IOSR Journal of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 7, Issue 3 Ver. IV (May. - Jun. 2015), PP 20-28
www.iosrjournals.org

Investigation of the Role of Substrate Temperature on the Electrical and Optical Properties of Zinc Oxide Doped With Aluminium Thin Film

[1]T.O. Daniel, [2]M. Alpha and [3]L.S. Taura

1&3 .Department of Physics, Sule Lamido University, P.M.B 048, Kafin Hausa, Jigawa State, Nigeria.
2. Department of Physics, Federal University of Technology Minna, P.M.B 65, Minna, Niger State, Nigeria.

Abstract: *ZnO:Al thin films were prepared by Electrostatic spray deposition on soda lime glass substrate. The role of substrate temperatures (300, 350, 400 and 450 ^{O}C) on the Electrical and Optical properties of the films were investigated.The electrical properties of the films were strongly dependent on the substrate temperature. ZnO:Al thin film has lowest resistivity ($1.8 \times 10^{-5} \Omega m$) and highest conductivity of 5.61 $\times 10^{4} (\Omega m)^{-1}$at substrate temperature of 400 ^{0}C. Also the optical transmittance of ZnO:Al thin films were obviously influenced by the substrate temperature. All films exhibit transmittance greater than 50% in the visible region with the highest value of 84% at 400 ^{0}C. More significantly, Aluminum doping leads to an evident widening of optical band gap from3.429 to 4.160 eV; and the increase is found to depend on substrate temperature.*

Keywords:*TCO, Substrate temperature, ZnO:Al Thin film, Transmittance, Resistivity.*

I. Introduction

In the quest for an alternative energy source due to environmental pollution, global warming and increase in energy demand, solar energy which is a renewable energy have been considered as an alternative[1]. The solar energy production is made possible by using a solar cell. At present, Silicon based solar cell tend to occupy the solar energy market, but thin film solar cell is currently gaining recognition due to its low cost in comparison to the high cost of silicon based solar cell which has make the entire production of solar energy to be expensive[2]. An essential material for the thin film solar cell is transparent conducting oxides [2].Transparent conducting oxides (TCOs) are electrical conductive materials with a comparably low absorption of light. They combine low electrical resistance with high optical transparency in the visible range of the electromagnetic spectrum[3].These properties are sought in a number of applications, notably as electrodes materials and window in solar cells where an electric contact needs to be made without obstructing photons from either entering or escaping from the optical active area[4].TCOs for use in solar cell is often required to have a minimum carrier concentration on the other of 10^{20} cm^{-3} for low resistivity, a transmittance greater than 80% and a band gap greater than 3.26 eV to avoid absorption of light over most of the solar spectra. Current TCOs used in industry are primarily n-type conductors. Suitable p-type TCOs is still being researched [1].

To date, the industry standard in TCOs is ITO (Tin doped indium oxide). This material boasts a low resistivity of about 10^{-4} Ωcm and a transmittance greater than 80%. However ITO has the drawback of being expensive as Indium which is the primary element is rare and its price fluctuates due to market demand. For this reason, doped binary compounds such as Aluminum doped Zinc oxide (ZnO:Al) and indium doped cadmium oxide have been much proposed as unique alternative materials. ZnO: Al consists of Aluminum and Zinc which are two common and inexpensive materials. Zinc Oxide has some advantages over commonly use materials such as ITO, Cd_2SnO_4 and In_2O_3 due to its unique combination of appealing properties: non-toxicity, good electrical, optical and piezoelectric behavior, stability in hydrogen plasma atmosphere, thermal and chemical stability and its abundance in nature which makes it cheaper than its competitors hence reason for its wide choice[5].

ZnOhasarelativelylargedirectbandgapofapproximately 3.3eVatroomtemperature. This enables it to have high breakdown voltages, ability to sustain large electric fields, lower electronic noise, high temperaturea nd high-power operation. The band gap of ZnO can further be tuned from 3 to 4eV by doping or co-doping[6]. ZnO basically has n-type character, even in the absence of intentional doping. Native defects such as oxygen vacancies or zinc interstitials are often assumed to be the origin of this, but the subject remains controversial. Unintentional substitutional hydrogen impurities are also assumed to be responsible for its n type character. Controllable n-type doping is easily achieved by substituting Zn with group-III elements (Aluminum(Al), Gallium(Ga), Indium(In)) or by substituting oxygen with group VII elements such as chlorine or iodine. Doping is the addition of impurity atoms to an intrinsic semiconductor in order to increase it conductivity. Aluminum is mostly used compared to indium due to its relative cost and scarcity[5] .Doping of ZnO films not only improve its electrical and optical properties, but also makes them highly stable.

The presence of intrinsic defects such as Oxygen vacancies and Zinc interstitials allows non stoichiometric ZnO to have intrinsic n-type conductivity with high electron densities of about 10^{21} cm^{-3}. However, the resistivity of ZnO is not as good as the ITO standard since ZnO native point defects are not efficient donors. Thus much research has focused on an intentional doped ZnO such as ZnO: Al which has more stable electrical and optical properties comparable to ITO which is a known TCO for thin film solar cell. However such Aluminum dopant requires a high degree of deposition control or the optimization of substrate temperature to obtain a carrier concentration suitable for use as a TCO in thin film solar cell due to its high reactivity with oxygen, since both carrier concentration and carrier mobility are sensitive to substrate temperature[7].The highest conductivity value for ZnO: Al thin films have been reported at an Al concentration of 2-3 atomic percent [7-9]. Above a certain level, the excess Al atoms exist in the films as interstitial atoms or tend to segregate into grain boundaries and poor crystallized area there by working as electrically inactive sites with a build-up of an energy barrier limiting carrier transport and decreasing carrier concentration.

