

Research Article

Potentiostatic electrochemical deposition and characterization of Zinc Sulphide (ZnS) thin films for application as window layer in solar cells

A. R. Lasisi^{a*}, H. Baqqiah^b, A. B. Alabi^c & O. A. Babalola^d

^a Department of Physics, Federal University of Education, Kontagora, Nigeria.

^b Department of Physics, University Putra Malaysia, Malaysia.

^c Department of Physics, University of Ilorin, Ilorin, Nigeria.

^d Physics Advanced Laboratory, Sheda Science and Technology Complex (SHESTCO), Abuja, Nigeria.

Abstract

This study addresses the persistence challenge of the toxicity associated with cadmium sulphide (CdS) thin films, typically synthesised via chemical bath deposition technique and used as window layers of thin film solar cells. Three-electrode potentiostatic electrochemical deposition technique was used to synthesize zinc sulphide (ZnS) thin films from aqueous solution of zinc acetate and sodium thiosulphate penta-hydrate as a source of zinc and sulphur respectively. The thin films were characterized using Field Emission Scanning Electron Microscope (FESEM) to study their morphology, X-Ray Diffractometer (XRD) to determine the structure of the samples, UV-Visible spectrometer (UV-Visible) to obtain the optical properties of the thin films, four-point probes to determine their resistivity/conductivity, Hall effect measurement to determine their conductivity type and two-point probes to study their I-V characteristics. The results obtained revealed that, the ZnS thin films were non-uniform but pin-hole free with average particle size of 4.18 μm , polycrystalline with zinc blende cubic structure. The thin film exhibited high transmittance in the visible region and the band gap is 2.94 eV. It is an n-type semiconductor with conductivity of $4.43 \times 10^3 \Omega^{-1}\text{cm}^{-1}$. The I-V characteristics of ITO/ZnS/Ag structure is linear which implies that the junction between the ITO/ZnS and ZnS/Ag are ohmic. The study therefore concludes that, zinc sulphide thin films synthesized using three-electrode potentiostatic technique is a suitable material for window layer of a thin film solar cells. Thus, it was recommended that ZnS thin films deposited via three-electrode potentiostatic deposition technique should be employed as a window layer in thin film solar cells to obtain environmental benign solar cells.

Keywords: Electrochemical deposition, zinc sulphide, thin films, window layer and solar cells.

1. Introduction

The thin film solar cells as a second generation of solar cells after Silicon solar cells is a promising solar cell. Its active layer is made up of a p-type semiconductor called absorber layer and n-type semiconductor called window layer. Most of these thin film solar cells uses cadmium sulphide (CdS) thin films synthesized through chemical bath technique as window layer. CdS contain cadmium (Cd) which is toxic couple with the chemical bath deposition technique mostly employed to synthesise it which introduces large amount of Cd waste to the environment. Thus, the process of fabrication and the Cd based solar cells are therefore not environmentally benign. Thus, the need to search for toxic free window layer and the deposition

technique that consume less material and introduce less waste to the environment.

The window material introduced in this study is zinc sulphide (ZnS) thin films. It is II-VI group semiconductor with a wide direct band gap of 3.5–3.7 eV (Vipin *et al.*, 2008). This is a wide energy band gap which permit transmission of more high-energy photons to the solar cell junction and thus enhance the blue response of the photovoltaic cells. Murali and Kumaresan (2009) state that ZnS thin films have n-type conductivity and is nontoxic to human body, very cheap and abundant in nature. Thus, ZnS is a good candidate material that can replace the toxic CdS which is the widely used material for window layer in thin

*Corresponding author: A. R. Lasisi

Email: lasisiar@yahoo.com (A.R.Lasisi)

ORCID: <https://orcid.org/0009-0002-2676-2700> ↗

Received: 05/10/2025; Accepted: 28/11/2025; Published: 30/11/2025



film solar cells.

In a similar vein, three-electrode potentiostatic electrochemical deposition technique uses less amount of material in deposition process and introduces less waste to the environment. Thus, this study aims to synthesise ZnS thin films via three-electrode potentiostatic electrochemical deposition technique and characterize it to study its suitability as an alternative window layer of thin film solar cells.

