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Fabrication of CO Gas Sensor based on Nano Crystalline CdO-Doped Cu thin Films Prepared by PLD

Hassan H. Darwoysh[a*], Ali A. Yousif[b] Kadhim A. Aadim[c]

[a,b]Department of Physics, College of Education, University of Mustansiriyah, Baghdad, Iraq

[c] Department of Physics, College of Science, University of Baghdad, Baghdad, Iraq

*E-mail : hassan.hadi66@uomustansiriyah.edu.iq

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ABSTRACT

Pulsed laser deposition (PLD) was used to create thin copper-doped cadmium oxide (CdO) films at various concentrations. The deposition process was done at room temperature (300 K). The surface morphology of the CdO thin films revealed an intricate network resembling a prism. The cubic crystal nanostructure and the CdO thin films are aligned in a (1 1 1) plane. At an operating temperature of 280 degrees Celsius, the sensing characteristics of CdO thin films with a carbon dioxide (CO) nanonanostructure were investigated. The results showed that increasing the copper concentration or increasing the gas concentration to 200 ppm would increase the sensitivity of the gas.

Keywords: *gas sensors; CdO thin films; PLD; SEM, EDS, XRD*

I. INTRODUCTION

It is crucial to consider the cost of the deposition method as well as the simplicity with which raw materials can be obtained when choosing the best Transparent Conducting Oxides (TCO) material. It is believed that CdO is a substance with a variety of advantageous characteristics, including a wide energy band gap, a high transmission coefficient in the visible spectral area, exceptional luminescence properties, and more. The band gap of bulk CdO, an n-type semiconductor, is enormous (2.3 eV), while its indirect band gap is 1.36 eV [1]. It can be used in a wide range of applications, such as flat panel displays, photo transistors, solar cells, windows, and so forth. The structural, electrical, and optical characteristics of a film have been demonstrated through experiments to be strongly dependent on both the film's nanostructure and the conditions under which it was deposited [2–5]. These translucent conductors are extensively used in optoelectronic devices [7] and thin film solar cells [5, 6]. A few techniques that can be used to create CdO layers are sputtering , chemical vapor deposition (CVD) , spray pyrolysis [8-10], thermal evaporation [11], and sol gel [12]. In the field of gas sensors, thin films of different oxide materials, such as SnO2 , ZnO, and CdO, among others, have shown significant results in regard to gas sensing properties [13], which has led to their tremendous use. The detecting mechanism is based on changes in the resistance of the film, which are controlled by gas species. These changes are caused by the presence of the gas species. The term "sensitivity" (S) refers to the relation between the surface resistance of the film in air (Rair) and the surface resistance of the film in gas.

II. EXPERIMENTAL WORK

CdO and Cu powder were purchased with high purity of 99.999 %, where CdO doped with Cu in different concentration according to Table (1) , where 2 g of material is taken and compressed under pressure of 5 ton by the hydraulic (Cold piston) piston under pressure (10-7mb) to form a target of 1 cm diameter and 1cm thickness. After that, it was dried for two hours at a temperature of one hundred degrees Celsius, and then it was chilled for twenty-four hours at room temperature.

Table (1) CdO: Cu with different ratio.

CdO	Cu
99%	1%
97%	3%
95%	5%

Samples that were produced using the PLD method, the experiment involving the pulsed laser deposition is carried out within a vacuum container at a pressure of 10-3 millibars by making use of a Varian DS219 Rotary pump. During the process of plasma generation in a vacuum, a Nd: YAG laser (Hua Fei Tong Da Technology ,Diamond ,288 Pattern EPLS) with varying peak energies was utilized (the beam of which was contained within a vacuum). Quartz lens with a focal length of ten centimeters was used to concentrate a Nd:YAG laser with a fundamental harmonic frequency of 1064 nm, 10 nanoseconds, and 6 hertz onto the target. The following list contains the primary technological parameters:

1. The Q-switched Nd:YAG laser model with first harmonic production as the laser model.
2. Laser maximal power: (6- 36) W.
3. The wavelength of the laser is 1064 nm.
4. The repetition rate ranges from one to six hertz.
5. The technique of cooling is an internal water circulation system.
6. The input voltage for the ac power source is 220 volts.