To date, scanty literatures exist on the role or effect of substrate temperature on the structural, electrical and optical properties of ZnO: Al thin film and all the literatures available makes use of sputtering technique of deposition [10-13] or the Pulsed laser deposition [14]. The sputtering methods used by the various researchers have a drawback of requirement of expensive vacuum chambers and equipment, while its operation and maintenance required highly skilled technicians. The pulsed laser deposition has problem of stability and cost such that how to increase growth rate and application to continuous, in-line manufacturing is a vital problem. TheElectrostatic spray Deposition (ESD) also called Electrostatic spray pyrolysis (ESP) or Electro sprayingmethod comprises of generating an aerosol by applying a high potential (5-25Kv) to a surface of a conducting liquid, which contains desired precursor materials.

Electrostatic spray deposition (ESD) is capable of dividing a liquid into fairly uniform and well distribute ddroplets with dimensions that can be controlled from several micrometres down to the nanometre range.It has a well-defined trajectory of spray droplets directed towards the substrate by the electric field, making it economical in precursor usage.

Comparedwithotherfilmfabricationtechniques,ESDoffers attractiveadvantagesof easycontroloffilmcomposition,easycontrolofsubstratetemperatureduringdeposition,highfilmgrowthrate,simplesetup, low cost and usage of chemicals and minimal waste .The process can be carried out in ambient atmosphere, in air or other gases and at low temperature, without the need for a complex reactor and vacuum systems. ESD can produce highly pure materials with structural control at the nanometre scale. The crystallinity, texture, film thickness, and deposition rate can be controlled by adjusting voltage, flow rate, and the substrate temperature [15-16]. The Electrostatic Spray Deposition which is the method employed in this research for the fabrication of ZnO: Al thin film has been rarely reported for ZnO: Al. Within the limit of open access journals, it has only been reported by [8] for the deposition of ZnO: Al thin film while there is no report on the role of substrate temperature on the properties of ZnO: Al thin film using ESD. Hence we investigate the role of substrate temperature on the structural, electrical and optical properties of Electrostatic spray deposited ZnO: Al thin film in order to find an optimum temperature for the fabrication of ZnO: Al thin film using ESD for use as a TCO in thin film solar cell with easy reproducibility of film properties.

II. Materials And Method

Soda lime glass substrate (Skytec microscopic glass slide of area 25.4 mm by 77.2 mm, Thickness-1.0 mm and Refractive index -1.52), was first cleaned in acetone and distilled water, after which it was dried in air for about 10 minutes and was then placed on the substrate heater via the substrate holder. 24.2506 ml of Zinc acetate solution plus 0.7500 ml of Aluminum chloride solution was used for doping at 3at% of Aluminum dopant concentration. This was achieved by mixing 0.2 M Zinc Acetate (99.99%, BDH) solution which was prepared by dissolving a solute quantity of 1.756 g of Zinc Acetate in 40ml of solvent (Ethanol: water (80:20v/v)) with 0.2M aluminum chloride (99.50%, BDH) solution which was prepared by dissolving a solute quantity of 1.0666g of Aluminum chloride in 40ml of solvent (Ethanol: water (80:20v/v)) at 3at % dopant concentration. This was enhanced by using a magnetic stirrer for about 15minutes with addition of a drop of acetic acid to facilitate the complete dissolution of the solute in the solvent and to obtain a transparent and homogenous solution. A syringe pump (5ml- Hypodermic syringe, manufactured by Shandong Zibo Shanchuan medical instrument Co. Ltd, Shandong China- LOT NO: 201312) was used to feed the precursor solution through a silicon tubing connected to a small stainless steel needle (0.184mm and 0.3366mm, inner and outer diameter respectively) for atomization. D.C voltage supply (5-20 kV) was applied between the needle tip and the hot plate to get a stable cone-jet mode by a D.C power supply. The distance between the nozzle and the substrate was kept constant at 10cm for all depositions. The Electrostatic spray was then conducted at varying substrate temperatures of 300-450 ^oC (i.e. 300, 350, 400 and 450 ^oC) for four samples during the deposition. The substrate temperatures were maintained at the desired temperature using an Aluminum heater and type K thermocouple attached to a digital temperature indicator while the environment inside the ESD equipment was surrounded with the solvent of choice via an external solution compartment to enhance improved thin film production. The spray rate of precursor solution was maintained at 0.05 mL/ min throughout the experiment. After the deposition the deposited films was allowed to cool down to room temperature before been taken out for characterization.

Avantes UV-Visible Spectrophotometer was used to determine the Transmittance T and the Reflectance R in the wavelength range of 400-780 nm at SHESTCO. The Absorbance A, the Absorption coefficient α, the Band gap E_g, Extinction coefficient k and Refractive index n of the Aluminum doped ZnO thin films were determined from the Transmittance and Reflectance according to the following equations [17]:

$$A = \mathrm{Log}\left(\frac{1}{T}\right) \quad (1)$$

$$\propto(\lambda) = \frac{1}{d}\ln\left(\frac{1}{T}\right) \quad (2)$$

Where d is the film thickness and T is the Transmittance

$$k(\lambda) = \frac{\propto\lambda}{4\pi} \quad (3)$$

Where α is the absorption coefficient and λ is the wavelength.

$$n(\lambda) = \frac{1+\sqrt{R}}{1-\sqrt{R}} \quad (4)$$

Where is R the reflectance

The band gap was determined from the Tauc's relation;

$$\alpha h v = B\,(hv - E_g)^m \quad (5)$$

Where B is band edge parameter and value of m determines the nature of optical transition ($m = \frac{1}{2}$ Indicates direct transition and $m = 2$ indicates indirect transition). Since ZnO has a direct transition[17].The band gap of the films was calculated by plotting $(\alpha hv)^2$ versus hv followed by extrapolation of the linear region of the absorption edge to find the intercept with the energy axis.

