Spectral selectivity of doped zinc and aluminium oxide thin films prepared by spray pyrolysis for solar energy applications

P C Simpemba[1,2], K Chinyama[1], J Simfukwe[1] and N R Mlyuka[3]

1 The Copperbelt University, School of Mathematics and Natural Sciences, Department of Physics, P.O. Box 21692, 10101 Kitwe, Zambia.

2 School of Physics, University of Witwatersrand, Private Bag 3, Wits, 2050, South Africa.

3 The University of Dar es Salaam, Faculty of Sciences, Physics Department, P. O. Box 35063, Dar es Salaam, Tanzania.

E-mail: pcs200800@gmail.com

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OUTLINE

- INTRODUCTION
- THEORY
- METHODOLOGY
- RESULTS AND DISCUSSION
- CONCLUSION
- ACKNOWLEDGEMENTS

INTRODUCTION

- ❖Hydro and fossil energy prices are rising rapidly with chance to double in a space of five years (Skyways, July 2013, pg 38).
- ❖Electricity load shedding is a norm rather than an exception –Eskom knows
- ❖Battle to meet country or regional energy demand
- ❖Utilization of solar technologies offer nearly an immediate solution for cheap, reliable green energy.
- ❖Looking to the skies for our energy requirements

✓Metal oxide thin films are used for thin film solar cells (TFSCs)

✓Development of cheap transparent conducting solid thin films –replacement of rare, expensive ITO.

✓These must be spectral selective

✓Spectral selectiveness is an important property in TFSCs

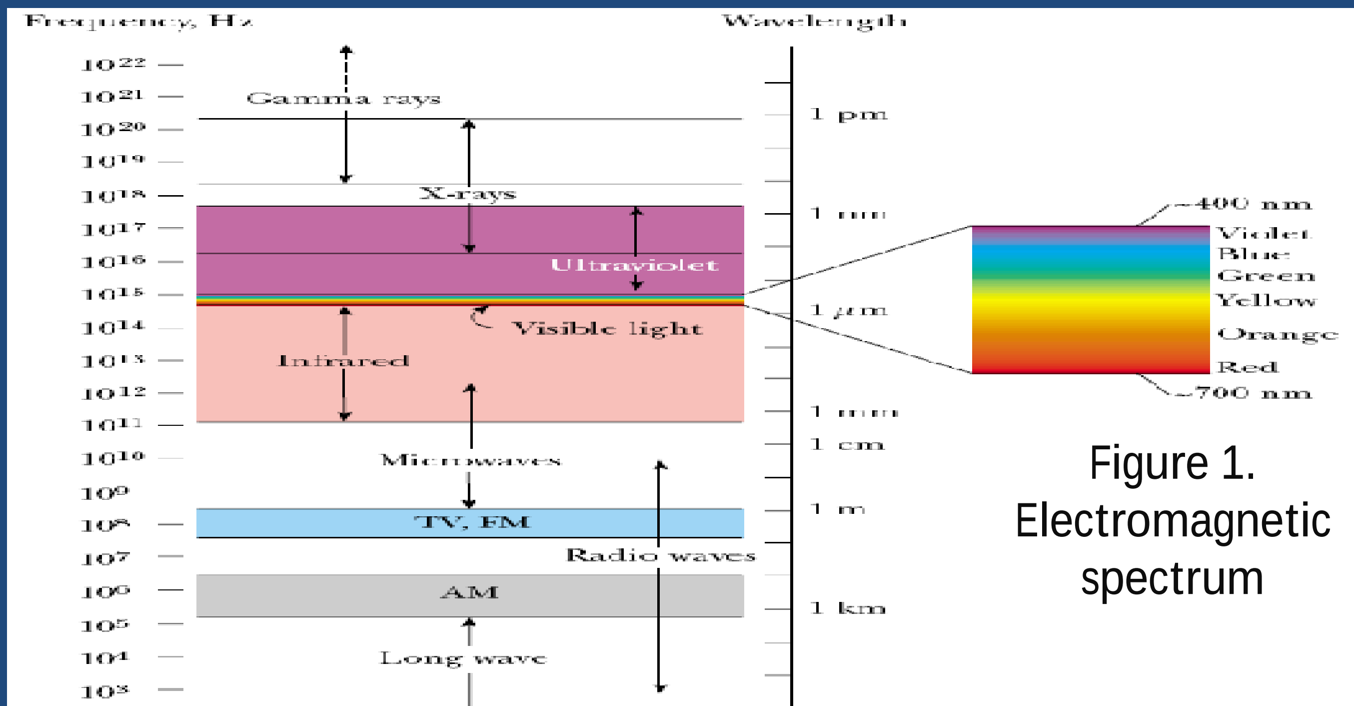


Figure 1. Electromagnetic spectrum

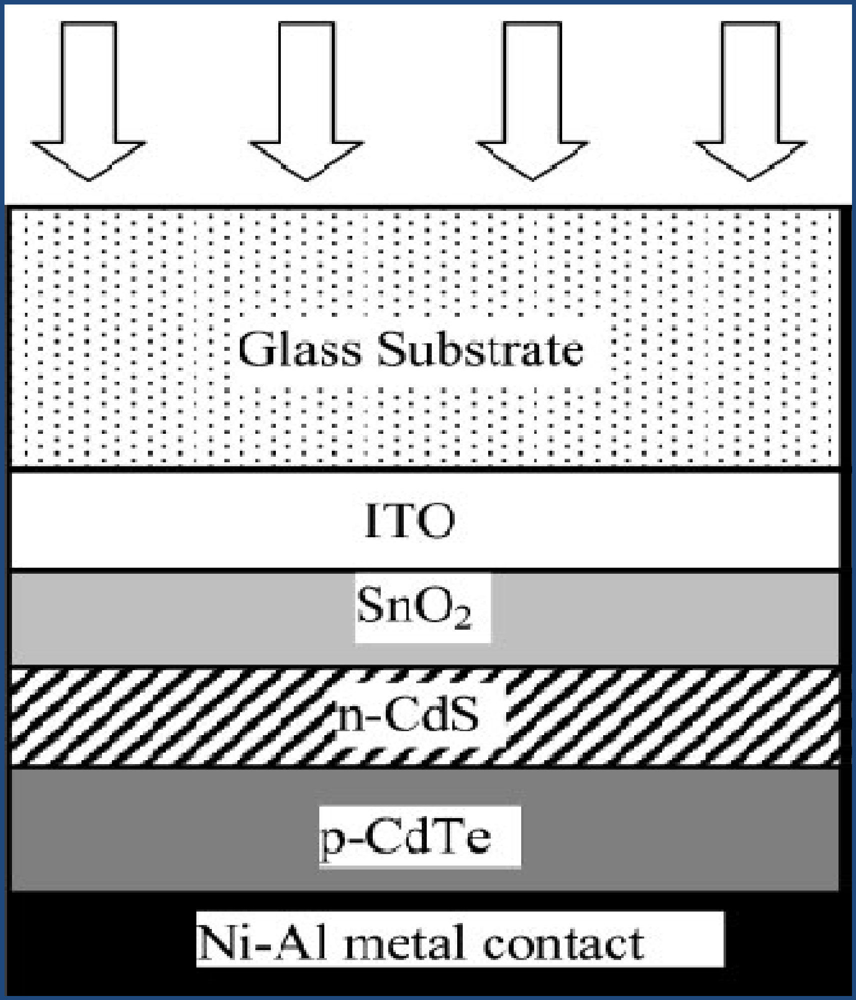


Figure 2. Typical thin film solar cell utilizing ITO as a TCO

A typical TFSC cell is made up of

- a substrate
- a transparent conducting oxide (TCO)
- a window layer
- an absorber layer and
- a metal contact layer

❖all of which have different physical, chemical, optical and electronic properties

❖Individual properties of the cell components affect the overall performance of the cell

Focus in this study is on the TCOs.

