Study of the Effect of Gallium (Ga) Doping on Different Properties of Cadmium Oxide (CDO) Thin Film

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Abstract: - The sprayed CdO and Ga doped CdO thin films were successfully fabricated onto glass substrate. The optical and electrical properties of the CdO films have been studied with respect to Ga doping concentration. The absorbance and reflectance of CdO thin films decreases with the increases of Ga content up to 3% and then increases afterwards. The value of absorption coefficient of deposited films is in the order of 10^6 increases and increases with increasing photon energy. The values of real part is higher than imaginary part of (0-5)% Ga doped CdO films. As the doping concentration of Ga increases, the optical conductivity of CdO initially decreases and then increases. The electrical conductivity of undoped & doped CdO films decreases with the increases of temperature i.e. all films has poor metal like behavior. Therefore, the electrical conductivity of the CdO thin films increases from 1.72×10^3 mho/cm to 8.17×10^3 mho/cm when the film is doped with 3% Ga and then decreases afterwards.

Key Words: — Spray pyrolysis, GCO thin films, Optical properties, Electrical properties.

I. INTRODUCTION

Cadmium oxide (CdO) is one of the important Transparent Conducting Oxide (TCO) semiconductors which have low electrical resistivity and transparency in the visible region of the electromagnetic spectrum [1-2]. Though CdO is toxic, it has found its place in many technological fields of applications like solar cell, photodiode, optical communication, thin film photovoltaics, phototransistor, IR heat mirror etc applications [1-3]. It also gained importance in the field of batteries, coloring agents, nuclear fission reactions, etc [4]. The main advantage of CdO is that it possesses natural point defects at cadmium interstitials and oxygen vacancies which dominate the electrical conductivity of CdO [4-5]. The properties of CdO thin films largely depend on the methods & conditions of fabrication and also on doping element. Usually, doped materials show different characteristics that cannot be observed in that host metal oxide [10]. Various dopant materials have been used for the purpose of improving and tailoring the electrical and optical performance of the CdO thin films [6].

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Therefore, we have used Gallium (Ga) as a doping element because gallium is a trivalent cation, which have the capabilities to donate an extra electron upon successful substitution. Thus the extra electron improves the optical and electrical properties of CdO. The undoped and doped CdO thin films have been fabricated using several fabrication methods like sputtering [3], sol–gel [4], chemical vapor deposition [7], pulsed laser deposition [8], spray pyrolysis [9] and so on. Among these deposition technique, spray pyrolysis have several advantages such as low cost, simple experimental set up, easy controlling, film can be deposited at air atmosphere etc. The present work focus on fabrication of CdO and Ga doped CdO thin films and to investigate the effect of Ga doping on optical and electrical properties of CdO thin films.

II. MATERIALS AND METHOD

In the present work, (0-5) mol% Ga doped CdO has been deposited by spray pyrolysis technique. The films were deposited on to normal glass slide. Cadmium acetate dihydrate ($Cd(CH_3COO)_2.2H_2O$) and gallium (III) nitrate hydrate ($Ga(NO_3)_3.xH_2O$) has been used as a source dopant of CdO and Ga respectively. Deionized distilled water was used to prepare the spray solution. The details spray pyrolysis process has been described in our previous work [9].

Therefore, the spray parameters which were followed during spray deposition process are as follows; (molarity of the spray solution: 0.1M, substrate temperature: 400°C, spray rate: 0.5 ml/min, spray media: pressurized atmospheric air). The optical properties were recorded by UV-visible spectrophotometer (UV-1900i Shimadzu, Japan). The electrical conductivity of the films was measured by four probe van der Pauw method.

III. Results and Discussion

The analysis of optical properties is very important for designing opto-electronic materials. Fig. 1 shows the optical absorption spectra of CdO and Ga doped CdO thin films as a function of wavelength. It has been observed that the absorption of all deposited films continuously decreases with the increase of wavelength of light. The absorbance of CdO thin films decreases with the increases of Ga content up to 3% and then increases afterwards. So 3% Ga doped CdO film possess minimum light absorption capability.

Fig. 2 shows the optical reflectance spectrograph of undoped and Ga doped CdO thin films. It is observed from fig 2 that the reflectance first increases up to a certain wavelength and then decreases onwards. Therefore, the CdO film has higher reflectance and the reflectance of CdO decreases with the increase of Ga content up to 3%. Then, with the addition of Ga above 3%, the reflectance again started to increase. This increase of reflectance due to the increase of scattering of photons by crystal defects [11].

