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Synthesis and Characterization of Cadmium-Oxide Thin Films Prepared by Sol–Gel Spin Coating Method

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In this work, cadmium-oxide films are prepared using the spin-coating technique. The study is focused on clarifying the effect of changing the thickness of the film on the optical properties of cadmium-oxide films deposited on 1.5×2 cm^2 glass substrates at a temperature of 400°C. The behaviour of the visible and ultraviolet absorption spectra of cadmium-oxide films are also studied as functions of wavelength. These results show that the intensity of absorption increases with increasing membrane thickness; this indicates an increase in the concentration of the membrane material. Some optical constants are also studied, such as the index of refraction and the real and imaginary dielectric constants, in addition to the extinction coefficient and electrical conductivity. As found, their values change with increasing film thickness. Through the absorption spectrum, the optical energy gap is calculated, and it is found that there is a slight change with increasing film thickness, as its value decreases from 2.22 eV to 2.20 eV, when the film thickness increases from 143 nm to 368 nm.

У цій роботі плівки оксиду Кадмію було одержано нанесенням покриття методом центрифуґування. Дослідження зосереджено на з'ясуванні впливу зміни товщини плівки на оптичні властивості плівок оксиду Кадмію, нанесених на скляні підкладинки площею 1,5×2 см^2 за температури у 400°C. Також досліджено поведінку спектрів видимого й ультрафіолетового вбирання плівок оксиду Кадмію як функцій довжини хвилі. Ці результати показують, що інтенсивність вбирання зростає зі збільшенням товщини мембрани, що вказує на збільшення концентрації матеріялу мембрани. Також досліджено деякі оптичні константи, такі як показник заломлення та дійсна й уявна діелектричні константи, на додаток до коефіцієнта екстинкції й електропровідности. Було виявлено, що всі їхні значення змінюються зі збільшенням товщини плівки. За допомогою спектру вбирання було розраховано ширину оптичної забороненої зони та виявлено, що спостерігається незначна зміна зі збільшенням товщини плівки, оскільки її значення зменшується з 2,22 еВ до 2,20 еВ, коли товщина плівки збільшується від 143 нм до 368 нм.

Key words: cadmium oxide, spin coating, energy gap, absorbance spectrum.

Ключові слова: оксид Кадмію, одержані методом центрифуґування покриття, заборонена енергетична зона, спектер вбирання.

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1. INTRODUCTION

In recent years, there has been a notable surge in interest in transparent conducting oxides (TCO) thin films, attributed to their unique chemical and physical properties that differentiate them from bulk materials and individual atoms [1].

Cadmium oxide (CdO), characterized by a direct optical band gap ranging from 2.2 eV to 2.7 eV and exhibiting *n*-type conductivity, is frequently employed in applications including spintronics, transparent electronics, optoelectronics, and sensors. Cadmium oxide (CdO) is a commonly favoured material for applications such as photodiodes, gas sensors, solar cells, and anti-reflective coatings [2–4]. Cadmium oxide (CdO) is regarded as a potential material for photovoltaic applications owing to its elevated electrical conductivity and optical transmittance in the visible spectrum. CdO thin films are produced using various deposition processes, including pulsed-laser deposition (PLD) and spray pyrolysis, chemical bath deposition, hydrothermal synthesis, and magnetron sputtering. In comparison to these approaches, the sol–gel process is effective for creating metal oxide coatings as it achieves a homogeneous structure and can be maintained under the management of each phase necessitates uncomplicated apparatus and is applicable at reduced temperatures. The sol–gel spin-coating technique involves the solutions formulated for the films and is applied to a substrate, which is subsequently spun at varying velocities and durations. The solution is applied to this base to create a film [5]. The spin-coating process allows for the straightforward diversification of required films, modifying parameters including film thickness, rotation speed, and rotation duration, number of coatings, solution volume, and annealing temperature. This approach is favoured because of its cost-effectiveness and rapid manufacturing capabilities [6]. As discovered, the thermal treatment of CdO thin films after deposition at different annealing temperatures reveals significant modifications in their optical and structural characteristics [7].

This work aims to prepare thin films of cadmium oxide using the sol–gel spin-coating technique, to study their optical properties, and to demonstrate the effect of film thickness and temperature on those properties.

