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Original Article

Effect of Time on the Optical and Structural Properties of Tin Oxide Thin Films as an Electron Transport Layer for Perovskite Solar Cell

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Abstract *- The performance of a perovskite solar cell is significantly influenced by the electron transport layer. It lessens the recombination of free charge carriers (holes and electrons) with their equivalents on interface imperfections. In this study, we developed tin oxide films utilizing chemical bath deposition as an electron transport layer for perovskite solar cells. Ammonia served as a complexing agent in the deposition bath, which also contained 0.2M of tin chloride dehydrate ($Sncl_4. 2H_2O$) and 0.1M of KOH. The time ranged from one to three hours at a constant temperature of 70°C and with continual stirring. Using a UV-spectrophotometer, it was possible to measure how time affected the optical properties of the deposited thin films, such as their absorbance and transmittance at normal incidence of light in the 190–1100nm wavelength range. The outcome showed a large band gap and high transmittance. SnO_2-ETL's chemical bath deposition method provides homogeneous thin film coverage and also makes it a great, affordable choice for manufacturing perovskite solar cells on a big scale.*

Keywords *- Electron transport layer, Chemical bath deposition, Perovskite solar cell.*

1. Introduction

Solar energy is a reliable substitute for fossil fuels in the search for a clean and renewable energy source. Solar energy from the sun is captured using a solar cell. A solar cell captures photons of incident light and transforms the light's energy into electrical energy either directly using the photovoltaic (PV) effect or indirectly by converting it to heat [1-2]. Perovskite solar cells showed the most potential for an efficient and affordable solar cell among the several solar cells that are currently available. Due to their exceptional qualities, including a tunable band gap, high visible light absorption, low reflectivity, low recombination rate, high ductility, superior charge-carrier mobility, and low excitation binding, perovskite materials have recently attracted significant interest from the scientific community [3]. Due to their innovative characteristics in the field of electronics, such as light-emitting diodes, photovoltaics, and solar-to-fuel energy conversion, the metal halide perovskite series is also widely employed. Perovskite solar cells, such as those with the formula ABX_3 (A = CH_3NH_3, $HC(NH_2)_2$ or Cs, B = Pb, Sn, or Ge, and X = I, Cl or Br), have received a lot of interest recently due to their simple construction and high conversion efficiency. The National Renewable Energy Laboratory most recently certified a conversion efficiency above 22% [4-6].

However, carefully selecting contacts is necessary if PSC devices perform to their maximum capacity. Therefore, recent efforts in this area have concentrated on creating and synthesising appropriate electron transport layers (ETL) and hole transport layers (HTL). Because they limit interfacial recombination, which has a direct impact on open-circuit voltage (VOC) and fills factor (FF), these selective layers are essential for producing high-efficiency solar cells [7].

The electron transport layer's (ETL's) primary job is to create an electron-selective contact with the perovskite light-absorbing layer in order to increase the extraction efficiency of photo-generated electrons and successfully block the hole from moving to the counter electrode to improve the carrier separation effect and minimize recombination [8]. The efficiency of perovskite solar cells is influenced by ETL characteristics, including charge mobility, energy level alignment, trap states, interface, and surface shape [9]. TiO_2 has often been employed as the ETL material for organic and inorganic PSCs up until this point. TiO_2 has certain limitations as a reliable and effective ETL for PSCs, though. TiO_2 has a slightly higher conduction band minimum (CBM) than $MAPbI_3$, which makes it more challenging to extract electrons from ETL [10]. TiO_2 decomposes over a lengthy period when exposed to ultraviolet (UV), making it unsuitable for commercializing PSCs. Complex device fabrication is hampered by the need to fabricate TiO_2 films, often at high temperatures [24]. Device performance harms by defect trap states, such as oxygen vacancy in TiO_2, which raise non-radiative loss [12]. Another popular ETL material is ZnO, which has a large band gap and strong electron

mobility. However, even when exposed to moderate acids and bases, ZnO lacks chemical stability, which is a significant downside [13].

