Studying of Thickness Effects on the Optical and Structural Properties of ZnO/Ag/ZnO Multilayer Thin Films by Using Surface Plasmon Resonance

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Abstract
In this paper, the Effect of Surface Plasmon's on Optical and structure Properties of Multilayer ZnO/Ag/ZnO thin film have been investigated. These properties could be tuned using the plasmonic properties of the two layers of ZnO. The two thin layers of ZnO with thicknesses varying from 30 nm to 40 nm and the intermediate Ag layer of 6 nm thickness have been deposited using radio frequency magnetron sputtering and Vacuum Deposition technique on glass substrate respectively. multilayered ZnO/Ag/ZnO thin films with *c*-axis-oriented wurtzite structure is obtained at a growth temperature 300 ◦C. X-ray diffraction shows that the full width at half maximum θ-2θ of (002) ZnO/Ag/ZnO is located at approximately 34.28°. UV-VIS Spectrometer has been used to measure the optical transparency. We also studied the influence of ZnO thickness on optical properties of the ZnO/Ag/ZnO composite and the effect mechanism by surface plasmon.
Keywords: Surface plasmon resonance, Dielectric/Metal/Dieletric thin films, Magnetron sputtering, Vacuum Deposition

Introduction

Surface plasmon resonance (SPR) is a quantum optical-electric phenomenon arising from the interaction of light with the oscillation of free electrons that propagates along with the surface bound to a dielectric medium i.e., surface plasmon (SP) [1] . Plasmonics based Multilayer Dielectric/Metal/Dielectric thin film structure are drawing great attention because they have been widely used in Transparent Conductive oxide applications, such as solar cells, optoelectronics, sensors, flat panel displays etc. because of their ability to improve optical transmittance [2]. Zinc oxide, ZnO, is a material with great potential for various applications, such as surface acoustic wave devices, optical waveguides, transparent conductive oxides, UV-light emitters, chemical and gas sensors, etc. ZnO has been considered as one of most promising candidates for photonic applications in the UV or blue spectra range due to its wide band gap (≈3.37 eV) at room temperature and high exciton-binding energy (60 meV) [3]. Recently, numerous authors like Wang and Zhang et al., demonstrated dramatic enhancement of transmission of electromagnetic wave through a multilayer structure of ZnO/Ag/ZnO/Glass [3], [4]. This phenomenon they attributed to the interaction of electromagnetic wave with metal island film, which acts as 2-D grating. These types of films are the special feature of sputtered deposited film as claimed by Wang et al. Another group of Lee et al. claimed this phenomenon can be explained using simply Fresnel's equation [5]. We have fabricated the same kind of structure of ZnO/Ag/ZnO on glass substrate using relatively simpler and cost effective techniques like Vacuum Deposition and radio frequency magnetron sputtering. In this research, we have presented some preliminary results of our study regarding structural and optical properties of multilayer ZnO/Ag/ZnO thin film, which can tune the Localized Surface Plasmon effect.

