

Effect of Binder on The Performance of SnO₂ Based ETL Perovskite Solar Cell

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Abstract— FTO (fluorine-doped tin oxide) based perovskite solar cell using SnO₂ as ETL which is a low temperature material has gained significant interest because of its wide band gap, high electron mobility, high chemical stability and good antireflective properties. However, other metallic oxide materials like TiO₂ have low charge mobility, high charge recombination rate, mismatch of band gap to the perovskite layer, low compatibility with perovskite layer and cause more degradation when exposed to light. Due to their outstanding optical, electrical, mechanical qualities, low temperature synthesis and good compatibility with the PSC layer SnO₂ material have been widely employed in PSCs to address these difficulties. Due to its many advantageous characteristics, SnO₂ is one of the most potential materials for high-performance PSC modules with high efficiency in the future. This study will demonstrate how we form SnO₂ solution and how we utilize SnO₂ to work as a ETL efficiently for that we examined how the addition of binder affect the optical, morphological, and structural characteristics of SnO₂ in PSC based on FTO. We use Terpineol as a binder using ethanol as a solvent with some additives like HCL to increase stability. The measurements taken 2.7g of SnCl₂·2H₂O, 10ml HCL and 10ml of ethanol. Stirred the mixture using magnetic stirrer at room temperature for 1hr with 1000 rpm on Hot plate. Utilizing the spin coating process, deposit the solution for 35 seconds at 2500 RPM. The morphology, crystallinity and transmittance of all the samples were characterized using atomic force microscope AFM, X-ray diffraction spectrometer and UV-VIS .

Keywords— Perovskite Solar Cell, Tin Oxide, Low Temperature, Binder.

I. INTRODUCTION

There are many materials used as a ETL, such as TiO₂, which have resulted in good power conversion efficiency (PCE) of up to 25%. Despite their better efficiency, they have some drawbacks, such as low charge mobility and high recombination rates, as well as their high processing temperature (>450°C) and long duration required to be fully crystallized into the desired

form, leading to high costs and greater energy consumption[1-4]. SnO₂, which not only acts as an excellent role in minimizing annealing temperature and time but also as an effective role in enhanced stability and efficiency. This is due to the fact that ETLs have good mobility of charges, are easier to synthesize due to lower temperatures, superior band gap well alignment of band energies. These are the driving forces used to transport the charges more efficiently from the absorber layer to ETLs and thus improve PCE[5, 6]. These characteristics of SnO₂ are crucial for many technical applications, including photocatalysis, gas sensors, lithium-ion batteries, transparent conductive electrodes, optoelectronic devices, photovoltaic cells, light sensors, and more. Practical performance of SnO₂ is influenced by its shape, surface properties, degree of crystallinity, and crystal defects. Therefore, in order to achieve the essential chemical and physical qualities throughout the preparation, it is vital to manage their morphology and size[7]. There are several techniques used to prepare SnO₂ (Tin Oxide) thin film for electron transport layer (ETL) in perovskite solar cell from the prepared simple precursor solution of SnO₂. Many methods including solvothermal, co-precipitation, sol-gel, hydrothermal, solid state reaction and microwave assisted methods are used to prepare SnO₂ (Tin Oxide) thin film for electron transport Layer[8]. Many methods including solvothermal, co-precipitation, sol-gel, hydrothermal, solid state reaction and microwave assisted methods are used to prepare SnO₂ (Tin Oxide) thin film for electron transport layer (ETL) in applications such as perovskite solar cells. SnO₂ nanostructures are then prepared from the prepared simple precursor solution of SnO₂ using the spin coating method which has several advantages including low temperature conditions, better homogeneity and simple equipment requirements[9-11]. Additionally, the binder solution can be used to efficiently modify the morphological, optical and structural characteristics of the tin oxide nanostructure[12].

The use of some semi-conducting metal oxide like lanthanum oxide and iron oxide as a binder for the features of SnO₂ as a gas sensor in order to design thick film sensor[13].