Tin oxide (SnO_2) is a promising alternative ETL material that recently gained popularity. SnO_2 has a wider bandgap, better optical transmittance, and higher conductivity when compared to TiO2 and ZnO. SnO_2 offers the option of low-temperature processing, in contrast to the most popular ETL material, TiO_2. According to reports, SnO_2 has electron mobility up to 1.28 103 cm^2 V1 s1, which is two orders of magnitude more than TiO2 [14]. Additionally, SnO_2 greater bandgap (above 3.6 vs 3.2 eV) results in a lower short-circuit current loss. Finally, due to the decreased photocatalytic activity, PSCs using SnO_2 ETLs are more stable than TiO_2-based devices under UV irradiation [15]. The tremendous potential of SnO_2 for use as an ETL in several types of PSCs, including flexible or Si/perovskite tandem solar cells, is a result of all these features.

SnO_2 Beyond these prehistoric methods, scalable approaches to depositing SnO_2 can be investigated. One such method is chemical bath deposition, which has proven to be quite effective for high-volume and low-cost applications. has been deposited using various methods as an ETL for perovskite solar cells. SnO2 nanoparticles and SnO2 planar films can be deposited using the more popular spin-coating methods and more useful industrial methods, including electrochemical deposition technique [17-23], sputtering, thermal evaporation, chemical vapor deposition, and plasma-enhanced chemical vapor deposition (CVD). Despite the widespread usage of some of these deposition techniques in current commercial processes, they still have a number of evident drawbacks, such as difficult vacuum systems and low deposition rates, which raise capital and operating costs [16]. Scalable strategies for depositing SnO_2 can be researched in addition to these ancient techniques. Chemical bath deposition is a technique that has shown to be quite efficient for high-volume and low-cost applications. Scalable strategies for depositing SnO_2 can be researched in addition to these ancient techniques. Chemical bath deposition is one such technique that has shown to be quite efficient for high-volume and low-cost applications.

2. Materials and Method

Detergent water, deionized water, and IPA were used to clean the substrates for ten minutes each. The air was then allowed to dry each substrate. Ammonia, potassium hydroxide, and tin chloride dihydrate are the reactants employed in the reaction. However, in this experiment, 0.1 moles of KOH and 0.2 moles of SnCl4 $2H_2O$ were dissolved in 100 and 200 ml, respectively, of pure water. The solution growth technique's experimental setup is affordable, convenient, and easy. The glass substrate is positioned in the center of the chemical bath and submerged vertically. Figure 1 illustrates the setup's schematic diagram.

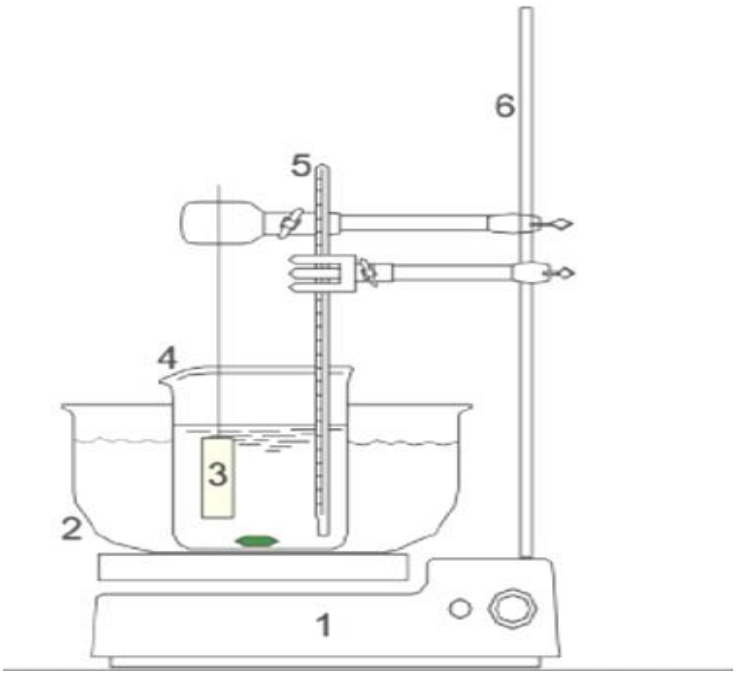

Fig. 1 Experimental setup of chemical bath deposition technique [10] (Yi-Cheng *et al.*, 2014)

A magnetic stirrer, a beaker, a glass substrate, a beaker containing the solution, a thermometer, and a clamp stand are shown in Figure 1 as the experimental setup for the chemical bath deposition process.