A QUADPRO-301-6 four point probe was used to determine the sheet resistance and the resistivity of the deposited films at SHESTCO Abuja, after which the conductivity was determine from the resistivity. The sheet resistant is given by [17]:

$$R_s = 4.53 \times \frac{V}{I} \quad (6)$$

Where V is the measured voltage between the two inner probes and I is the current passed through the outer probes. The resistivity was determined from the relation [18]:

$$\rho = R_s \times d \quad (7)$$

Where d is the thickness of the conducting layer,ρis the resistivity and $R_s$is the sheet resistance. From the value of ρ, the conductivity σ was determined using the relation [18]:

$$\sigma = \frac{1}{\rho}(8)$$

A Profilometer (VEECO DEKTAK 150) was used to carry out measurement of the thickness of the deposited films at SHESTCO Abuja.

III. Results And Discussion

3.1 Effects of substrate temperature on electrical properties of ZnO: Al thin films

Table 1 gives a summary of the electrical properties of ZnO: Al thin film.

Table 1: Summary of the electrical properties of ZnO: Al thin film

Temperature T_s (°C)	Sheet resistance $R_s \times 10^2(\Omega)$	Resistivity $\rho \times 10^{-5}(\Omega m)$	Resistance $R \times 10^1(\Omega)$	Thickness $d \times 10^{-7}(m)$	Conductivity $\sigma \times 10^4(\Omega m)^{-1}$
300	13.8	31.7	30.4	2.3	0.317
350	1.17	2.45	2.58	2.10	4.22
400	1.0	1.8	2.21	1.80	5.61
450	2.03	3.04	4.48	1.50	3.29

The plot of the relationship between Conductivity and substrate temperature is shown in Figure 1

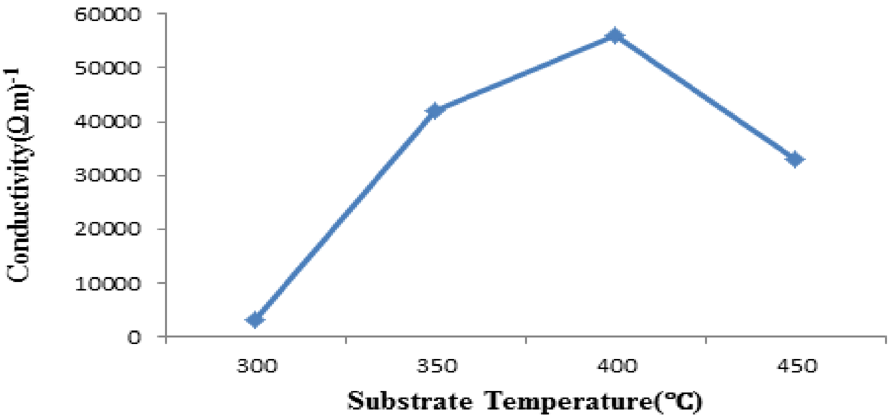

Figure 1: Variation of Conductivity with substrate temperature

From Table 1, the measured resistivity is found to vary in the range of $31.7 \times 10^{-5}\Omega m$ to $1.8 \times 10^{-5}\Omega m$as the substrate temperature increases from 300 to 450 ^{o}Cfor the ZnO: Al thin films. The resistivity of the ZnO: Al thin films decreases with increasing substrate temperature from 300 to 400 ^{o}C and then rises a little at 450℃, which indicates the semi conducting nature of the deposited films. The decrease in resistivity is matched by increase in conductivity from $0.317\times 10^{4}(\Omega m)^{-1}$ at 300 ^{o}C to $5.61 \times 10^{4}(\Omega m)^{-1}$at 400 ^{o}C followed by a slight decrease to $3.29 \times 10^{4}(\Omega m)^{-1}$ at 450 ^{o}C as shown in table 1 and Figure 1which is consistent with the report of other researches[19-23]. Generally the observed decreased in the resistivity of ZnO: Al thin films compared to ZnO may be due to the smaller difference in the Electronegativity and ionic radius of Al ($r^{3+} = 0.054\, nm$) and Zn ($r^{2+} = 0.074\, nm$), because the dopant element efficiency is a function of its electronegativity as well as the difference between its ionic radius[8,12]. Since the radius of Al^{3+} is smaller than that of Zn^{2+} ion, there is a replacement of relatively bigger Zn ion by a smaller Al ion during the formation of the Al doped ZnO thin films. These replacements of Zn^{2+} by Al^{3+} ions introduces a large number of electrons in the doped films, thereby increasing the number of charge carries and hence increase in the conductivity of the doped thin film. Similar results have been reported[5, 13].

