Наносистеми, наноматеріали, нанотехнології
Nanosistemi, Nanomateriali, Nanotehnologii
2026, т. 24, № 2, сс. 477–488
https://doi.org/10.15407/nnn.24.02.0477

© 2026 ІМФ (Інститут металофізики
ім. Г. В. Курдюмова НАН України)
Надруковано в Україні.

PACS numbers: 78.20.Ci, 78.40.Fy, 78.66.Li, 81.15.-z, 81.16.Pr, 81.40.Tv

Study of the Some Optical and Structural Properties of Cadmium-Oxide Thin Films Prepared Using Spin-Coating Technique

Mohammed Al-Badrani, Yasir Yahya Kassim, and Mutaz Salih Hasan Aljuboori

College of Education for Pure Sciences,
Department of Physics,
University of Mosul,
41001 Mosul, Iraq

In this research, cadmium-oxide thin films are prepared using spin-coating technique. The study is focused on clarifying the effect of changing temperature on the optical properties of cadmium-oxide films deposited on glass substrates with an area of 1.5×2 cm^2 at different temperatures. The behaviour of the visible absorption spectra of cadmium-oxide films is also studied as a function of wavelength. These results show that the absorption intensity decreases with increasing temperature, which indicates an increase in the concentration of the film material. Some optical constants are also studied, such as the refractive index, the real and imaginary parts of dielectric constant, the extinction coefficient, and the electrical-conductivity coefficient. As found, all values of these constants change with increasing temperature. Through the absorption spectrum, the optical energy gap is calculated and it is found that there is a slight change with increasing temperature, as its value decreases from 2.27 to 2.24 eV, when the temperature increases from 400°C to 500°C. The results obtained contribute to understanding the suitability of the material for optical and electronic applications.

У цьому дослідженні тонкі плівки оксиду Кадмію було одержано методом спінінґового нанесення покриттів (одержаних методом центрифуґування). Дослідження було зосереджено на з'ясуванні впливу зміни температури на оптичні властивості плівок оксиду Кадмію, нанесених на скляні підкладинки площею у 1,5×2 $см^2$ за різних температур. Також вивчалася поведінка спектрів вбирання видимого світла плівками оксиду Кадмію як функція довжини хвилі. Ці результати показали, що інтенсивність вбирання зменшується з підвищенням температури, що вказує на збільшення концентрації матеріялу плівки. Також досліджувалися деякі оптичні константи, такі як показник заломлення, дійсна й уявна частини діелектричної константи, коефіцієнт згасання та коефіцієнт електропровідности. Було виявлено, що всі значення цих констант змінюються зі збільшенням температури. За допомогою спектру вбирання було розраховано ширину оптичної забороненої зони та виявлено, що спостерігається незначна зміна зі збільшенням температури, оскільки її значення зменшується від 2,27 до 2,24 еВ, коли температура зростає від 400°C до 500°C. Одержані результати сприяють розумінню придатности матеріялу для оптичних та електронних застосувань.

Key words: cadmium oxide, spin coating, optical properties, absorption spectrum, energy gap.

Ключові слова: оксид Кадмію, спінінґове покриття, оптичні властивості, спектер вбирання, заборонена енергетична зона.

(Received 26 January, 2025; in revised form, 18 April, 2026)

1. INTRODUCTION

In recent years, there has been a notable surge in interest in thin films of transparent conducting oxides (TCO) attributed to their unique chemical and physical properties, which differentiate them from bulk materials and individual atoms [1]. Cadmium oxide (CdO), characterized by a direct optical band gap ranging from 2.2 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 antireflective 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. Thin CdO 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, which are applied to a substrate that 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, rotation duration, number of coatings, solution concentration, and annealing temperature. This approach is favoured because to its cost-effectiveness and rapid manufacturing capabilities [6]. As discovered, the thermal treatment of thin CdO 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, study their optical properties, and demonstrate the effect of film thickness and temperature on those properties.