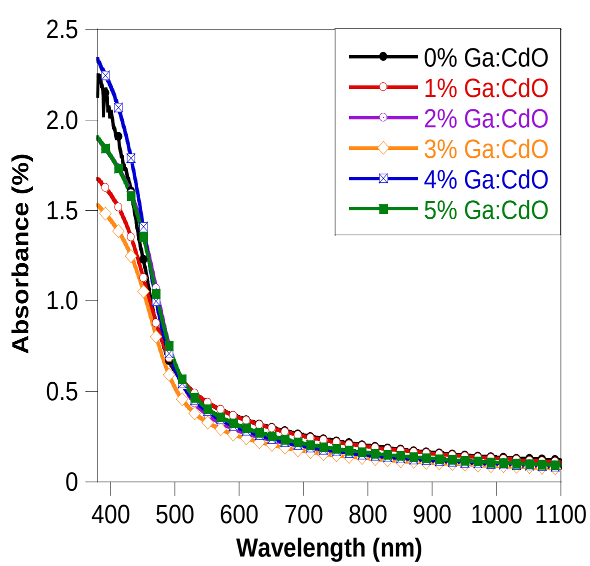

Fig.1. Optical absorption spectra of (0-5)% Ga:CdO thin films

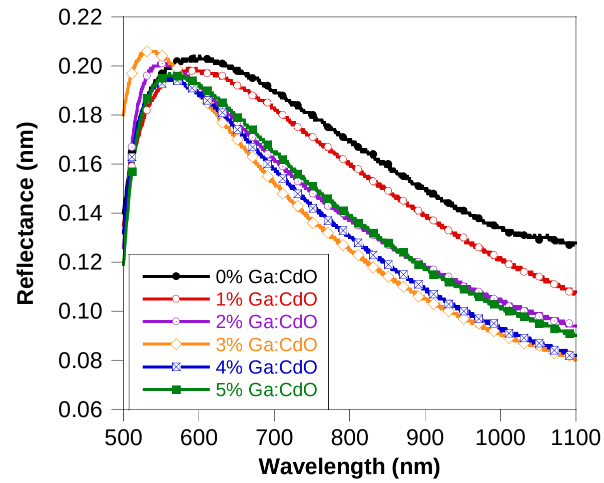

Fig.2. Optical reflectance spectra of (0-5)% Ga:CdO thin films

The absorption coefficient characterizes how easily a material or medium can be penetrated by a beam of light and it can be obtained through beer Lambert's law [11-12]. The absorption coefficient of CdO and Ga doped CdO thin films as a function of photon energy is shown in Fig. 3. The absorption coefficient of deposited films increases with increasing photon energy and have the value is in the order of 10^6. The overall absorption coefficient of CdO decreases with increasing Ga concentration up to 3% and the increases onwards.

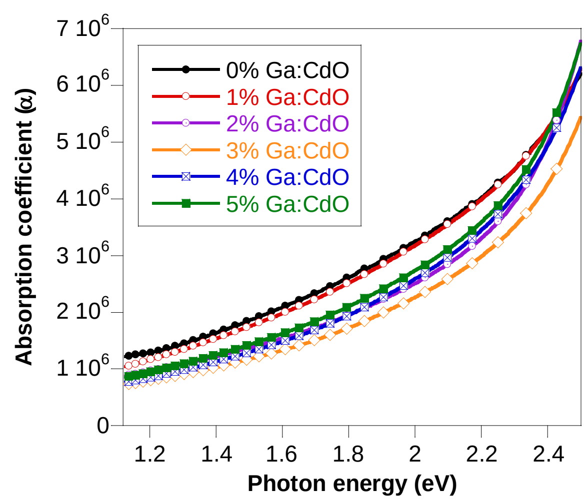

Fig.3. Absorption coefficient spectra of (0-5)% Ga:CdO thin films as a function of photon energy

The skin depth or penetration depth (δ) is related to the absorption coefficient (α) by the following simple relation

$\delta=1/\alpha$ [13]. From fig. 4 it is observed that with the increase of photon energy, the skin dept decreases. However, the minimum skin depth has been observed for CdO thin films. Therefore the maximum skin dept value of CdO thin film has been found for 3% Ga doped films. Subsequently the value of skin depth decreases above 3% Ga doping.

