

Cs₂TiBr Solar Cell Performance Enhancement by Different Absorber Layer Thickness

Saleh K. Meza'al, and N. K. Hassan*

Department of physics, College of Education For pure sciences, Tikrit University, Tikrit, Iraq



ARTICLE INFO

Received: 22/2/2021

Accepted: 18/4/2021

Available online: 1/6/2021

DOI:

<http://dx.doi.org/10.37652/JUAPS.2021.15.1.6>

Keywords:

SCAPS-1D.

Cs₂TiBr₆.

transformation efficiency > enhancement.

First time simulated.

ABSTRACT

Cs₂TiBr₆ is a promising material as an Absorber layer of Solar cell. Further studies showed that this compound is more stable, and possess an appropriate electrical and optical properties. The compound of (FTO/V₂O₅/Cs₂TiBr₆/CdTe) is simulated for the first time in this work by using the Solar Cell Capacitance Simulator (SCAPS-1D) program and the obtained transformation efficiency (η) was (10.09) with (0.5 μ m) of (Cs₂TiBr₆) thickness. The effect of (Cs₂TiBr₆) thickness was studied in this paper used different variations of absorber layer thickness (0.5 – 4.0 μ m). Solar cell enhanced by absorber layer thickness showed (18.17 mA/cm², 0.924V, and 86.58%) (J_{sc} , V_{oc} , FF) respectively which led to increase of transformation efficiency (η) from (10.09 % to 14.55%).

1. INTRODUCTION

Perovskite solar cell is the new promising low cost source to achieve high transformation efficiency which it is the most important issue in solar cells performance, optimized band gap, increases in short circuit current, open circuit voltage and fill factor by engineering the absorber layer.

A new family of halide perovskite based on Ti(IV), especially Cs₂TiBr₆, was reported to be a suitable compound for solar cell applications[1]. Cs₂TiBr₆ can sustain high thermal stress under constant irradiation and in humid environments due to the stable oxidation state of Ti. The material shows a combination of tetravalent cations and vacancies, creating 'vacancy-ordered' double perovskite structure with tunable bandgap. Such excellent properties make it an ideal candidate for Pb-free PSCs[2].

perovskite solar cells have also been developed, sequentially. As a new kind of photovoltaic semiconductor, organometal halide perovskite materials can be prepared by various methods[3], with appropriate direct band gap, high absorption coefficient[4], excellent carrier transport properties[5], good tolerance of defects[6], small exciton binding energy[7] as well as tunable composition and structure [8]. SCAPS-1D used to simulated inverted solar cell (FTO/V₂O₅/Cs₂TiBr₆/CdTe) and we obtain a transformation efficiency increasing from (10.09% to 14.55 %). This work can provide some important guidance for device design and optimization from the considerations of both theory and experiment.

2. NUMERICAL ANALYSES

The performance of this solar cell depends on (FF, Voc and Jsc) because these factors are determined by the (J-V) property curve. The efficiency (η) determined by these three factors.

2.1. Short Circuit Current

The short circuit current is the maximum current generated by the solar cell when the solar cell ends are in contact with one another (ie, short circuit). The solution of Jsc equation can be obtained from the net current density J-V Solar system and from the following equation[9, 10]

$$J(V) = J_{sc} - J_{dark}(V) \dots \dots (1)$$

Where: (J_{dark}) the density of the dark stream is given by the following equation:

$$J_{dark}(V) = J_0(e^{qv/k_B T} - 1) \dots \dots (2)$$

The equation of the bright solar cell giving by compensating equation (2) in equation (1):

$$J(V) = J_{sc} - J_0(e^{qv/k_B T} - 1) \dots \dots (3)$$

The short circuit current is given by the following equation:

$$J_{sc}(V) = J(v) + J_0(e^{qv/k_B T} - 1) \dots \dots (4)$$

V: is the voltage across the junction, T: is the absolute temperature. J_0 : The density of the saturation current is during darkness.

*Corresponding author at: Department of physics, of Education For pure sciences, Tikrit University, Tikrit, Iraq E-mail address : nadimkh4@tu.edu.iq

2.2. Open Circuit Voltage

V_{oc} : Is the voltage in which no current flows through the outer circle when the solar cell ends are not connected to each other and can be given by the following equation[11].

$$V_{oc} = \frac{k_B T}{q} \ln\left(\frac{J_{ph}}{J_0} + 1\right) \dots \dots \dots (5)$$

From the above condition, open circuit voltage (V_{oc}) relies upon the light produced (I_L) furthermore, immersion current (I_0). I_0 relies upon recombination in the solar cell. Along these lines, V_{oc} is a proportion of the measure of recombination in a sun based cell.