2. EXPERIMENTAL DETAILS

2.1. Prepare the Solution

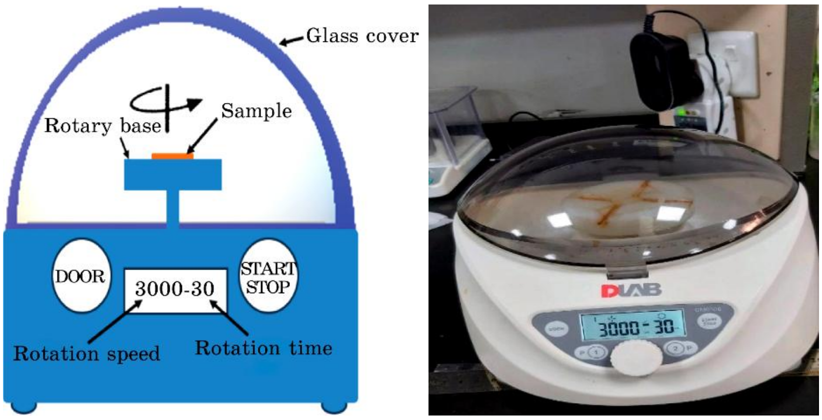
The solution was prepared by dissolving 1.33 gm of aqueous cadmium acetate in 10 mL of 2-methoxyethanol and stirring it with a magnetic stirrer for 20 min at room temperature. After that, the temperature of the solution is raised to 70°C. Then, ethanolamine (MONO) is added drop wise to the solution. 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 left for 24 hours.

2.2. Preparation of Glass Substrates

A glass substrate with dimensions of 1.52 cm was prepared. These substrates are cleaned by first washing them with water for 3 min, then, they are immersed into 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 then cleaned with distilled water for 3 min and then dried using hot air for 1 min. 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 for spin coating as shown in Fig. 1. The parameters used were 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



a *b*

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

calculate the thickness of the film prepared by the gravimetric method.

3. RESULTS AND DISCUSSIONS

3.1. Optical Absorption Analysis

The optical properties of cadmium oxide (CdO) thin films were analyzed by studying their interaction with light using a Shimadzu UV-1800 UV-Vis spectrophotometer. Absorption spectra were measured in the spectral range from 190 to 1100 nm to investigate the effect of wavelength and annealing temperature on absorptivity. The results showed that the absorptivity changes significantly with wavelength, and the effects of two annealing temperatures of 400°C and 500°C on the behaviour of the films were studied. Figure 2 illustrates the relationship between absorptivity and wavelength for thin CdO films. The absorptivity was found to reach its maximum at a wavelength of 350 nm and then decrease exponentially with increasing wavelength until reaching a minimum at 850 nm. In the range from 900 to 1100 nm, the absorptivity remained nearly constant.

This behaviour is attributed to the insufficient energy of incident photons in this spectral range to excite electrons from the valence band to the conduction band. As the photon energy decreases with increasing wavelength, it becomes less than the energy band gap of cadmium oxide, leading to a reduced probability of electron transitions. The results also indicated that increasing the annealing temperature reduces absorptivity. The highest absorptivity was ob-

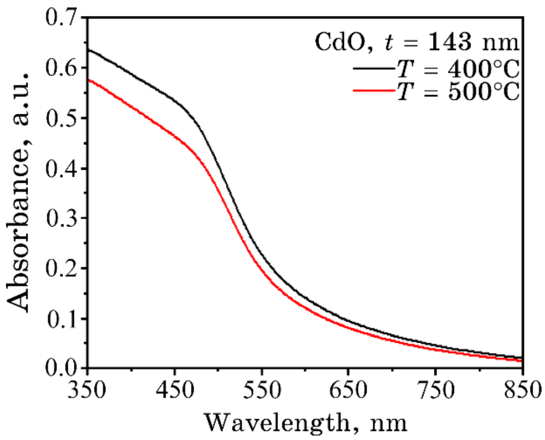


Fig. 2. UV–Vis absorbance curves of CdO for different temperatures.

served at 400°C, while the lowest was observed at 500°C. This behaviour can be attributed to changes in the crystalline structure of the films, as higher annealing temperatures may improve crystallinity and enhance the uniformity of the crystal lattice, increasing light transmittance through the film. This study highlights the inverse relationship between absorptivity and transmittance, where transmittance increases as absorptivity decreases. This behaviour explains the optical properties of thin CdO films within the studied spectral range, providing deeper insight into the potential applications of these films in optical and electronic devices.

3.2. The Absorption Coefficient

The absorption coefficient is defined as the rate of decrease in the radiant energy flux per unit distance in the direction of wave propagation within the medium. The absorption coefficient depends on the energy of the incident photon ($h\nu$), the semiconductor properties, including the energy band gap, the type of electronic transitions, and the energy of the incident photon. The absorption coefficient for cadmium-oxide (CdO) films was calculated using the following equation:

$$\alpha = 2.303A/t, \tag{1}$$

where d is the thickness of the sample, A is the absorptance, and t is the thickness of the film, which was of 143 nm in our study.