On the other hand, since the conductivity of a semiconductor is determined by availability of free carrier concentrations and carrier mobility, while temperature is a measure of the average kinetic energy of the particles of a material, its follows that both carrier concentration, carrier mobility and electrical resistivity are sensitive to substrate temperature. As such, the relatively low conductivity value observed at 300 ^{o}C compared to other substrate temperatures may be due to the poor crystallinity of the film which indicates the presence of few atomic layers of disordered atoms. Due to the limited disorderliness of atoms, large number of defects exists in the sample due to incomplete atomic bonding which results in decrease of carrier concentration as the trap becomes electrically charged after trapping the mobile carriers, creating a potential energy barrier which impedes the motion of carriers from one crystallite to another. This is in agreement with other results[24, 14]. As the substrate temperature increases from 300 to 400 ^{o}C, there is increase in carrier mobility causing a corresponding increase in carrier concentration and decrease of resistivity due to thermal excitation of electrons into the conduction band hence increase in conductivity. This is in agreement with other results[25-27]. It can be inferred that the lowest resistivity of $1.8 \times 10^{-5}\Omega m$ was obtained that appropriate temperature of 400 ^{o}C, due to appropriate substitution of Zn lattice sites by Al leading to the production of more donor states and oxygen vacancies, thereby increasing carrier concentration which greatly decreases the resistivity of the film. The increase in carrier concentration indicates that most of the Al^{3+} substitutes uniformly for Zn^{2+} in the lattice as an effective n type dopant rather than forming a second phase[14].

With respect to grain size, by increasing the substrate temperature from 300 to 400 ^{o}C, the surface gets fully covered with fine and large grains. This increase in the grain size leads to a decrease in the density of the grain boundaries which is due to the improvement of crystallinity and film orientation leading to a decrease in the donor sites that are trapped at the dislocations and grain boundaries. As a result, there is enhancement in the carrier concentration due to decrease in resistivity leading to increase in conductivity.[28-29]have reported similar phenomenon. The electrical conductivity and dislocation density are found to be directly related in all samples. As such the film deposited at 400 ^{o}C, which are less strained and having minimum dislocation density shows maximum electrical conductivity.

However, a further increase in substrate temperature from 400 to 450 ^{o}C causes degradation of the electrical properties which could be due to two possible reasons: The first could be due to increase in chemisorbed oxygen, which acts as electron trap at grain boundaries and results in decrease of carrier concentration and possible interstitial impurities at higher temperature. This vigorous oxygen adsorption on the film surface causes decrease in the conductivity at 450 ^{o}C. This is consistent with other reports[8, 25, 30]. The second reason could be due to a slight increase in surface roughness and granularity of the film at higher substrate temperature of 450 ^{o}C, which could results in an increase in structural defects and hence decrease in conductivity.

3.2.Effects of substrate temperature on Optical properties of ZnO:Al thin films

3.2.1.Optical band gap

The optical band gap is defined as the minimum energy needed to excite an electron from the valence band to the conduction band. The plot of optical band for ZnO: Al thin films as a function of substrate temperature is shown in Figure 2.

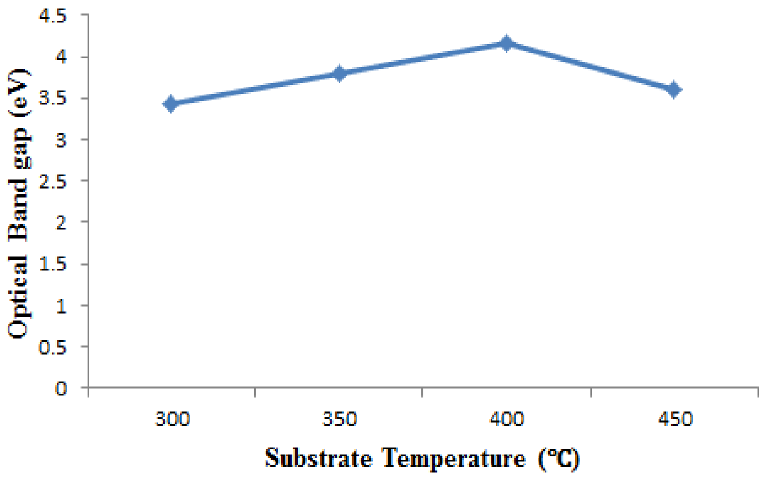

Figure 2: Plot of Optical band gap against Substrate Temperature

The optical band gap is could be seen to increase in the range of 3.43 to 4.16 eV for ZnO:Al thin films deposited at 300 to 400 ^{o}C. ZnO is naturally an n type material with the Fermi level inside of the conduction band when it is doped with Al and an Optical band gap of 3.37 eV[5]. In undoped ZnO the optical gap equals the energy separation between the band edges, but on doping the donor electrons occupy states at the bottom of the conduction band, since Pauli principle prevents states from being doubly occupied. The optical band gap is given by the energy difference between the states with Fermi momentum in the conduction and valence band[12].

The band gap difference of the ZnO:Alfilm could be due to the existence of grain boundaries and imperfections in the polycrystalline thin films. The atomic structure at the grain boundary is different from that in the grain, which leads to larger free carrier concentrations (free electron concentration) and existence of potential barriers at the boundaries, leading to the formation of an electronic field and hence an increase of the band gap. This is consistent with the results of other researchers who also reported that the band gap difference between the ZnO:Alfilm and bulk ZnO is due to the grain boundary, the stress and the interaction potentials between defects and host materials [31-32]. The increase in band gap could be attributed to the partial filling of the conduction band of ZnO: Al thin film resulting in a blocking of the lowest states. This widening (Blue shift) of the optical band gap or the blocking of low energy transition is termed as Burstein-Moss shift[25].