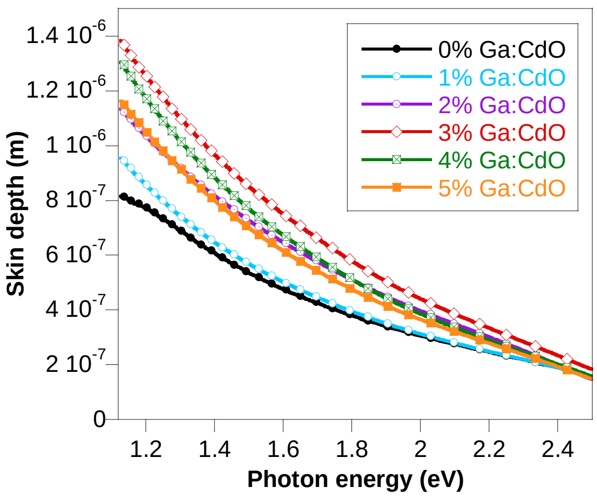

Fig.4. Skin depth of (0-5)% Ga:CdO thin films as a function of photon energy

The optical density (D) was calculated using the following equation, $D_{opt} = \alpha t$ [13]. Here, t is the thickness of the films. Fig. 5 represents the variation of optical density with photon energy. It has been observed that the optical density follows the same pattern as absorption coefficient.

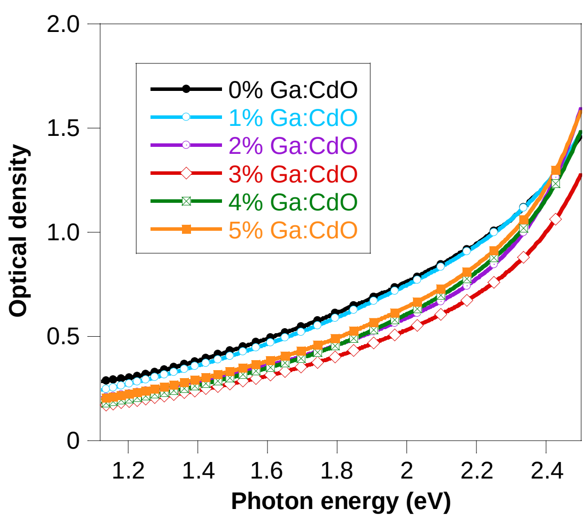

Fig.5. Optical density of (0-5)% Ga:CdO thin films as a function of photon energy

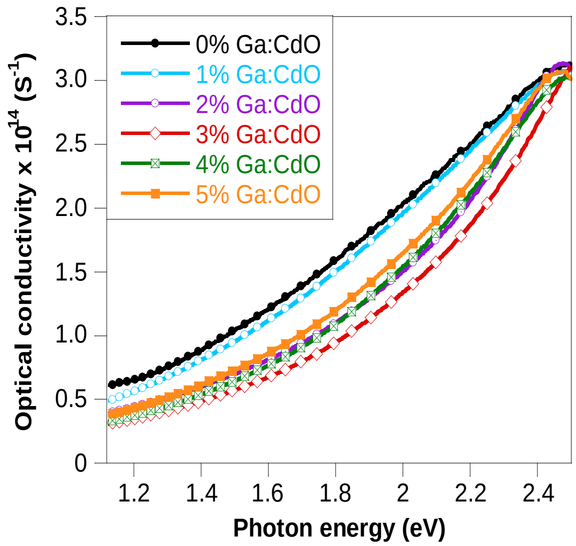

Fig.6. Optical conductivity of (0-5)% Ga:CdO thin films as a function of photon energy

The optical conductivity represents the optical response and electronic states of thin films materials [14-15]. The optical conductivity was calculated by using, $\sigma = \alpha nc/4\pi$ [14].

The value of optical conductivity of all deposited films has been found in the range of 10^{14} S^{-1}. This higher order of value of optical conductivity indicates that the films have high photo responses capability [15]. It is also noticeable from fig 6 that the optical conductivity of undoped and doped CdO thin films increases with photon energy. Besides, the optical conductivity decreases continuously with Ga doping concentration up to 3 mol% and then increases afterwards.