Figure 3 shows the variation of the absorption coefficient as a function of wavelength for cadmium oxide (CdO) films at all the

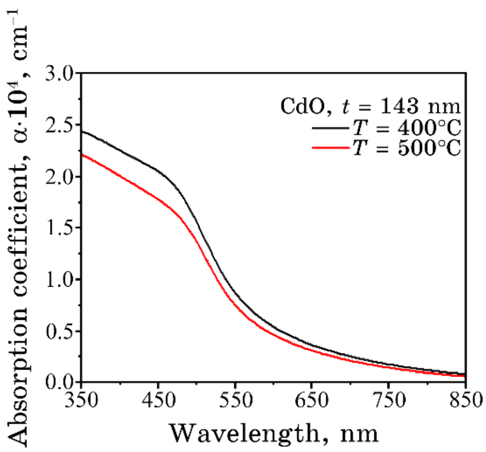


Fig. 3. Absorption coefficient of thin CdO films as a function of wavelength for different film temperatures.

studied temperatures. It is observed that the absorption coefficient values for CdO films are high, with $\alpha > 10^4$ cm^{-2} at the absorption edge that supports the prediction of allowed direct electronic transitions. The values of the absorption coefficient decrease with increasing substrate temperatures, indicating an improvement in the crystallization of the prepared films and a reduction in crystal defects.

3.3. Optical Band Gap

An important factor affecting the materials' optical and electronic properties is the optical band gap. The optical band gap of the thin CdO films was determined using the Tauc's plot and calculated by fitting the following equation [12] to the data:

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

where r is a number that indicates the type of electronic transition that causes the absorption and takes values of 1/2 or 3/2 for direct transitions and of 2 or 3 for indirect ones, depending on whether the transition is allowed or forbidden; $h\nu$ is the photon energy, α is the absorption coefficient, and k is a constant of effective mass.

Figure 4 illustrates the relationship between $(\alpha h\nu)^2$ and $h\nu$, the energy of the incident photon. The optical energy gap for the deposited films is found to be of 2.27 eV at the deposition temperature of 400°C. But, as the deposition temperature is increased to 500°C, the optical energy gap of the deposited films is decreased to 2.24 eV.

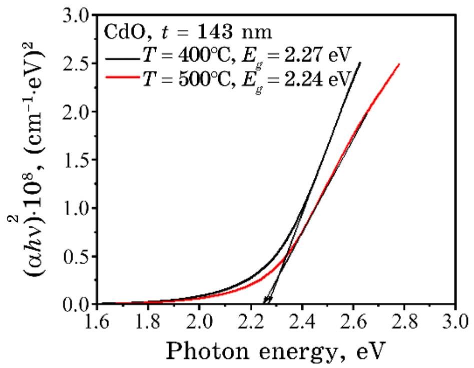


Fig. 4. Optical band-gap values of thin CdO films prepared for two different thicknesses.

This reduction is attributed to the narrowing of the gap between the valence band and the conduction one due to the increased deposition temperature that improves the oxide properties [13].

3.4. The Refractive Index (n)

The refractive index (n) describes how a beam propagates through a transparent medium. The optical parameters of the samples can be used to determine the refractive index using the following relationship:

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

Reflectivity (R) is calculated from absorption and transmission spectra, using the law of conservation of energy ($R = 1 - T - A$).

On the other hand, Fig. 5 shows that the nature of the refractive-index curves is similar to the reflectance curves, as reflectance is related to the refractive index according to the mentioned equation. It is observed that the refractive-index values decrease with increasing temperature in the visible wavelength region. This change in the refractive-index curves due to temperature variation is attributed to the way, by which the grains in these films aggregate and grow that, in turn, affects the density of the films.

3.5. The Extinction Coefficient (K)

The extinction coefficient (K) depends on the absorption coefficient and wavelength of the incident beam as given by Ref. [11]:

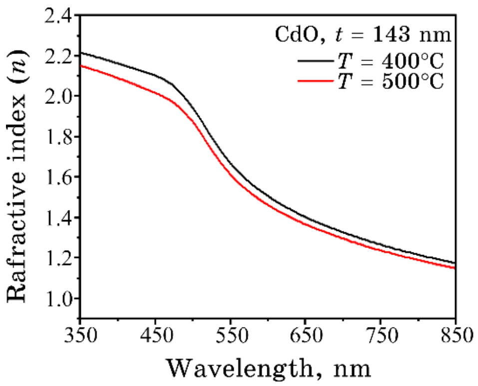


Fig. 5. Illustrates the relationship between the refractive index and wavelength for CdO films.

