709	30.778628	68.01	30.79
250	1.4836	31.952901	70.26	33.30
300	1.4449	32.810481	74.83	35.47
350	1.3584	33.498903	78.00	35.49
400	1.2359	34.013773	76.84	32.30
450	1.0863	34.362837	76.41	28.52
500	0.9506	34.634793	75.26	24.78



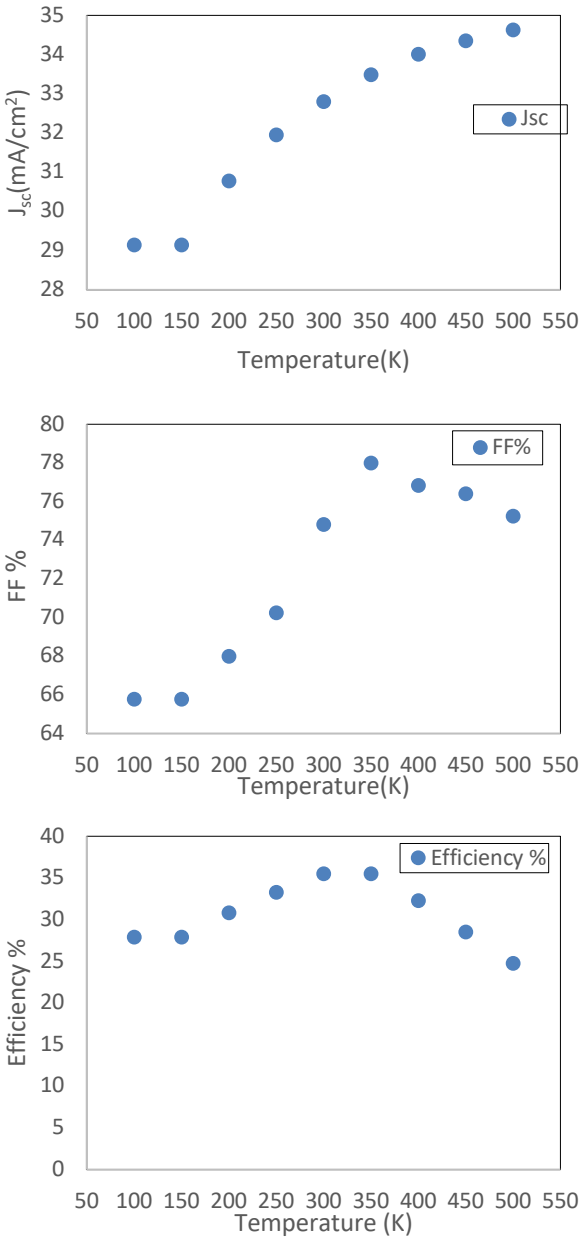


Fig. 8: Solar cell parameters change with temperature used in simulation changes.

4.6. Effect of different back contact material

Fig 9 shows the effect of change back contact on efficiency. Increase work function lead to increase in open-circuit voltage from 0.7280 (volt) to 1.4449 (volt) and also lead to increase in current density from 9.343896 (mA/cm^2) to 32.810481(mA/cm^2), And we note also, perovskite solar cell efficiency increasing with increase the work function where it reaches the value 35.47 % at Pt=5.6 eV, while filling factor increases with increasing the work function then decreases at Ir=5.25 eV. Pt is one of the prospective rear contact materials that can develop perovskite solar cell performance, according to the simulation results.

Table 8: The effect of metal contact change on the efficiency of the solar cell used in this simulation.