The electrical conductivity of CdO and Ga doped CdO thin have been calculated from the measured electrical resistivity (ρ) data using the following equation, $\sigma = 1/\rho$ [16] and is shown in fig 7.

It has been found that the undoped CdO has electrical conductivity is 1.72×10^3 mho/cm. Therefore, the conductivity increases to 8.17×10^3 mho/cm when the film is doped with 3% Ga.

After that, the conductivity started to decrease. The increment behavior of electrical conductivity may due to the successful substitution of Cd^{2+} ion by Ga^{3+} ion. On the contrary, the dopant ion may be ineffective to substitute Cd^{2+} ion of the CdO lattice and thus the conductivity decreases [9].

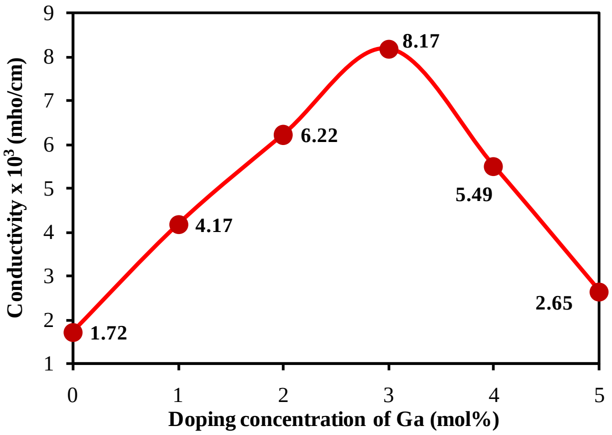

Fig.7. RT Electrical conductivity of (0-5)% Ga:CdO thin films

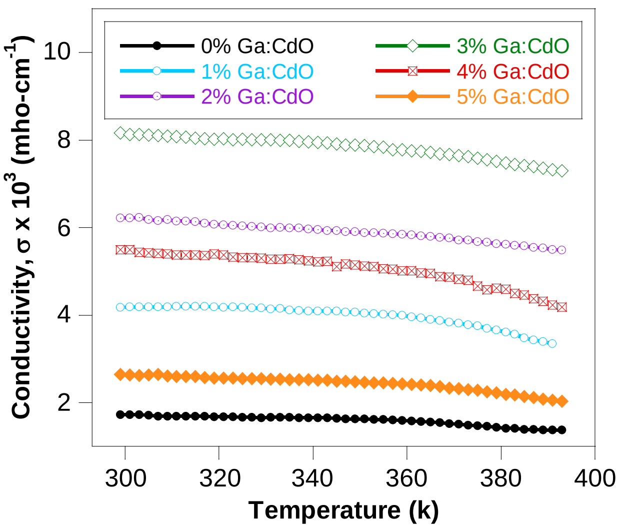

Fig.8. Electrical conductivity of (0-5)% Ga:CdO thin films as a function of temperature

Fig.8 shows the electrical conductivity behavior of (0-5%) Ga doped CdO films as a function of temperature. It is observed that the electrical conductivity of undoped & doped CdO films decreases with the increases of temperature. Several author [9, 16] reported that the increasing temperature increases the thermal scattering of carriers and which decreases the conductivity of films.

IV. CONCLUSION

The spray pyrolyzed CdO and Ga doped CdO thin films were successfully fabricated onto glass substrate at 400°C temperature. Several optical and electrical properties of the CdO films have been analyzed and compared with respect to Ga doping concentration. The absorbance and reflectance of CdO thin films decreases with the increases of Ga content up to 3% and then increases afterwards. The absorption coefficient of deposited films increases with increasing photon energy and have the value is in the order of 10^6. The overall values of real part is higher than imaginary part of (0-5)% Ga doped CdO films. As the doping concentration of Ga increases, the optical conductivity of CdO initially decreases and then increases. The electrical conductivity of undoped & doped CdO films decreases with the increases of temperature i.e. all films has metal like behavior. Therefore, the electrical conductivity of the CdO thin films increases from 1.72×10^3 mho/cm to 8.17×10^3 mho/cm when the film is doped with 3% Ga and then decreases afterwards. Thus the 3% Ga doped CdO films possess optimum optical and electrical properties. The obtained results show that Ga doping affects the optical and electrical properties of CdO thin films.

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