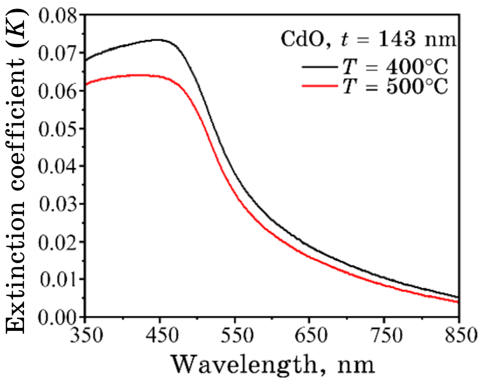


Fig. 6. Illustrates the relationship between the extinction coefficient and wavelength for CdO films.

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

In Figure 6, which represents the variation of the extinction coefficient as a function of wavelength for cadmium oxide (CdO) films, it is observed that the behaviour of the extinction-coefficient curves is nearly identical to that of the absorption coefficient due to their interrelationship. The extinction coefficient decreases with increasing substrate-deposition temperature.

3.6. The Real (ε_r) and Imaginary (ε_i) Parts of the Dielectric Constant

The real (ε_r) and imaginary (ε_i) parts of the dielectric constant were calculated using Eqs. (5) and (6), respectively.

$$\varepsilon_r = n^2 - K^2, \qquad (5)$$

$$\varepsilon_i = 2nK. \qquad (6)$$

Figures 7 and 8 illustrate the relationship between the real (ε_r) and imaginary (ε_i) parts of the dielectric constant of nanostructured CdO films as a function of wavelength (λ) at different annealing temperatures. The results show a gradual and noticeable decrease in the values of both real and imaginary parts of the dielectric constant with increasing wavelength, regardless of the annealing tem-

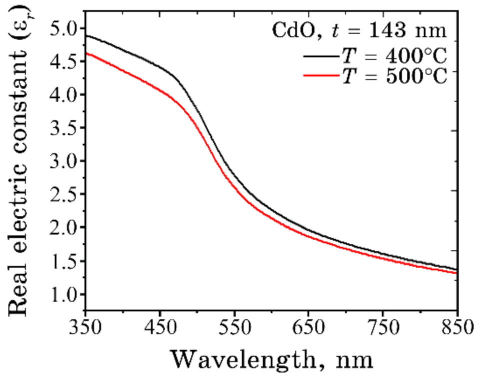


Fig. 7. The real dielectric constant of CdO films as a function of wavelength.

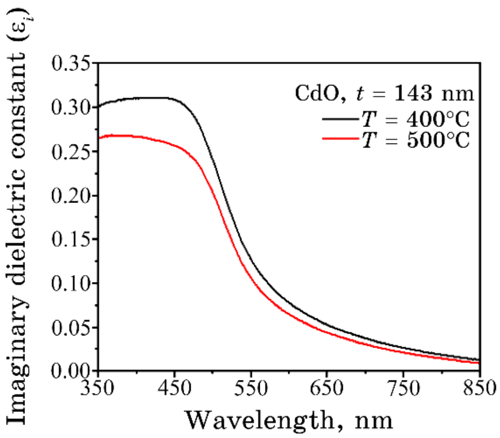


Fig. 8. The imaginary dielectric constant of CdO films as a function of wavelength.

perature. This decrease can be explained by the polarization effect within the film. As the field frequency increases, the ability of charge carriers to respond to changes in the electric field decreases, leading to a reduction in a wavelength. Additionally, the results indicate a significant decrease in the real dielectric constant values with increasing annealing temperature. This decrease becomes more pronounced with increasing wavelength. This behaviour is attributed to the increase in the charge-carriers' density within the nanostructured CdO films with higher annealing temperatures that enhances the electrical conductivity (σ) of the films. Consequently, the real and imaginary dielectric-constant values are reduced [14].

3.7. The Optical Conductivity

The optical conductivity of nanostructured CdO films prepared at different temperatures was evaluated as a function of wavelength, using the following equation:

$$\sigma = \frac{\alpha n c}{4\pi}, \tag{7}$$

where c is the speed of light in a vacuum.

Figure 9 shows a noticeable decrease in optical conductivity with increasing temperature, and this decrease becomes more pronounced at longer wavelengths. This indicates that the effect of temperature is more significant at longer wavelengths compared to shorter wavelengths.