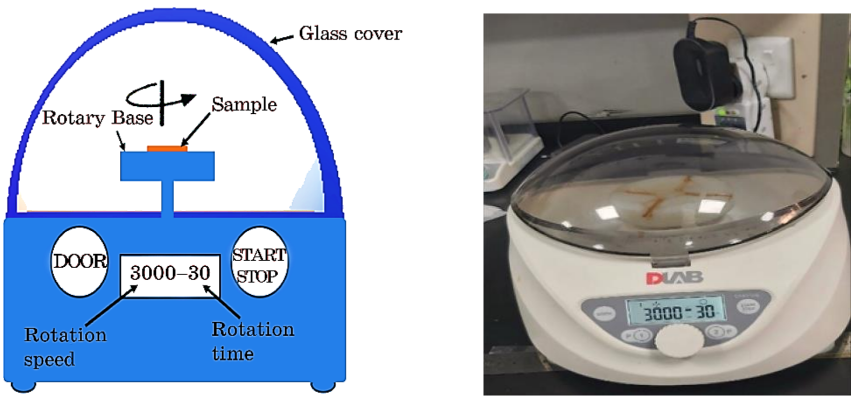
2. EXPERIMENTAL DETAILS

2.1. Preparation of the Solution

The solution was prepared by dissolving 1.33 gm of aqueous cadmium acetate $[(CH_3COO)_2Cd_2H_2O)]$ in 10 mL of 2-Methoxyethanol and stirring it with a magnetic stirrer for 20 min at room temperature. After that, the temperature of the solution is raised to 70°C. Then, ethanolamine (MONO) is added dropwise to the solution. This process takes 120 min in order to obtain a homogeneous, transparent and colourless solution. The temperature of the final solution is reduced to room temperature, then, filtered using filter paper, and then, left for 24 hours.

2.2. Preparation of Glass Substrates

A glass substrate with dimensions 1.5×2 cm was prepared. These substrates are cleaned by first washing them with water for 3 min, then, they are immersed in a solution (distilled water + acetone) with 20% acetone. The substrates and the solution are placed in the ultrasound machine for 15 min at room temperature. The slides are cleaned then with distilled water for 3 min and dried then using hot



a *b*

Fig. 1. (*a*) Device diagram for spin coating; (*b*) photo of spin coating.

air for 1 minute. Sample weights are measured using a very sensitive four-stage balance.

2.3. Deposition Process

The sol–gel solution is coated on glass substrates using a device spin coating as shown in Fig. 1. The parameter used was of 3000 rev/min for 30 s. The samples are then dried using an electric heater at a temperature of 200°C for 15 minutes to get rid of solvents and organic contamination. The thin films are then annealed in an oven at temperatures of 400–500°C. Finally, the weights of the samples are measured after the deposition process in order to calculate the thickness of the film prepared by the gravimetric method.

3. RESULTS AND DISCUSSIONS

3.1. The Optical Absorption Analysis

The interaction of light with CdO thin films was studied to learn more about the optical properties. We used a UV–Visible spectrometer (Shimadzu UV-1800) to characterize the optical properties of CdO thin films; the absorption spectra from 190 nm to 1100 nm were obtained. When light interacts with the thin film, an optical absorption process occurs against the wavelength spectra of the thin films deposited at an annealing temperature of 400°C. Figure 2 shows an increase in absorption with increasing film thickness. The spectra also showed a clear increase in absorption, indicating the presence of a direct optical transition in the thin films, as well as a red shift with increasing thickness of the deposited films. High

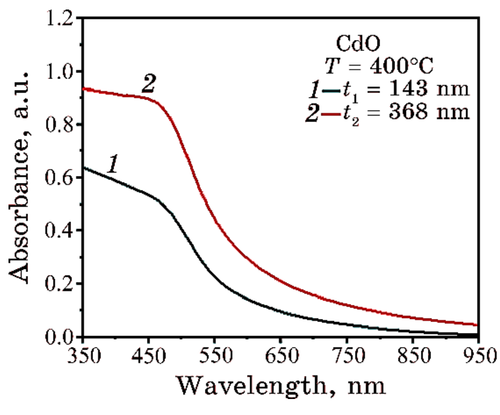


Fig. 2. UV–Vis absorbance curves for CdO films with different thickness.

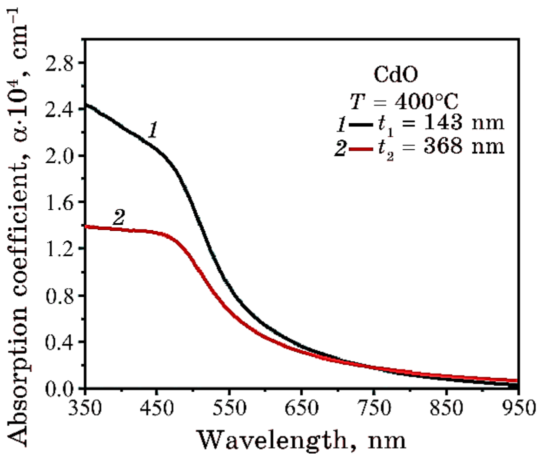


Fig. 3. Absorption coefficient of CdO thin films with difference of film thickness as a function of wavelength.