2.3. Efficiency and Fill Factor

The ratio of output power to input power that is the efficiency of and can be defined in regime (0 to V_{oc}) in which solar cell will deliver power. The output power density is given by equation (6).

$$P_{max} = J_{max} V_{max} \dots \dots \dots (6)$$

Maximum of the (P_{max}) reached at cell max power point shown in Figure 2.17. So, efficiency of solar cell is defined by equation (7) $\eta = J_{max} V_{max} / P_s \dots \dots \dots (7)$

P_s : sunlight incident power.

We can rearranged Equation 8 to find fill factor (FF) that is the solar cell performance quality measurement according to the maximum power delivered by a solar cell to the theoretical power of a solar cell or by interpreted as the rectangular areas ratio that shown in figure 2.17 for maximum power point and (MPP) and theoretical maximum power P_{max} .

$$FF = J_{max} V_{max} / J_{oc} V_{oc} \dots \dots \dots (8)$$

From equation (8) and (9) the efficiency equation can have rewritten as: $\eta = J_{oc} V_{oc} FF / P_s \dots \dots \dots (9)$

2.4. Quantum efficiency Q_E

Defined as percentage between numbers of electrons that generated to the number of photons that absorbed per unit wavelength that fall on the surface of the device.

$$Q_E = \frac{(I_{ph}/q)}{(P_{in}/hv)} \dots \dots \dots (10)$$

(I_{ph}/q) : Number of carries generated.

(P_{in}/hv) : Number of dropped photons.

And quantitative efficiency from equation:

$$Q_E = R_\lambda \frac{hc}{q\lambda} \dots \dots \dots (11)$$

(hc/q) : constant that equal to (1.24) so equation (11)

can be written: $Q_E = 1.24 (R_\lambda/\lambda) \dots \dots \dots (12)$

R_λ : Response in units (A/W), λ : wavelength (nm)

Table (1) the parameter used in simulation

| Layers | CdTe | Cs ₂ TiBr ₆ | n-V ₂ O ₆ | FTO |
|--|----------|-----------------------------------|---------------------------------|----------|
| thickness (μm) | 0.100 | 0.5-4.0 | 0.300 | 0.300 |
| band gab (eV) | 1.5 | 1.8 | 2.2 | 3.5 |
| electron affinity (eV) | 4.28 | 4 | 4 | 4 |
| Dielectric permittivity | 10.3 | 10.00 | 10 | 9 |
| CB effective density of state (1/cm ³) | 2.50E+19 | 6.00E+20 | 2.50E+18 | 2.20E+18 |
| VB effective density of state (1/cm ³) | 1.80E+19 | 2.14E+20 | 1.80E+18 | 1.80E+19 |
| electron thermal velocity (cm/s) | 1.00E+07 | 1.00E+07 | 1.00E+07 | 1.00E+07 |
| hole thermal velocity (cm/s) | 1.00E+07 | 1.00E+07 | 1.00E+07 | 1.00E+07 |
| electron mobility (cm ² /Vs) | 4.50E+02 | 4.4 | 3.20E+02 | 2.00E+01 |
| hole mobility (cm ² /Vs) | 4.00E+01 | 2.5 | 4.00E+01 | 1.00E+01 |
| ND (1/cm ³) | 0.00E+00 | 0.00E+00 | 1.00E+18 | 1.00E+19 |
| NA (1/cm ³) | 1.00E+15 | 1.00E+17 | 0.00E+00 | 0.00E+00 |
| References | [12] | [13] | [14] | [15] |

3. RESULT and DISCUSSION

Enhancement of (FTO/V₂O₅/Cs₂TiBr₆/CdTe) solar cell with different absorber layer thickness (0.5 – 4.0 μm) shown in fig (1) that the (I-V) curve characteristics at the best thickness of absorption layer.

