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Optical Studies of Silver Oxide Deposited Thin Films Using the RF Sputtering Technique

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Abstract

Background/Objectives: Silver Oxide is an efficient material because it is used in batteries. Apart from this, it is a moderate oxidizing agent in a variety of processes including the oxidation of aldehydes to carboxylic acids. The objective of the study is to synthesize silver oxide films by RF sputtering technique so that synthesized films can be inserted in the spectrophotometer for optical study. **Methods**: Silver Oxide films were deposited on Fluorine-doped Tin Oxide (FTO) glass using Radio Frequency (RF) sputtering method and annealed at 200 °C, for two hours, and then it was used in DK2 Ratio recording Spectrophotometer to analyze absorption and transmission data. **Findings**: The thickness of the films was measured using a non-contact optical Profilometer, in the range of (42– 660) nm. The films were subsequently exposed to optical characterization, revealing exceptionally low transmittance and high absorbance. The band gap is estimated to be 2.2 eV. The X-ray diffraction (XRD) studies reveal that the material is crystalline and Miller indices have also been determined. The morphology and topography of the thin films were analyzed using Field Emission Scanning Electron Microscope (FESEM) and the chemical composition was estimated using EDS. **Novelty**: The present work reveals that the optical properties are highly dependent on the thickness and the material distribution. The direct band gap energy is evaluated from the absorption spectrum which comes out to be 2.2 eV. The XRD spectra synthesized Silver Oxide films are crystalline in nature.

Keywords: Silver Oxide; Band gap; XRD; FESEM

1 Introduction

Silver (Ag) is commonly thought of as a non-reactive substance. Silver Oxide (Ag_2O) has been discovered to be a p-type semiconductor with an energy gap of roughly 1.2

to 3.4 eV [1,2]. The Ag_2O nanoparticles have numerous applications because of their outstanding antimicrobial actions, good conducting and optical characteristics, and their main application for solar cells. It has been discovered that the size and shape of Ag_2O have a significant impact on its optical characteristics. Due to the fact that silver nanoparticles are used in batteries, the spectral response of these particles in the visible range of the electromagnetic spectrum has garnered even greater attention. It functions as a mild oxidizing agent in numerous processes, such as those that convert aldehydes to carboxylic acids. Several different chemicals can be synthesized with it. It is also employed in the creation of Tollen's reagent. Films are attracted by scientists for their novel application and intense density optical storage gadgets, gas sensors, solar cells, and disinfectant coatings [3,4]. Hence, we have made a systematic investigation on the optical properties of silver oxide thin film coatings in the thickness range (42-660) nm. The films were grown in a conventional vacuum coating unit under a base pressure of $3x10^{-6}$ mbar. According to our knowledge, only a few reports were available on the study of Ag_2O thin film in the literature. We synthesized and optical characterization was done to give a full knowledge of the optical characteristics of Ag_2O. The novelty of the present work is that we have estimated the band gap energy of Ag_2O thin films and the microstructure obtained from XRD analysis is crystalline in structure.

1.1 Theoretical Section

One of the most effective methods for finding the band structure and energy gap is the analysis of optical absorption spectra. The equation describes how an object's optical absorption coefficient (α) relates to its transmittance (T) Equation (1).

$$\alpha = [\frac{1}{t}\ln\frac{1}{\tau}] \tag{1}$$

Where, t = film thickness.

Silver oxide is a P-type semiconductor and a direct band gap material; the absorption coefficient (α) is linked to band gap energy by the relation [4] and is represented in Equation (2).

$$ah\nu = \sqrt{B\,(hv - E_g)} \tag{2}$$

Where hv is the energy of the incident photon.

E_g is the Ag_2O film's optical band gap energy, and B is a constant that varies in value depending on the kind of transition. The band gap changes with the thickness of the film, and the energy gap is determined for various thicknesses (t).

