



The Effect of Deposition Time and Temperature on the Optical and Structural Properties of CdO Thin Films Prepared by the Chemical Bath Deposition Method

Khadeejah Ali Mohammed Othman
University of zawiya – Faculty of Education

k.othman@zu.edu.ly

<https://orcid.org/0009-0005-9391-7794>

Abstract:

This research investigates the effect of deposition time and temperature on the optical and structural properties of cadmium oxide (CdO) thin films prepared by the chemical bath deposition (CBD) method. (CdO) thin films were deposited on glass substrates at different temperatures and deposition times. The optical and structural properties of the prepared films were studied using optical spectroscopy and X-ray diffraction (XRD). The results showed a clear variation in the values of transmittance, absorbance, and energy bandgap of the prepared films.

Which aims to:

1) Understanding the crystal structure (structural properties):

To determine the arrangement of atoms within the material (whether it is crystalline or not), the grain size, growth orientation, and the presence of defects or impurities.

2) Determining the quality of the thin film:

By studying uniformity, thickness, and structural regularity, since these factors directly affect the material's performance.

3) Analyzing the interaction with light (optical properties):

Such as transmittance, absorbance, and reflectance, which are important for understanding how the material behaves when exposed to optical radiation.

4) Calculating the energy band gap:

One of the most important properties that determines the suitability of the material for electronic and optical applications such as solar cells or sensors.

5) Relating preparation conditions to final properties:

Such as temperature and deposition time, to understand how they influence the structure and optical properties, and thus improve the preparation method.



6) Guiding practical applications:

Such as using thin films in solar cells, smart windows, or optical device.

الخلاصة:

يتناول هذا البحث دراسة تأثير ظروف زمن الترسيب ودرجة الحرارة على الخواص البصرية والتركيبية لأغشية أكسيد الكاديوم الرقيقة والمحضرة بطريقة الترسيب بالحمام الكيميائي، إذ تم ترسيب أغشية رقيقة من أكسيد الكاديوم على قواعد زجاجية بدرجات حرارة وازمنة ترسيب مختلفة، ودرست الخصائص البصرية والتركيبية للأغشية المحضرة باستخدام مطيافية الضوء وحيود الأشعة السينية، حيث أظهرت النتائج تبايناً واضحاً في قيم النفاذية والامتصاصية وفجوة الطاقة للأغشية المحضرة.

Introduction:

Cadmium oxide (CdO) is an important chemical compound of cadmium. It is characterized by its insolubility in water and alkalis, while it is soluble in acids and ammonium salts (ammonia). The color of this oxide ranges from dark brown to greenish-yellow, and it can be obtained by strongly heating cadmium in air [1].

Cadmium oxide is classified as a semiconductor belonging to the Group II–VI compounds of the periodic table. It possesses a cubic crystal structure with a face-centered cubic (FCC) unit cell, which is similar to the crystal structure of sodium chloride (NaCl).

It is classified as one of the transparent conducting oxides (TCOs), characterized by a relatively wide bandgap ranging between 2.2 and 2.7 eV, high transparency in the visible and near-infrared (NIR) regions, high reflectivity in the red region of the electromagnetic spectrum, high carrier mobility [2], and high electrical conductivity comparable to n-type metals. CdO also exhibits desirable luminescence properties, making it suitable for applications in optoelectronic devices, photovoltaic devices, and display technologies [3].

(CdO) possesses low electrical resistivity due to the presence of cadmium atoms at interstitial sites or oxygen vacancies. It has a cubic crystal structure with a face-centered cubic (FCC) unit cell [4], resembling the NaCl crystal structure. (CdO) is widely used in various optical and electronic applications, including solar cells, gas sensors, phototransistors, transparent electrodes, and anti-reflective coatings



Several methods have been used to synthesize CdO thin films, such as chemical spray pyrolysis (CSP), thermal evaporation in vacuum (CVD), sol-gel processing [5], pulsed laser deposition (PLD), and the chemical bath deposition (CBD) method. In this study, we examine the effect of deposition time and temperature on the optical and structural properties of CdO thin films prepared using the CBD method.