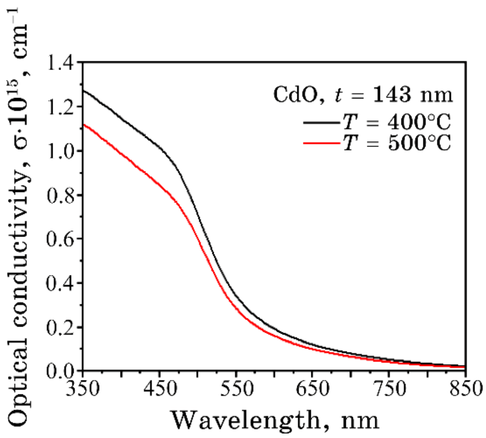


Fig. 9. Optical conductivity as a function of wavelength for thin CdO films for different temperatures.

4. CONCLUSIONS

1. The study demonstrated that the absorptivity and optical conductivity as functions of wavelength for the prepared films are significantly affected by the increase in annealing temperature. It was also observed that the absorptivity gradually decreases with increasing wavelength.
2. The results of the spectral analysis using UV–Vis spectroscopy showed that the studied films undergo direct electronic transitions. Additionally, it was noted that increasing the annealing temperature leads to a reduction in the values of certain optical constants, such as the absorption coefficient, the extinction coefficient, the refractive index, and the optical conductivity, with a significant wavelength-dependent effect.
3. Optical measurements revealed that the energy band gap for allowed direct transitions decreases with increasing annealing temperature. The energy band gap values were found to be 2.27 eV and 2.24 eV at annealing temperatures of 400°C and 500°C, respectively.

ACKNOWLEDGEMENTS

The researchers would like to thank the Department of Physics, College of Education for Pure Sciences, University of Mosul for providing support to accomplish this research.

REFERENCES

1. Yoon-Heung Tak, Ki-Beom Kim, Hyoung-Guen Park, Kwang-Ho Lee, and Jong-Ram Lee, *Thin Solid Films*, **411**, Iss. 1: 12 (2002); https://doi.org/10.1016/S0040-6090(02)00165-7
2. M. Soylu and H. S. Kader, *Electron. Mater.*, **45**, Iss. 11: 5756 (2016); https://doi.org/10.1007/s11664-016-4819-4
3. Jeevitesh K. Rajput, Trilok K. Pathak, Vinod Kumar, and L. P. Purohit, *Appl. Surf. Sci.*, **409**: 8 (2017); https://doi.org/10.1016/j.apsusc.2017.03.019
4. Murugasamy Ramamurthy, Murugan Balaji, and Perumal Thirunavukkarasu, *Optik*, **127**, Iss. 8: 3809 (2016); https://doi.org/10.1016/j.ijleo.2016.01.031
5. Nida Kati, *Mater. Sci. Pol.*, **37**, Iss. 1: 136 (2019); https://doi.org/10.2478/msp-2018-0104
6. Sungjun Park, Chang-Hyun Kim, Won-June Lee, Sujin Sung, and Myung-Han Yoon, *Mater. Sci. Eng. R Rep.*, **114**: 1 (2017); https://doi.org/10.1016/j.mser.2017.01.003
7. Jeevitesh K. Rajput, Trilok K. Pathak, V. Kumar, H. C. Swart, and L. P. Purohit, *Phys. B: Condens. Matter*, **535**: 314 (2018);

https://doi.org/10.1016/j.physb.2017.08.014
8. W. Kittel and E. A. De Wolf, *Soft Multihadron Dynamics* (World Scientific: 2005); https://doi.org/10.1142/5805
9. E. Weingartner, H. Saathoff, M. Schnaiter, N. Streit, B. Bitnar, and U. Baltensperger, *Aerosol Sci.*, **34**, Iss. 10: 1445 (2003); https://doi.org/10.1016/S0021-8502(03)00359-8
10. Yesem Kurt, *Turk. J. Chem.*, **34**: 67 (2010); https://doi.org/10.1080/01611190903225421
11. M. D. Migahed and H. M. Zidan, *Current Applied Physics*, **6**, Iss. 1: 91 2006); https://doi.org/10.1016/j.cap.2004.12.009
12. J. Tauc, R. Grigorovici, and A. Vancu, *phys. status solid (b)*, **15**: 627 (1966); https://doi.org/10.1002/pssb.19660150224
13. M. Fernández-Rodríguez, V. J. Rico, A. R. González-Elipe, and A. Álvarez-Herrero, *phys. stat. sol. (c)*, **5**: 1164 (2008); https://doi.org/10.1002/pssc.200777790
14. Qiang Zhou, Zhenguo Ji, BinBin Hu, Chen Chen, Lina Zhao, and Chao Wang, *Mater. Lett.*, **61**, Iss. 2: 531 (2007); https://doi.org/10.1016/j.matlet.2006.05.04