2 Methodology

Silver oxide thin films were prepared and deposited onto Fluorine doped Tin oxide (FTO) glass substrate using a radio frequency magnetron sputtering technique [5,6]. A silver target of 99.9% purity was used as a sputtering target the base pressure was around $3x10^{-6}$ mbar obtained in the sputter chamber using a diffusion pump backed with rotary pump assistance. Argon was used as a sputter gas, and oxygen was employed as a reactive gas [7]. The requisite volumes of reactive gas, Oxygen, and sputter gas Argon were permitted to enter the sputter cabin by a fine-regulated needle valve, with a spacing of roughly 70 mm between the target and the substrate material. The advanced radio frequency energy source was used to power the sputter target. The sputter target received 80 watts of electricity. At ambient temperature, silver oxide films were created using an oxygen partial pressure of $2x10^{-6}$ mbar and a sputter pressure of 4 Pascal. The parameters of sputter deposition are given in Table 1 for the development of silver oxide films.

Table 1. Shows Silver Oxide parameters for deposition

Coating technique	RF magnetron sputtering
Sputter material	Silver, 3 inch
Base pressure	$3x10^{-6}$ mbar
Oxygen partial pressure	$3x10^{-6}$ mbar
Substrate temperature	273 K
Sputter power	80 W
Duration of deposition	1min, 3min, 5min, 7min and 9 min.

From the knowledge of the deposition time, we have estimated the thickness of Silver Oxide films. All the films were grown and annealed at 200 °C for 2 hrs then these films were used for optical measurements. The fabricated Ag_2O films were characterized by an Analytika Jena Spectrophotometer in the incident photon wavelength range (180 -1100) nm. Then these films were subjected to X-ray diffraction studies using a monochromatic Rigaku smart lab SE X-ray tube as Cu at an angular range of 2° to 150°. The wavelength of the monochromatic X-ray used was 1.504 Å. The film's topography and morphology were examined using a FESEM. The presence of Ag and Oxygen in the film was determined by using EDS.

3 Result and Discussion

Figure 1**a** depicts the % transmittance vs wavelength of incident radiation for a Silver oxide film of thickness 660 nm only. Figure 1**b** indicates transmission spectra of Ag_2O films of different thicknesses in the wavelength region of (300-800) nm of incident photon energy. It is noticed that for all the films % transmittance decreases with the increase of film thickness, in the incident wavelength interval from 300 to 800 nm. However, for the region of incident wavelength (0-300) nm with the increase in the wavelength, the transmittance decreases and later increases and remains almost constant in the wavelength region (300-800) nm as shown in Figure 1 **b**. F A Jasim et al, have reported that with an increase in the wavelength of incident radiation, the transmittance first decreases and then increases with the increase in the wavelength [2] which contradicts the results obtained by us.

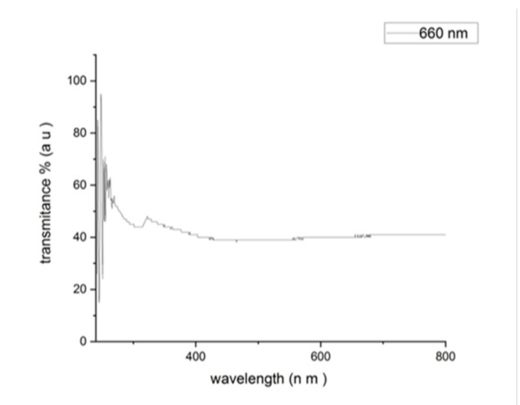

Fig 1. (a) % Transmittance vs wavelength of incident radiation for 660 nm film thickness Ag_2O. (b) Transmittance Vs wavelength of incident radiation for all the film

In Figure 2**a** we have drawn the graph of % absorbance against the wavelength of incident radiation for the film thickness 660 nm. Figure 2 **b** illustrates the absorption spectrum of Ag_2O films for various thicknesses for the incident wavelength region (300-800) nm.