Chemical Bath Deposition Method (CBD) :

The Chemical Bath Deposition (CBD) method is one of the Chemical Solution Deposition (CSD) techniques used for depositing semiconductor compounds onto solid substrates through a chemical reaction that takes place within an aqueous solution. It is considered the solution-based counterpart of the Chemical Vapor Deposition (CVD) technique.

The deposition process involves several stages, [6] including the transport of reactant species, followed by condensation, diffusion, and/or chemical reactions. These processes lead to the deposition of material, nucleation, and subsequent growth on the film surface. Chemical bath deposition can be effectively used for the preparation of semiconductor thin films due to its simplicity, low cost, and ability to produce uniform and high-quality coatings.

Theoretical part:

X-ray Diffraction (XRD):

X-ray diffraction (XRD) can be used to identify the nature of the crystalline structure, the main crystalline phases, and the preferred orientation of thin films prepared under certain conditions for a given material. It is also used to study the atomic arrangement of the material. When X-rays with a single wavelength are directed at the surface of the film over a range of angles, peaks appear as a result of Bragg reflections from parallel crystalline planes [7]. The basic condition for the occurrence of Bragg reflections is that the inequality ($\lambda < 2d_{hkl}$) must be satisfied.

Most of the physical properties of materials are closely related to their structural properties. Therefore, the structural properties can be studied as a function of the deposition conditions or the substrate used. Polycrystalline CdO thin films possess a cubic crystal structure with a face-centered cubic (FCC) unit cell. This structure is similar to that of sodium chloride crystals [8].



Optical Properties Techniques:

By studying the optical properties of thin films, it is possible to determine the energy band structure of the thin film material, as well as the value of the energy band gap and whether it is direct or indirect. Therefore, the techniques used to investigate optical properties vary depending on how the material interacts with the incident light wave.

Numerous studies have been conducted on the optical properties of (CdO) thin films, particularly their transmittance and optical absorption spectra, using various deposition methods and techniques. The investigation of these spectra is generally aimed at determining whether the employed deposition technique produces high-quality or poor-quality films. Poor-quality films are often associated with the formation of gummy deposits or residues on the sample surface during the deposition process, resulting in non-uniform film growth. Such inhomogeneous growth leads to light scattering, which consequently affects the optical properties being investigated.

Through the study of the optical properties of thin films, it is possible to determine the energy band structure of the thin film material, as well as to identify the value of the energy band gap and whether it is direct or indirect [9]. Therefore, the techniques used to study optical properties vary depending on how the material interacts with the incident light wave.

Optical Absorption:

Optical absorption is considered one of the important methods in the study of solid-state physics. The absorption processes in semiconductors depend on the energy of the incident photons and the optical energy band gap. If the photon energy ($h\nu$) is equal to the energy band gap (E_g), the photons are absorbed to generate electron-hole pairs. If the photon energy is greater than the band gap, absorption can also occur [10]. However, if the photon energy is less than the band gap, absorption will not occur unless there are energy levels within the forbidden gap caused by chemical impurities and physical defects. This process is known as extrinsic transition.

Transmittance:

As is well known, when a semiconductor material is illuminated with a beam of light, a portion of the incident radiation is transmitted. The intensity of this transmitted light



depends largely on the energy of the incident photon and the properties of the semiconductor material. Transmittance represents the ratio of the transmitted light intensity

Absorbance:

When a light beam with energy ($h\nu < E_g$) is incident on a semiconductor material of thickness (t) and initial intensity (I_0), a portion of this beam is absorbed. The absorption rate depends on the wavelength of the incident light and the thickness of the sample [11]. Where α is the absorption coefficient, measured in units of (cm^{-1}). This coefficient varies with the wavelength of the incident light and the nature of the material.