The present research used the spin coating technique to synthesize rutile tetragonal phase SnO₂ (ETL). An investigation was carried out into how the use of binder affected the optical, morphological, and structural characteristics of SnO₂.

II. EXPERIMENT DETAILS

A. Materials and Methods

1) Material:

The experiment was conducted using the following materials.

The materials used are FTO (fluorine doped tin oxide) substrate, stannous chloride di-hydrate SnCl₂.2H₂O, Ethanol, Conc.HCL 37% and Terpeneol as a binder.

2) Methods:

This study used three steps in its methods which are as follows.

a) Synthesis of SnO₂ Solution

Dissolved 2.7g of SnCl₂.2H₂O in 10 ml of Ethanol in a beaker. Stirred the mixture using magnetic stirrer at room temperature at about 1hr with 1000 rpm on Hot plate. Then 10ml of conc. HCL was added to this solution. Stirred the mixture for 20 to 30 minutes. The solution was then mixed once more after a small amount of terpeneol was added. After that, the precursor solution was allowed to age for a few days in open air the final solution be look like pale yellow.

b) Sonication

Following a series of ultrasonic cleanings of laser etched FTO glass in De-ionized(DI)water, iso-propylealcohol, ethanol, acetone and then dried using air blower.

c) Spin Coating

Now, using a spin coater set to 2500 rpm for 35 sec, 5 drops of the sample are taken and dispensed in the center of FTO/glass substrate. By applying centrifugal force, this fast rotation assists in the uniform coating of nano film on the substrate.

d) Annealing

The SnO₂ solution was spin coated and the films were then placed on a hot plate at 1800 c in the air for one hr to create SnO₂ film.

III. RESULTS AND DISCUSSION

A. Structural Studies

XRD analysis of SnO₂ thin films with a binder using spin coating method has been performed. The results has been compared with the general results of SnO₂ as in the literature. This demonstrated that the produced nanoparticles have a rutile type tetragonal structure of SnO₂, as all of the measured peak position matched the results reported in the literature. We came to know that using terpeneol as a binder instead of ethyl cellulose is more feasible as it is relatively volatile organic compound which evaporate easily during annealing process of SnO₂ and also environmentally friendly. It increases viscosity of SnO₂ solution due to which it is much easy to deposit a smooth layer. The major peak appeared more intensive is 110 plane indicate well-crystallized growth along the crystallographic

direction. However, other peaks might also emerge based on certain circumstances (such the substrate's temperature, doping, and manner of deposition). The XRD peaks were used to compute the lattice constants (a=b, and c) for tetragonal structure using equation(1)

$$\frac{1}{d_{hkl}^2} = \frac{h^2+k^2}{a^2} + \frac{l^2}{c^2} \quad (1)$$

In the above equation d_{hkl} the plane spacing given by the Bragg's law (nλ= 2dhkl sin(θhkl), n is the order of diffraction (typically n = 1 for first order), θ is Bragg diffraction angle, λ is the X-ray wavelength and Miller indices (hkl). The mean crystallite size (D) was determined using the FWHM of the three best diffraction peaks (110), (101) and (211) based on Scherrer's formula (Eq.2).

$$D = \frac{k\lambda}{\beta \cos \theta} \quad (2)$$

Here 'k' represents the shape factor having value 0.9, 'θ' the diffraction angle, 'λ' is X-ray wavelength having value 1.5406 Å and 'β' is the width of half maximum of the diffraction peak in radian. The average crystalline size calculated using scherrer's formula varied between 23.74nm to 26.28nm with binder, suggesting that the crystal structure is more crystalized when binder terpeneol is use. The average values of the crystal size "D" can be determined from the following dislocation density equation that shows the amount of defects.

$$\delta = \frac{1}{D^2} \quad (3)$$

The values are shown in the following Table I and Table II.