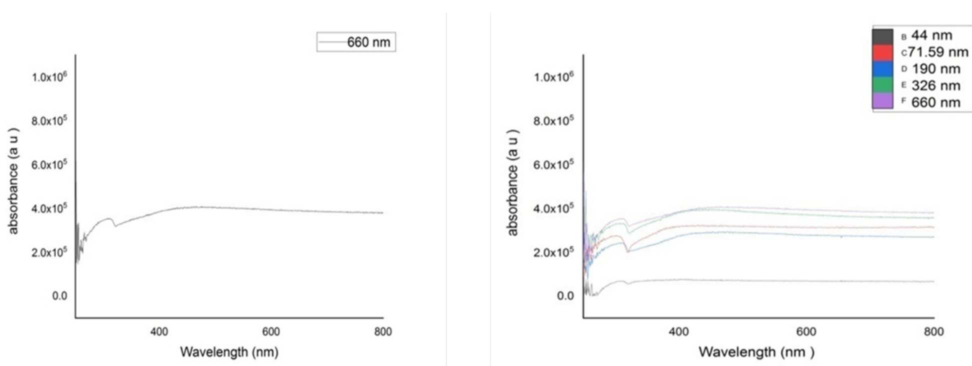

Fig 2. (a) % absorbance vs Wavelength of incident radiation for film thickness. (b) % absorbance vs wavelength of incident radiation 660nm for all films

According to these plots as the thickness of film increases, the absorbance also increases in the entire spectral region of the incident photon. The absorbance Vs wavelength Ag_2O films first increase and then decrease in the spectral region mentioned[8]. However, in the case of Ag_2O films with the increase of wavelength of incident radiation, the absorbance first decreases and then increases as shown in Figure 2**a** and **b**. The result is contradictory to that compared to Ag_2O films.

Figure 3 shows according to Equation (2) in order to estimate the binding energy at different film thicknesses, we have drawn $(ahv)^2$ versus hv graph for all film thicknesses. Then the tangents were drawn to these curves, and the intercepts of the straight line on the x-axis gave band gap values which we got 2.2 eV. From Figure 3, the plot shows $(ahv)^2$ vs hv we obtained the value of the energy gap as 2.2 eV which is of the same order reported by[9,10].

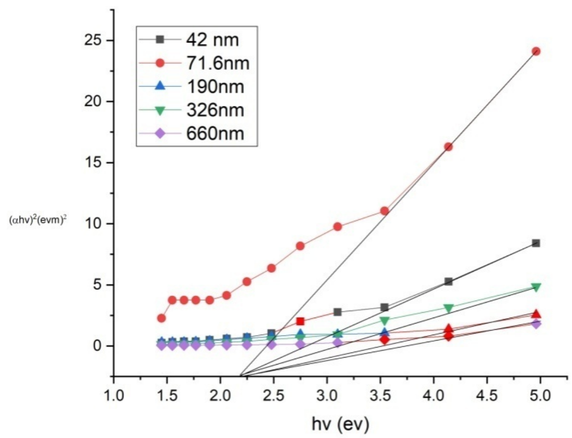

Fig 3. (ahv) ^{2} versus hv in eV

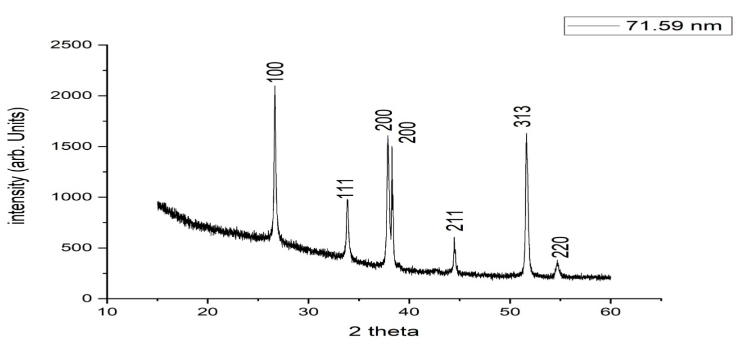

Fig 4. XRD analysis of 326 nm thickness

In order to show the stoichiometry of the prepared AgO thin film electrode, X-ray diffraction was used. The crystalline and cubic structure of the AgBragg's angles, as illustrated in Figure 4. Furthermore, it is noted that the crystal structure supports BCC and FCC when seen from the Braggs angle. Similar kinds of outcomes have been reported for AgO films by others.[11,12]

FESEM Figure 5 (**a, b, c, and d**) exhibits typical FESEM micrographs of of Ag_2O thin film surface morphologies. The formation of silver oxide film surface is rough and made up of small nanoparticles. The crystalline size becomes more distinct, with a mix of tiny and large granules, spherical and non-spherical granules deposited. The below images depict homogenous and dense surfaces.[13,14]

Electron dispersive spectroscopy (EDS) investigation yields information on the quantitative analysis of the films, which was performed using FESEM measurements in order to study the stoichiometry of the films. Figure 6 shows how to analyze the composition of silver and oxygen using EDS spectra. The range, varies from 0 to 153 keV, The below figure shows that conventional peaks of silver and oxygen atoms are present in the EDS spectra, which has been relatively analyzed, and it confirms that the materials used in the present research are silver and oxygen. This indicates that there are no additional impurities in the silver oxide thin films[15,16].