✓generally n-type semiconductor metal oxides

✓exhibit high transmittance of the visible (VIS) and near infrared (NIR) radiation

✓have high conductivity for efficient charge carrier transport when used as thin film electrodes or contacts in solar cells

✓In figure 2, ITO/SnO_2 transparent conducting oxides bi-layer were used …….expensive

We propose a new innovation

- ✓ to have a combination of mutually doped zinc and aluminium oxides making a bi-layer in a solar cell
- ✓ acting as the transparent oxides replacing the ITO/SnO_2 combination used in a typical solar cell in figure 2.
- ✓……cheaper approach

We have

- ✓produced mutually doped spectrally selective solid thin films of ZnO and Al_2O_3
- ✓investigated optical, electrical and structural properties
- ✓theoretically modeled these properties
- ✓tailor them for applications in efficient solar energy structures

THEORY

$$R = \frac{(n-1)^2}{(n+1)^2}$$

Reflectance as a function of reflective index for air-substrate interface

$$\alpha_\lambda = \frac{1}{d}\ln\left(\frac{1}{T_\lambda}\right)$$

Absorption coefficient for negligible reflectance

$$R = \int_{x_1}^{x_2} \rho \frac{dx}{2\pi x d} = \int_{s}^{2s} \rho \frac{dx}{2\pi x d}$$

$$R = \frac{V}{2I} = \frac{\rho}{2\pi d}\ln 2$$

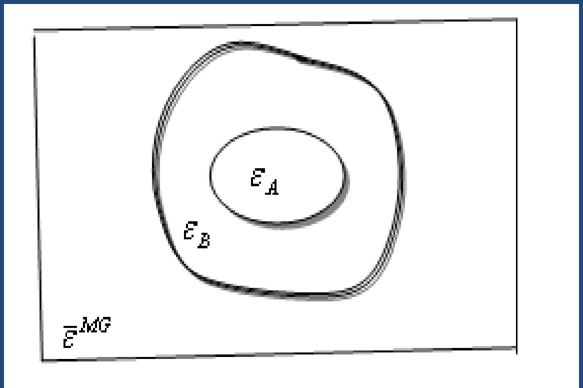
Electrical resistance

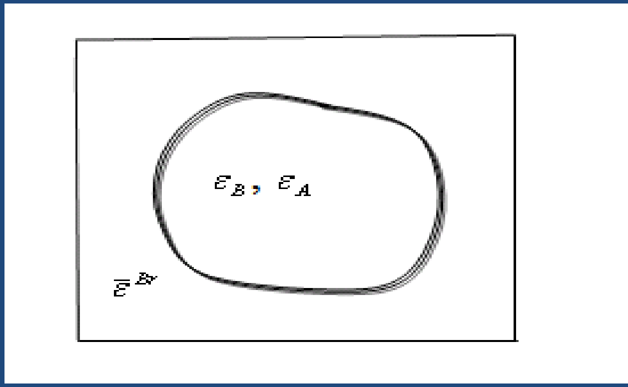
For an effective medium.

$$\bar{\varepsilon}^{MG}=\varepsilon_B\left(\frac{\varepsilon_A+2\varepsilon_B+2f_A(\varepsilon_A-\varepsilon_B)}{\varepsilon_A+2\varepsilon_B-f_A(\varepsilon_A-\varepsilon_B)}\right)$$

Maxwell-Garnett effective medium having respective dielectric permeability ε_A and ε_B

$$f_A = \frac{a^3}{b^3}$$





Bruggemann effective medium

$$f_A\left(\frac{\varepsilon_A-\bar{\varepsilon}^{Br}}{\varepsilon_A+2\bar{\varepsilon}^{Br}}\right)+(1-f_A)\left(\frac{\varepsilon_B-\bar{\varepsilon}^{Br}}{\varepsilon_B+2\bar{\varepsilon}^{Br}}\right)=0$$

METHODOLOGY

Raw materials:

✓zinc chloride ($ZnCl_2$)

✓aluminium chloride hexahydrate ($AlCl_3.6H_2O$)

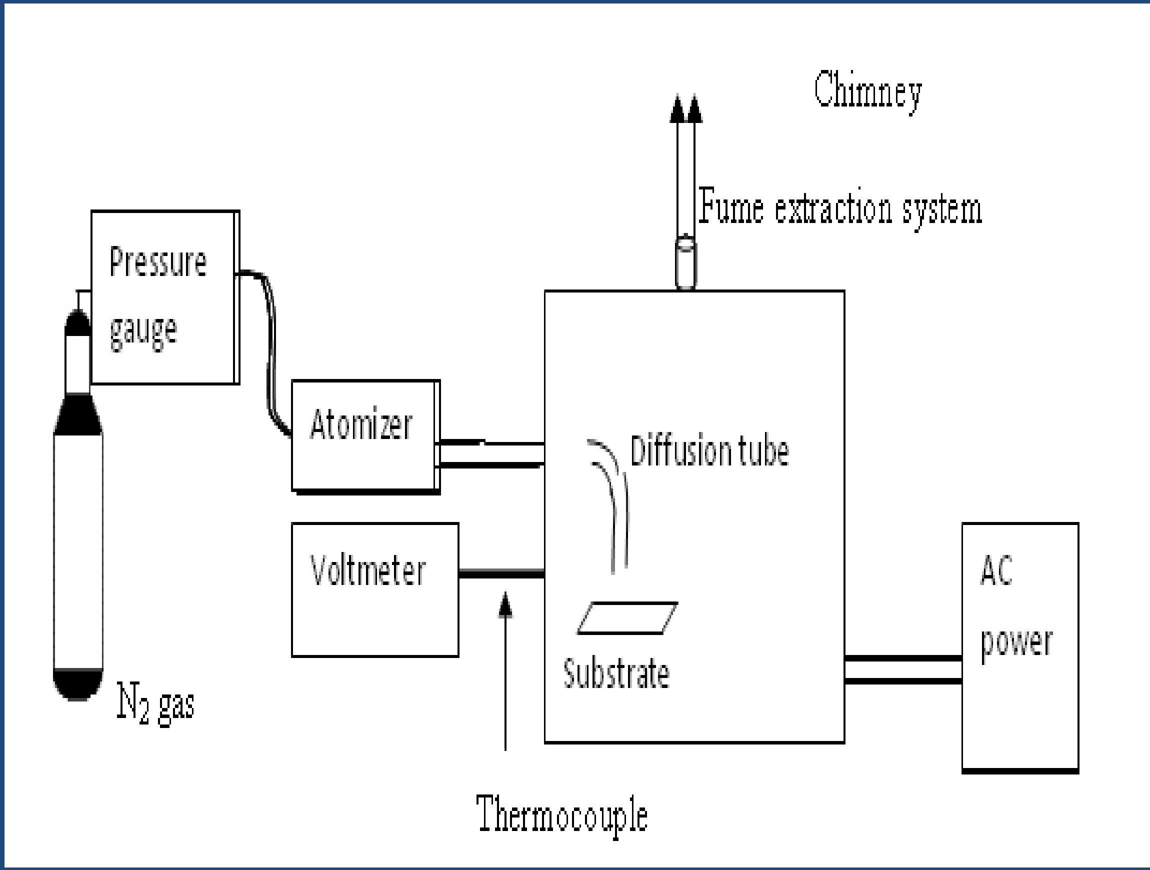
❖ The $ZnCl_2$ and $AlCl_3.6H_2O$ were weighed on an electronic balance

❖Mutual doping was done by adding a determined amount to either chloride

❖Mixture was dissolved in distilled water, forming aqueous solutions of different molar concentrations and doping levels

❖hydrochloric acid was added to the solution to prevent precipitation to hydroxide