According to Burstein-Moss effect the band gap would increase with increasing carrier concentration ($\Delta E_g{}^{BM} \propto (3\pi^2 n)^{\frac{2}{3}}$, where $\frac{h^2}{2M_\tau}$ are constants). Doping of ZnO with Al will increase the carrier concentrations thereby blocking the lowest state in the conduction band owing to the filling up of low energy levels by the conduction electrons, thus increasing the band gap. The enhancement of band gap also ensures that aluminum was successfully doped in the ZnO thin films [33].The increase in band gap up to400 ^{0}C could also be related to the phase change from mixed (Cubic and hexagonal) to the hexagonal phase especially at 300 ^{o}Cwhere incomplete thermal decomposition is suspected to have taken place[20, 22, 34].Also stress is greater in films deposited at lower temperature and basically, high substrate temperature will create more defects such as oxygen vacancies and those increased defects will lead to increase in band gap due to increase in carrier concentration.

On the other hand as the substrate temperature increases from 400-450 ^{o}C, the optical band gap decreases to 3.61 eV which could be due to many body effects like the exchange energy due to electron-electron and electron-impurity interactions which occurs when the donor density exceeds a certain value and causes narrowing (red shift) of the band gap energy [35]. The reduction of the band gap could also be attributed to reduction in stress, increase in interplanner distances (equivalently the lattice parameter) which appears as a shift in the XRD diffractogram towards smaller angles, change in the density of charge carriers with increase in substrate temperature and the movement of dopants from grain boundaries to the grains[36].

The rise (3.43 to 4.16 eV) and fall (4.16 to 3.61 eV) of the band gap can also be related to quantum confinement which has primarily two consequences: First it splits the conduction band into discrete levels and secondly, it reduces the density of states available in the conduction band such that at 400 ^{o}C, the carrier concentration gets to its critical value leading to the collapse of the potential at the grain boundaries and hence abrupt decrease in the optical band gap at 450 ^{o}C. This is in agreement with some research reports[37].

3.2.2. Transmittance

The effect of substrate temperature on the optical transmittance of ZnO:Al thin films is shown in Figure 3.

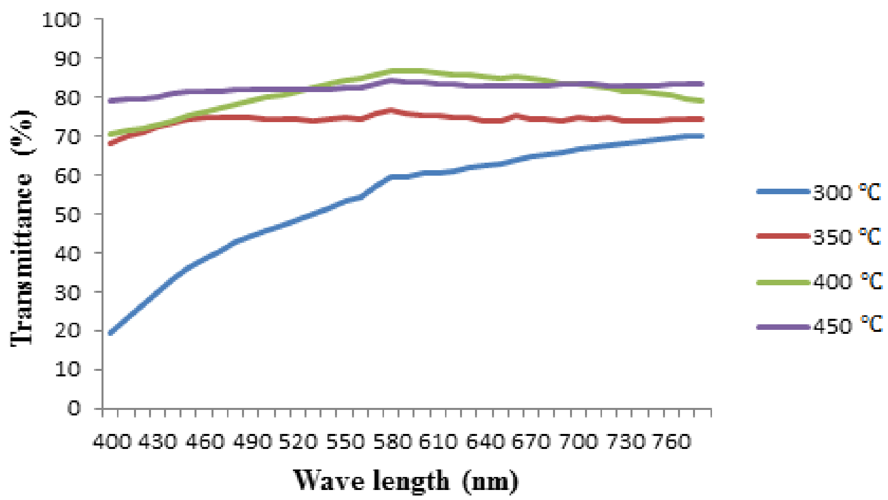

Figure 3: Transmittance spectra of ZnO: Al thin film at 300, 350, 400 &450°CType equation here.

The average transmittance was estimated by taking the average of the transmittance at wavelength range of 400 nm – 780 nm. From Figure 3, the average transmittance varied in the range of 53.97 to 84.01 % for substrate temperatures of 300 to 450 ^{o}C. The maximum transmittance; 76.69% for 350 ^{o}C, 83.12% for 400 ^{o}C and 86.91% for 450 ^{o}Cis greatest at 580 nm wavelength while the maximum transmittance for 300 ^{o}C which is 59.52% is at 770 nm wavelength. The maximum transmittance at 580 nm wavelength is of interest since solar maximum is around the same wavelength. This is in agreement with some research reports[38].

Peaks and valleys seen on the transmittance spectra are associated with interference effect [38].The transmittance variation with substrate temperature is principally due to interference phenomenon. Since the thickness is not uniform, the interference effects are smoothed out in the transmittance curve at higher substrate temperature of 450°C. The films had interference fringes in the 460-710nm range which are due to the interference of the light reflected between air film and film substrate interference as seen in Figure 3[39].

At substrate temperature of 300 ^{o}C, the average transmittance was 53.97 %. The deposited films have a low transmittance in comparison to those deposited at temperatures of 350-450 ^{o}C. This could be attributed to the formation of milky films at 300 ^{o}C due to the incomplete decomposition of the sprayed droplets. The increase in transmittance at temperatures of 350 to 400 ^{o}C, could be due to the better crystallinity of the films and the less optical scattering by the surface morphology and grain boundaries of the ZnO:Al films. This is consistent with research results [40-41]. Also since the higher substrate temperature is associated with increase of carrier concentration, the increase of carrier concentration could be helpful in increasing the transmittance due to the enlargement of the band gap[8].Also according to Burstein-Moss theory, the Al atoms incorporation provides an increase in Fermi level in the conduction band of semiconductors due to enhancement in carriers leading to the widening of the direct optical band gap. Hence the larger band gap would increase the optical transmittance in the visible region. The high transmittance value of 84% for the substrate temperature of 400 may be attributed to the uniform, well adherent and highly crystalline nature of the film due to uniform nucleation and improvements in lattice arrangements. Similar results have been reported[14, 42].The slight decrease of the transmittance at 450 to 82 may be attributed to enhancement of impurity scattering due to high carrier density beyond the critical value as the carriers might also act as impurity scattering centers.