TABLE I. SnO₂ WITHOUT BINDER

S. No	Annealing Temperature (°C)	SnO ₂ without Binder (d-spacing Å)			Crystal Size D (nm)	Dislocation Density ×10 ¹⁵ (lines/m ²)
		(110)	(101)	(211)		
1	180	3.125	2.785	1.800	23.74	1.77

TABLE II. SnO₂ WITH BINDER

S. No	Annealing Temperature (°C)	SnO ₂ without Binder (d-spacing Å)			Crystal Size D (nm)	Dislocation Density ×10 ¹⁵ (lines/m ²)
		(110)	(101)	(211)		
1	180	0.706	0.869	1.339	26.28	1.44

So we came to the conclusion that using terpeneol as a binder will results into better crystallinity and smooth surface.

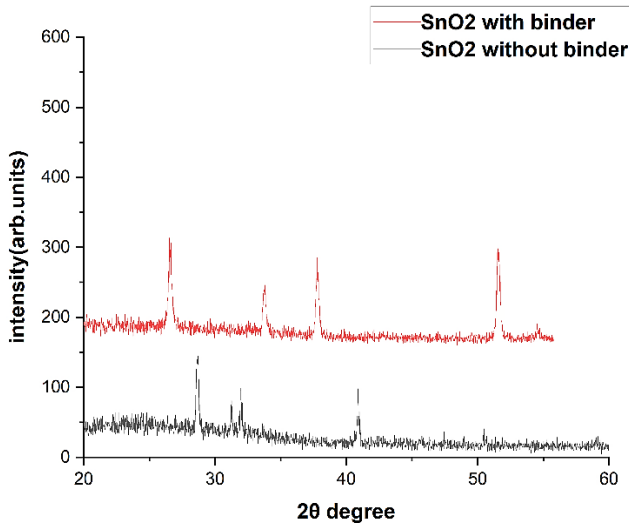


Figure 1. The X-ray diffraction patterns of SnO₂ thin films with and without binder using spin coating method

B. Optical Studies

This test has been performed in order to find the optical properties like transmittance, reflectance and absorbance of SnO₂ thin film. As it has been showed that the transmittance For SnO₂ without binder in the visible range of 400-800nm the transmittance is 85%,the absorbance is 13% while the reflectance is 2%. Similarly for SnO₂ with binder in the visible range of 400-800nm the transmittance is 88%,the absorbance is 11%. while the reflectance is 1%. This is because of using terpineol as a binder which caused the SnO₂ particles to be evenly distributed throughout the solution and to pack more tightly. This increases transparency by minimizing air holes in the film and facilitating light transmission. In certain cases, terpineol can aid in the annealing process by encouraging the development of a more crystalline and ordered SnO₂ structure. Defects and grain boundaries that cause light scattering are reduced by a well-defined crystalline structure[14]. 3.6 eV is the SnO₂ energy band gap reported in the standard literature. A tauc plot which is frequently employed in the study of optical absorption data, allows us to determine the band gap energy of material. The tauc equation serves as the foundation of for the tauc plot approach.

$$(\alpha hv)n = A(hv - E_g) \quad (4)$$

Here α is the absorption coefficient, $h\nu$ is the photon energy (where h is Planck's constant and ν is the frequency of the light), E_g is the band gap energy, A is a constant and n is a constant that depends on the type of the electronic transition (e.g., $n=1/2$ for indirect allowed transitions, $n=2$ for direct allowed transitions). Here's how to use the tauc plot to find the band gap energy. Obtained the absorbance data from the transmittance and reflectance. Measured the absorption coefficient (α) as a function of photon energy ($h\nu$).

$$\text{As } \alpha = 2.302 * A \quad (5)$$

Measured the incident energy value from the following equation

$$E = h\nu \quad (6)$$

Where $\nu=c/\lambda$, put in the above equation,the equation becomes as

$$E = hc/\lambda \quad (7)$$

The Planck's constant(h) value is $= 6.62 \times 10^{-34}$ J·s, the value of $C=2.998 \times 10^8$ (m/s). By putting values in equation (7) we got the final value in eV which is $E=1240/\lambda$ (eV)