temperatures in the annealing process can affect structural properties such as crystallinity, grain size, and defect density, which in turn affects the optical behaviour of the material. The surface plasmon resonance (SPR) peak of CdO thin films on glass was observed at 350 nm. The peak shape is due to the light pooling caused by the CdO thin films and the peak position due to the agglomeration of nanoparticles deposited on glass and the interactions between CdO particles and different substrates. It is worth noting that the UV–Vis spectrum of CdO nanoparticles on glass substrate shows only the SPR peak corresponding to the in-plane dipole. Crystallization is enhanced at higher temperatures during thin film growth better, the density of defects such as grains and dislocations decreases and, as a result, the light absorption increases. This in turn leads to the increase in the overall absorption.

The incident photon energy (as well as the properties of the material itself) has an impact on a materials' absorption coefficient. According to Beer's law, the transmission (T) and reflection (R) spectra are related to the absorption coefficient [8]:

$$\alpha = \frac{1}{d}\log\left[\frac{(1-R)^2}{2T} + \frac{(1-R)^2}{\sqrt{2T^2+R^2}}\right], \tag{1}$$

where d is the thickness of the sample. The absorption coefficient (α) at the wavelength of maximum absorption decreases with increasing membrane thickness of CdO thin films as shown in Fig. 3.

An important factor affecting the materials' optical and electronic properties is the optical band gap $E_g^{opt.}$. The optical band gap of

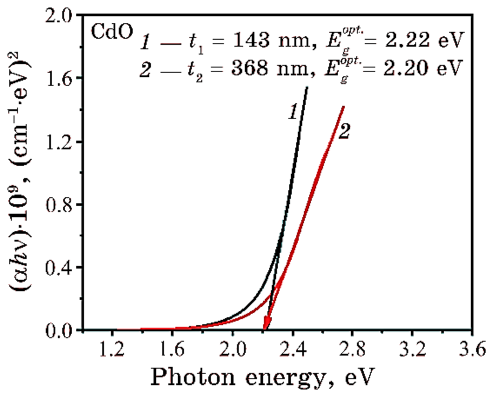


Fig. 4. Optical band gap values of CdO thin films prepared for two different thicknesses.

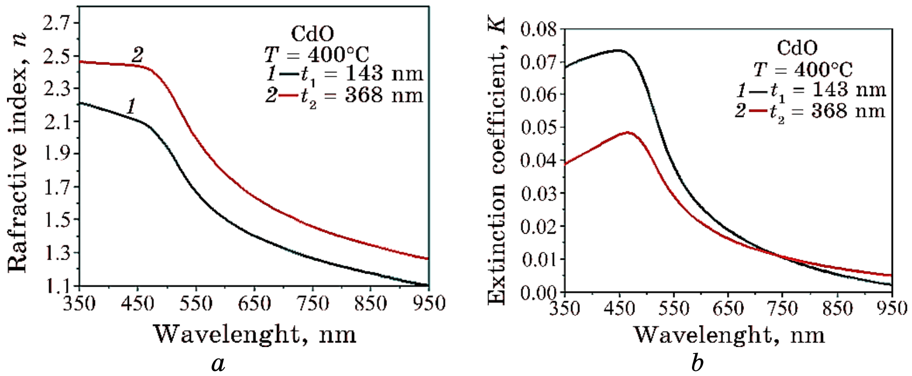


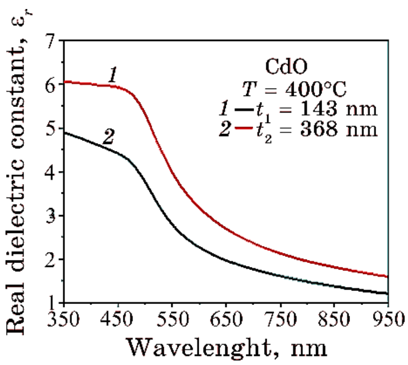
Fig. 5. Refractive index (a) and extinction coefficient (b) as functions of wavelength for CdO thin films with different thicknesses.

the CdO thin films was determined using the Tauc plot and calculated by fitting the equation to the data of Ref. [9]:

$$(\alpha h\nu)^{1/r} = B\left(h\nu - E_g^{opt.}\right), \quad (2)$$

where r is a number that indicates the type of electronic transition that causes the absorption and takes values of 1/2 or 2/3 for direct transitions and 2 or 3 for indirect ones, depending on whether the transition is allowed or forbidden, respectively. $h\nu$ is the photon energy; α is the absorption coefficient, and B is a constant of effective mass. Figure 4 presents the optical energy gap decreasing with increasing film thickness.