Furthermore, the improvement in transmittance can also be attributed to the decrease in thickness besides the improvement in structural perfection[43]. From the relationship between the optical transmittance and the film thickness given by the Beer- Lambert equation, the transmittance of ZnO:Al thin films will decrease inversely proportional to the film thickness[44].As such the increase in substrate temperature from 300 – 400 ^{0}C causes a decrease in the thickness of the films leading to an increase in the transmittance according to lambert's law from 53.97% to 84.01.%.

3.2.3 Reflectance

Figure 4 shows a plot of average reflectance against wavelength as a function of substrate temperature for ZnO: Al thin film.

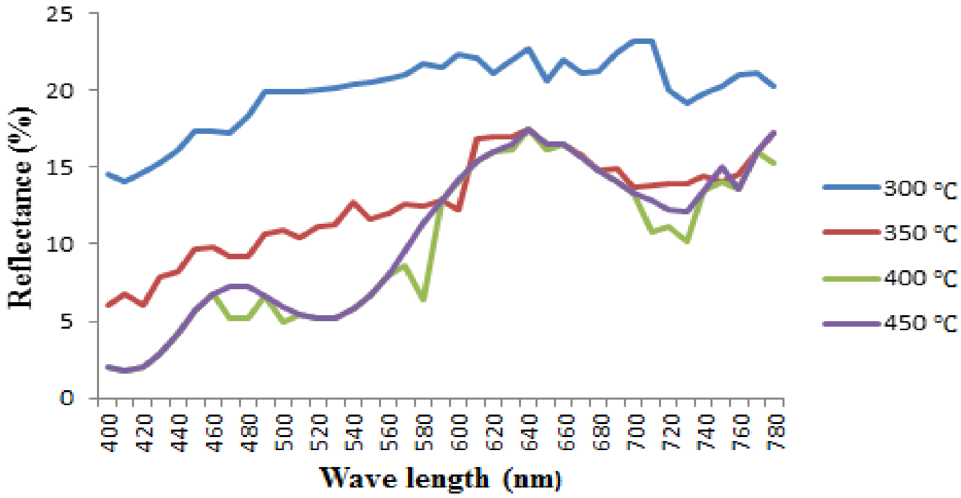

Figure 4: Reflectance spectra of ZnO: Al thin film at 300, 350, 400 &450°CType equation here.

The average reflectance was estimated by taking the average of the reflectance within the wavelength range of 400 -780 nm. The average reflectance were estimated to be 19.25%, 12.54%, 8.42% and 9.0% respectively for substrate temperature of 300, 350, 400 and 450 ^{o}C. The reflectance values decreases with increase in substrate temperature. The high value of reflectance (19.25%) at 300 ℃ and 350 ℃ indicates that the films deposited at these substrate temperatures will reflect much of the incident radiation compared to the films deposited at substrate temperature of 400 and 450 ^{o}C. As such confirming one of the reasons for low transmittance at 300 ℃ and high transmittance of 84% at 400 ^{o}C.

3.2.4. Refractive index

The plot of refractive index as a function of substrate temperature is shown in Figure 5.

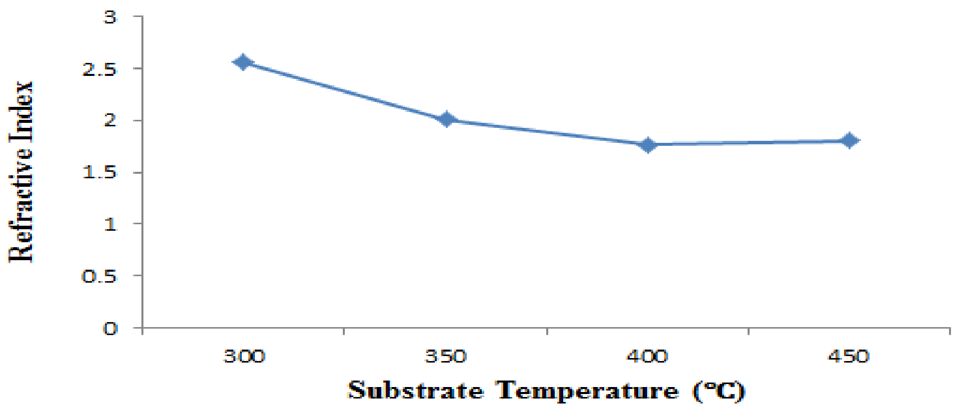

Figure 5: Plot of Refractive index (n) against substrate temperature

From Figure 5, the high value of n (2.56) obtained at 300 ^{0}C for ZnO: Al thin film could be attributed to an increase in its surface roughness which acts to decrease the effective mean free path through increased surface scattering, and strongly favours the reason for the reduction in its transparency. Similar results have been reported[12]. The reduction or decrease of the refractive index with increasing substrate temperature from 350-450℃ could be due to the larger grain size and lower strain in the film deposited at these substrate temperatures[41].

3.2.5. Extinction coefficient

Figure 6 shows a plot of Extinction coefficient against substrate temperature.