Absorption Coefficient:

The absorption coefficient (α) is defined as the rate of decrease in the energy flux of the incident radiation per unit distance along the direction of wave propagation the medium [12]. It depends on the photon energy ($h\nu$) and the properties of the semiconductor, particularly the type of electronic transitions and its energy band gap [13].

Significance of the Research :

Controlling the deposition temperature and time helps reduce defects and impurities within the film. It also enables control over thickness and uniformity, as deposition time affects the film thickness, while temperature influences its uniformity and stability.

In summary, this study is essential because it links the preparation conditions with the final properties of the film, allowing for improved film quality and more efficient use in practical applications.

Experimental Method:

Substrate Preparation :

The substrate serves as the deposition site for the material, where the material is deposited in the form of a thin film on the substrate for the purpose of studying its optical and structural properties. In this work, ordinary glass substrates with dimensions of (2.5×2.5) cm^2 and a thickness of 0.1 cm, manufactured in Germany, were used. This type of substrate was selected because of its high resistance to elevated temperatures, which helps minimize the development of internal stresses within the deposited film during the deposition process, particularly during repeated heating and cooling cycles.



The glass substrates were carefully cleaned to remove impurities and contaminants, as their presence can significantly affect the properties of the prepared films. The preparation procedure involved the following sequential steps [14]:

- 1 - The glass slides were cut into square pieces with dimensions of (2.5×2.5) cm².
- 2 - The substrates were thoroughly washed with running water and conventional cleaning detergents to remove any adhering dirt and contaminants.
- 3 - The substrates were rinsed with distilled water and then placed in a beaker containing distilled water. The beaker was subsequently placed in an Ultrasonic Cleaner for 10 minutes.
- 4 - The glass substrates were held using a special tweezer and immersed in a flask containing diluted hydrochloric acid (HCl) with a concentration of 37%. They were then rinsed with distilled water, followed by immersion in ethanol (C₂H₅OH) to remove any residual grease or organic contaminants from the substrate surface. Finally, the substrates were washed again with distilled water.
- 5 - The substrates were dried using a special lens-cleaning tissue that does not leave residues on the glass surface.
- 6 - After drying, each substrate was weighed, and its weight was recorded. The substrates were then stored in appropriate containers until use.

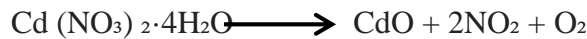
The CBD process requires simple and locally available equipment, including:

- 1- Magnetic stirrer with temperature control
- 2- Thermometer
- 3- Glass beakers of various sizes
- 4- Holder with clamp.

The glass substrates were cleaned following a standard cleaning procedure. Initially, they were washed with tap water and detergent to remove surface contaminants and dust. The substrates were then rinsed with distilled water and immersed in a diluted hydrochloric acid (HCl) solution (37%) for further surface cleaning. Afterward, they were thoroughly rinsed with distilled water and treated with ethanol (C₂H₅OH) to eliminate any remaining grease and organic residues. The substrates were subsequently rinsed again with distilled water and finally dried using hot air before being used for the deposition process To

prepare CdO films via CBD, an aqueous solution of cadmium acetate ($\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$) was used as a precursor. The compound is a white powder with a molecular weight of 230.50 g/mol and 99.9% purity. A molar concentration of 0.2 M was used. A high-precision balance (Mettler AE-160, Germany) with a sensitivity of 10^{-4} g was used to weigh the required material, which was then dissolved in a specific volume of distilled water. The solution was stirred using a magnetic stirrer (MsH-300, Germany) for 15 minutes to ensure complete dissolution. The prepared solution was stored at room temperature in a volumetric flask for 24 hours to eliminate any precipitates and ensure homogeneity before deposition [15].

The deposition process occurs via the following reaction:



The following relationship was used to calculate the weights of the materials:

$$W = M_w \times M \times V$$

To control the pH, ammonium hydroxide (NH_4OH) was added dropwise [16]. Initially, the solution turned milky but became clear and colorless again upon further addition of NH_4OH , reaching a pH between 11.5 and 12. Glass substrates were immersed vertically in the bath, with the deposition parameters set as follows [17].