The refractive index (n) describes how a beam propagates through



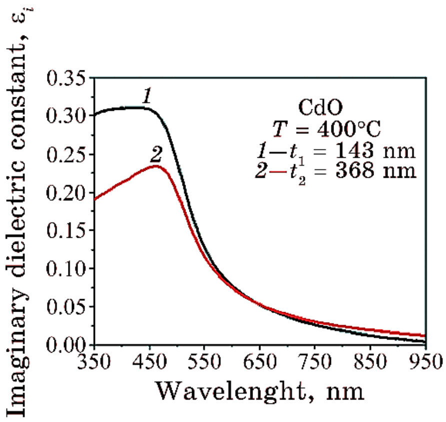


Fig. 6. Real dielectric constants (*a*) and imaginary dielectric constants (*b*) as functions of wavelength for CdO thin films with different thickness.

a transparent medium. The optical parameters of the samples can be used to determine the refractive index using the following relationship [10]:

$$n = \frac{1+R}{1-R} + \sqrt{\frac{4R}{(1-R)^2} - K^2} . \quad (3)$$

Reflectivity (R) is calculated from absorption and transmission spectra using the law of conservation of energy ($R = 1 - T - A$). On the other hand, the extinction coefficient (K) depends on the absorption coefficient and wavelength of the incident beam and is given by [11]

$$K = \frac{\alpha\lambda}{4\pi} . \quad (4)$$

The refractive index and extinction coefficient *versus* wavelength are given in Eq. (3) and Eq. (4). It can be seen that the extinction coefficient (K) of CdO thin films decreases and the refractive index (n) increases with increasing film thickness and in the visible region. Increased thickness can result in better crystallinity and larger grain sizes, which can result in reduced light scattering and absorption [12]. This in turn leads to an increase in the refractive index and a decrease in extinction coefficient as shown in Fig. 5.

The complex dielectric constant caused by photon interactions with medium charges is commonly referred to as polarization. Using Maxwell's relations, evaluation of the real (ε_r) and imaginary (ε_i) parts of the dielectric constant can be calculated for optical wave-

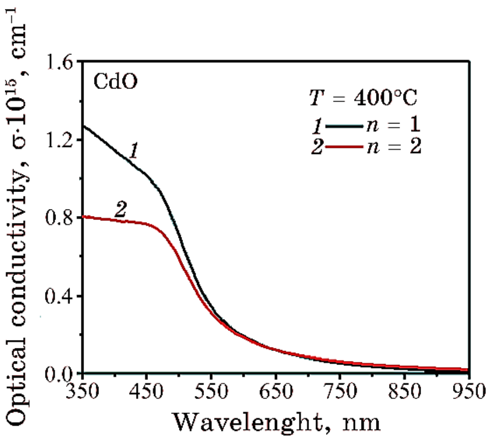


Fig. 7. Optical conductivity as a function of wavelength for CdO thin films for different thickness.

lengths based on optical constants. The refractive index and extinction coefficient are connected to the real and imaginary parts of the dielectric constant through the following relationships [13]:

$$\varepsilon_r = n^2 - K^2\,,\ \ \varepsilon_i = 2nK\,. \tag{5}$$

It can be seen from Fig. 6 that the real dielectric constant increases, while the amount of the imaginary dielectric constant decreases with the increase in membrane thickness.

The optical conductivity of CdO thin films can be determined using the correlation between the absorption coefficient and the refractive index [12]:

$$\sigma_{opt.} = \frac{\alpha n c}{4\pi}\,, \tag{6}$$

where c is the speed of light in a vacuum. The decrease in optical conductivity can be attributed to decrease for absorption coefficient and the refractive index with increasing the substrate temperature, as shown in Fig. 7.

4. CONCLUSIONS

It was shown through this research that the thickness of the film has a direct effect on the optical properties of cadmium-oxide films. It was found that the absorption increases with increasing film thickness (t), and this indicates the occurrence of the crystal growth process. By analysing the absorbance spectrum using a UV–

Vis device, it was found that the refractive index, the real dielectric constant, and the optical conductivity increase with increasing film thickness, but that both the extinction coefficient and the imaginary dielectric constant decrease with increasing film thickness. It was also found that the optical energy gap decreases slightly from 2.22 eV to 2.20 eV with increasing film thickness from 143 nm to 368 nm.

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