Comparative Study on the Influence of Different Growth Mechanisms on the Structural and Optical Properties of Aluminum Doped Zinc Oxide Thin Film, AlZnO

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ABSTRACT

Comparative study of the influence of the difference deposition techniques on the properties of aluminum doped Zinc Oxide has been carried out in which the morphological, crystal structures including the spectral Transmittance, Reflectance were studied using scanning electron microscope, XRD and spectrophotometer, respectively.

(Keywords: zinc oxide, ZnO, aluminum, Al, doping influence, thin film, deposition methods, structural and optical properties, semiconductors)

INTRODUCTION

Zinc oxide thin film is a group II-VI compound semiconductor with a hexagonal wurtzite crystal lattice structure which characteristically a transparent conducting film and above all possesses very interesting properties in the optical application fields (Mousaghfir, et al., 2003). ZnO is a wide and direct band gap semiconductor with numerous potential applications for next generation of opto-electronic devices working in the short (ultra-violet) wavelength region (Ozgur, et al., 2005). However, a true realization of bipolar ZnO-based devices is hindered by the well-known doping asymmetry issue, typical for II-VI semiconductors (Park, et al., 2002). Indeed, similar to other II-VI semiconductors, one of the interesting characteristic is that it can be readily doped n-type, while a stable and reproducible p-type doping is still lacking.

The difficulties of p-type doping are usually attributed to low dopant solubility, lack of dopants having a shallow acceptor level, compensation by spontaneously formed intrinsic defects (hole killers) such as zinc interstitials (Zni) and oxygen vacancies (VO), interaction with impurities, or self-compensation effects (Park et al., 2002; Zhang, 2002). Recently, it was theoretically predicted that group-Ib elements (Cu, Ag, and Au) incorporated on Zn site have a potential for p-type doping, where AgZn is the most promising candidate as shallow acceptor with an ionization energy of 0.2–0.4Ev (Yang, et al., 2006; Volnianska, et al., 2009) although our interest is not to analyze the influence of the above mentioned elements on zinc oxide thin film.

Naturally, the un-doped ZnO thin film is n-type intrinsic semiconductor that displays n-type conductivity with high electron densities (Minami,1985) is due to its deviation from stoichiometry as a result of the presence of intrinsic defect occasioned by oxygen vacancies and Zni interstitial (Ozgur, et al., 2005). At the moment, it is still known that unintentionally doped ZnO is n-type whether the donor are Zni or oxygen vacancies (Savas and Erdi, 2014), thus when doping ZnO, one thing is obvious, to compensate the film for which the compensation strategy is to add on the isoelectronic impurities that would occupy the oxygen vacancies for which group III elements such as Aluminum, Indium, Gallium, Tellurium, etc. had been studied by many researchers during which it was found that they influence the physical and optical properties of the film (Porter, et al., 2005, Samina and Nasser, 2013).

Sequel to the focus of attention in recent time the plasmonics and metamaterials (Lal, et al., 2007, Smith and Pendry, 2004) many unconventional functionalities, such as negative refractive index material (Soukoulis, et al., 2007), sub-diffraction imaging (Liu, et al., 2007), and invisibility cloaks (Cai, et al., 2007) have been studied in which noble metals were conventionally used as the primary building blocks for such optical metamaterials (Wang, et al., 2018). In recent times, heavily doped semiconductors such as aluminum–doped zinc oxides, AZO (Lin, et al.,

2016) have been found to be a better replacement for the noble metals in plasmonics and metamaterial applications as a result of their tunable free carrier concentrations and this off course has rejuvenated the focus of interest by material scientists based on the influence of some these elements on the ZnO. Different mechanisms have been used to develop AZO based thin film such Sol-Gel, (Xu, et al., 2006; Srinivasan, et al., 2007), spray pyrolysis method (Mujdat, et al., 2008; Kumar, et al., 2017), ultrasonic spray technique (Gahtar, et al., 2013), radio frequency magnetron sputtering (Park, et al., 2006; Kar, et al., 2010), atomic layer deposition technique (Zheng, et al., 2018, etc.). and their structural and optical properties studied.