Results and Discussion:

The thickness of the (CdO) films was measured for different deposition times. It was found that the film thickness increased with deposition time until it reached a saturation point where no further increase occurred (Figure 1).

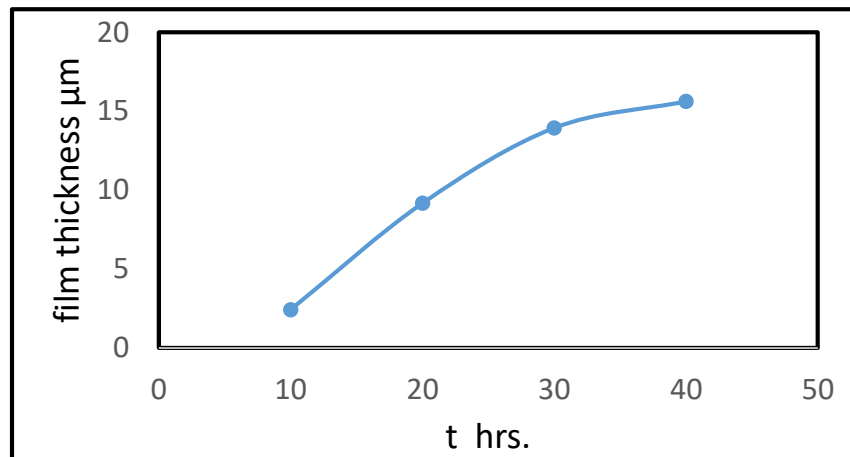


Figure (1) Change in film thickness with deposition time

Optical Properties:

From Figure 2, it was observed that transmittance increased with increasing temperature, while absorbance exhibited an inverse relationship. The energy bandgap also increased as the temperature rise.

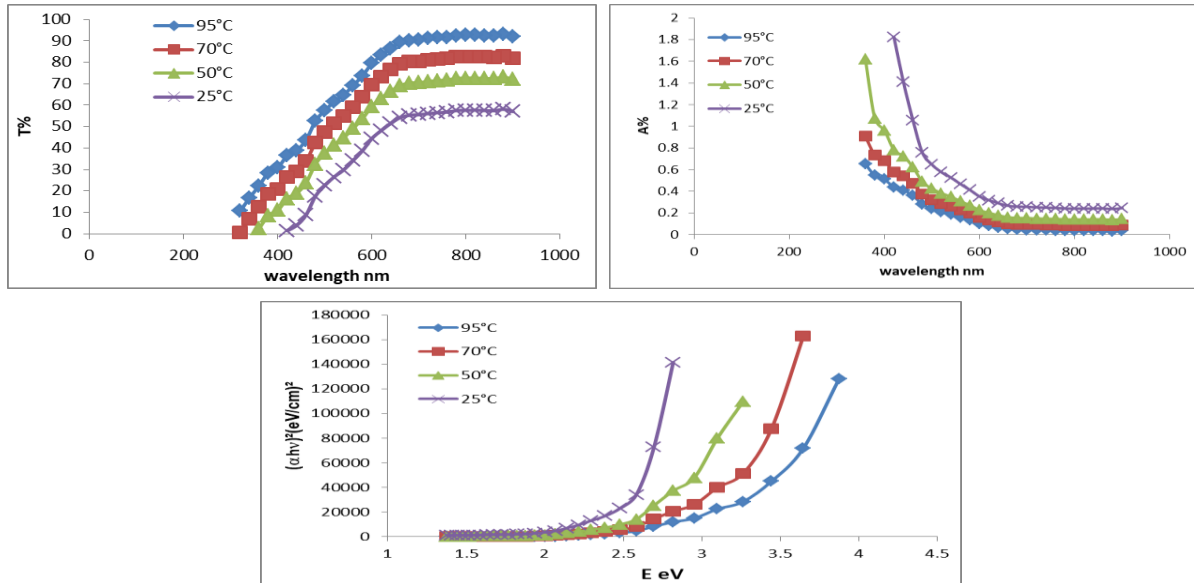


Figure (2) shows the change in transmittance, absorbance and energy gap with deposition temperature for CdO films.