The focused Nd:YAG Q-switching laser beam that is entering the room through a window will make an angle of 45 degrees with the surface of the object when it strikes it. The substrate is positioned so that its surface is horizontal to that of the target, and it is then set in front of the target. A separation large enough is maintained between the target and the substrate to prevent the holder for the substrate from blocking the path of the incoming laser beam. Many researchers occasionally make adjustments to the deposition procedure in order to improve the quality of the films that can be produced using this method. The primary objective of these adjustments is to improve film quality. Among these are things like rotating the target in accordance with the location of the substrate. A target semiconductor of is deposited on the substrate using pulse laser with specification the energy (200)mJ and number of shot. Pulse laser deposition is used for the deposition of films CdO:Cu with different ratios (1,3, and 5%). (200). There is approximately a ten centimeter gap between the target and the substrate.

III. RESULTS AND DISCUSSION

Using an X-ray diffract meter (XRD-6000, Shimadzu), the structural characteristics of the prepared films were analyzed. Figure 1 shows that all of the films have a poly-crystalline nanostructure, and the diffraction peaks were indexed to the spinel nanostructure of CdO. The X-ray diffraction pattern of an annealed CdO thin sheet is depicted in Figure 1. It demonstrates that the videos have a strong orientation along the 111 and 200 planes as well as the 311 and 222 planes. The existence of diffraction peaks demonstrates that the material in question is polycrystalline and has a cubic (face-centered) crystal nanostructure (JCPDS 5-0640) [14].

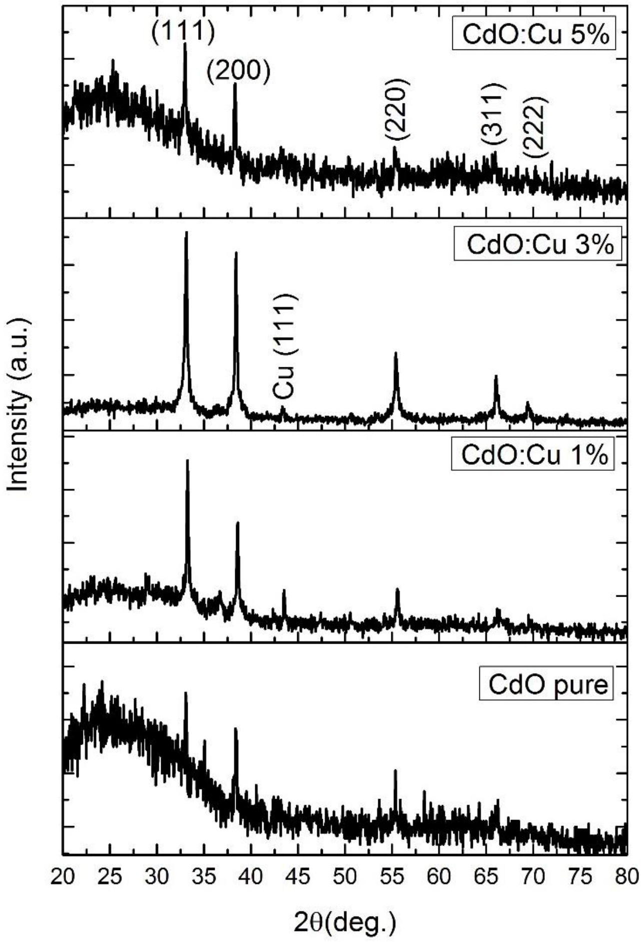

Fig. 1 XRD spectra of CdO and CdO :Cu thin films

Atomic force, scanning electron microscope types (AFM-AA3000) and (Tescan, VEGA 3SB SEM) respectively have been used to study the topographic and morphological characteristics of the prepared films. Figure 2 displays AFM micrographs of pure and Cu-doped CdO thin films; it is evident that the films are free of cracks with nanometric grains, and RMS roughness varies with Cu concentration (see table 2), reaching a maximum value (7.3 nm) in CdO