Plot $(\alpha hv)n$ against $h\nu$ (eV) which is the incident energy in electron volt. The value of n depends on the nature of electronic transition in the material. Here is for SnO₂ $n=2$ which is a direct band gap transition. Identified the linear portion of the Tauc plot. This region corresponds to the onset of absorption due to electronic transitions. Extend the linear portion of the plot to intersect the $h\nu$ (photon energy) axis. The intercept of this line with the energy axis gives the band gap energy E_g . The energy band gaps are decreases as the transmittance increase by using binder. So for high transmittance the energy band gap value must be less than the literature results[12].So we came to the conclusion that using terpineol as a binder will give better results as compared to without binder of SnO₂ solution for low temperature fabrication solar cell. The values are shown in the following Table III.

TABLE III. OPTICAL PROPERTIES OF BOTH SAMPLES

Samples	T(%)	A(%)	R(%)
SnO ₂ without Binder	85	13	2
SnO ₂ with Binder	89	10	1

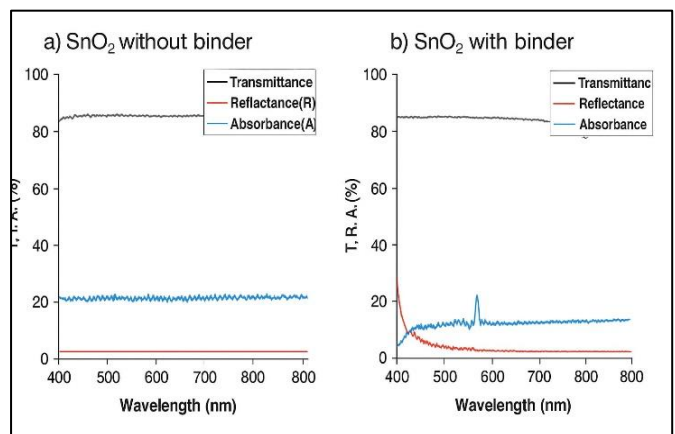


Figure 2. a)Optical properties of SnO₂ with terpineol as a binder,b) Optical properties of SnO₂ without binder

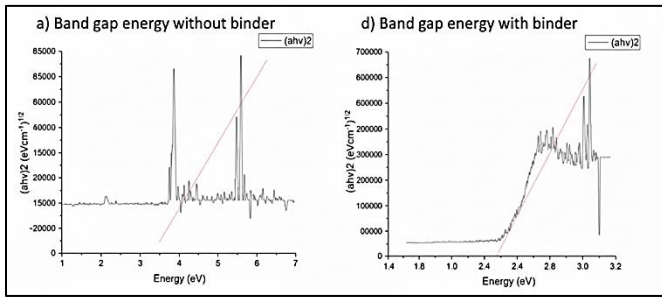


Figure 3. c) Band gap energy of SnO₂ without binder,d) Band gap energy of SnO₂ with binder

C. Atomic force microscope (AFM) Analysis:

The instrument used are dimension edge AFM model by Broker Company. AFM of SnO₂ based thin film with binder has been performed which is prepared by spin coating. In the results Rq shows roughness of surface. For spin coating method SnO₂ without binder we got roughness of 1.98nm and for SnO₂ with binder we got roughness of 1.8nm as shown in the Table IV. Here it has been achieved more roughness for without binder so came to the results that by using spin coating with binder will give more uniform layer. It has been compared to General results of SnO₂ as in the literature there is roughness range of SnO₂ from 1.6 to 2.3 nm.