A magnetic stirrer was used to stir 0.1M of KOH continuously for 5 minutes after it had been dissolved in 100 ml of distilled water. Additionally, 200 ml of $SnCl_4.2H_2O$ were dissolved in 0.2 mol and agitated for 10 min. The precursor solution was created by combining KOH and $SnCl_4$. $2H_2O$ in a 1:2 ratio, with drops of ammonia added to correct the pH ETL was deposited for a range of times (from 60 to 180 minutes) while maintaining a steady temperature and pH. For deposition to take place, the precursor solution-containing beaker was set up on the magnetic stirrer and constantly swirled at a fixed pH and temperature

3. Results and Discussion

3.1. Optical Studies

On a glass substrate, SnO_2 thin films were successfully formed over a range of deposition times as an electron transport layer for perovskite solar cells. With the aid of a UV-Vis spectrophotometer, the films were examined for optical research, and it was discovered that they were remarkably transparent. The optical transmittance spectra in the visible light spectrum (300 nm–800 nm) for samples deposited at various times are shown in Fig. 2. The transmittance of each SnO_2-ETL film improved as the spectrum advanced, i.e., it improves as the wavelength increases in the visible range. The lowest transmittance was found in films deposited at 150 minutes, while the highest transmittance was found in films placed at 120 minutes, at about 70%. SnO_2 is a useful material for an electron transport layer in a perovskite solar cell because of its high transmittance in the visible region, which allows photons to travel through readily and be absorbed by a perovskite absorber [12]. The lowest transmittance was found in films deposited at 150 minutes, while the highest transmittance was found in films placed at 120 minutes, at about 70%. SnO_2 is a useful material for an electron transport layer in a perovskite solar cell because of its high transmittance in the visible region, which allows photons to travel through readily and be absorbed by a perovskite absorber [13]. The fluctuation of optical conductivity with photon energy for various time periods is shown in Figure 3. All films' optical conductivity is lowest in the low-energy range and slowly rises with photon energy in the visible range. For the films, the highest optical conductivity was attained between photon energies of 3.8 eV and 4 eV, indicating that the least disorder in the crystal structure is achieved in this energy range. Thin SnO_2 films can be used as transparent contacts in PV cells [12-13].

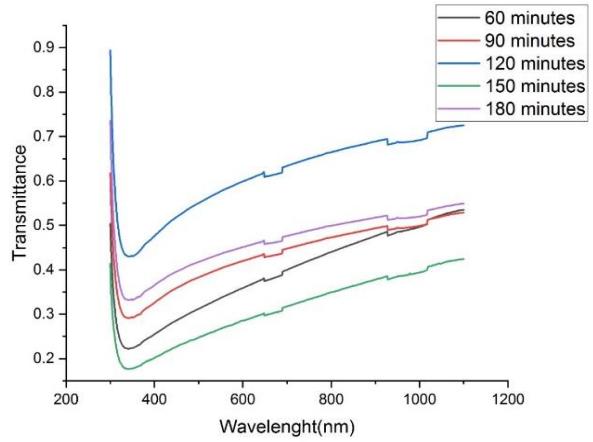

Fig. 2 Transmission spectra of SnO_2-ETL films deposited at different time intervals

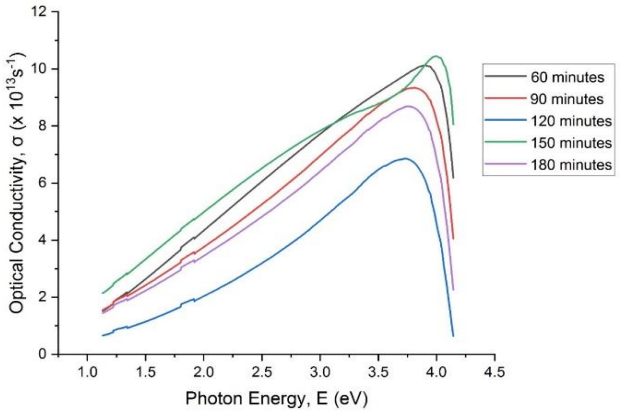

Fig. 3 Plot of Optical conductivity of SnO_2 films versus photon energy at different time intervals.