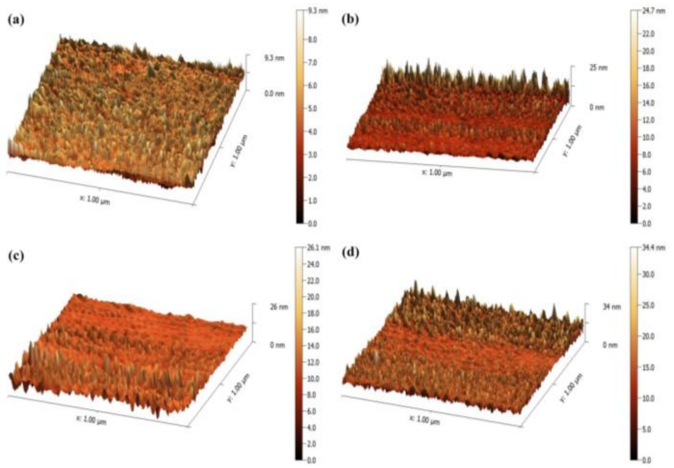

Fig. 2 AFM topography of (a) CdO (b) CdO:Cu 1% c)) CdO:Cu 3% and (d) CdO:Cu 5% thin films

Table 2 AFM characteristics of CdO :Cu thin films

Sample	Grain size (nm)	RMS Roughness (nm)
Pure CdO	20	5.5
CdO:Cu 1%	25	4
CdO:Cu 3%	15	5.5
CdO:Cu 5%	8	7.3

Figure 3 represented that the SEM micrographs of the sprayed coatings; the surface of CdO changes in morphology as Cu concentration rises. Cu 5% thin coatings have a porous topology that offers a lot of surface area, making them ideal for gas sensing applications.

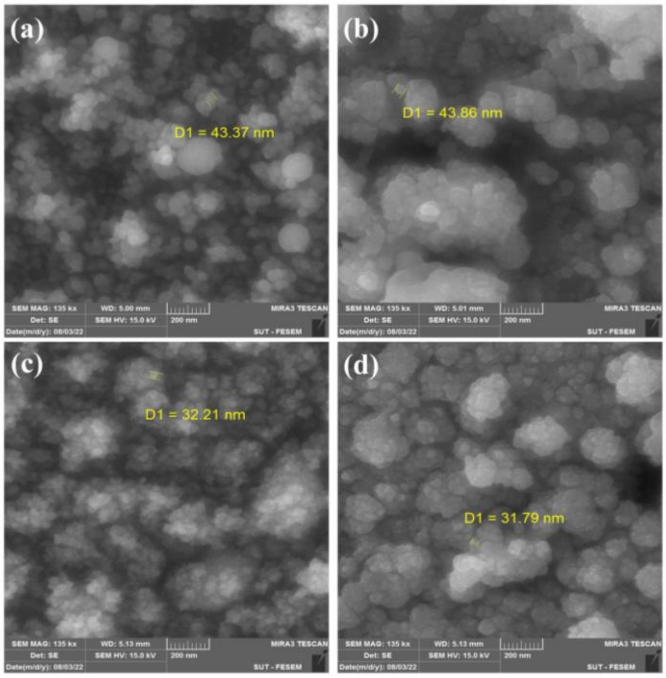

Fig. 3 SEM images of (a) CdO (b) CdO:Cu 1% (c) CdO:Cu 3% and d) CdO:Cu 5% thin films

The chemical nanocomposition of both CdO and CdO:Cu thin films was examined using energy dispersive spectroscopy (EDS). According to the concentration ratio of [Cu]/[Cd] utilized in the production method, Figure 4's EDS spectra of the created films with various concentration ratios confirm the presence of Cd, O, and Cu elements. In addition, Au is created during the SEM study's sample preparation phase to improve the image quality [17].

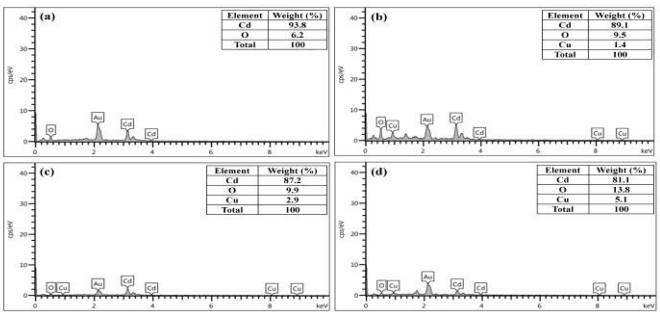

Fig.4 EDS spectra of (a) CdO (b) CdO:Cu 1% (c) CdO:Cu 3% and d) CdO:Cu 5% thin films

The absorbance spectra of the sprayed films are shown in Figure 5 as a function of wavelength. It is evident that the absorbance varies with Cu concentration and that CdO:Cu 3% films had the highest absorbance. This might be because of the surface's many reflections within its pores and its inherent porosity, which is a possibility.