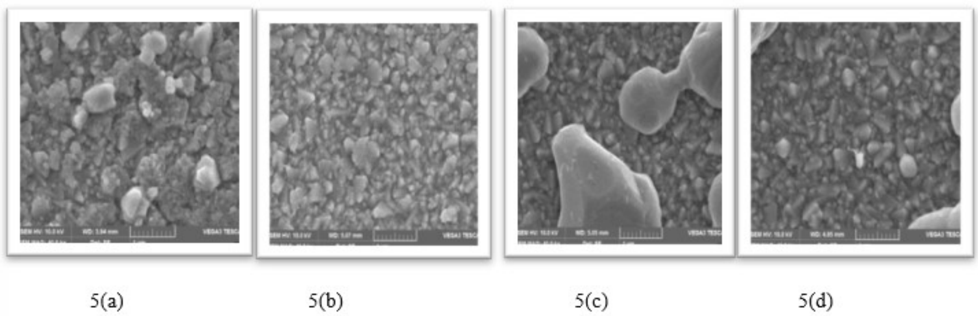

Fig 5. (a, b, c and d) shows FESEM image ofmagnification 40 k

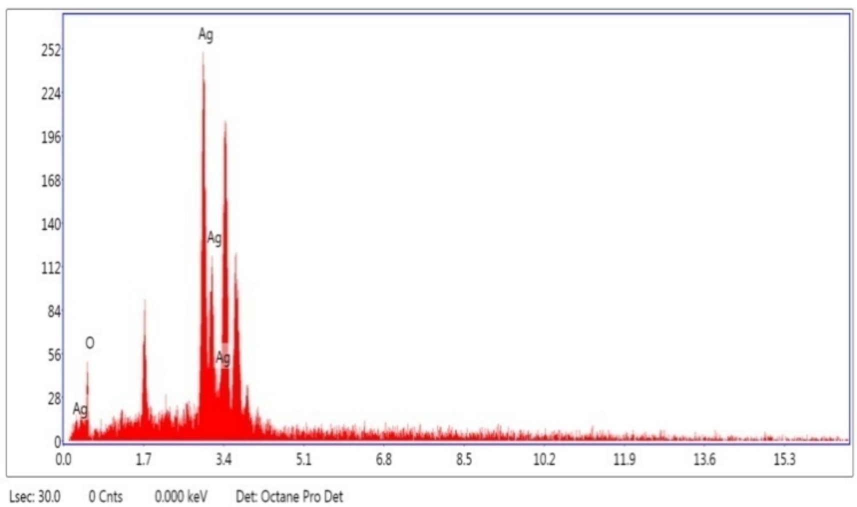

Fig 6. EDS patterns for Ag_2O film thickness of 326 nm. The Y-axis shows the counts. (Number of X-rays received and processed by the detector), and the X-axis shows the energy level of those counts

4 Conclusion

The Ag_2O thin films were successfully grown on FTO glass by using the RF sputtering technique. The deposition process has been done in 5 stages with different times of deposition (1, 3, 5, 7, and 9 min). The prepared samples were annealed at 200 °C. Using a non-contact optical Profilometer, we have identified that the film thickness varies from 42 nm to 660 nm. In the transmittance spectra, as the thickness increases, the transmittance intensity decreases but in absorbance, as the thickness of the film increases, the absorbance also increases. The XRD analysis reveals that the structure of Ag_2O is in a crystalline state. The direct band gap energy calculated from the absorption data is 2.2 eV. FESEM reveals the homogeneous and dense surface of the films. The EDS analysis confirms that the material contains Ag and O, as observed in the EDS spectra.

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