3.2. Bandgap

By extrapolating the linear portion of the curve to the point where $(\alpha h\nu)^2$ equals zero in the plot of $(\alpha h\nu)^2$ versus photon energy, the direct band gap of the SnO_2 films at different time intervals was obtained. The band gap was found to vary between 2.75 eV and 2.84 eV for the time between 60 minutes and 120 minutes, as shown in figure 4(a-e) [12-13].

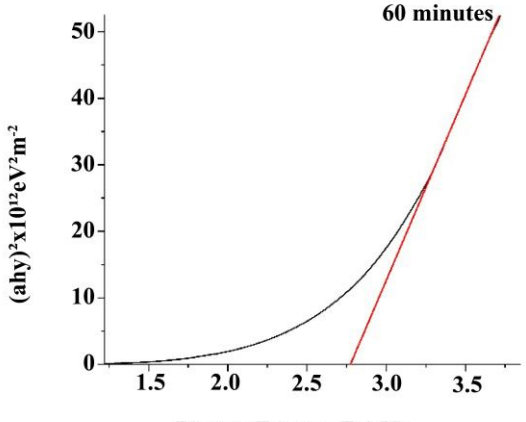

Fig. 4a Plot of $(\alpha h\nu)^2$ versus photon energy for SnO_2 films at 60 minutes

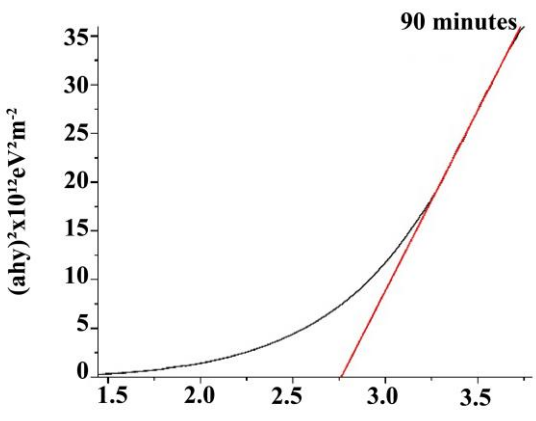

Fig. 4b Plot of $(\alpha h\nu)^2$ versus photon energy for SnO_2 films at 90 minutes

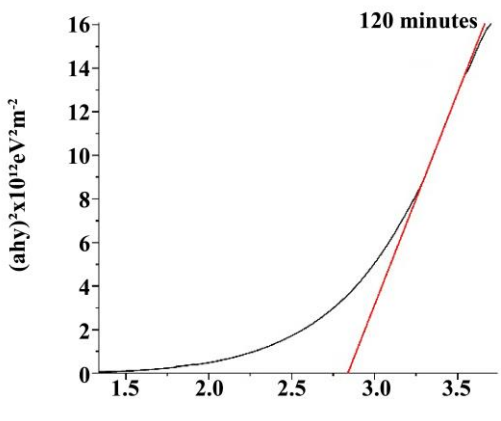

Fig. 4c Plot of $(\alpha h\nu)^2$ versus photon energy for SnO_2 films at 120 minutes