2.0 Materials and Methods

2.1 Materials

The materials employed in this study are zinc acetate dihydrate ($C_6H_6O_4Zn \cdot 2H_2O$) as a source of zinc ion, sodium thio-sulphate penta-hydrate ($Na_2S_2O_3 \cdot 5H_2O$) as a source of sulphur ion and hydrochloric acid (HCl) was used to adjust the pH. The substrate employed in this study is ITO coated glass. They were all of analytical grades from Sigma – Aldrich and were used as received. The solvent employed was Nano-pore deionized water prepared in the laboratory. The substrate and all the glass wares employed were clean ultrasonically in the isopropanol medium and rinsed ultrasonically with nano-pore deionized water.

2.2 Deposition and Characterization of the Samples

The ZnS thin films were deposited using three-electrode potentiostatic electrochemical deposition technique. 10.98 g of zinc acetate dihydrate was dissolved in 250 ml of nano-pore deionized water to make 0.20 M. 12.41 g of Sodium thio-sulphate pentahydrate was also dissolved in 250 ml of nano-pore deionized water to make 0.20 M. 25 ml of 0.20 M of Zinc acetate dihydrate was measured into the cell container, 25 ml of 0.20 M sodium thio-sulphate pentahydrate was also measured and added to the content of the container. HCl was added drop wise to adjust the pH of the content to 2.0. A potential of -0.60 V was applied for 1800 s. The samples obtained were removed, rinsed with nano-pore deionized water, dry in the air and kept in sample holder.

The thin films were characterized using Field Emission Scanning Electron Microscope (FESEM) to study their morphology. The morphology of the thin film was obtained using Nova Nano Sem 230 at FESEM laboratory, ITMA, U. P. M., Malaysia. The beam current was 15 KV. Cobalt was used as a standard to optimize the machine and the working distance is 5 mm. The data obtained were analysed using ImgeJ software package.

X-Ray Diffractometer (XRD) to determine the structure of the samples. An Xpert-Pro Diffractometre was used to obtain the structure of the samples at XRD laboratory, Agency Nuclear, Malaysia. A High Score Plus software package was used to analyse the data obtained. UV-Visible spectrophotometer (UV-Visible) to obtain the optical properties of the thin films, Four-point probe to determine their resistivity/conductivity, Hall effect measurement to

determine their conductivity type and a two-point probe configuration to study their I-V characteristics of ITO/ZnS/Ag junction formed by using Silver paste to create a contact on ZnS thin film surface. The Four-point probing technique used to determine the resistivity of the samples uses Keithley sourcemetre instrument with Leios Tm Tracer software using Vander pauw array mode with Indium pellet as ohmic contact. The Hall measurement was carried out using the same arrangement but with Hall Tm Xpert Professional software. These studies were carried out at Electrical Properties Laboratory, Department of Physics, University Putra Malaysia, Malaysia. The I-V characteristics of the samples were obtained using Keithley sourcemetre 2611 attached with labtracer 2.0 software at Functional Device Laboratory, ITMA, U. P. M., Malaysia.

3. Results and Discussions.

3.1. Morphological study of ZnS thin films

The morphology as shown in fig. 1 shows that, the films is continuously distributed and is pin hole free. It reveals further that, the particle grains agglomerates to form Polycrystals. The particle size was estimated to be 4.18 μm . These are in agreement with the work of Sanders and Kitai (1990), Liu et al. (2012) and Patil et al. (2015).