Efficiency %	F.F (%)	J_{sc}(mA /cm^2)	V_{oc}(V)	Work Function (ev)	Metals
4.62	67.96	9.343896	0.7280	4.26	Al
5.95	71.17	9.422077	0.8880	4.42	Sn
7.47	73.63	9.495905	1.0680	4.6	Cu
8.32	74.71	9.533903	1.1680	4.7	Ag
9.18	75.61	9.571443	1.2679	4.8	Fe
14.43	76.81	13.230065	1.4197	5.1	Au
17.94	76.43	16.464692	1.4257	5.15	Ni
28.48	75.36	26.264640	1.4388	5.25	Ir
35.47	74.83	32.810481	1.4449	5.6	Pt

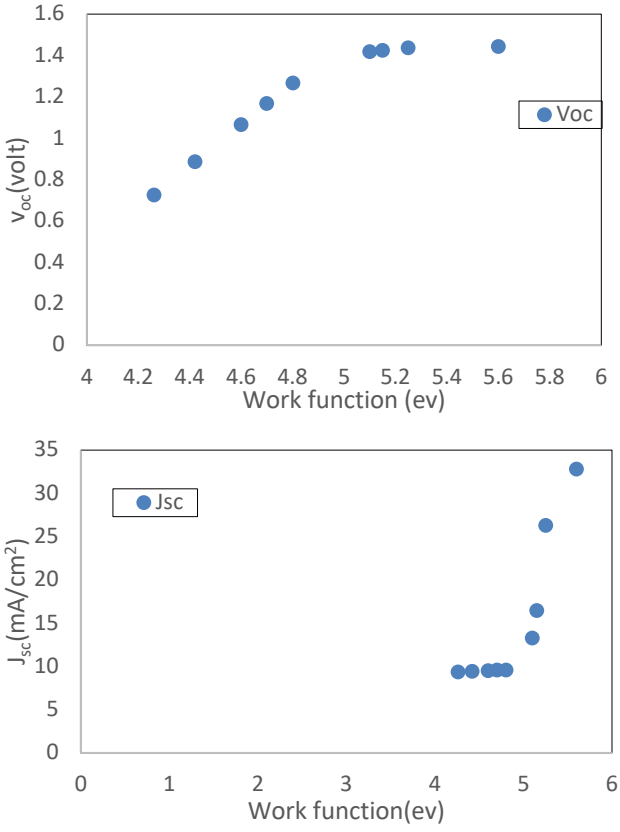


Fig. 9: Chang photovoltaic parameters V_{oc}, J_{sc} , FF and η% with metal function change.

5. Conclusions

In this work, has been analyzed perovskite solar cells with SCAPS-1D simulation software. The thickness was changed from 0.1µm to 0.7µm for NiO as the ETL, from 0.01µm to 0.1µm for PCBM and thickness for $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$ from 0.1µm to 1.6µm, a device's performance is good at 0.3 µm thickness, therefore the ideal efficiency at 0.03µm thickness is 0.57%. Controlling in the defects lead for high efficiency of solar cells, the minimum defect density for the good efficiency was $1*10^{13}$ $N_t(1/cm^3)$ where top efficiency of the structure NiO/ $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$ /PCBM device which reached to 35.47%. After that the temperature change was studied from 100K 500K to observe the changes in the photovoltaic parameters (efficiency, voltage, filling factor and current density) of the device. Then, we changed work functions, which improved efficiency by 35.47% at 5.6ev. The simulation shows that the $C_{s_2}AgBi_{0.75}Sb_{0.25}Br_6$, attain a PCE of 35.47%.

References

[1] M. A. Reyes-Belmonte, "Quo vadis solar energy research?," *Appl. Sci.*, vol. 11, no. 7, 2021.

[2] O. D. Miller and E. Yablonovitch, "Photon extraction: the key physics for approaching solar

cell efficiency limits," *Act. Photonic Mater. V*, vol. 8808, no. September 2013, p. 880807, 2013.

[3] M. Burgelman, P. Nollet, S. Degrave, Modelling polycrystalline semiconductor solar cells, Thin Solid Films, 361 (2000) 527-532.

[4] K. Decock, S. Khelifi, M. Burgelman, Modelling multivalent defects in thin film solar cells, Thin Solid Films, 519 (2011) 7481-7484.

[5] M. Burgelman, J. Marlein, Analysis of graded band gap solar cells with SCAPS, Proceedings of the 23rd European Photovoltaic Solar Energy Conference, Valencia, 2008, pp. 2151-2155.