TABLE IV. ROUGHNESS RQ OF ABOVE METHODS

Methods	Roughness Rq (nm)
SnO ₂ without binder	1.98
SnO ₂ with binder	1.8

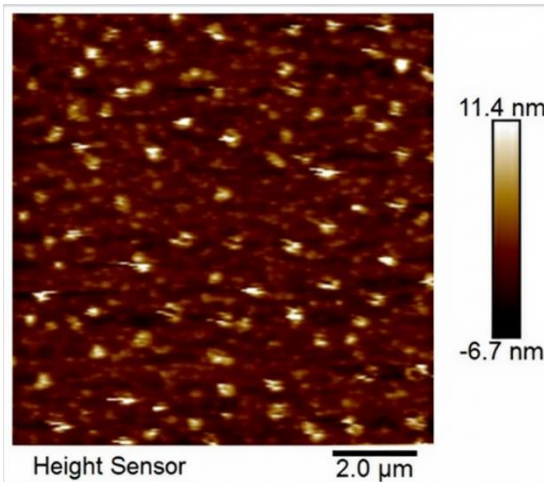


Figure 4. AFM results of SnO₂ With Binder Using Spin Coating Technique

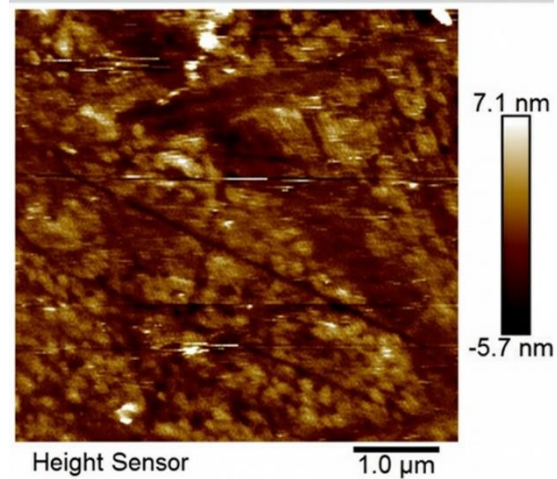


Figure 5. AFM results of SnO₂ Without Binder Using Spin Coating Technique

CONCLUSION

Tin oxide (SnO₂) thin films were created on a glass substrate by adding terpineol as a binder in as prepared SnO₂ solution with the annealing temperature of 18 C. The prepared films were described by XRD analyses which demonstrated that the prepared samples had a tetragonal with polycrystalline structure. The prepared films' uniformity and crystallite size rises with the addition of binder. There is a decrease in crystallites per unit area (N), the strain (ϵ), number of dislocation density (δ). From the optical transmittance studies the transmission in the observable spectrum has been found to be between 80% and 89% based on the addition of binder and there is decrease in band energy as the we used terpineol as a binder. An increase in the transmittance observed with the addition of binder. Further binders like ethyl cellulose etc are also can be use for further enhancement.

REFERENCES

- [1] J. Peng, L. Lu, and H. Yang, "Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems," *Renewable and sustainable energy reviews*, vol. 19, pp. 255-274, 2013.
- [2] R. Pulselli, E. Simoncini, F. Pulselli, and S. Bastianoni, "Emergy analysis of building manufacturing, maintenance and use: Em-building indices to evaluate housing sustainability," *Energy and buildings*, vol. 39, pp. 620-628, 2007.
- [3] V. Tyagi, N. A. Rahim, N. Rahim, A. Jeyraj, and L. Selvaraj, "Progress in solar PV technology: Research and achievement," *Renewable and sustainable energy reviews*, vol. 20, pp. 443-461, 2013.
- [4] Y. Chu and P. Meisen, "Review and comparison of different solar energy technologies," *Global Energy Network Institute (GENI), San Diego, CA*, vol. 1, pp. 1-52, 2011.
- [5] M. M. Tavakoli, P. Yadav, R. Tavakoli, and J. Kong, "Surface engineering of TiO₂ ETL for highly efficient and hysteresis - less planar perovskite solar cell (21.4%) with enhanced open - circuit voltage and stability," *Advanced Energy Materials*, vol. 8, p. 1800794, 2018.
- [6] D. Prochowicz, M. M. Tavakoli, M. Wolska-Pietkiewicz, M. Jędrzejewska, S. Trivedi, M. Kumar, et al., "Suppressing recombination in perovskite solar cells via surface engineering of TiO₂ ETL," *Solar Energy*, vol. 197, pp. 50-57, 2020.
- [7] Y. Wang, J. Wan, J. Ding, J. S. Hu, and D. Wang, "A rutile TiO₂ electron transport layer for the enhancement of charge collection for efficient perovskite solar cells," *Angewandte Chemie International Edition*, vol. 58, pp. 9414-9418, 2019.