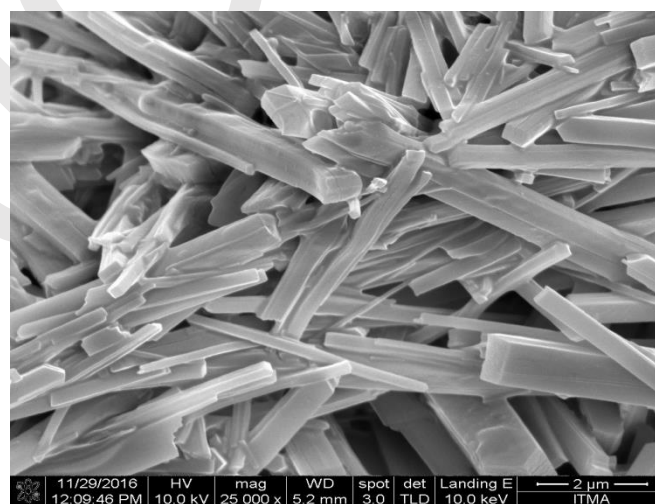
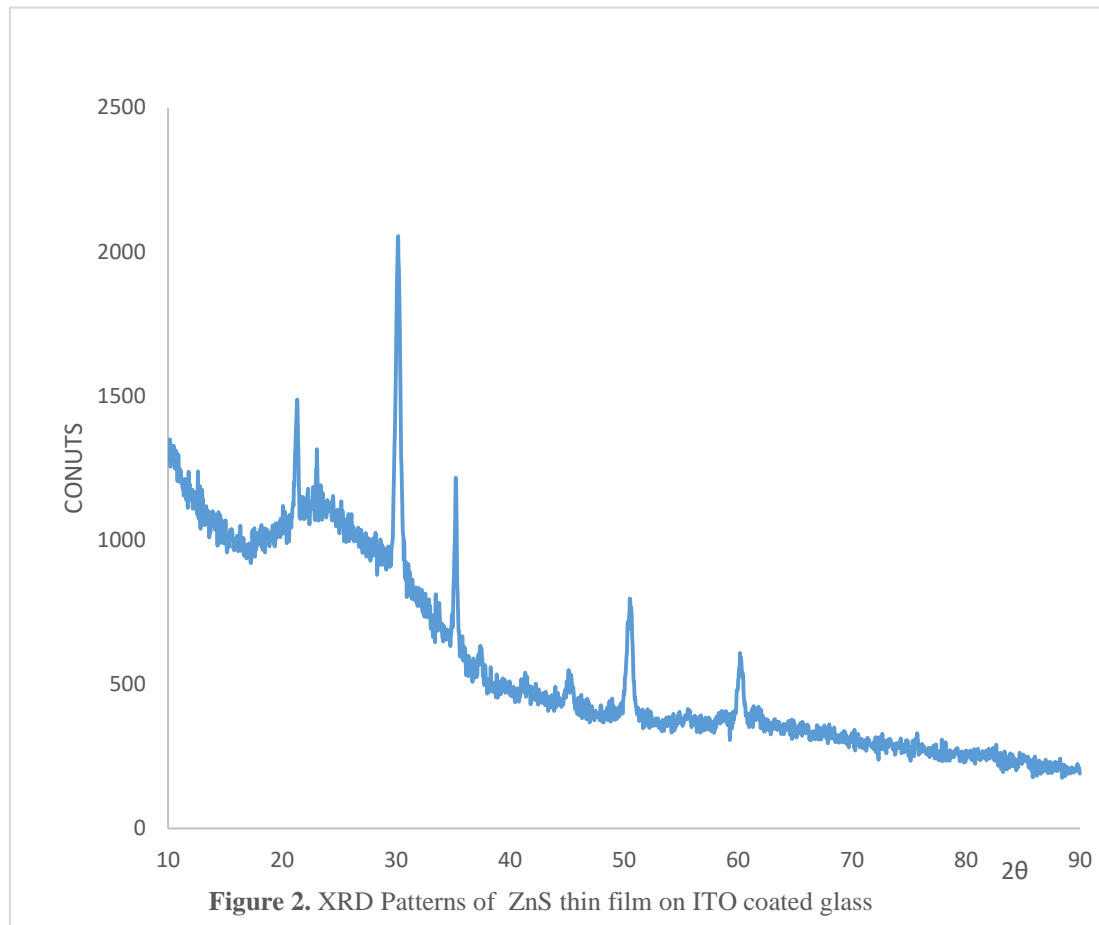


Figure 1. FESEM micrograph of ZnS thin films on ITO coated glass

3.2. Structural study of ZnS thin films

The XRD pattern as shown in fig. 2 reveals eight (8) observed peaks. The compound with the best match was ZnS (ICDD card number 01-079-0043). It has Zinc Blende cubic crystal structure with lattice parameter $a = b = c = 5.318 \text{ \AA}$. The Grain size was estimated to be 263.8632 \AA using Debye-Scherrer equation and inter-planar spacing was estimated to be 2.96387 \AA . The absence of observed secondary phases indicates phase purity. This result is in agreement with Sanders and Kitai, (1990), Kassim, et al, (2010) and Liu et al, (2012) who have found various cubic structure for ZnS thin film