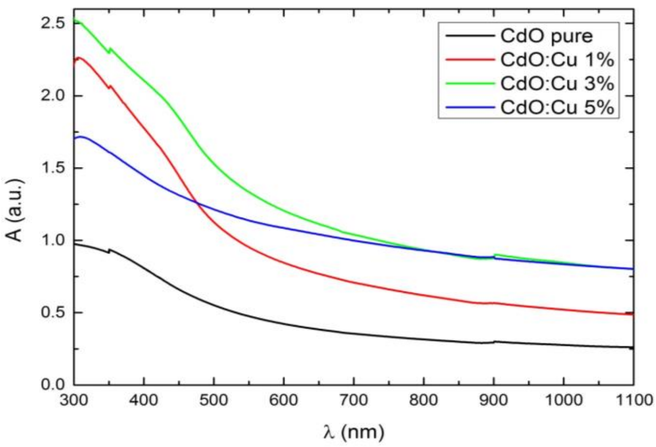

Fig. 5 Absorbance spectra of CdO and CdO :Cu thin films

The band gap of the sprayed films was calculated using Tauc's relation using the following equation [13]:

$$(\alpha h\nu)^2 = B(h\nu - Eg)^n \quad (5)$$

Where α, B and Eg is the coefficient of absorption, proportionality constant and optical band gap; respectively, the absorption coefficient was calculated by the following equation [14]:

$$\alpha = 2.303\frac{A}{t} \quad (6)$$

Figure 6, where A and t are the absorbance and thickness, respectively, illustrates the band gap of pure and Cu-doped CdO thin films. The figures are somewhat in line with the study that was discussed in the cited literature [9,11,14,15]. Band gap is observed to vary with increasing Cu concentration, reaching a minimum value of 2.25 eV in CdO:Cu1% thin films. The reduction in band gap may be caused by an increase in RMS roughness and crystallite size, as reported earlier [16,17], and it is also observed that as Cu concentration increases.

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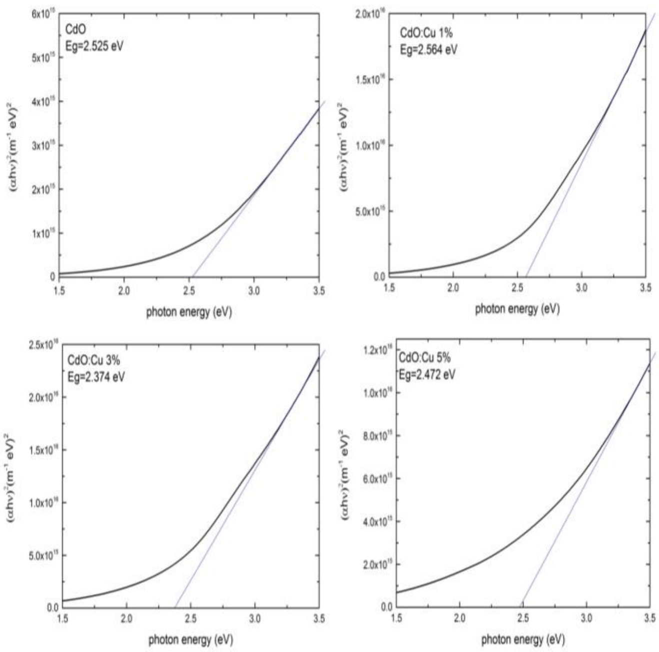