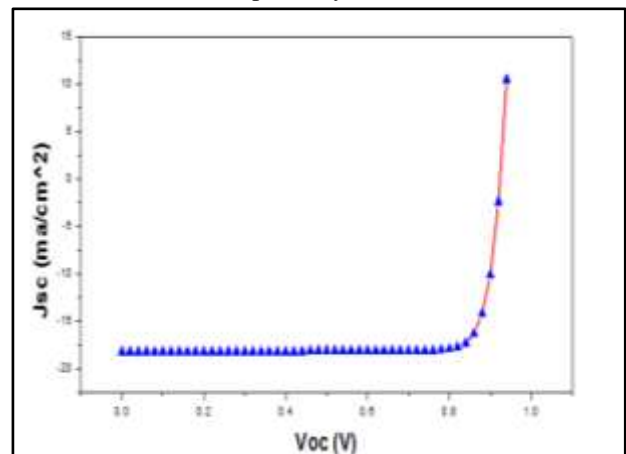


Fig .1: I-V Characteristics at (4 μm)

Fig (1) show that (I-V) curve will increase due to thickness so that mean short circuit current (J_{sc}) increase from (13.821 mA/cm²) to (18.176 mA/cm²) fig (2) because material thickness increase the contribution to generation of electron – gab pairs due to absorbing more photons[9, 11].

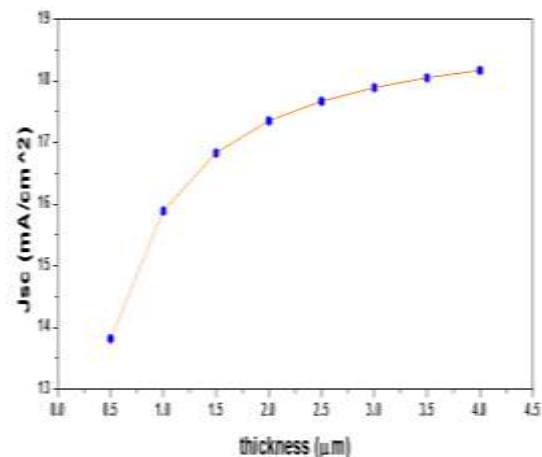


Fig .2: Effect of thickness of absorber layer on (J_{sc})

Open circuit current increased too from (0.43 V) to (0.53 V) as shown in fig (3).

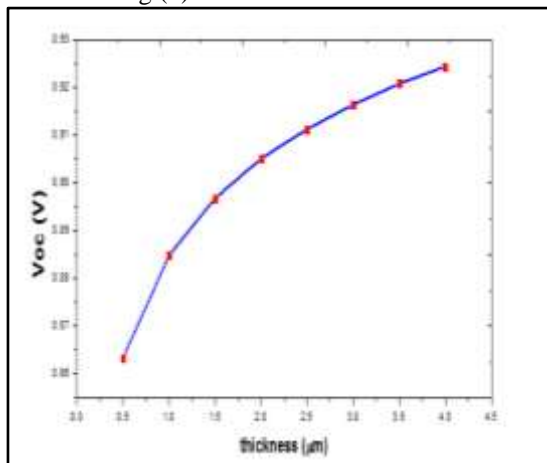


Fig. 3: Effect of thickness of absorber layer on (Voc)

The increase of thickness and interface which generates a constraint that work to capturing electron and reducing current depletion environment that negatively affects to the filling factor as shown in fig (4) after increased it will be decreased and because of the re union in the interface that will capturing electrons and reducing current and that lead to let filling factor decreased. Filling factor affected by the resistivity that respectively increased because high thickness[16].

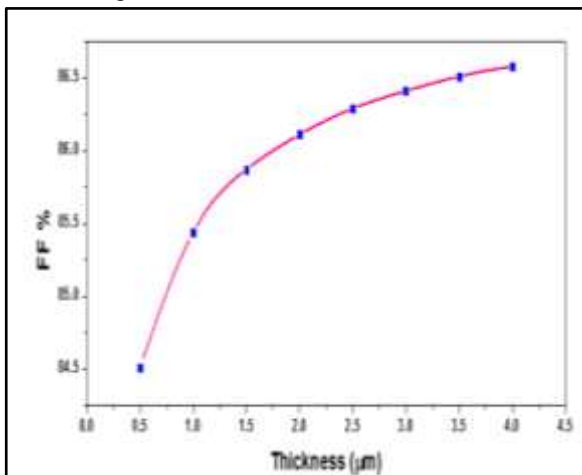


Fig. 4: Effect of thickness of absorber layer on (FF %)