Spray pyrolysis technique was employed for coating thin films



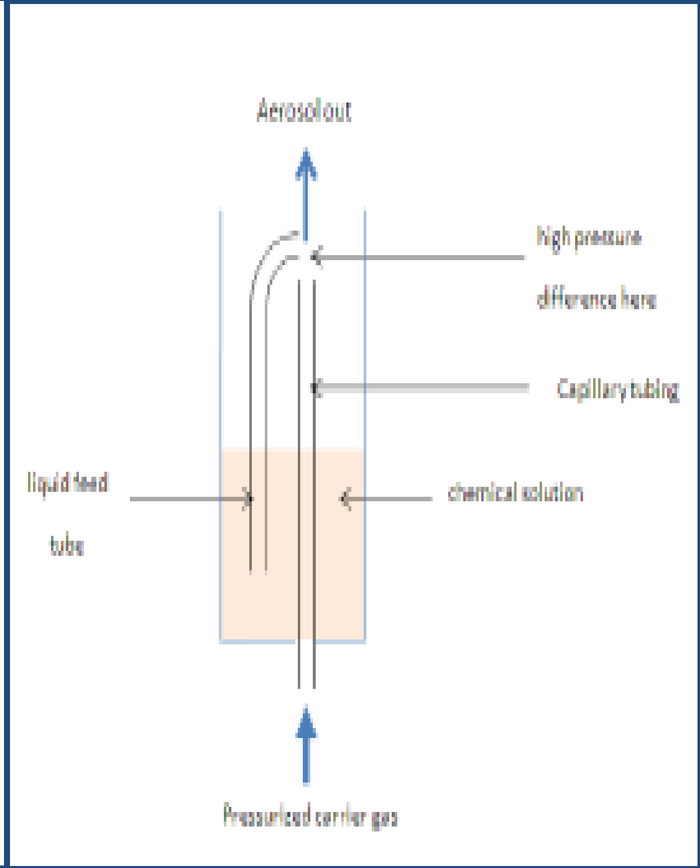


Figure 3. Spray pyrolysis unit

Transmittance and reflectance measurements

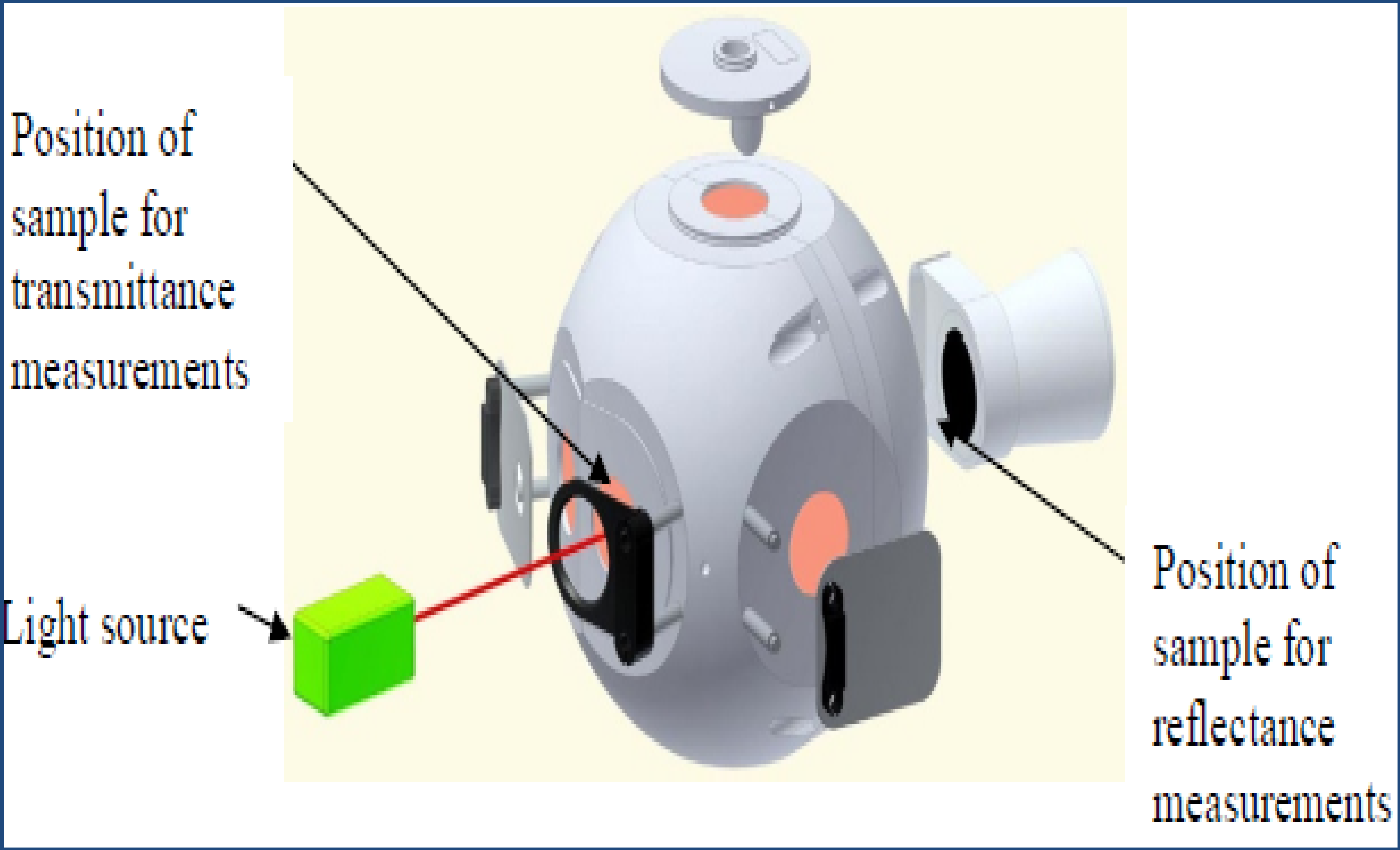


Figure 4. Integrating sphere of a spectrometer

Thickness measurements

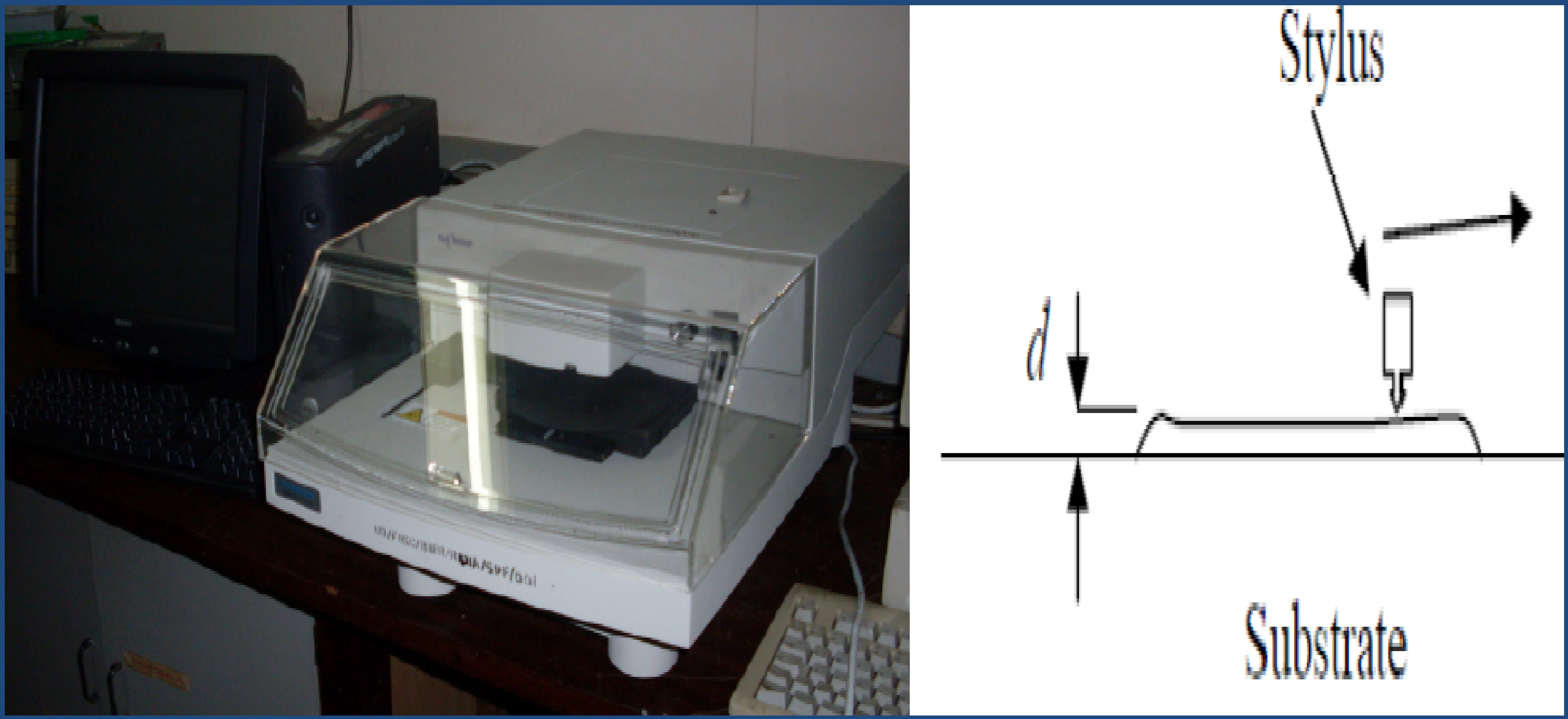


Figure 5. Tencor Alpha Step profiler

Film surface characterization

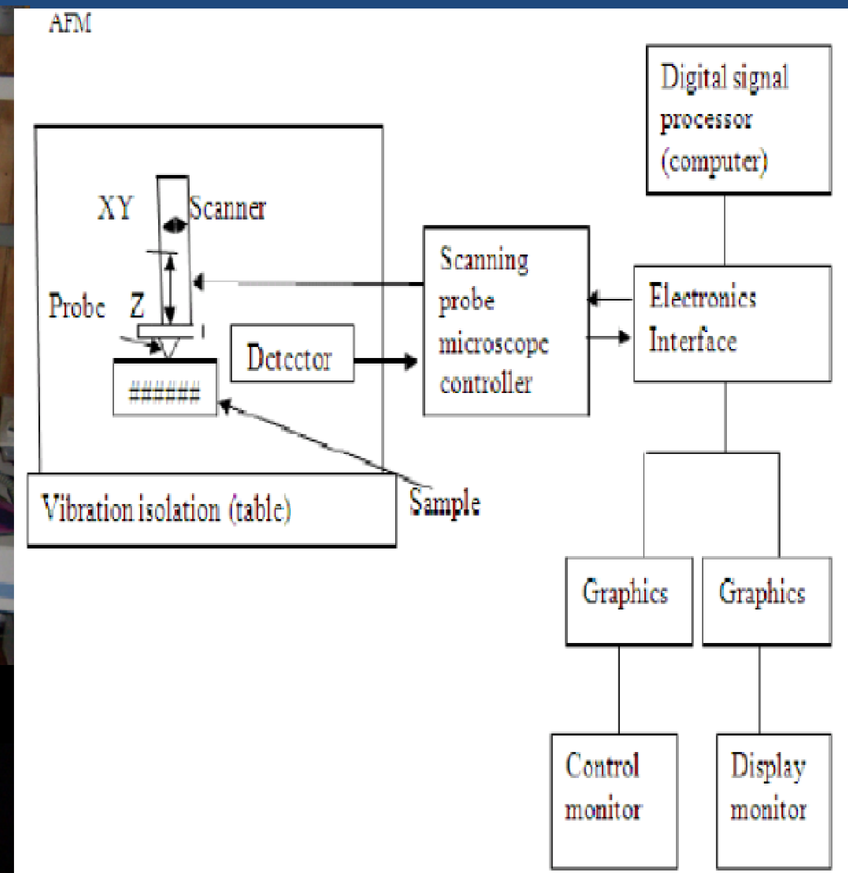


Figure 6. System components of the AFM: electronics interface, microscope, objective lens, Optical lighter, control monitor, display monitor and CPU.