Different methods have been used to synthesize aluminum doped ZnO thin films either as deposited or annealed at different temperatures, but there has been no analysis on the influence of these different deposition mechanisms on the structural and optical properties of the thin film. It is worthwhile to look at this concept so as to have the knowledge of the method that optimizes the structural and optical characteristic of the AZO based thin film for optoelectronics and other field applications. Thus, in this work the analytical study of the influence of the different deposition techniques on AZO based thin film is to be carried out.

MATERIALS AND METHODS

Various deposition techniques were used to grow AZO thin film at different time and places such as Sol–gel growth techniques, radio-frequency magnetron sputtering, spin coating technique on the glass substrate, and spray pyrolysis techniques. During the deposition process, the Al as the dopant was varied and some cases annealed at various temperature while some were as-deposited.

The structural properties were studied using various kinds of X-ray machines while morphological analysis was done by Scanning Electron Microscope, SEM and the spectral transmittance and reflectance were studied by spectrophotometer at room temperature. The results obtained from each of these aforementioned techniques were analyzed in order to observe whether they were affected by the deposition techniques. The band gaps of the samples were studied using the plot of as a function of photon energy.

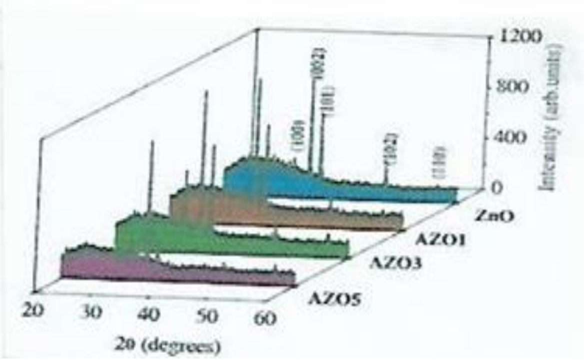

Figure 1: XRD of AZO by Spray Pyrolysis Technique for Different % of Al Dopants.

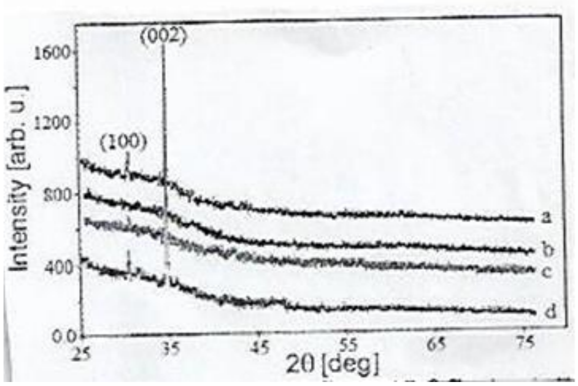

Figure 2: XRD of AZO by Ref. Magnetron Sputtering Considering Different % of Al Dopant.

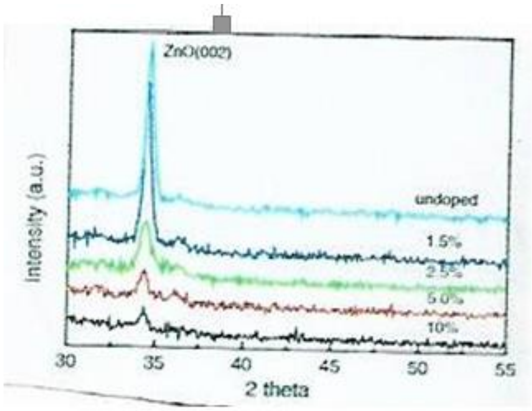

Figure 3: XRD of AZO by Sol-gel Deposition Mechanism for Different % of Al Dopant.

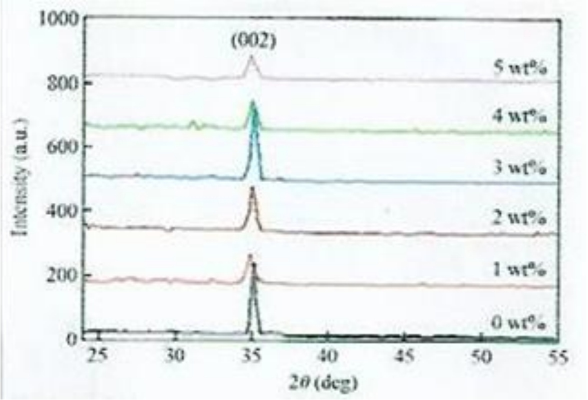

Figure 4: XRD of AZO by Chemical Bath Deposition for Different % of Al Dopant.