X-ray Diffraction Analysis:

Figure 3 presents the X-ray diffraction (XRD) patterns of (CdO) films deposited at different temperatures. Films deposited at 95°C exhibited a polycrystalline hexagonal structure with a preferential (100) orientation at $2\theta = 28.49^\circ$. In contrast, films deposited at 25°C showed a mixed hexagonal and cubic structure with (100) and (111) orientations at $2\theta = 28.49^\circ$ and $2\theta = 32.74^\circ$, respectively.

Figure 4 illustrates the effect of film thickness on the optical properties of (CdO) films. As film thickness increased, transmittance decreased while absorbance increased. The energy bandgap was also found to increase with increasing thickness.

Further XRD analysis of CdO films deposited for 10 and 40 hours at 95°C (Figure 5) revealed a cubic structure with a predominant (111) orientation at $2\theta = 33.52^\circ$ and 32.79° . The decrease in XRD peak intensity with increasing thickness indicated a polycrystalline nature, with additional peaks appearing at $2\theta = 28.33^\circ$ and 52.26° , corresponding to the (100) and (110) orientations of the hexagonal hydroxide phase [18].

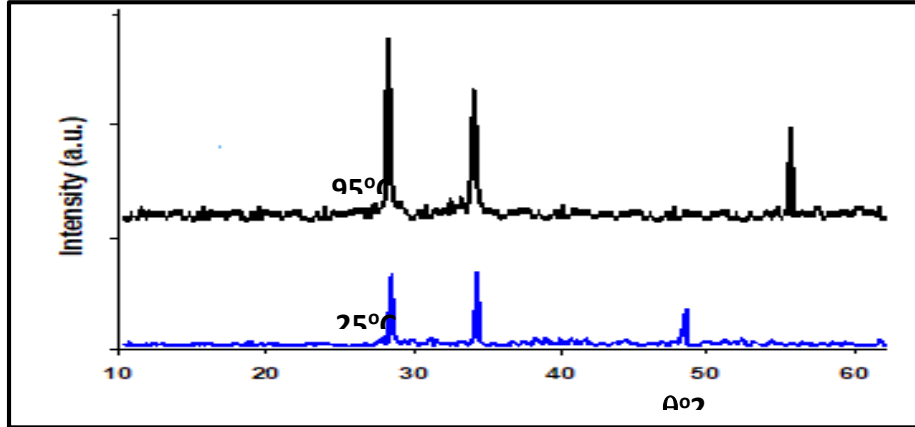


Figure (3) X-ray spectrum of prepared CdO films at deposition times of 10 and 40 hours.

Conclusions:

- 1) CdO thin films were successfully deposited on glass substrates using the CBD method at different deposition temperatures and times.
- 2) Optical and structural properties were investigated using spectroscopy and XRD, revealing significant variations in transmittance, absorbance, and energy bandgap values [19].
- 3) Transmittance increased with temperature, while absorbance decreased. However, transmittance was inversely related to film thickness.
- 4) whereas absorbance increased with thickness. Energy bandgap values were strongly affected by deposition temperature and time.
- 5) XRD analysis further demonstrated the structural changes in the films due to variations in deposition conditions [20].

Keywords: Chemical Bath Deposition, Cadmium Oxide Films, Thin Films, Semiconductor Materials, Surface Morphology, Optoelectronic Properties.

Recommendations:

- 1) Study of the electrical properties of cadmium oxide thin films prepared by the spray pyrolysis method.
- 2) Study of the optical and structural properties of cadmium oxide thin films prepared by the evaporation method.
- 3) Study of the effect of annealing on the structural and optical properties of cadmium oxide thin films prepared by the chemical pyrolysis method.
- 4) Study of the effect of substrate variation on the structural and optical properties of cadmium oxide thin films prepared by the spray pyrolysis method.



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