Electrical measurements

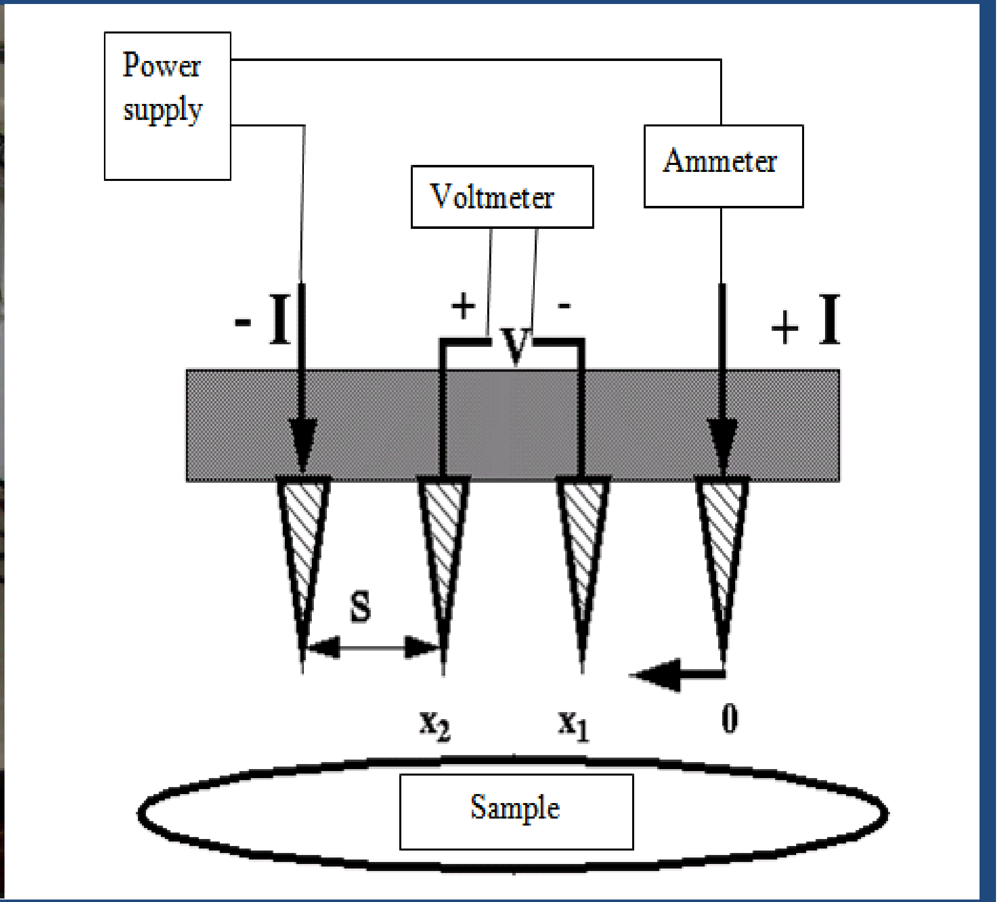


Figure 7. Physical arrangement of the four point resistance probe

RESULTS AND DISCUSSION

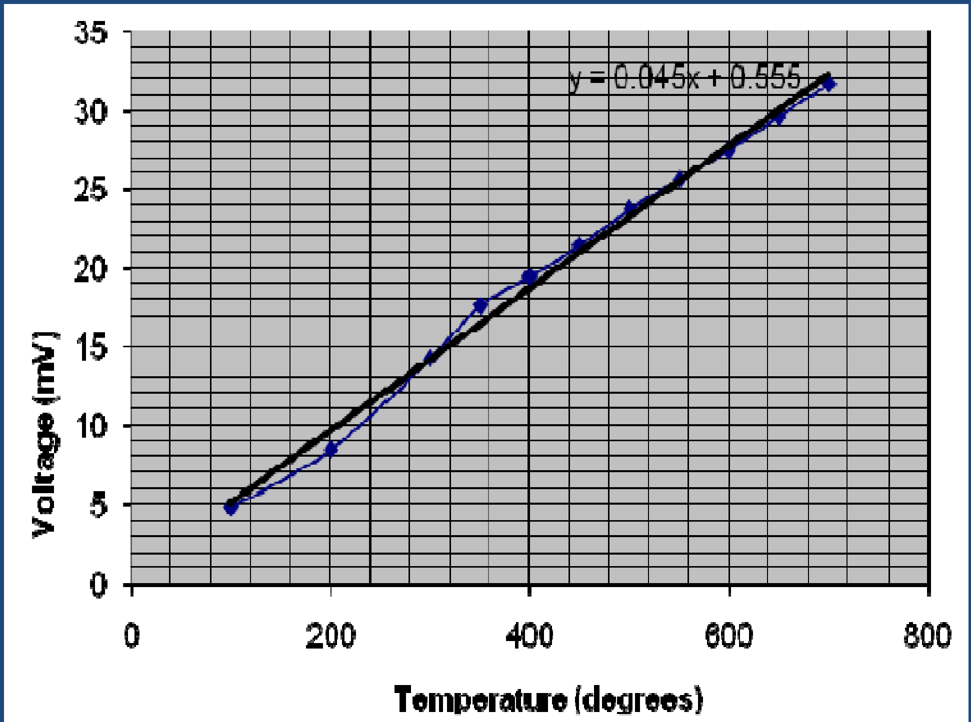


Figure 8. Thermocouple temperature calibration curve

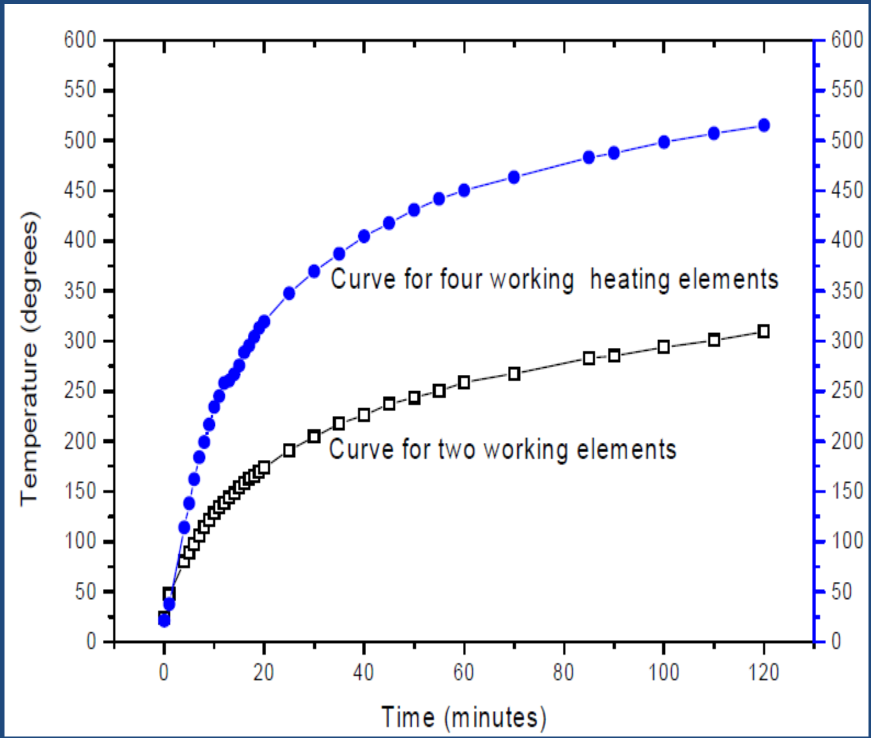


Figure 9. Oven temperature as a function of time.