[6] J. Verschraegen, M. Burgelman, Numerical modeling of intra-band tunneling for heterojunction solar cells in SCAPS, Thin Solid Films, 515 (2007) 6276-6279.

[7] S. Degrave, M. Burgelman, P. Nollet, Modelling of polycrystalline thin film solar cells : new features in SCAPS version 2.3, Proceedings of the 3rd World Conference on Photovoltaic Energy Conversion, Osaka, 2003, pp. 487-490.

[8] A. Niemegeers, M. Burgelman, Numerical modelling of ac-characteristics of CdTe and CIS solar cells, Proceedings of the 25th IEEE Photovoltaic Specialists Conference, Washington DC, 1996, pp. 901-904.

[9] Niemegeers A, Burgelman M, Decock K. SCAPS Manual. University of Gent. 2014.

[10] Minemoto T, Murata M. Device modeling of perovskite solar cells based on structur-al similarity with thin film inorganic semiconductor solar cells. Journal of Applied Physics. 2014;116: 5, 054505.

[11] D. E. Tareq, S. M. Abdul Almohsin, and H. H. Waried, "High Efficiency (41.85) of Br Perovskites base solar cells with ZnO and TiO2 comparable study as ETM," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 928, no. 7, 2020.

[12] F. Anwar, R. Mahbub, S. S. Satter, and S. M. Ullah, "Effect of Different HTM Layers and Electrical Parameters on ZnO Nanorod-Based Lead-Free Perovskite Solar Cell for High-Efficiency Performance," vol. 2017, 2017.

[13] S. Cell and C. Efficiency, "Device Optimization of a Lead-Free Perovskite/Silicon Tandem Solar Cell with 24.4% Power Conversion Efficiency," 2021.

[14] Eperon, G.E.; Leijtens, T.; Bush, K.A. Perovskite-perovskite tandem photovoltaics with optimized band gaps. Science 2016.

[15] Dong, H.; Pang, S.; Zhang, Y.; Chen, D.; Zhu, W.; Xi, H.; Chang, J.; Zhang, J.; Zhang, C.; Hao, J. Improving Electron Extraction Ability and Device Stability of Perovskite Solar Cells Using a Compatible PCBM/AZO Electron Transporting Bilayer. Nanomater. Multidiscip. Digit. Publ. Inst. 2018, 8, 720.

[16] Gao, H.; Qin, C.; Zhang, H.; Wu, S. Theoretical Characterization of a Typical Hole/Exciton-Blocking Material Bathocuproine and Its Analogues. J. Phys. Chem. A 2008.

[17] Kim, K.; Lee, J.W.; Lee, S.H.; Lee, Y.B.; Cho, E.H.; Noh, H.-S.; Jo, S.G.; Joo, J. Nanoscale optical and photoresponsive electrical properties of P3HT and PCBM composite nanowires. Org. Electron. 2011, 12, 1695–1700.

[18] Minbashi, M.; Ghobadi, A.; Ehsani, M.H.; Rezagholipour Dizaji, H.; Memarian, N. Simulation of high efficiency SnS-based solar cells with SCAPS. Sol. Energy. 2018, 176, 520–525.

[19] Hutchby, J.A.; Markunas, R.J.; Bedair, S.M. Material Aspects of the Fabrication of Multijunction Solar Cells. Photovoltaics. In International Society for Optics and Photonics; 1985; p. 40. Available online: https://www.spiedigitallibrary.org/conferenceproceedings-of-spie/0543/0000/Material-Aspects-Of-The-Fabrication-Of-Multijunction-Solar-Cells/10.1117/12.948195. short (accessed on 5 April 2021).

[20] NMendil, D.M.; Berkai, Z. Study of PEDOT: PSS and BCP Thicknesses Effect on SubPc/C60 Organic Solar Cell Efficiency. Available online: https://www.spiedigitallibrary.org/conference-proceedings-of-spie/9567/1/Study-of-PEDOT--PSS-and-BCPthicknesses-effect-on/10.1117/12.2188651. short ? SSO=1 (accessed on 28 March 2021).