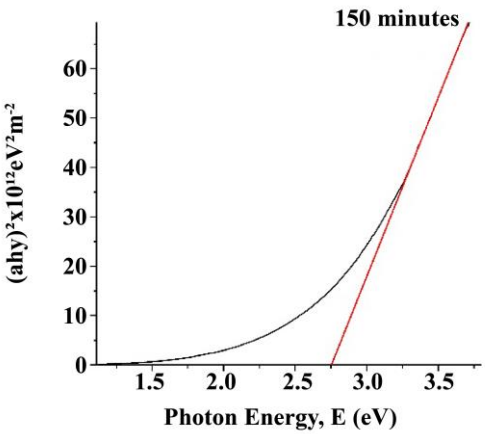

Fig. 4d Plot of $(\alpha h\nu)^2$ versus photon energy for SnO_2 films at 150 minutes

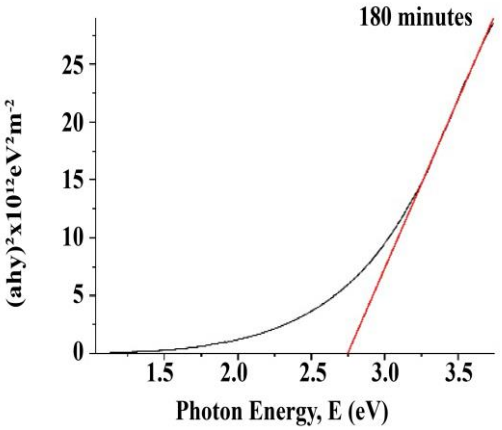

Fig. 4e Plot of $(\alpha h\nu)^2$ versus photon energy for SnO_2 films at 180 minutes

3.3. X-ray Diffraction (XRD) Studies

Figures 5a and 5b display the XRD pattern of SnO_2 films deposited at different deposition times. From figure 5a, the XRD pattern of the films shows a crystalline peak at 8.28^0 and a broad, amorphous hump in the $12.22^0 – 20.58^0$, $24.2^0 – 32.42^0$, $38.56^0 – 44.36^0$, $45.08^0 – 54.7^0$, $57.42^0 – 67.8^0$ 2θ range.

From figure 5b, the XRD pattern of the films shows a crystalline peak at 8.5^0 and a broad, amorphous hump in the $13.98^0 – 19.88^0$, $22.44^0 – 28.36^0$, $30.86^0 – 37.5^0$, $39.4^0 – 49.2^0$, $50.72^0 – 59.32^0$ 2θ range [12-13].

3.4 Morphological Analysis

A scanning electron microscope was utilized to take images of the facial/top view and cross-sectional view with varied resolutions to analyze the morphology and interfacial quality of the cells created for this study. The thin film deposits of SnO_2-ETL are generally regular in structure, as can be seen by closely examining the SEM images below. At the same time, bigger particles may result from the agglomeration of smaller crystallites. Figures 6a and 6b display SEM pictures of several SnO_2 film.