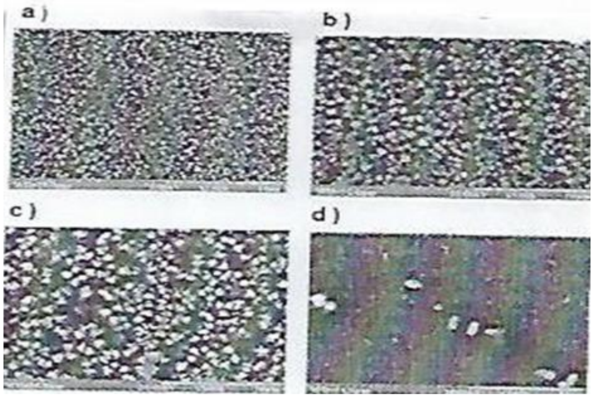

Figure 5: SEM of AZO for CBD Deposition Technique for Different % Al Dopant.

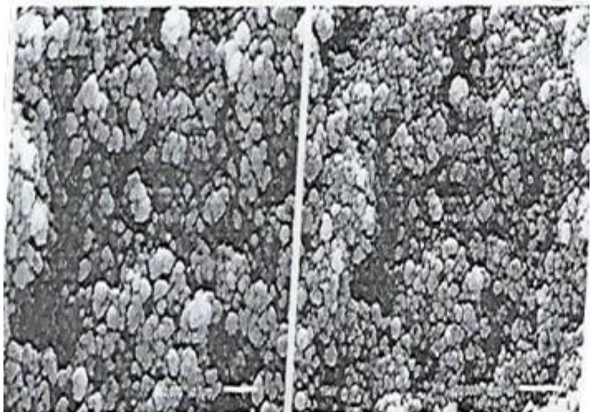

Figure 6: SEM of AZO for Sol-gel Deposition Mechanism.

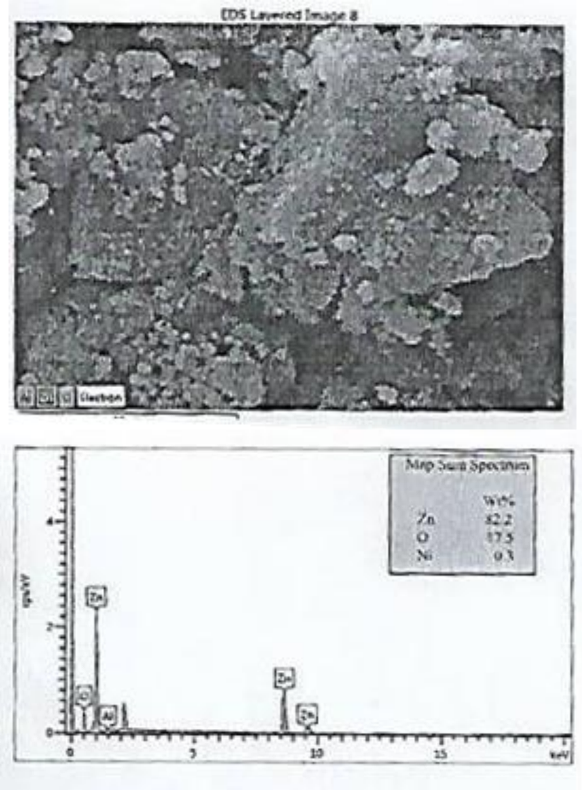

Figure 7: SEM AZO Annealed at Different Temperatures.