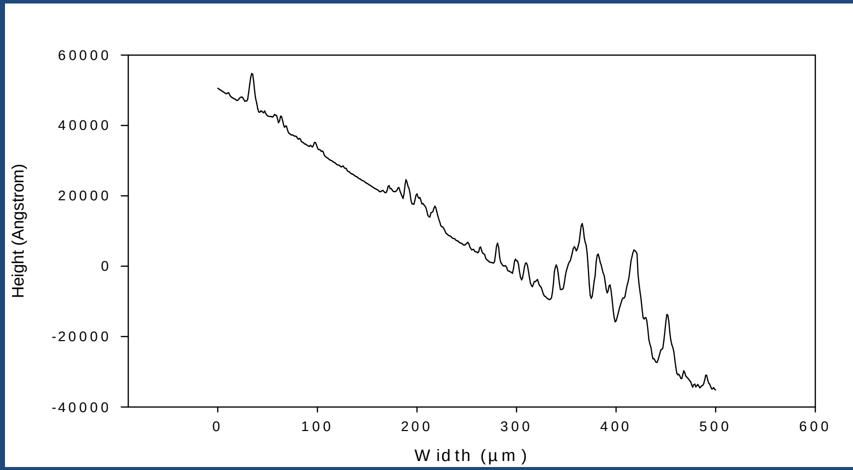


Figure 9. Thickness profile of double layer Al_2O_3 thin film

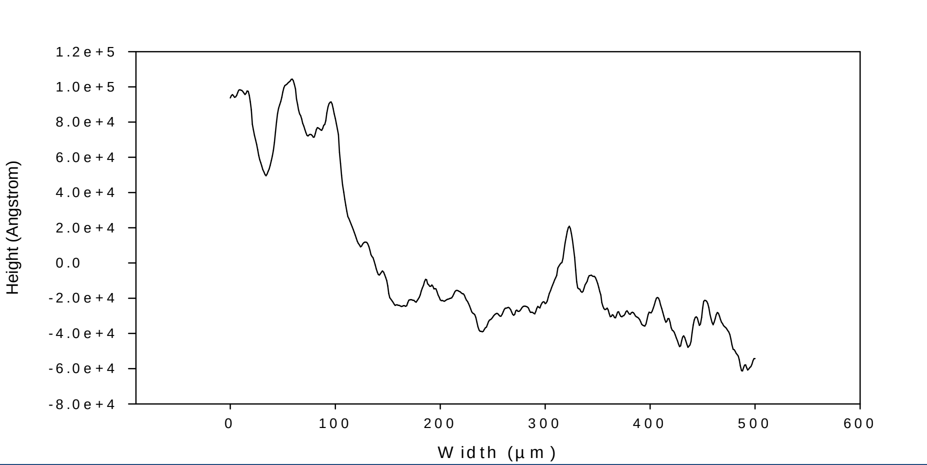


Figure 10. Thickness profile of single layer ZnO thin film

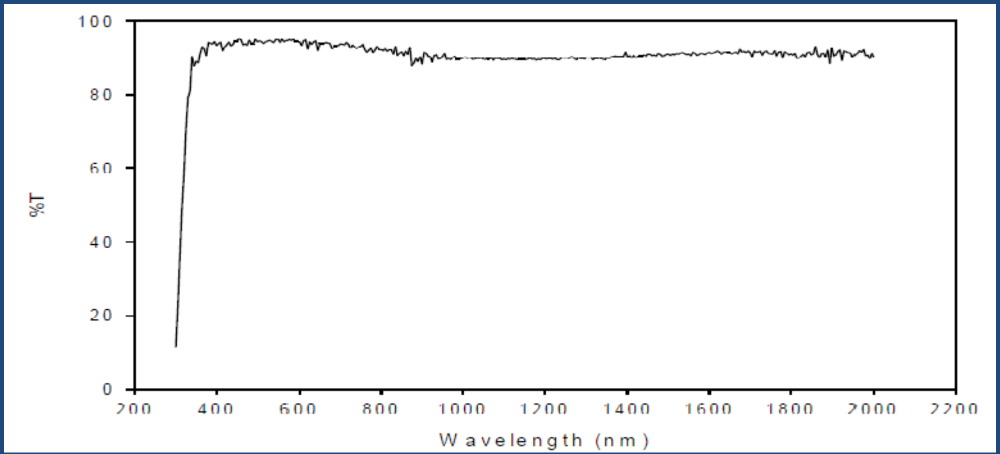


Figure 11. Transmittance curve for uncoated glass slide in UV-VIS-NIR region

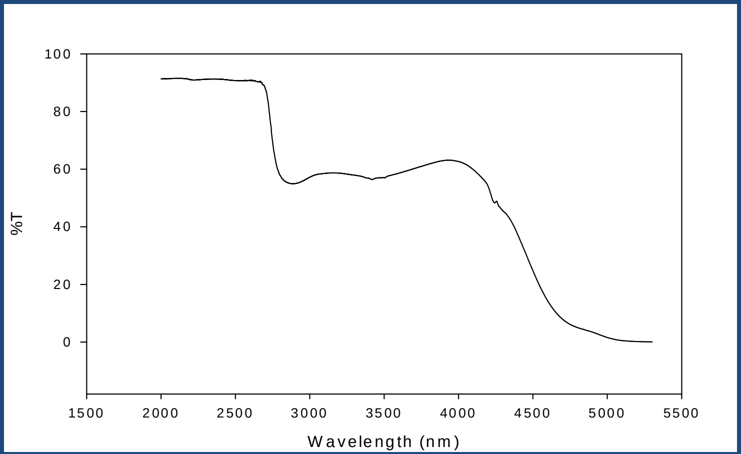
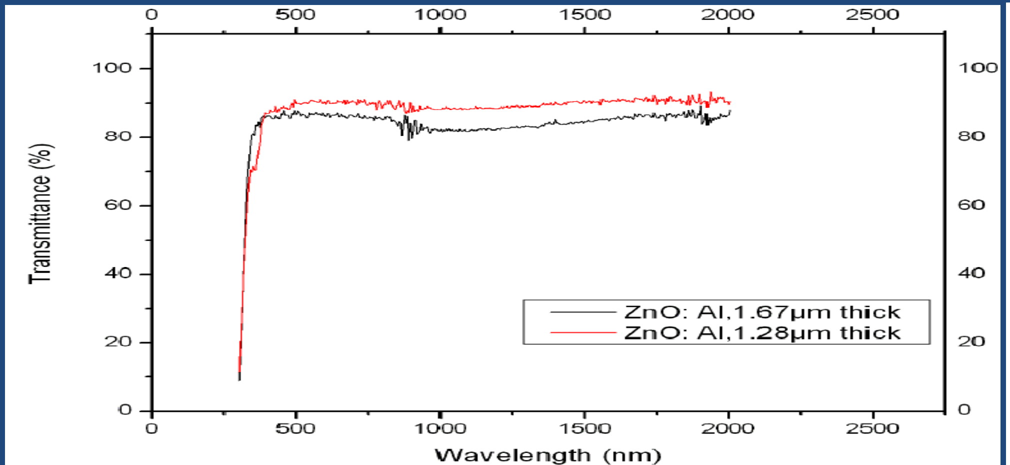


Figure 12. Transmittance curve for uncoated glass slide in the IR region