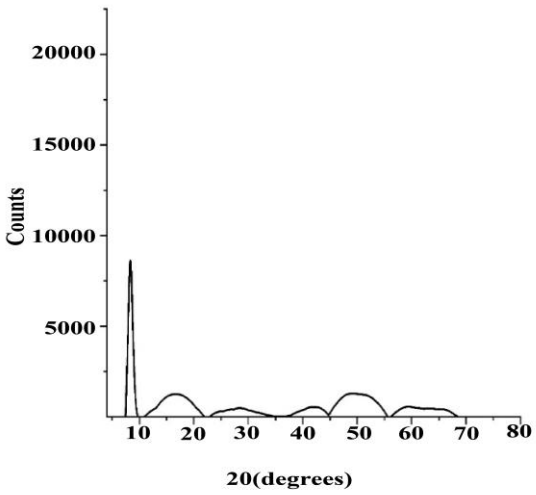

Fig. 5a X-ray diffraction pattern of SnO_2 films obtained at 90 minutes

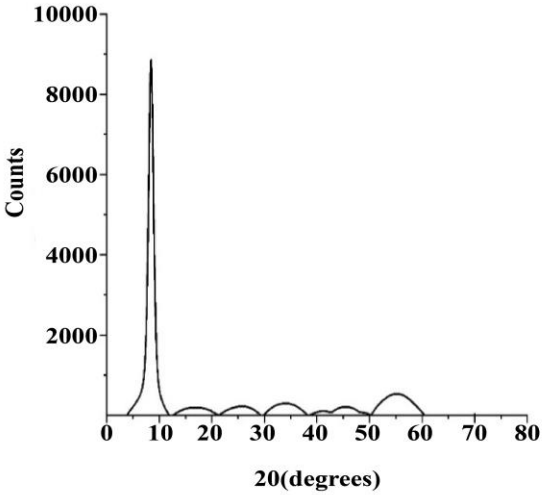

Fig. 5b X-ray diffraction pattern of SnO_2 films obtained at 180 minutes

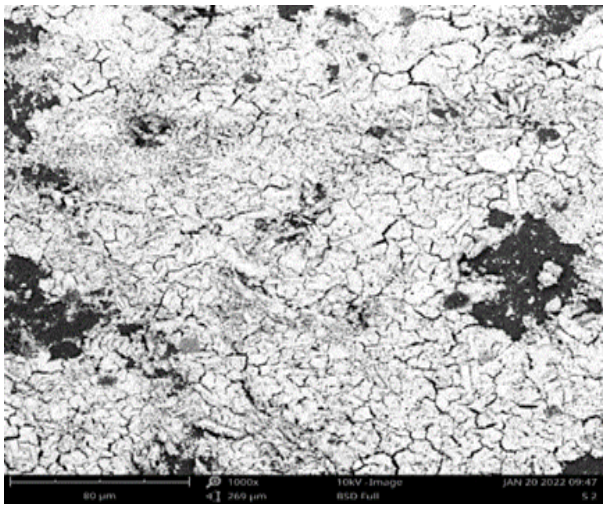

Fig. 6a SEM images of SnO_2 films deposited at 90 minutes

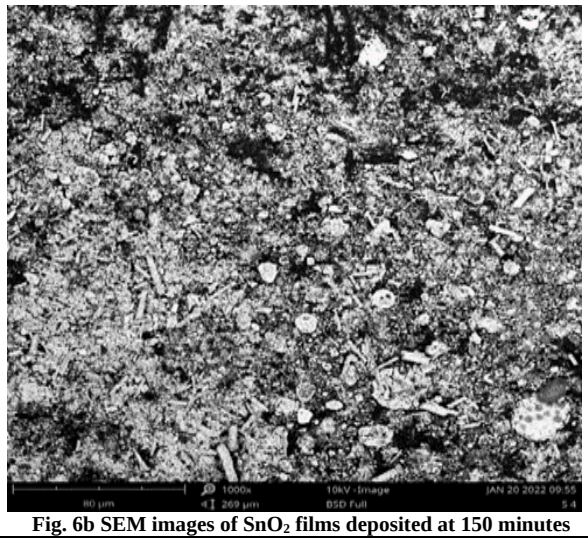

Fig. 6b SEM images of SnO_2 films deposited at 150 minutes

4. Conclusion

We have successfully used a chemical method to synthesise tin oxide thin films as an electron transport layer for perovskite solar cells. Optical studies show that all the SnO_2 films are highly transparent in the electromagnetic spectrum's visible region and possess a wide band gap. This makes it suitable for use as an electron transport layer for a perovskite solar cell. The performance of a perovskite solar cell is significantly influenced by the electron transport layer. It lessens the recombination of free charge carriers (holes and electrons) with their equivalents on interface imperfections. The outcome showed a large band gap and high transmittance. SnO_2-ETL's chemical bath deposition method provides homogeneous thin film coverage and also makes it a great, affordable choice for manufacturing perovskite solar cells on a big scale.