Figure 6 Band gaps of CdO and CdO : Cu thin films

At different temperatures (RT to 280 °C), the performance of the prepared films against various concentrations of CO gas (50, 100, 150, and 200 ppm) at 50% relative humidity (RH) is studied. The working temperature is discovered at 290 oC (see fig. 7), where the highest sensitivity is observed.. Interestingly the decrease in resistance during exposure to CO gas (reducing gas) reveals the major types in the pure and Cu-doped CdO films is n-type semiconductor with electrons being the majority carriers; Since reductive gas molecules adsorb on surfaces and cause charge transfer, CdO gas sensors have been shown to be sensitive to reductive gases. This is because CdO's carrier concentrations are affected by reductive gas concentrations. The CdO thin film sensor's CO gas sensing method is based on the interaction of gas molecules with thin films' surfaces, which leads to a change in resistance. Adsorbed oxygen molecules capture electrons in the valence band of pure and CdO-doped Cu thin films, create additional electrons, and ionize into oxygen species, which will dominate at high working temperatures of 280 oC[20,21]. The fabricated CdO:Cu sensors exhibit high sensitivity to a range of CO gas concentrations, as shown in fig. 7. The sensitivity increased with Cu doping, with the best results being obtained in CdO:Cu 5% and CdO:Cu 5% thin films. This may be because of the porosity nature, high roughness, and redshift in band gap. These results are in good agreement with the work reported in Ref.s [9,23-24].

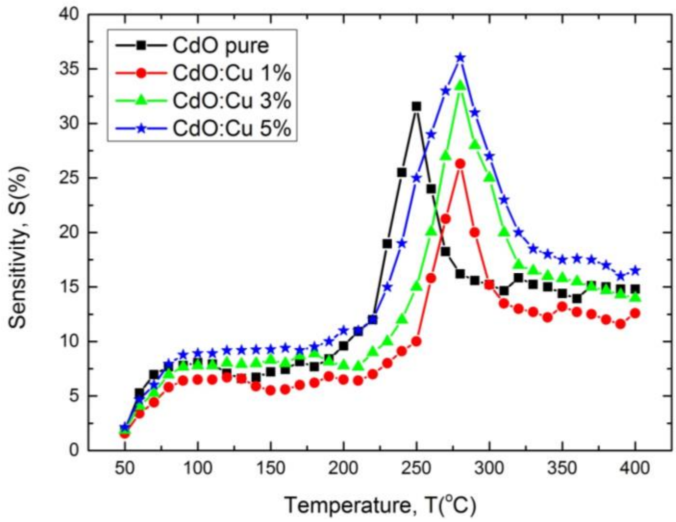

Fig. 7 Sensitivity vs. of temperature towards 200 ppm of CO gas for CdO doped CdO:Cu thin films

Gas performance for different CO gas concentrations (50, 100, 150, and 200) ppm was tested and tends to linear behavior as seen in figure 8. It is evident that the sensitivity rises as thickness rises, generally favoring lowering gases [25–26].

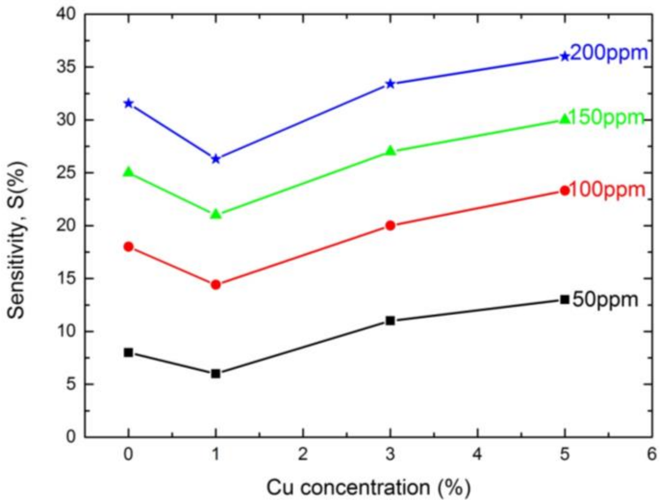

Figure 8 Sensitivity vs. Cu doping concentrations for 50-200 ppm of CO gas

IV. CONCLUSION

In summary, CdO and CdO: Cu thin films were successfully synthesized by pulse laser ablation (PLD) technique, and gas sensors were made based on these films to investigate their gas sensing performance towards low concentrations of CO gas at 280 °C. The best results were reported in CdO:Cu 5% thin films, which had better crystallinity, high roughness, and diverse morphologies as CdO content in the Cu lattice rose. Our findings demonstrate the importance of CdO: Cu gas sensors for detecting CO gas at low concentrations and their suitability as n-type semi-conductor gas sensors.

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