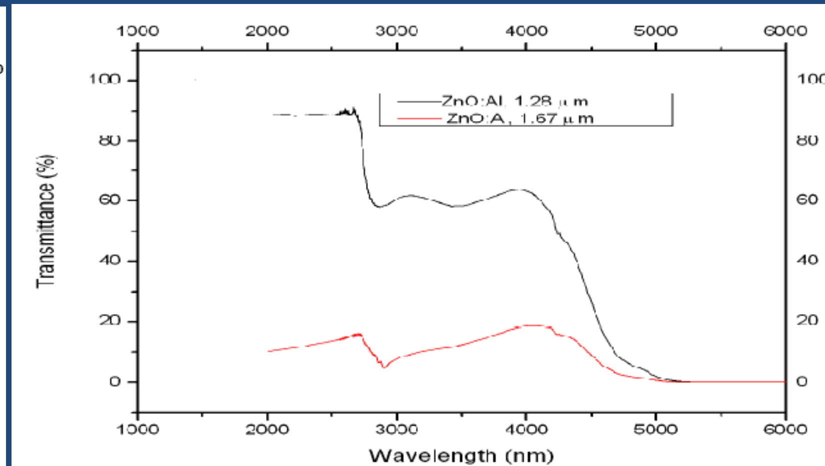
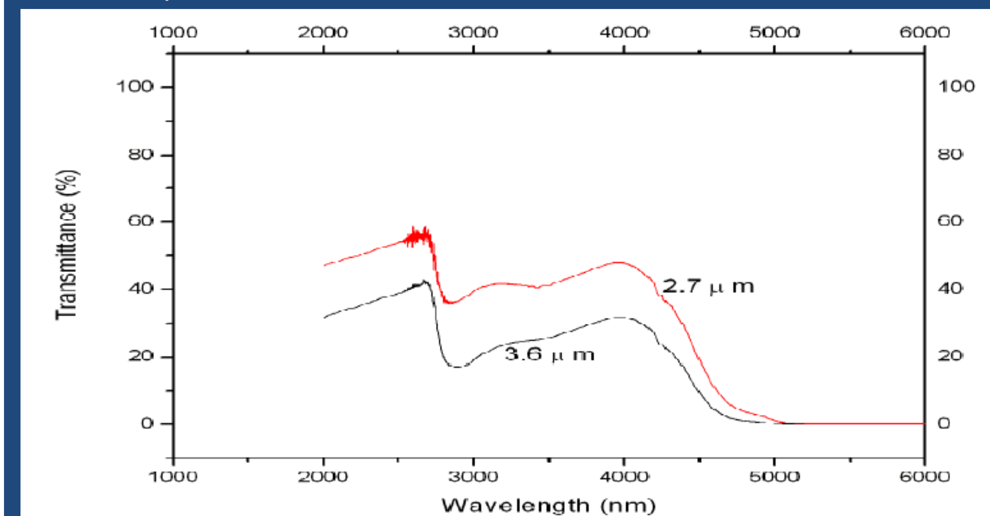


Figure 13. Solar transmittance curves for ZnO: Al films of thicknesses 1.67µ m and 1.28 µ m fabricated at 320º C and 340º C.

Figure 14. NIR and IR transmittance curves for ZnO:Al films of thicknesses 1.67µ m and 1.28 µ m fabricated at 320º C and 340º C.



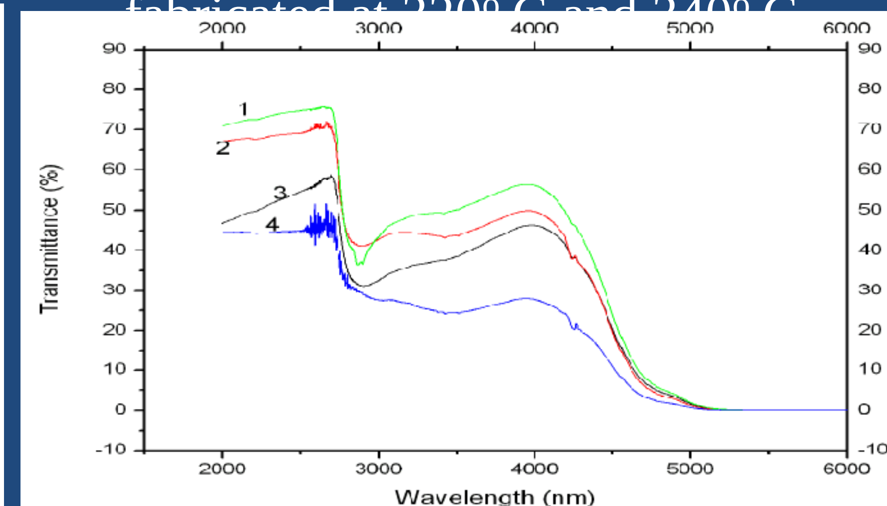
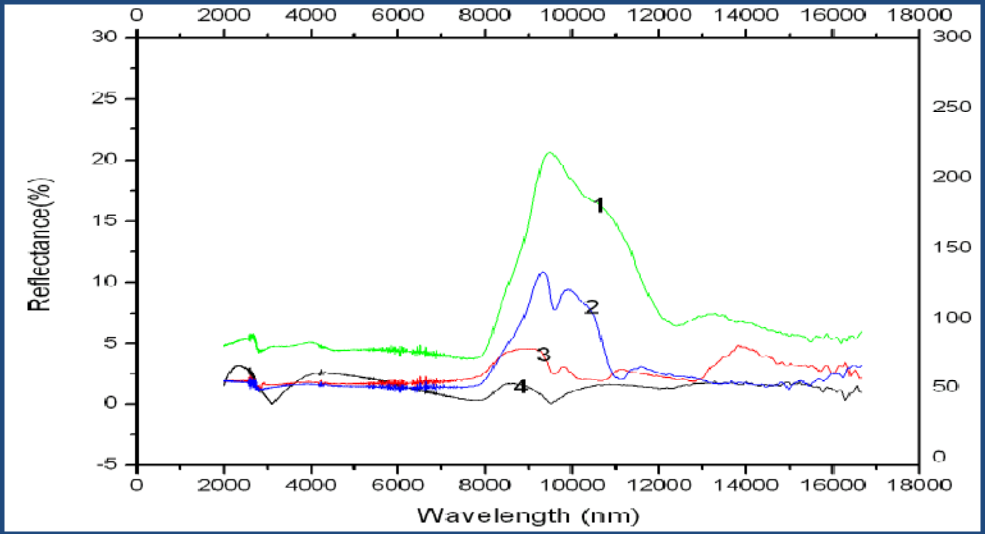