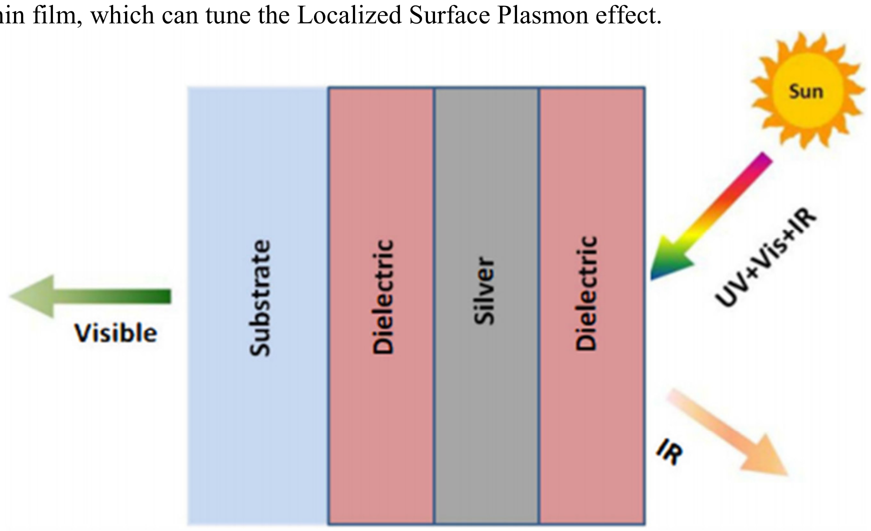

Fig.1 Thin film multilayer Dielectric/Metal/Dielectric

Experimental procedure:

Multilayered ZnO/Ag/ZnO thin films were grown by using RF magnetron sputtering and Vacuum Deposition technique. Glass slides were used as substrates. Microscopic glass slides were used as substrates. Prior to loading the samples into the system, the substrates were first washed with detergent and then ultrasonically degreased with acetone, ethanol and distilled water. ZnO thin films with thicknesses varying from 30 nm to 45 nm were deposited by RF magnetron sputtering using a PLASSYS setup with embedded microbalance for controlling the deposition thickness. The quality of the prepared films has been very sensitive to deposition parameters, which have been, therefore, optimised in order to obtain highly oriented ZnO fillms. The zinc oxide target (purity 99.99%) diameter was 15 cm and 6 mm thick. The distance between the cathode and the substrate holder was 6 cm. The deposition chamber was pumped down to a base pressure of 2×10^{-7} Torr by a turbo molecular pump prior to the introduction of the argon gas for ZnO thin film production. After the deposition of ZnO, Ag layer of desired thickness were deposited by thermal evaporation under the base pressure of $6\text{x}10^{-5}$Torr. These films were deposited at room temperature and the source–to-substrate distance was kept at 20cm. Thickness of the films were measured using a quartz crystal thickness monitor. Another layer of ZnO thin film of same thickness was deposited using the RF magnetron sputtering. After fabrication films were annealed at 300°C under vacuum of about $1\text{x}10^{-3}$ Torr.The Crystal structures of the multilayer films were analysed by X-ray diffraction (XRD)from type(Philips pw 1840) using the Cu $K\alpha$ (with λ = 1.5405 Å) radiation. The optical characteristics were of ZnO/Ag/ZnO was measured in the range 300-900 nm using UV-VIS Spectrophotometer (Jasco V-570.).

Results and Discussion:

Structural and morphological properties

Fig. 2 shows the XRD patterns of ZnO/Ag/ZnO multilayer structure of different thickness after post annealing at temperature about 300°C. At first we did not notice any peak at thickness(30/6/30nm), but We observe only one strong peak with the increasing thickness of the layer ZnO at $2\theta \approx 34.4^{\circ}$, which is attributed to the (002) line of the hexagonal ZnO wurtzite phase. This indicates the polycrystalline nature of ZnO thin film with preferential orientation along (0 02) plane, with the *c*-axis perpendicular to the substrate surface [6]. That when Ag thin films with protective layers were heat treated, crystalinity was improved. Annealing after deposition was effective in increasing the transparency and decreasing the resistivity of all coatings. We did not notice the appearance of any silver peak in all the films, perhaps due to the low thickness (6nm). The mean grain size d is obtained by the Scherrer formula [7], $d = 0.94\lambda/(B \cos \theta)$, where λ, θ and B are the X-ray wavelength (1.54 Å), the Bragg diffraction angle, and the line width at half maximum of the peak, respectively. The increase of the intensity of the diffraction peak and the decrease of the full width half maximum (FWHM) of SPR peaks, from (0.005 to 0.004rad), with increasing thickness of ZnO film, is an evidence of the improvement in crystallinity of the films. As the samples have compressive stress and since the strain is gradually relaxed. After increasing the thickness of ZnO film, this reduction in FWHM could be attributed to the improvement in crystallinity [8].