- [8] Z. Arshad, S. Shakir, A. H. Khoja, A. H. Javed, M. Anwar, A. Rehman, et al., "Performance analysis of calcium-doped titania (TiO₂) as an effective electron transport layer (ETL) for perovskite solar cells," *Energies*, vol. 15, p. 1408, 2022.
- [9] J. Song, E. Zheng, J. Bian, X.-F. Wang, W. Tian, Y. Sanehira, et al., "Low-temperature SnO₂-based electron selective contact for efficient and stable perovskite solar cells," *Journal of Materials Chemistry A*, vol. 3, pp. 10837-10844, 2015.
- [10] J. Barbé, M. L. Tietze, M. Neophytou, B. Murali, E. Alarousu, A. E. Labban, et al., "Amorphous tin oxide as a low-temperature-processed electron-transport layer for organic and hybrid perovskite solar cells," *ACS applied materials & interfaces*, vol. 9, pp. 11828-11836, 2017.
- [11] L. Xiong, Y. Guo, J. Wen, H. Liu, G. Yang, P. Qin, et al., "Review on the application of SnO₂ in perovskite solar cells," *Advanced Functional Materials*, vol. 28, p. 1802757, 2018.
- [12] Y. T. Gebreslassie and H. G. Gebretsaie, "Green and cost-effective synthesis of tin oxide nanoparticles: a review on the synthesis methodologies, mechanism of formation, and their potential applications," *Nanoscale research letters*, vol. 16, p. 97, 2021.
- [13] S. Lim, N. Huang, and H. Lim, "Solvothermal synthesis of SnO₂/graphene nanocomposites for supercapacitor application," *Ceramics International*, vol. 39, pp. 6647-6655, 2013.
- [14] J. Chatelon, C. Terrier, E. Bernstein, R. Berjoan, and J. Roger, "Morphology of SnO₂ thin films obtained by the sol-gel technique," *Thin solid films*, vol. 247, pp. 162-168, 1994.
- [15] L. Tan, L. Wang, and Y. Wang, "Hydrothermal synthesis of SnO₂ nanostructures with different morphologies and their optical properties," *Journal of Nanomaterials*, vol. 2011, p. 529874, 2011.
- [16] R. L. Orimi and M. Maghoul, "Optical characterization of SnO₂ nanostructure thin films, annealed at different temperatures," *Optik*, vol. 127, pp. 263-266, 2016.
- [17] E. Akarsu, D. İskenderoğlu, and M. Ertuğrul, "The Effect of Adding La₂O₃ and Fe₂O₃ Binder to the Thick Film SnO₂ Sensor on the Sensor's Properties," *International Journal of Innovative Research and Reviews*, vol. 6, pp. 22-29, 2022.
- [18] J. Zhao, R. Tan, Y. Yang, W. Xu, J. Li, W. Shen, et al., "High-performance Sb: SnO₂ compact thin film based on surfactant-free and binder-free Sb: Sn₃O₄ suspension," *Journal of Materials Science & Technology*, vol. 31, pp. 815-821, 2015. G. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," *Phil. Trans. Roy. Soc. London*, vol. A247, pp. 529-551, April 1955. (references)



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