Figure 15. NIR and IR transmittance curves for ZnO:Al films of thicknesses 2.7 µm and 3.6 µm fabricated at 340º C and 290º C.

Figure 16. NIR and IR transmittance curves for Al_2O_{318} coatings



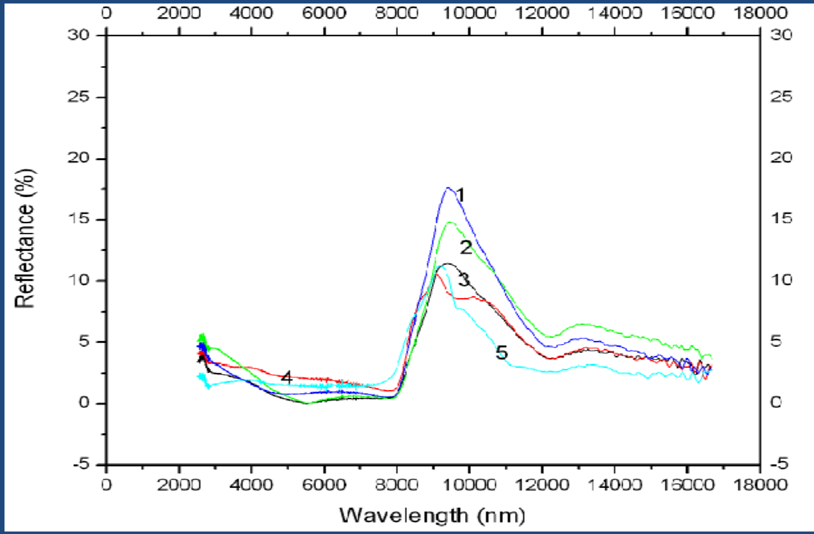


Figure 17. Reflectance curves for ZnO:Al   Figure18. Reflectance curves for Al_2O_3

❖Spectral selectivity of the thin films is established.
❖The thin films are therefore suitable for use as TCOs in RFSCs.

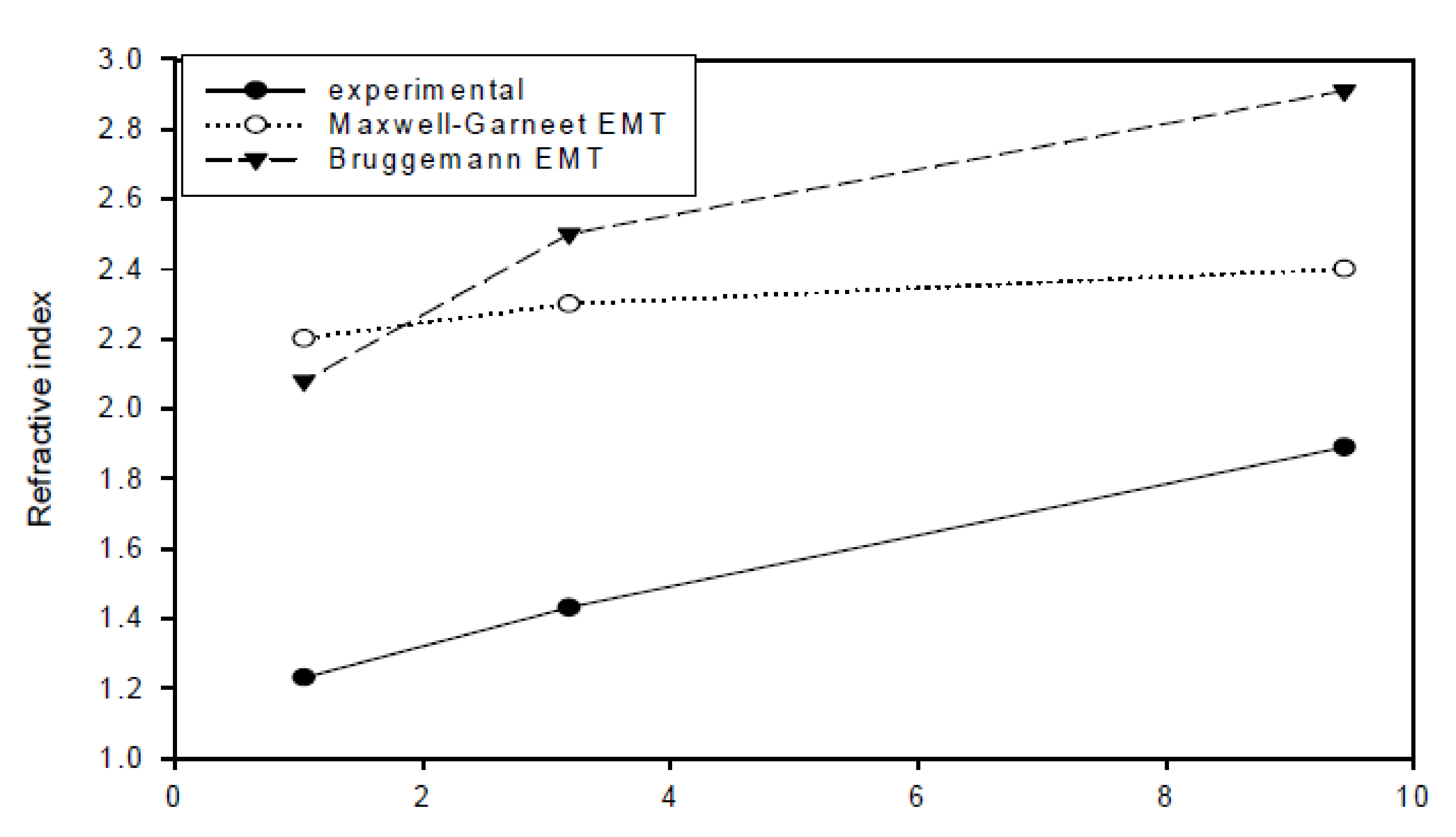


Figure 19. Refractive index as a function of reflectance, effective media effect applied to figure 19 (d)