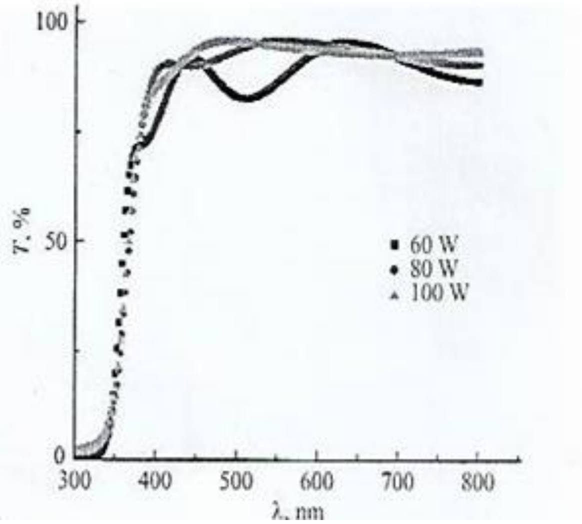

Figure 8: Percentage Transmittance as Function of Wavelength for Spray Pyrolysis Deposition Technique.

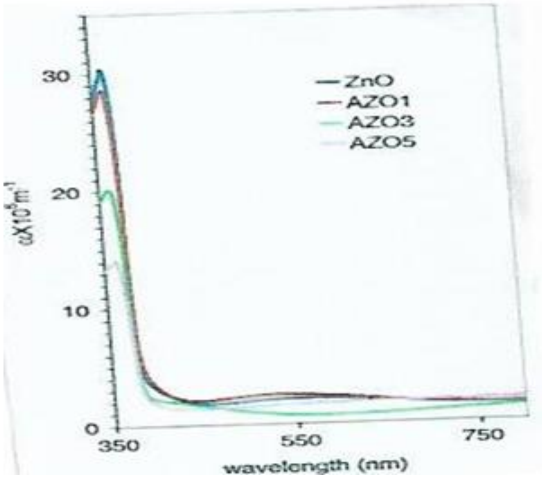

Figure 9: Absorption Coefficient Spectra of AZO for Various % of Al Dopants by Spin Coating Technique.

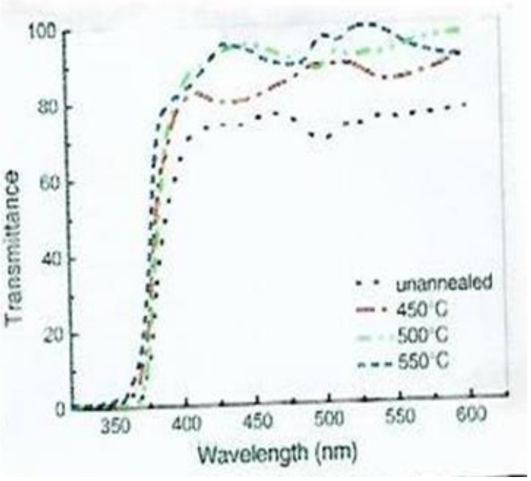

Figure 10: Transmittance vs Wavelength of AZO Annealed at Different Temperature by Fef. Magnetron Technique.

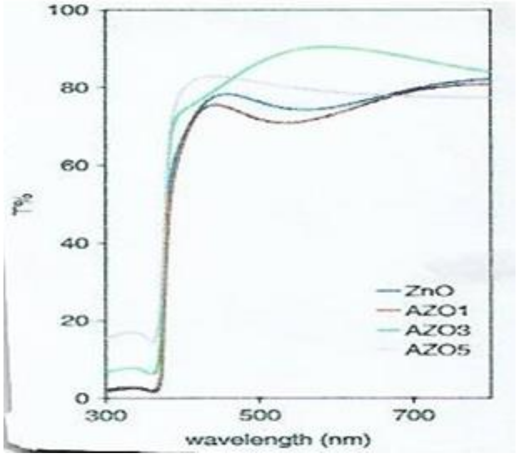

Figure 11: % Transmittance of AZO for Different % of Al Dopant by Spin Coating.

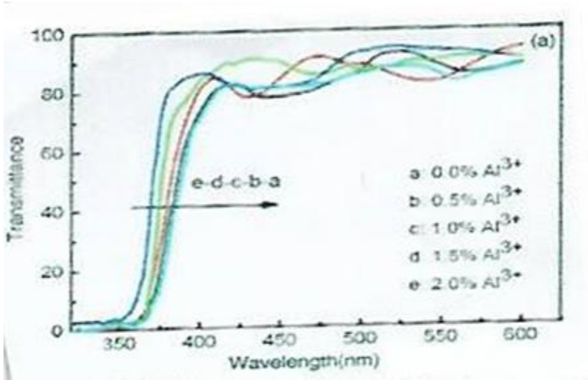

Figure 12: Percentage Transmittance as a Function Wavelength for Various Values of Al Dopants.