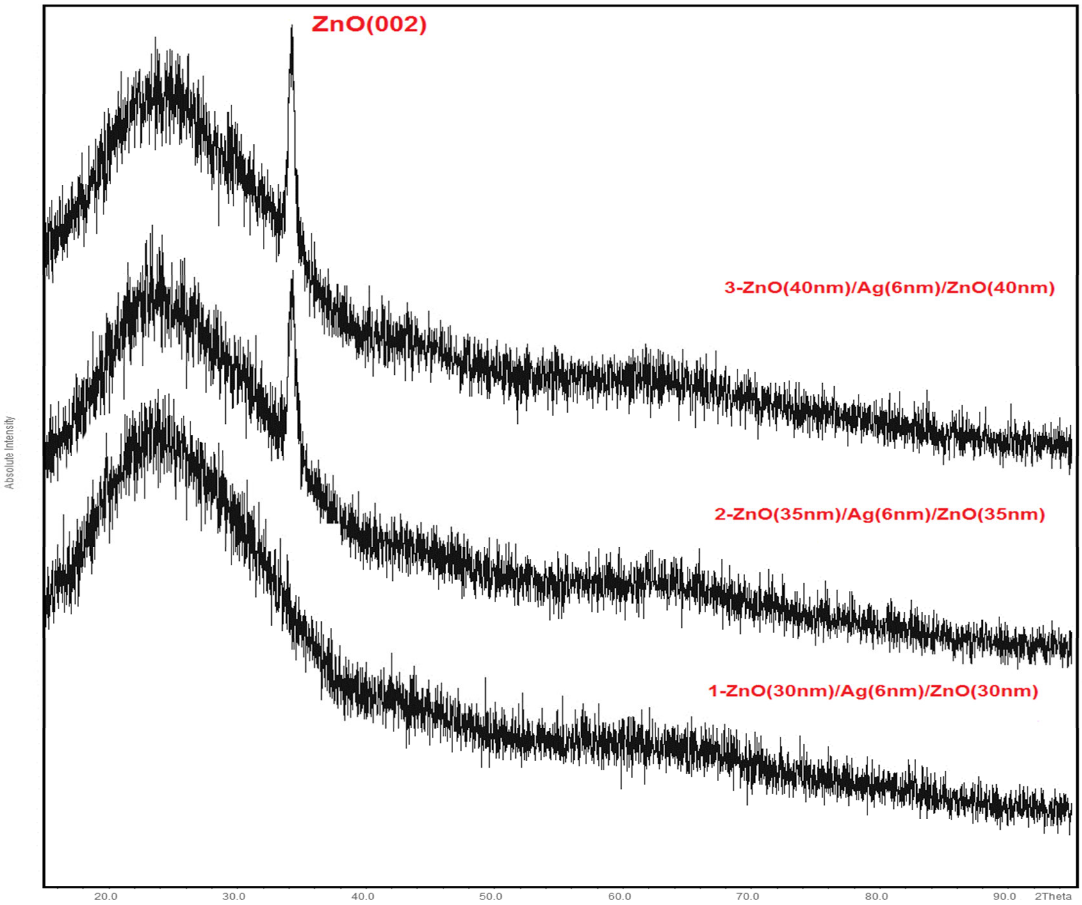

Fig. 2 XRD Pattern for ZnO/Ag/ZnO Multilayered thin film of various ZnO layers thickness.

Optical Properties:

Figure. 3a shows the optical transmission spectra of ZnO/Ag/ZnO multilayered for various ZnO thicknesses ranging from 30nm to 40 nm and Ag thickness 6nm. All the transmittance spectra show an enhanced transmission area in the visible range (above 625 nm) compared to ZnO film. The decrease in transmission about 42% at the wavelength (λ<400nm) to the absorption by ZnO[9]. All the optical spectra of ZnO/Ag/ZnO samples exhibit a distinctive transmission dip or Surface plasmon resonance wavelength (SPRW) at wavelength (about550 nm-625nm) due to the Surface Plasmon Resonance (SPR) effect. Transmission spectrum of ZnO has absorption edge in ultraviolet spectral region at a wavelength 300nm. This absorption edge was shifted to 370 nm in ZnO/Ag/ZnO multi-layer films [10]. It represents the increment of electrical conductivity with Shifting absorption edge 300 nm to 370 nm. When the ZnO film thickness increases from 30 nm to 40 nm transmittance minimum dip (SPR Peak) was shifted wavelength at 560 nm to higher wavelength of 620nm due to increasing the fill factor with ZnO thickness increases and interparticle distance [10] For ZnO film thickness increasing for 40 nm transmittance becomes lower in near infrared. We have noted that SPR depth also increasing with ZnO thickness Due to increased density of ZnO particles About the Ag film. The absorption coefficient of a thin layer is expressed, as an approximation, by the following formula:

$$\alpha = A(hv - Eg)^{1/2} \text{ ……(1)}$$

Where Eg is the band gap, hv is the photon energy, A is a constant and the value of ($1/2$) for allowed direct transitions in ZnO. The optical band gap Eg of ZnO thin flms can be deduced from Fig. 3b, which demonstrates a plot of $\alpha2$ versus hv that is expected to be linear within the approximation limit of Eq(1). One may extend the linear part of $\alpha2$ as a straight asymptotic line that intercepts the horizontal axis ($\alpha2 = 0$) yielding Eg from hv value [11]. Thus, we find an optical band gap at 3.22, 3.25, and 3.27 ev for samples 1, 2, and3, respectively As in Fig.2a. The largest value of the optical band gap (3.27 eV) is probably related to the nanoscopic size of crystallites [12]

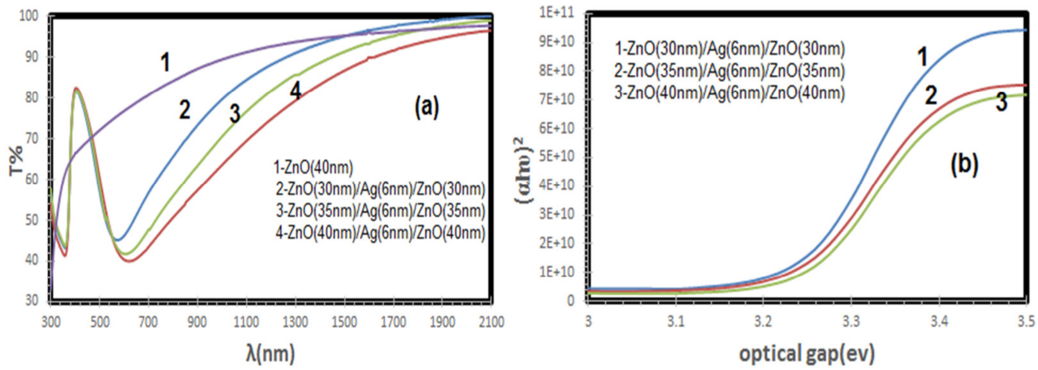

Fig.3.(a) Optical transmission spectra of ZnO/Ag/ZnO film with various ZnO thickness,(b) variations of $\alpha 2$ as a function of photon energy for flms at different thickness.

CONCLUSION

In summary, we have studied the structural and optical properties of transparent conductive ZnO/Ag/ZnO multilayer films, which were prepared using RF magnetron sputtering for ZnO and Vacuum Deposition technique for Ag films. We have correlated the Optical properties of multilayer thin film with thickness and structural of the high and low ZnO two layers. Study of X-ray diffraction showed these films were polycrystalline in nature. X-ray diffraction analysis indicates that the films exhibited preferential orientation (002). We also studied the influence of ZnO thickness on optical properties of the ZnO/Ag/ZnO composite and And the effect mechanism by surface plasmon. Due to the localized surface plasmon these films show a strong extinction peak at around 600 nm which can be tuned changing the morphology of the two layers of ZnO. The largest value of the optical band gap (3.27 eV) is related to the nanoscopic size of crystallites.

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