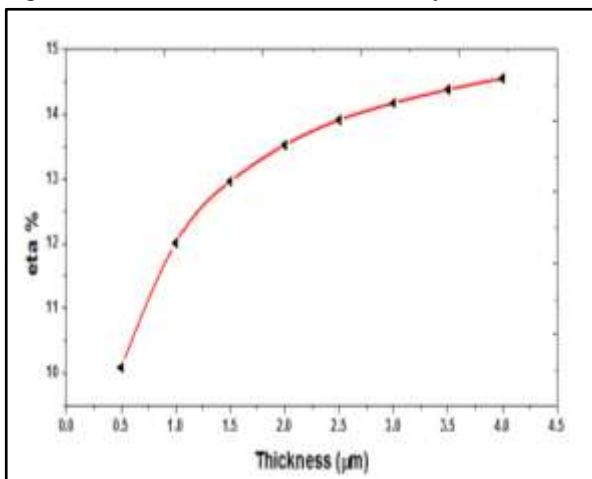


Fig. 5: The effect of thickness on the efficiency

Fig (6) The effect of thickness change on quantitative efficiency, which is defined as: the ratio between the number of carriers collected by the cell to the number of photons that fall on it, was studied through which the efficiency of the outside and entering the cell was determined and the figure (6) shows the extent of the change in quantitative efficiency from changing thickness to the ideal thickness (3.5)μm, and we note from the figure that the highest absorption of the cargo carriers is at long wave lengths[17].

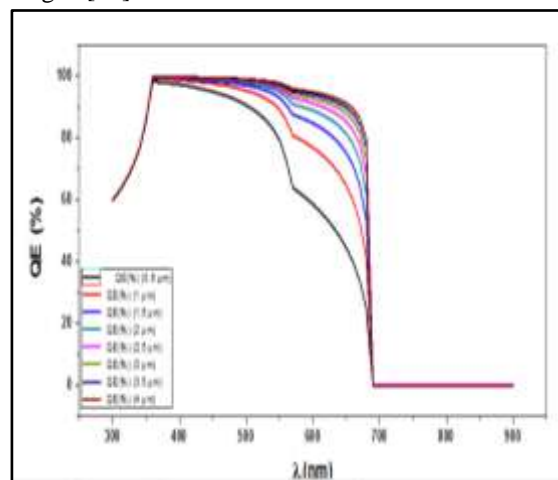


Fig. 6: Thickness effect on the quantitative efficiency

4. CONCLUSIONS

The studying software in the simulation from deferent studies show that the simulation is very near to the ideal of manufacturing parameter of deferent solar cell.

Absorbing ideal thickness (4μm) showed increasing in the properties of solar cell so short circuit current (Jsc) increased from (13.82 mA/cm²) to (18.17 mA/cm²), Open circuit current increased too from (0.84 V) to (0.92 V), Fill factor (FF) also increased from (84.51%) t0 (86.58%) and the efficiency (η) increased from (10.09%) to (14.55%).

REFERENCES

- [1] Chen, M., Ju, M. G., Carl, A. D., Zong, Y., Grimm, R. L., Gu, J., and Pature, N. P. (2018). Cesium titanium (IV) bromide thin films based stable lead-free perovskite solar cells. *Joule*, 2(3), 558-570.
- [2] Chakraborty, K., Choudhury, M. G., & Paul, S. (2019). Numerical study of Cs₂TiX₆ (X= Br⁻, I⁻, F⁻ and Cl⁻) based perovskite solar cell using SCAPS-1D device simulation. *Solar Energy*, 194, 886-892..
- [3] Liu, M., Johnston, M. B., and Snaith, H. J. (2013). Efficient planar heterojunction perovskite solar cells by vapour deposition. *Nature*, 501(7467), 395-398.
- [4] De Wolf, S., Holovsky, J., Moon, S. J., Löper, P., Niesen, B., Ledinsky, M., and Ballif, C. (2014). Organometallic halide perovskites: sharp optical absorption edge and its relation to photovoltaic performance. *The journal of physical chemistry letters*, 5(6), 1035-1039.
- [5] Stranks, S. D., Eperon, G. E., Grancini, G., Menelaou, C., Alcocer, M. J., Leijtens, T., and Snaith, H. J. (2013).