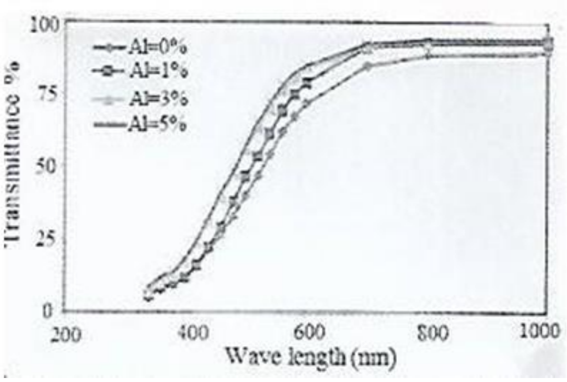

Figure 13: Transmittance as a Function of Wavelength for Sol-gel Growth Technique.

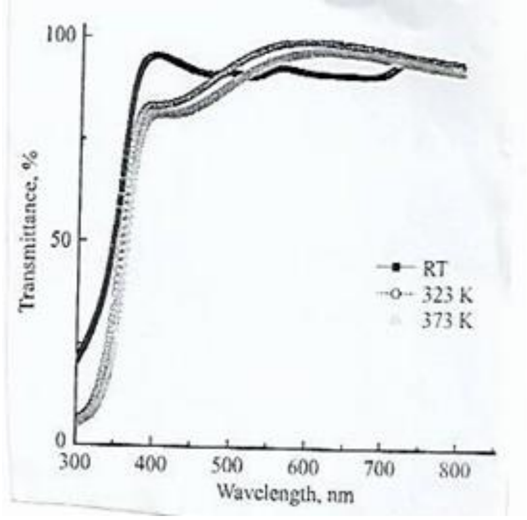

Figure 14: % Transmittance as a Function of Wavelength for Annealed AZO,

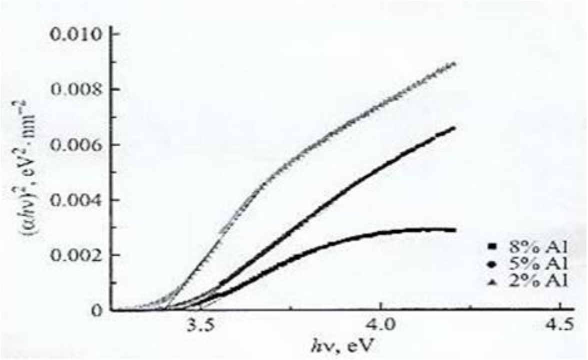

Figure 15: Graph of (ahv)2 vs Photon Energy for Sol-gel Growth.

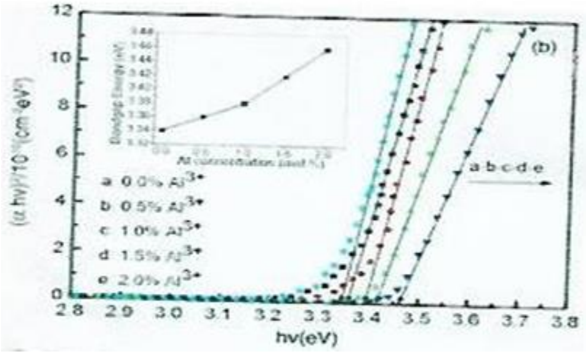

Figure 16: Graph of (ahv)2 vs Photon Energy for Spin Coating.

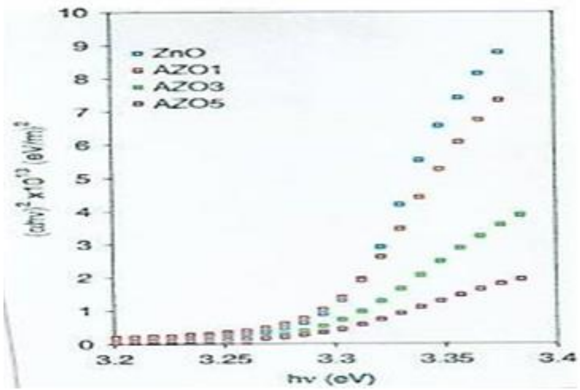

Figure 17: Graph of (ahv)2 vs Photon Energy for Magnetron Sputtering.