3.3. Optical study of ZnS thin films

The graph of transmittance and absorbance against wavelength as shown in fig. 3 reveals that, ZnS thin film has transmittance > 90 % and absorbance < 5 % in the Uv-Visible region. This implies that, the film is a high optical transmittance and a very low optical absorbance of Uv-Visible light. This confirm the suitability of the deposited film as a suitable material for window layer of thin film solar cells. These results agree very well with the work of Sander and Kitai (1990), Ndukwe (1996) and Liu et al. (2012) that have found out that ZnS thin film is a high transmittance and a very low absorber of Uv-Visible light and therefore can be used as a material for window layer of thin film solar cells. The Tauc plot of $(\alpha h\nu)^2$ versus energy (eV) (fig. 4) reveals that, the film has direct optical transition.

The energy band gap is found to be 2.94 eV. This is quite differed from the results of Sze (1985), Sanders and Kitai (1990), Ndukwe (1996), Liu et al. (2012) and Patil et. al. (2015) who have reported energy band gap ranging between 3.6 eV and 4.0 eV for ZnS thin films but is in agreement with the work of Ahmad et. Al. (2011) who have reported 2.96 eV for ZnS nanoparticle. This observed difference may be due to the fact that the value of the energy band gap reported in this study is for as-deposited (unannealed) samples and annealing has been reported to improve the surface smoothness, grain size and widen the band gap of thin films. (Gedi et al., 2021; Nogami et al., 2025).

*Corresponding author: A. R. Lasisi

Email: lasisiar@yahoo.com (A.R.Lasisi)