References

[1] Nwamaka I. Akpu et al., "Investigation on the Influence of Varying Substrate Temperature on the Physical Features of Yttrium Doped Cadmium Selenide Thin Films Materials," *SSRG International Journal of Applied Physics*, vol. 8, no. 2, pp. 37-46, 2021. *Crossref*, https://doi.org/10.14445/23500301/IJAP-V8I2P106

[2] L. Imosobomeh et al., "Effect of Precursor pHon Cadmium Doped Manganese Sulphide (CdMnS) Thin Films For Photovoltaic Application," *SSRG International Journal of Applied Physics*, vol. 6, no. 2, pp. 1-8, 2020. *Crossref*, https://doi.org/10.14445/23948884/IJMSE-V6I2P101

[3] Imosobomeh Lucky Ikhioya, Donald Okoli, and Azubike Josiah Ekpunobi, "Effect of Temperature on SnZnSe Semiconductor Thin Films for Photovoltaic Application," *SSRG International Journal of Applied Physics (SSRG-IJAP)*, vol. 6, no. 2, pp. 55-67, 2019. *Crossref*, http://dx.doi.org/10.14445/23500301/IJAP-V6I2P109

[4] Imosobomeh Lucky Ikhioya et al., "The Influence of Precursor Temperature on the Properties of Erbium-Doped Zirconium Telluride Thin Film Material Via Electrochemical Deposition," *SSRG International Journal of Applied Physics*, vol. 7, no. 1, pp. 102-109, 2020. *Crossref*, http://dx.doi.org/10.14445/23500301/IJAP-V7I1P115

[5] Ikhioya, I. L, and A. J. Ekpunobi, "Effect of Deposition Period and pH on Electrodeposition Technique of Zinc Selenide Thin Films," *Journal of Nigeria Association of Mathematical Physics*, vol. 28, no. 2, pp. 281-288, 2014.

[6] Ikhioya, I. L, and A. J. Ekpunobi, "Electrical and Structural properties of ZnSe thin films by Electrodeposition Technique," *Journal of Nigeria Association of Mathematical Physics*, vol. 29, pp. 325-330, 2015.

[7] Imosobomeh Lucky Ikhioya, Ugbo F. C, and Ijabor B. Okeghene, "Growth and Characterization of Manganese Sulphide (MnS) Thin Films," *International Journal for Research in Applied and Natural Science*, vol. 4, no. 1, pp. 1-9, 2018.

[8] Dianyi Liu, and Timothy L. Kelly, "Perovskite Solar Cells with a Planar Heterojunction Structure Prepared Using Room Temperature Solution Processing Technique," *Nature Photonics*, vol. 8, no. 2, pp. 133-138, 2014. *Crossref*, http://dx.doi.org/10.1038/nphoton.2013.342

[9] Di Zhou et al., "Perovskite-Based Solar Cells: Materials, Methods, and Future Perspectives," *Journal of Nanomaterials*, vol. 2018, pp. 1-15, 2018. *Crossref*, https://doi.org/10.1155/2018/8148072

[10] Wegene Lema Lachore et al., "Recent Progress in Electron Transport Bilayer for Efficient and Low-Cost Perovskite Solar cells: A Review," *Journal of Solid-State Electrochemistry*, vol. 26, no. 17, pp. 295-311, 2021. *Crossref*, https://doi.org/10.1007/s10008-021-05064-z

[11] Yi-Cheng Lin, Yen-Tai Chao, and Pin. Chuan Yao, "Influence of Humidity on the Growth Characterization and Properties of Chemical Bath-Deposited ZnS Thin Films," *Applied Surface Science*, vol. 307, pp. 724-730, 2014. *Crossref*, http://dx.doi.org/10.1016/j.apsusc.2014.04.111

[12] Ankur Kumar Bansal, Dr.Mukesh Kumar, and Dinesh Kumar, "Research Paper on Advanced Material used in Solar Panel - Perovskite, A Organic, Inorganic and Halide Compound," *SSRG International Journal of Mechanical Engineering*, vol. 6, no. 6, pp. 48-55, 2019. *Crossref*, https://doi.org/10.14445/23488360/IJME-V6I6P109

[13] Khalid Mahmood, Saad Sarwar, and Muhammed Taqi Mehran, "Current Status of Electron Transport Layers in Perovskite Solar Cells: Materials and Properties," *RSC Advances*, vol. 28, no. 7, pp. 17044-17062, 2017. *Crossref*, https://doi.org/10.1039/C7RA00002B

[14] Sunday S. Oluyamo, and David B. Agunbiade, "Spin Coated Tin Oxide Thin Film for Optical and Optoelectronic Material Application," *International Jounal of Innovated Research and Advanced Studies (IJIRAS)*, vol. 3, no. 8, pp. 394-398, 2016.