RESULTS AND DISCUSSION

From the results of the XRD spectra for the various deposition techniques of Al-doped ZnO thin film analyzed in this work, there is a manifestation of variation of grain size as a function of doping level irrespective of the XRD machine model used in the analysis. In some cases, the grain size increased with percentage increase of Al- dopant to certain optimum % value. In a situation where this is the case, there is a clear observed enhancement of crystallinity of the doped thin film which invariably affected the c-axis orientation of the film. This observation collaborates with the report by (Srinivasan, et al., 2006) from Sol-gel pin coating technique where it was seen that the aluminum doped zinc oxide; AZO thin film has less XRD intensity at (002) when compared to pure ZnO thin film. This collaborated with the report of AZO prepared by RF magnetron sputtering where even the sputtering temperatures were considered to have effect, but the intensity was also found to be more prominent at (002) (Park, et al., 2006).

AZO deposited by Spray Pyrolysis showcased its diffraction peak at (002) according to the reports of (Yavuz et al 2007; Kuo et al 2006; Hao et al 2006; Hau et al 2006).It was inferred that aluminum dopant affects the crystalline of the thin film as a result of the formation of stresses by ion size difference between zinc and the dopant which leads to the segregation of the do pants in the grain boundary. This collaborated with the report of Sing, et al. (2017) that says that the intensity peak of aluminum doped ZnO thin film is affect with increase in percentage Al dopant (Xu, et al., 2006). Zheng, et al., who synthesized AZO by chemical spray pyrolysis technique also report that the crystallinity of ZnO is more distorted by the presence of Al dopant and then this may be the reason why its preferred orientation shifts to (100) plane as reported by Akday, et al. (2016).

In a similar manner, the report from atomic layer deposition method reveals also that pure ZnO thin film has intense diffraction at (002) in which the peak is observed to disappear at that point and shift to (100) preferred plane with introduction of Al dopant (Zhai, et al., 2016).

The results so far showcased here indicates that the film commonly exhibited different dominant peaks corresponding to (002) plane with other corresponding peaks at (100) and (101) portending the polycrystalline nature of the films.

Another clear observation is that the relative intensity of the (002) peak is due to increase in the concentration of the Al- dopant. Generally, another common features paramount for the XRD analysis in all these deposition mechanism looked at here in this work is slight shift with the peak in the direction of lesser angles which has been attributed by some researchers as a result of small increment in the bond (Pogrebnjak, et al., 2013).

CONCLUSION

From the analysis, it was observed that there was not a clear cut difference in these properties as showcased by the various deposition techniques because in the case of XRD analysis the peak in the intensity was observed at similar position for difference depositions and similar situation was also seen the spectral transmittance and reflectance.

In all of these case, the energy band gap has the same range in all the various deposition methods. What appeared to have influenced these properties is the annealing temperature.

CONCLUSION

Transparent ZnO thin films doped with aluminum were prepared by Chemical Bath Deposition techniques and the effect of aluminium concentrations on the optical properties were studied. The absorbance plot reveals that all the deposited ZnO thin films are absorbing in the visible region of the spectrum at different maxima wavelength between 300nm – 450nm and that increase in Al concentrations causes decrease in absorbance value of the film is a proof that Al dopant have a profound effect on the optical properties of the films.

High absorbance in the UV region also makes the films better material for the building of poultry roofs and walls to warm the inside of the poultry house and the high absorbance of the deposited ZnO thin films suggests that they can also be used in solar cell fabrication as an absorber.

From the transmittance plots, the deposited ZnO films have relative high transmittance at the visible to infra-red region and the transmittance increases with increase in Al concentrations. High transmittance in the visible region and wide energy band gap shown by these films, suggest that these films could be employed in solar cell architecture as window layer.

The energy band gaps of these films fall within the range of (3.5-3.9eV). This increase in band gap as doping concentration increases shows that aluminum dopant enhances the band gap and the wide band gap exhibited by these films, suggest that these films are good materials for application in laser diode and photovoltaic applications. In general, the deposited film is a possible material that can be used for solar application.

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