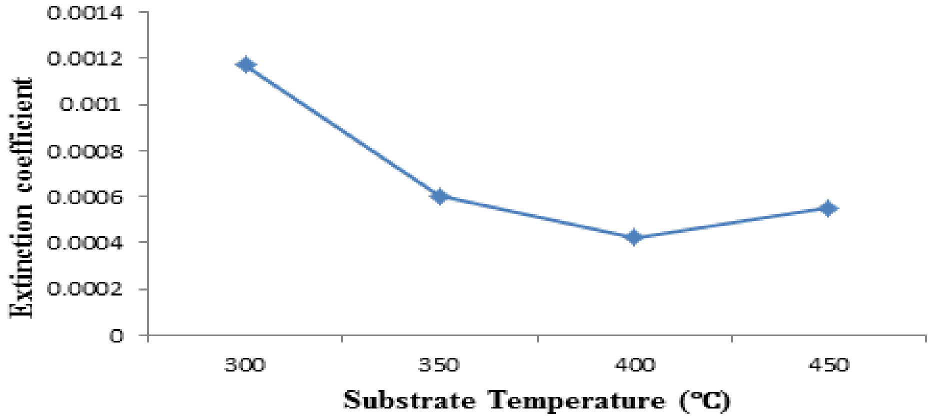

Figure 6: Plot of extinction coefficient against Substrate temperature

From Figure 6, the Extinction coefficient decreases with increasing substrate temperature. The fall in the extinction coefficient from 300-400 ^{o}Ccouldbe attributed to the absorption of light at the grain boundary. [10] While the high value of K obtained for the film deposited at 300 indicates high absorption and reduced transmittance as the variation in extinction coefficient is parallel by the absorbance of ZnO:Al thin films.

3.2.6.Absorption coefficient

Figure 7 shows a plot of absorption coefficient against substrate temperature.

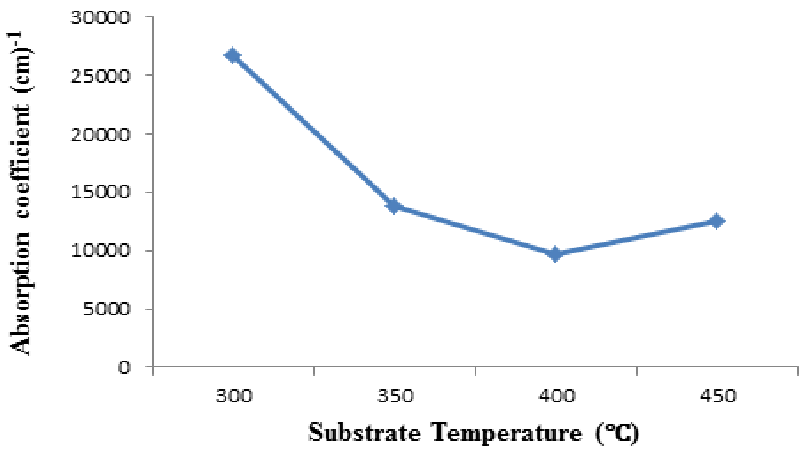

Figure 7: Plot of absorption coefficient against Substrate temperature

Table 2 shows a summary of the absorbance, the absorption coefficient and other optical parameters of the deposited ZnO:Al thin films at substrate temperatures of 300 to 450 ℃. The values shown in Table 2 are indication of the absorption capability of the deposited films. From Figure 7, the values of absorption coefficient are seen to decrease with increase in substrate temperature. The high value of absorption coefficient obtained for the film deposited at 300 ^{o}C indicates high absorption and reduced transmittance as compared to films deposited at other substrate temperatures. This is consistent with other research results. [20, 12, 34]

IV. Conclusion

ZnO:Al thin films were deposited on soda lime glass substrate by Electrostatic spray deposition at different substrate temperatures with Aluminum dopant concentration of 3 atomic percent. The effects of substrate temperature on the Electrical and Optical properties of the deposited films were investigated. Four point probe analysis shows lowest resistivity of $1.8 \times 10^{-5}(\Omega m)$ for the film deposited at 400 ^{0}C substrate temperature. The optical band gap was found to vary from 3.43 to 4.16 eV for various substrate temperatures while the highest value of 84.01% transmittance was obtained at substrate temperature of 400 ^{0}C. The low electric resistivity and the high solar transmittance makes the ZnO:Al thin film a promising candidate as Transparent conducting Oxide in Solar cells.

Substrate temperature is found to play a key role in the Electrical and Optical properties of the Electrostatic spray deposited ZnO:Al thin films. The highest transmittance and the highest conductivity obtained in this research which is suitable requirement for a thin film solar cell is at substrate temperature of 400 ^{o}C, making it the optimum temperature for the fabrication of ZnO:Al thin film by ESD for use as a TCO in thin film solar cell.

Acknowledgements

The authors acknowledged the Staff and management of Sheda Science and Technology (SHESTCO), Sule Lamido University Kafin Hausa, Jigawa state and Federal University of Technology Minna.