- Electron-hole diffusion lengths exceeding 1 micrometer in an organometal trihalide perovskite absorber. *Science*, 342(6156), 341-344.
- [6] Huang, Y., Sun, Q. D., Xu, W., He, Y., and Yin, W. J. (2017). Halide perovskite materials for solar cells: a theoretical review. *Acta Physico-Chimica Sinica*, 33(9), 1730-1751.
- [7] Hirasawa, M., Ishihara, T., Goto, T., Uchida, K., and Miura, N. (1994). Magnetoabsorption of the lowest exciton in perovskite-type compound (CH₃NH₃)PbI₃. *Physica B: Condensed Matter*, 201, 427-430.
- [8] Zhao, Y., and Zhu, K. (2016). Organic-inorganic hybrid lead halide perovskites for optoelectronic and electronic applications. *Chemical Society Reviews*, 45(3), 655-689.
- [9] Ahemad, M., and Kibret, M. (2014). Mechanisms and applications of plant growth promoting rhizobacteria: current perspective. *Journal of King saud University-science*, 26(1), 1-20.
- [10] A Amu, T. L. (2014). *Performance optimization of tin halide perovskite solar cells via numerical simulation* (Doctoral dissertation).
- [11] Vardhanan, R.V.Z., L., and Gao, Z, *Schottky and heterojunction diodes based on poly (3-octylthiophene) and poly (3-methylthiophene) films of high tensile strength* (1999). *Thin Solid Films*,. 350(1-2):283-288.
- [12] Min Chen, M.-G.J.,(2018) *Cesium Titanium(IV) Bromide Thin Films Based Stable Lead-free Perovskite Solar Cells*. Chen et al., *Joule*, 2, 558–570.
- [13] Yousaf Hameed Khattak, , Faisal Baiga,, Shafi Ullah, Bernabé María, Saira Beg, Hanif Ullah, (2018), *Numerical modeling baseline for high efficiency (Cu₂FeSnS₄) CFTS based thin film kesterite solar cell*. *Optik*, 2018. 164 547–555.
- [14] Chen, Z. Y., and Yang, J. L. (2006). Theoretical study on geometrical and electronic properties of anionic and neutral V₂O₆ clusters. *Chinese Journal of Chemical Physics*, 19(5), 391.
- [15] Ahmed, S., Jannat, F., Khan, M. A. K., & Alim, M. A. (2021). Numerical development of eco-friendly Cs₂TiBr₆ based perovskite solar cell with all-inorganic charge transport materials via SCAPS-1D. *Optik*, 225, 165765.
- [16] Pronko, P. P., VanRompay, P. A., Horvath, C., Loesel, F., Juhasz, T., Liu, X., & Mourou, G. (1998). Avalanche ionization and dielectric breakdown in silicon with ultrafast laser pulses. *Physical Review B*, 58(5), 2387.
- [17] Anwar, F., Mahbub, R., Satter, S. S., & Ullah, S. M. (2017). Effect of different HTM layers and electrical parameters on ZnO nanorod-based lead-free perovskite solar cell for high-efficiency performance. *International Journal of Photoenergy*, 2017.

تحسين أداء الخلايا الشمسية Cs₂TiBr₆ من خلال مختلف سمك طبقة امتصاص

صالح مزعل ونديم خالد حسن

جامعة تكريت، كلية التربية للعلوم الصرفة، تكريت ، العراق

الخلاصة

Cs₂TiBr₆ تعد مادة واعدة كطبقة امتصاص للخلايا الشمسية. اظهرت الدراسة ان هذا المركب أكثر ثباتا لما له من خصائص كهربائية وبصرية مناسبة. استخدم لأول مرة برنامج (SCAPS-1D) برنامج محاكاة سعة الخلايا الشمسية (FTO/V₂O₅/Cs₂TiBr₆/CdTe)، بينت الدراسة ان كفاءة التحويل (η) كانت (10.09) مع سمك (0.5 ميكرومتر). اظهر تأثير السمك للطبقة الامتصاص (Cs₂TiBr₆) ضمن المدى (0.5 – 4.0 μm). اظهرت الخلايا الشمسية المعززة بسمك الطبقة الماصة (18.17 مللي أمبير / سم²، 0.924 فولت، 86.58%) (FF ، Voc ، Jsc) على التوالي مما أدى إلى زيادة كفاءة التحويل (η) من (10.09)٪ إلى (14.55)٪.