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Effect the Distance on the Optical Properties of CdO Thin Films Prepared by Thermochemical Spray Method at Moving Substrate Mode

Alaa Gh. N.[1], Hakam B. Y.[2], Narmeen F. Z. [3]*, Ahmed M. T.[4], Wand H. M.[5], Layla H. A.[6], Hazem S. A. [7]

[1]*University of Mosul, Presidency of the University of Mosul, Mosul City, Iraq*
[2]*Ministry of Health, Ninavah Health Director, AL- Hadbaa Specialist Hospital, Mosul City, Iraq*
[3,4,6]*University of Mosul, College of Science, Department of Physics, Mosul City, Iraq*
[5]*University of Technology, Department of Applied Science, Baghdad City, Iraq*
[7]*University of Mosul, College of Science, Department of New and Renewable Energy, Mosul City, Iraq*

**Corresponding author, Email address: narmeen.sc1332@student.uomosul.edu.iq*

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Abstract: Thin film of Cadmium oxide at different substrate distances (15,20,25,30) cm prepared via spray pyrolysis at moving substrate mode on glass substrates at 200 °C. Effect the Distance on the Optical Properties of CdO thin film was studied. UV-VIS spectrophotometer in the range of (320-1000) nm of wavelength was used to measuring the optical properties. As the length increases (from 15 cm to 30 cm) the transmittance increases and the films recorded the lowest absorbance at a distance of 30 cm, and the highest absorbance was recorded at a distance of 15 cm. The optical energy gap increased from 2.226 eV for CdO film at distance 15 cm to, 2.252 eV, 2.288 eV and 2.499 eV for CdO films at distance 20,25 and 30 cm respectively. According to these results, the best distance for CdO films is 30 cm. Other optical properties such as refractive index, extinction coefficient and separation coefficient.

Keywords: *CdO Thin Film; Thermal spraying method; Moving substrate mode; Optical properties*

1. Introduction

The versatile thin-film materials consist of thin, flexible layers formed from polymers, metals, and other substances, and they have multiple industrial uses because of their unique characteristics. Technology heavily depends on thin films since these materials improve mechanical attributes above bulk-level properties while enabling extensive research possibilities and theoretical applications, according to (Halin *et al.*, 2024). The pharmaceutical field embraces thin films as emerging drug delivery solutions because these systems provide easy use, quick medicine dispersal, and enhanced patient experience. These delivery methods encompass transdermal and buccal administration besides ocular and oral pathways to achieve local and systemic medication effects (Darshit *et al.,* 2024 ; Ram *et al.,* 2022). The film development process includes drug and polymer pharmacological evaluation, pharmaceutical understanding, and optimal characterization techniques to overcome formulation obstacles (Darshit *et al.,* 2024). Virtual films serve the demand for anti-microbial applications while providing innovative and scalable energy usage features and self-healing properties in coating systems. 3D printing and Industry 4.0 technologies increase their potential, according to (Mwema *et al.,* 2022). Thin films represent a critical element in the photovoltaic and solar thermal areas of solar energy production where the plasma-enhanced chemical vapour deposition method and magnetron sputtering method achieve efficient performance for solar cells and thermal films (Wang and Wu, 2023). Thin films present diverse opportunities throughout different scientific and industrial applications.

The unique properties of thin films enable their widespread use in electronics, optics, and sensors industries because they display significant differences from the properties of bulk materials. Technology development depends on these films because they provide application-specific features, including transparent conductors and solar cells (Sharma *et al.,* 2024). The material called Cadmium oxide (CdO) shows potential as an excellent candidate since it demonstrates optical behaviour together with insulating characteristics suitable for transparent conductive oxides along with various optoelectronic device (Vijayanarayanan *et al.,* 2024; Majid & Bibi, 2018; Chandiramouli & Jeyaprakash, (2013); aldwayyan *et al.,* 2013; Buckley *et al.,* 2024). Applying nebulized spray pyrolysis for CdO thin film deposition results in visually transparent layers that present adjustable optical band gaps essential for gas sensor development and other electronic components (Vijayanarayanan *et al.,* 2024). The optical properties of CdO receive additional enhancement when doped with manganese since the material becomes sensitive to ethanol vapours and maintains high selectivity as a sensor (Umarani *et al.,* 2024). Annealing procedures can optimize the structural and optical features of CdO films because these processes regulate their transmission and absorption properties for broader optical device applications (Habeeb, 2024). The research demonstrates that CdO thin films are uniquely positioned in next-gen sustainable electronics and optoelectronic device development because of their extensive technological utilization (Buckley *et al.,* 2024). The thermochemical spray method provides an important solution for producing superior-quality coatings and nanocrystals. The thermospray technique is a budget-friendly solution for semiconductor salt solutions to become monodispersed droplets that eventually produce solid nanocrystals through solvent drying. The method achieves its importance through its capability to regulate nanocrystal size distribution as researchers manage spray parameters like temperature and flow rate values (Amirav and Lifshitz, 2008). Research innovation includes applying a substrate mechanism similar to the substrate vibration-assisted spray coating (SVASC) technology that produces highly conductive and uniform thin films through surface finish enhancement and defect reduction. The presented research method breaks new ground by combining substrate movement mechanics to boost film characteristics because this approach demonstrated a fourfold increase in electrical conductivity beyond conventional coating methods (Zabihi and Eslamian, 2015). The study demonstrates how membrane optical and insulating characteristics depend on spray distance because different distances control spray thermal and kinetic energies, which shape coating quality (Jafarzadeh *et al.,* 2024). The systematic approach enables a better understanding of spray-based coating techniques and provides new possibilities to improve high-performance material manufacturing methods.