[15] Zhongze Liu et al., "Coagulated SnO_2 Colloids for High Performance Planer Perovskite Solar Cells with Negligible Hysteresis and Improved Stability," *A Journal of the German Chemical Society*, vol. 58, no. 33, pp. 11497-11504, 2019. *Crossref*, http://dx.doi.org/10.1002/anie.201904945

[16] Jiiajiu Ye et al., "Doped Bilayer Tin (IV) Oxide Electron Transport Layer for High Open-Circuit Voltage Planer Perovskite Solar Cells with Reduced Hysteresis," *Small*, vol. 17, ID: 2005671, pp. 1-10. *Crossref*, https://doi.org/10.1002/smll.202005671

[17] Oliver Zhao et al., "Low Temperature Open-Air Plasma Deposition of Amorphous Tin Oxide for Perovskite Solar Cells," *Thin Solid Films*, vol. 730, 2021. *Crossref*, https://doi.org/10.1016/j.tsf.2021.138708

[18] Imosobomeh L. Ikhioya et al., "Influence of Varying Molar Concentration on the Properties of Electrochemically-Deposited Zirconium-Doped ZnSe Thin Films," *Journal of Indial Chemical Society*, vol. 99, no. 9, p. 100641, 2022, *Crossref*, https://doi.org/10.1016/j.jics.2022.100641

[19] Imosobomeh L. Ikhioya, Agnes C. Nkele, and Donald N. Okoli, "Effects of Temperature and ph Variations on Electrochemically-Deposited Zirconium-Doped Zinc Selenide Thin Films," *Optik (Stuttg).*, vol. 260, p. 169055, 2022. *Crossref*, https://doi.org/10.1016/j.ijleo.2022.169055

[20] Imosobomeh L. Ikhioya et al., "Effect of Cobalt on the Photovoltaic Properties of Zinc Selenide Thin Film Deposited on Fluorine-Doped Tin Oxide (FTO) Via Electrochemical Deposition Technique," *Curremt Research Green Sustainable Chemistry*, vol. 5, p. 100328, 2022. *Crossref*, https://doi.org/10.1016/j.crgsc.2022.100328

[21] Imosobomeh L. Ikhioya, Osolobri Blessing Uyoyou, and Obed Oyibo, "Preparation and Characterization of Molybdenum Assimilated Zinc Selenide Materials for Photovoltaic and Solar Cells Application," *Journal of Material and Environmental Science*, vol. 13, no. 5, pp. 515-525, 2022.

[22] Imosobomeh L. Ikhioya et al., "A Study on the Effects of Varying Concentrations on The Properties of Ytterbium-Doped Cobalt Selenide Thin Films," *Optical Materials*, vol. 101, p. 109731, 2020. *Crossref*, https://doi.org/10.1016/j.optmat.2020.109731

[23] Imosobomeh L. Ikhioya, Nwamaka I. Akpu, and Faith U. Ochai-Ejeh, "Influence of Erbium (Er) Dopant on the Enhanced Optical Properties of Electrochemically Deposited Zinc Oxide (ZnO) Films for High-Performance Photovoltaic Systems," *Optik*, vol. 252, p. 168486, 2022. *Crossref*, https://doi.org/10.1016/j.ijleo.2021.168486

[24] B.C.N. Obitte et al., "The Effects of Doping and Temperature on Properties of Electrochemically Deposited Er3+ Doped ZnSe Thin Films," *Optical Materials*, vol. 124, p. 111979, 2022. *Crossref*, https://doi.org/10.1016/j.optmat.2022.111979

[25] Taewan Kim, Jongchul Lim, and Seulki Song, "Recent Progress and Challenges of Election Transport Layers in Organic – Inorganic Perovskite Solar Cells," *Energies*, vol. 13, no. 21, pp. 1-16, 2020. *Crossref*, https://doi.org/10.3390/en13215572