References

[1]. M.M. Aliyu, R.S.Shehu, Elect ElectEngConf proc.**2011**, 97.
[2]. T. Minami, Semiconsci and Tech,**2005,**20(4),535.
[3]. L.Huiyong, V.Avrutm, U. Ozgar, H.Morkec,Superlat and microstruc.**2010,** 458.
[4]. C.O.Mugah, Okumu, K. Njoroge, W, Inter Jour of Res in Elect and Elect Eng, **2012,** 1(1),001
[5]. S. Tewari, Bhattacharjee, A, Pra Jour of Phys,**2010,**76(1), 153.
[6]. J.K. Behera, Depart of Phys, NalInsti of Tech, **2012** Rourkela-769008.Orissa India
[7]. J.I. Hong, H. Paik, H. Hwang, S. Lee, A. deMello, K. No, Physics Status.**2009,** A206, 4, 697.
[8]. K. Mahmood, S.B. Park, S.B,Electron mater letters, **2013,**9(2), 161.
[9]. P.P. Sahay, R.K. Nath,Advanin applied Sci Res, **2012,**3(5), 2501.
[10]. Kim, Y.H., Lee, K.S., Lee, T.S., Cheong, B., Seong, T.Y., &Kim, W.M ,Thin solid films, 9,537
[11]. Sun, Y., Wang, Y., Cai, H., Liu, F., & He, Q, Solar Energy Materials and solar cells, 91, 659-663. doi: 10.1016/j.solmat.2006.11.018
[12]. Z.B. Ayadi, L.E. Mir, K. Djessas, S. Alaya, Thin solid films,**2011,** 519,7572
[13]. X. Li, H. Li, Z.Wang, H. Xia, Z. Xiong, J. Wang, B. Yang, Optics communications,**2009,**282, 247.
[14]. M.Alauddin, J.K. Song, A.Park, Applied Physics A.**2010,** 101,707.
[15]. A. Jaworek, A, A review Journal of material sciences, 42 (1)(2007)266
[16]. A.K. Abduev,Akhmedov, A.S. Asvarov, A.A. Abdullaev, S.N. Sulyanov, Semiconductors, **2010,** 44(1),32.
[17]. M.R. Islam, J. Podder, Crysl Res Tech,**2009,** 44 (3): 286.
[18]. B.L. Theraja, B.L, Textbook of Electrical Technology, S.C. Hard and Company Ltd., **2007**.
[19]. C. Rajashree, A.R. Balu, V.S. Nagarethinam, Inter jour of ChemTechnResear, **2014,** 6(1), 347.
[20]. S.J. Ikhmayies, Advan in Applsci Res, **2010,** 2(2),337.
[21]. S.J. Ikhmayies, R.N. Ahmad-Bitar, R.N, ApplsurSc,256**(2010),** 3541.
[22]. V. Bilgin, S. Kose, F. Atay, I. Akyuz, Mater, Chem and Phy,**2005,**94,10.
[23]. M. Oztas, M. Bedir, Y.A. Neemeddin, E. Vural-Kafadar, H. Toktamiz, H, Physica, **2006,** B.38
[24]. Z. Biju, H. Wen, Journal of semiconductor processing, **2013,**34(5),1674
[25]. Lin J.P., & Wu, J.M. (2008). Applied Physics Letter. 92,134103 (2008)
[26]. M. Alaf, M.O. Guler, D. Gultekin, H.Akbulut, Proceedings of the 2nd International congress.APMAS**2012,** April 26-29, Antalya, Turkey.
[27]. A.B. Khatibani A.A. Ziabari, S.M. Rozati, Z. Bargbidi, G.Kiriakidis, Substrate temperature effect. Transactions on electrical and Electronic materials, **2012,** 13(3),111.
[28]. R. Davood,R . Taha,Applied surface science.**2009,** 255, 5812
[29]. J. Steinhauser, S. Fay, N. Oliveira, E. Vallat-Sauvain, C. Ballif, Applied Physics Letter. **2007,** 90, 142.
[30]. D. Bao, H. Gu, A.Kuang, Thin solid films,**1998,**312, 37-39.
[31]. L. Zhang, Q. He, W. Jiang, F. Liu, C. Li, Y. Sun, SolarEnerMater&SolarCells,**2009,** 93,114.
[32]. M. Jun, S. Park, J. Koh, Nanoscale Research Letters **2012,**7,639.
[33]. A. Ashour, Turkish Journal of Physics. **2003,** 551.
[34]. N. Sharma, R. Kumar, Advances in Applied science Research, **2014,**5(2), 111.
[35]. S. Ikhmayies, A. Ahmad-Bitar, MaterialsScienceinSemiconductorProcessing,**2009,**12, 122.
[36]. B.J. Babu, A. Maldonado, S. Velumani, R. Asomoza, Thin films, **2010**. 13
[37]. S. Abdullahi, M. Momoh, K.U. Isah, The fourth international renewable energy congress. Dec 20-22, 2012-Sousse, Tunisia.
[38]. S.Chacko, N.S. Philip, V.K. Vaidyan,WILEY-VCH Verlag GmbH &co. KGaA, Weinhein.**2003.**
[39]. D.M. Tatar, Turgut,B. Duzgun, Roman Journal of Physics, **2013,** 58 (1-2), 143.
[40]. A.A. Yadav, E.U. Masumdar,A.V. Moholkar, M. Neumann-Spallart, K.Y. Rajpure,
[41]. C.H. Bhosale, Journalof Alloys andCompounds,**2009,**488,350.
[42]. K.L. Chopra, K.Indraject, Thin Film Device Applications, Plenum Press, New York. 1983
[43]. A.E. Ibrahim, R.A. Ismail, A.Y. Ali, Tikrit Journal of pure science, **2012**, 17, 101.
[44]. V.S. Reddy, K. Dias, A. Dhar, S.K. Ray, Semiconductor Science and Technology,**2006,**21(12), 1747.
[45]. H.R. Ali,International Letters of Chemistry, Physics and Astronomy, **2014**, 8, 47.