ORCID: <https://orcid.org/0009-0002-2676-2700>

Received: 05/10/2025; Accepted: 28/11/2025; Published: 30/11/2025



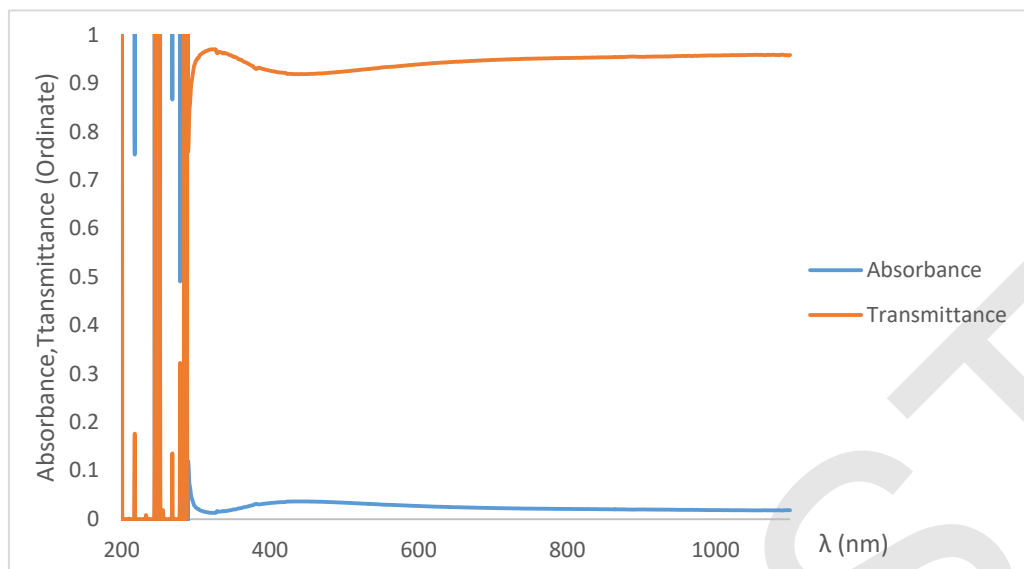


Figure 3. Absorbance/Transmittance of ZnS thin film

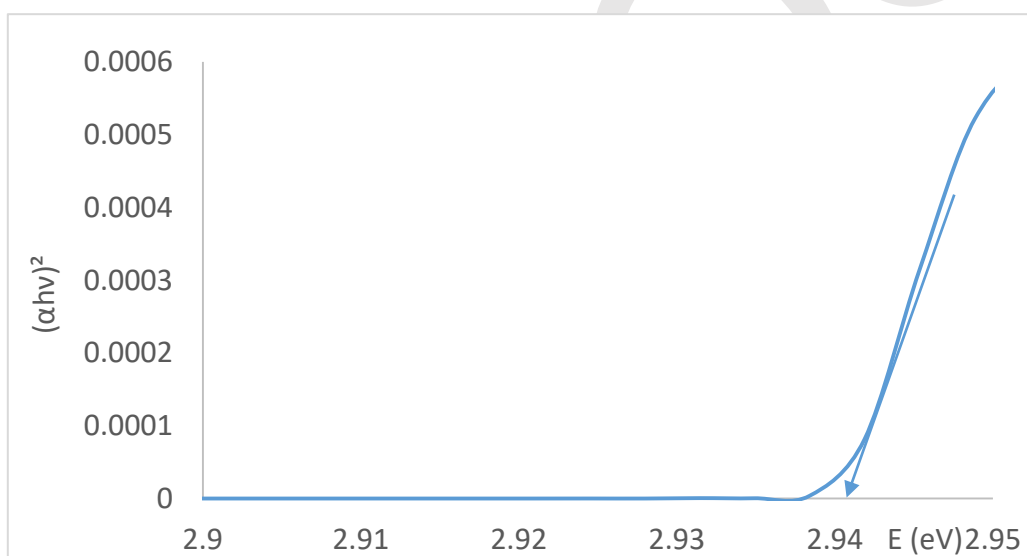


Figure 4. Graph of $(\alpha h\nu)^2$ versus Energy (eV) for ZnS thin film

3.4. Electrical study of ZnS thin films

The resistivity/conductivity is found to be $2.26\text{E-}04 \text{ } \Omega\text{cm}/4.43\text{E+}03 \text{ } \Omega^{-1}\text{cm}^{-1}$. The Hall coefficient R_H is $-1.35\text{E-}06 \text{ cm}^2/\text{C}$, Hall mobility μ_H is $-3.30\text{E+}02 \text{ cm}^2/\text{V-S}$ and Carrier density σ is $-7.41\text{E+}05 \text{ C/cm}^3$. This implies that, the ZnS thin

film deposited is an n-type semiconductor. The I-V characteristics of ITO/ZnS/Ag junction as shown in fig. 5 is linear. This implies that, the junction between ITO/ZnS and ZnS/Ag are Ohmic.