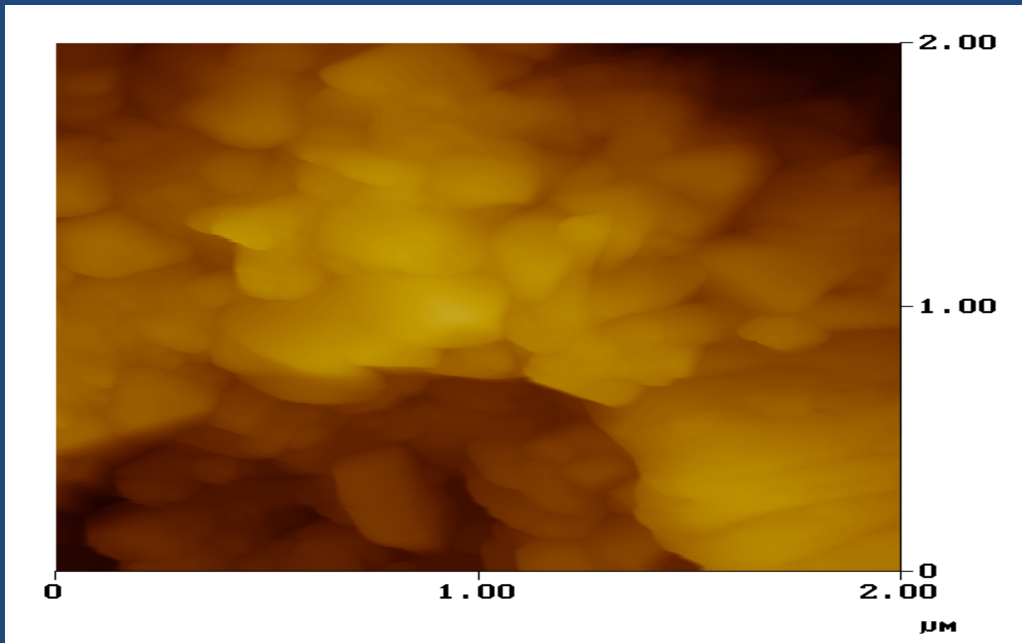


Figure 20. Surface roughness of ZnO:Al

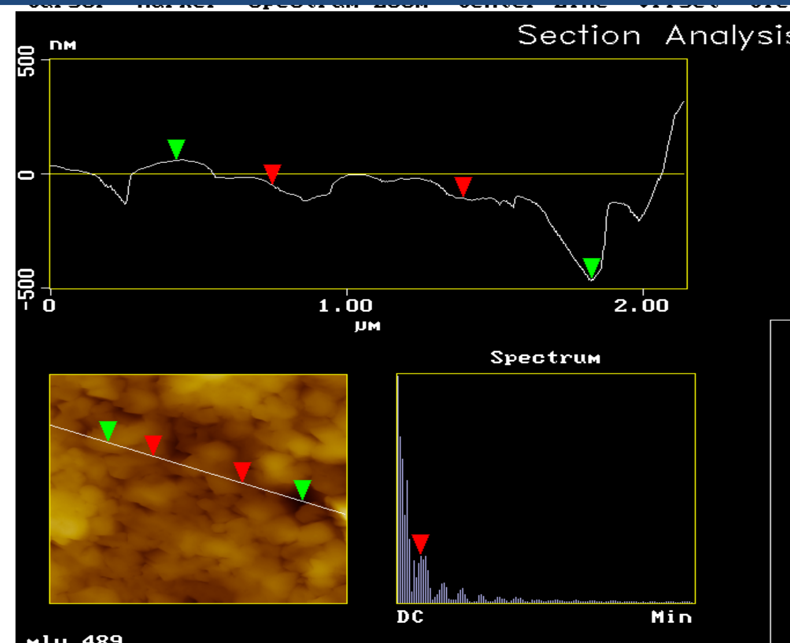


Figure 21. Section analysis

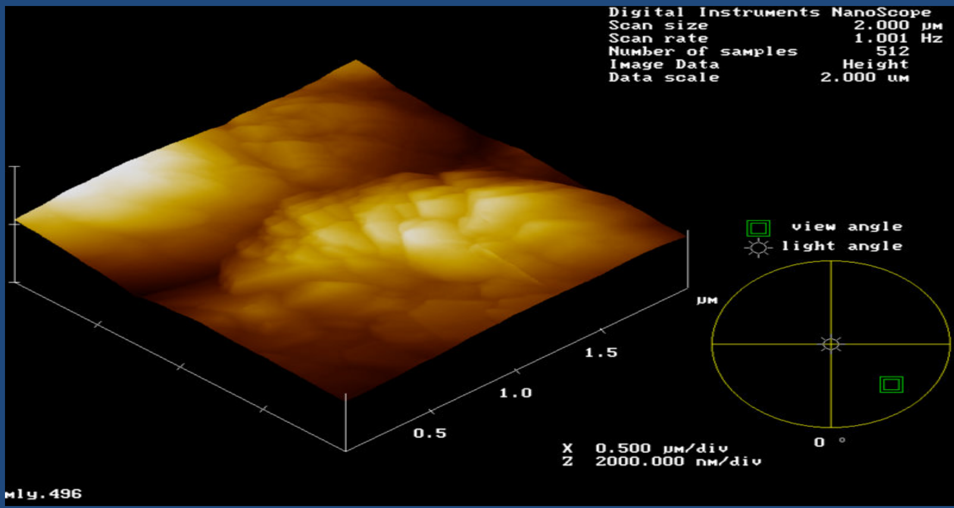


Figure 22. Surface plot for undoped ZnO thin film deposited at 340°C

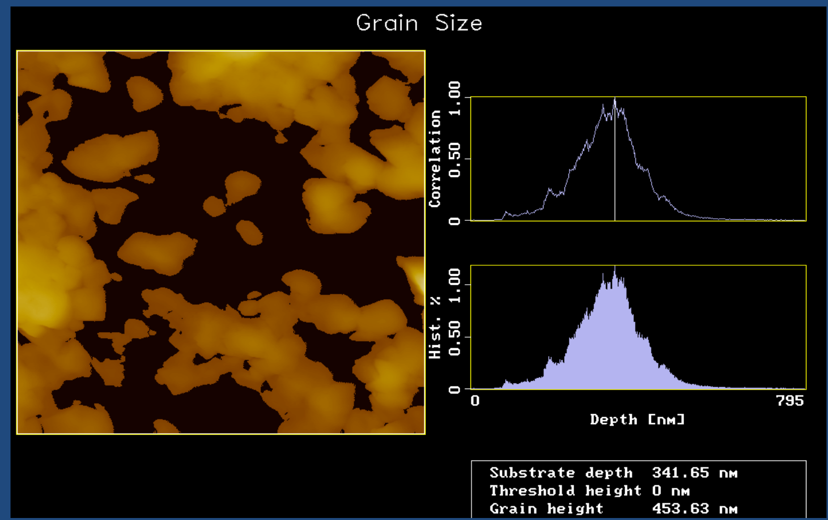


Figure 23. Distribution of grains in the thin film

Ω

SPECTRUM	AVERAGE REFRACTIVE INDEX		
	ZnO	ZnO:Al	Al_2O_3:Zn
VIS-NIR	1.80	1.96	2.00
FIR	1.28	1.53	1.30

Table 1. Wavelength-dependent refractive indices of selected thin films in the VIS-NIR and FIR wavelength regimes.

Sample	Resistance (Ω)	Average resistance (Ω)	Resistivity (10^{-4} Ωm)
25B	0.75	5.24	0.0959
26A	9.54		2.43

Table 2. Calculated electrical values for ZnO: Al

Sample	Resistance (Ω)	Average resistance(Ω)	Resistivity (10^{-4} Ωm)
S5	5.56	8.78	11.8
10-03A	12		4.47

Table 3. Calculated electrical values for Al_2O_3:Zn

CONCLUSION

- ❖We have utilized a simple and cheap process of fabricating spectrally selective thin solid films by way of the spray pyrolysis process.
- ❖The films' optical, electrical and structural properties have been investigated
- ❖A solar transmittance of 88 per cent was obtained for doped zinc oxide and 71.9 per cent for aluminium oxide films
- ❖This result is good for thin film application in solar cell manufacture
- ❖reflectance peaks were observed in the wavelength range 8,000-13,000 nm

❖Film resistivities obtained were to the order of 10^{-4} m. This result was good for possible application in thin film solar cells

❖The Maxwell-Garnett and Bruggeman effective medium theories were applied to obtain effective dielectric permeabilities of the film coatings

❖A new transparent conducting thin film combination of a ZnO:Al/Al_2O_3:Zn TCO combination has been proposed to replace the ITO/SnO_2 combination as a cheaper alternative.

SAVE THE ENVIRONMENT BY PROMOTING GREEN ENERGY

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- ✓The University of Zambia (UNZA)

- ✓Authors of reference materials –see paper.

THANK YOU ALL