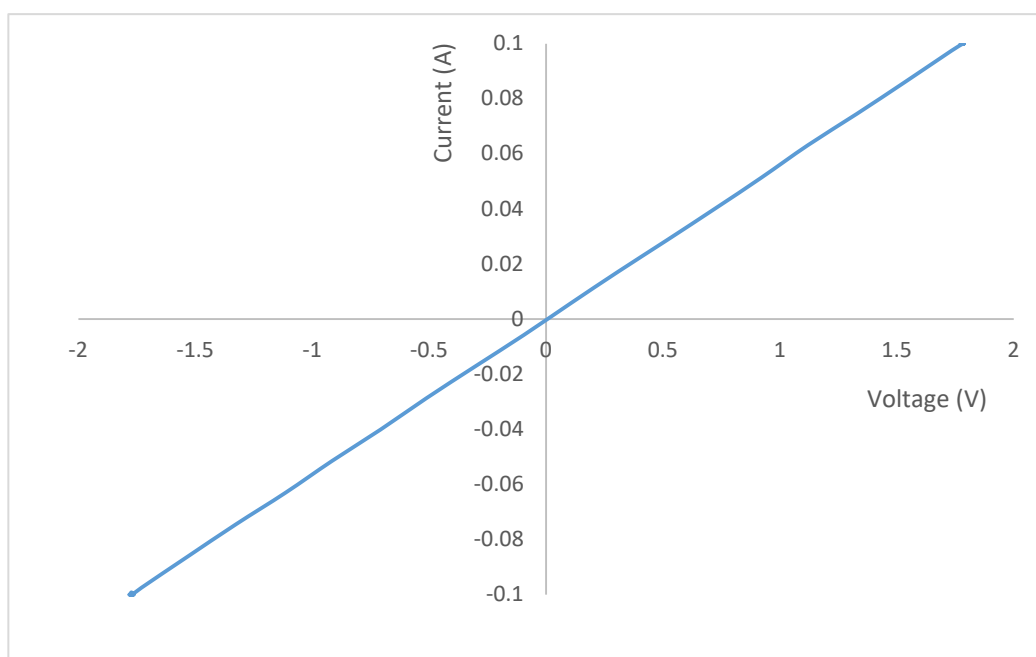


Figure 5. I-V characteristics of ITO/ZnS/Ag heterostructure

5. Conclusion and Recommendation

The study demonstrates that ZnS thin films can be successfully synthesized via a three-electrode potentiostatic electrochemical deposition method. The films exhibit continuous morphology, high transmittance, a direct band gap of 2.94 eV, and n-type conductivity, confirming their potential as window layers for thin-film solar cells. Based on the results obtained in this study, it is recommended that future studies should explore the effects of annealing and thickness variation on the optoelectronic properties to further optimize ZnS for application in developing environmentally benign photovoltaic devices.

Abbreviations

CdS	Cadmium sulphide
ZnS	Zinc Sulphide
FESEM	Field Emission Scanning Electron Microscope
XRD	X-Ray Diffractometer

Acknowledgements

The corresponding author is grateful to the duo of Prof. Z. A. Talib of Electrical properties laboratory, Department of Physics, University Putra Malaysia, Malaysia and Prof. Z. Zainal of Laboratory for Nano-materials and Environmental Catalysis, PUTRACAT, University Putra Malaysia, Malaysia for hosting me in their laboratories where this work was carried out.

Author Contributions

Lasisi, Akangbe Ramoni: Conceptualization, Methodology,

Writing- original draft,

Baqqiah, H: Electrical measurement, Review and Editing

Alabi, Aderemi Babatunde: Supervision , Review and Editing

Babalola, O. A: Supervision , Review and Editing

Conflicts of Interest

The author(s) declare that they have no known competing financial interests, professional affiliations or personal relationships that could have appeared to influence the work reported in this paper,

Funding

None

References

- Ahmed, S. M., L. A. Latif, A. and KH., Salim (2011) The effect of substrate temperature on the optical and structural properties of SnS thin films, *Journal of Basrah Researches*, 37, 3A.
- Gedi, S., Minnam Reddy, V. R., Alhammadi, S., Park, H., Jang, C., Park, C., & Kim, W. K. (2021). Synthesis and Characterization of π -SnS Nanoparticles and Corresponding Thin Films. *Nanomaterials*, 11, 3, 767.
- Kassim A, S. Nagalingam, H.S. Min and N. Karrim (2010) XRD and AFM Studies of ZnS Thin films produced by electrodeposition method. *Arabian Journal of Chemistry*, 3, 243-249.

- Liu W-L, Chen W-J, Hsieh S-H and Yu J-H (2012) Growth Behavior of Nanocrystalline ZnS Thin Films for Solar Cells Using CBD Technique. *Procedia Engineering* 36, 46-51.
- Murali, K. R. and S. Kumaresan. (2009). Characteristics of Brush Plated ZnS Films. *J. Chalcogenide Letters*. 6,1, 17-22.
- Ndukwe, I.C. (1996) Solution growth, characterization and application of Zinc Sulphide thin films. *Solar Energy Materials and Solar Cells*. 40, 123-13.
- Nogami, T., Suzuki, I., Motai, D., Tanimura, H., Ichitsubo, T., & Omata, T. (2025). Non-stoichiometry in SnS: How it affects thin-film morphology and electrical properties. *APL Materials*, 13,3, 031115.
- Sanders B.W and Kitai, A. H. (1990) The Electrodeposition of Thin Film Zinc Sulphide from Thiosulphate Solution. *Journal of Crystal Growth*. 100, 405-410
- Sze, S M (1985) *Physics of Semiconductor Devices* 2nd edition, Wiley Eastern Ltd, New Delhi.
- Vipin, K., Sharma, M.K., Gaur, J., Sharma, T.P. (2008). Polycrystalline ZnS Thin Films By Screen Printing Method and Its Characterization. *J chalcogenide Letters* 5, 11, 289 - 291.