Chemical and physical deposition techniques are essential for the fabrication of thin films used in various electronic applications. CVD is a chemical deposition technique that involves the deposition of thin films through the reaction of volatile precursors (Toma *et al.*, 2024; Chandiramouli & Jeyaprakash, (2013); Naciri *et al.*, 2009; Choy *et al.*, 2003). It is widely used in the production of semiconductors, solar cells, and other electronic devices. CVD is a key technique for depositing thin films with high purity and uniformity. (Kern, 1989; Frey, 2015). PVD is a physical deposition technique that involves the deposition of thin films through the evaporation or sputtering of target materials. It is commonly used in the production of thin films for optical, electrical, and mechanical applications. PVD is a versatile technique that can be used to deposit a wide range of materials (Shahidi et al., 2015; Aliofkhazraei & Ali, 2014). Sputtering is a physical deposition technique that involves the deposition of thin films through the bombardment of target materials with high-energy ions. It is widely used in the production of thin films for optical, electrical, and mechanical applications. Sputtering is a versatile technique that can be used to deposit a wide range of materials (Hilliard, 2001) . Sol-gel deposition is a chemical deposition technique that involves the deposition of thin films through the hydrolysis and condensation of metal alkoxides. It is commonly used in the production of thin films for optical, electrical, and mechanical applications. Sol-gel deposition is a low-cost and versatile technique for depositing thin films (Sporn *et al.*, 2002). PLD is a physical deposition technique that involves the deposition of thin films through the ablation of target materials using high-powered laser pulses. It is widely used in the production of thin films for electronic, optical, and biomedical applications. PLD is a precise technique that allows for the deposition of thin films with high purity and uniformity (Koren, 2014). And there are also another types of Physical and chemical methods for thin film preparation thermal evaporation, electron beam evaporation, sputtering, atomic layer deposition (ALD), spin coating, dip coating.

2. Methodology

The thin film of Cadmium oxide prepared via spray pyrolysis at moving substrate mode on glass substrates measuring 1.5×76.2 mm with a thickness of 1.2 mm. The glass substrates were cleaned by immersion in acetone for ten minutes with stirring to remove organic contaminants, then washed with distilled water. Afterwards, the glass substrates were dried using special tissues. Cadmium oxide was prepared by mixing 2.2915 gm of $CdCl_2$ in 25 ml distilled water with 0.28 gm of KOH in 25 ml distilled water to obtain CdO. Then the two solutions were mixed together in a mixing device with a temperature of 85 °C for 15 min. Four thin cadmium oxide were prepared at different substrate distances (15,20,25,30) cm. When preparing the films, the temperature of the glass substrate was fixed at 200 °C, the solution flow rate was 3 ml/min controlled by a valve in the spray device, and the sample spraying time was (10 sec) followed by a 2 min pause and then repeating the process again. This pause is necessary to avoid cooling the glass substrates, and the air pressure used was 1 pa. Using UV-VIS spectrophotometer (Shimadzu) in the range of (320-1000) nm of wavelength were the optical properties measured

3. Results and Discussion

Optical transmittance and absorbance of prepared films were measured using UV-VIS spectrophotometer in range (320-1000) nm. Figure 1. shows the transmittance versus wavelength (nm) for four CdO (cadmium oxide) samples with different lengths (15 cm, 20 cm, 25 cm, 30 cm), where the transmittance increases with increasing wavelength, and the sample becomes more transparent at higher wavelengths. As the length increases (from 15 cm to 30 cm), the transmittance increases, indicating the effect of length on the optical properties of the samples. This effect may be due to a decrease in absorption or scattering within the material, allowing more light to pass through. The physical structure of the samples may also play a role in improving the transmission of light through them.

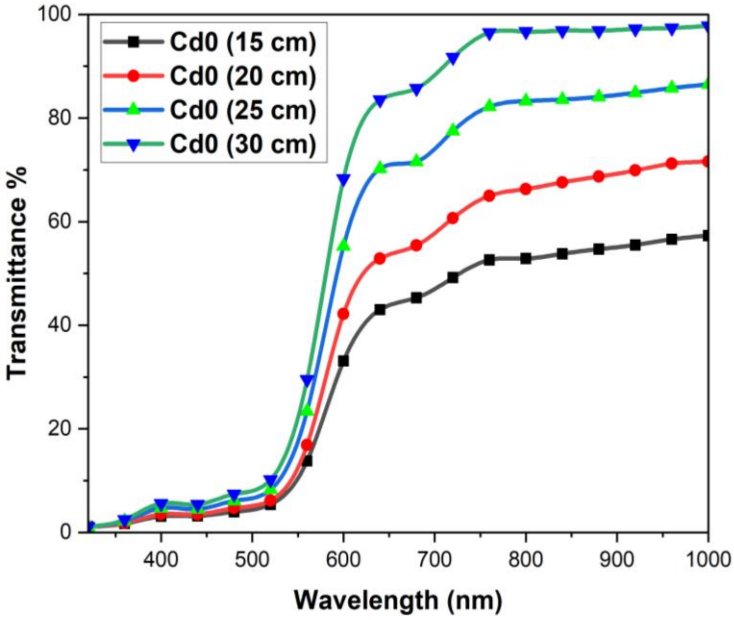

Figure 1. Optical transmittance spectra of CdO films at different substrate distances (15,20,25 and 30) cm

The Figure 2. represents the absorbance of the prepared films as a function of the wavelength. We notice that the absorbance gradually decreases as the wavelength increases. The films recorded the lowest absorbance at a distance of 30 cm, and the highest absorbance was recorded at a distance of 15 cm. We notice that at short distances the absorption is very high compared to long distances.

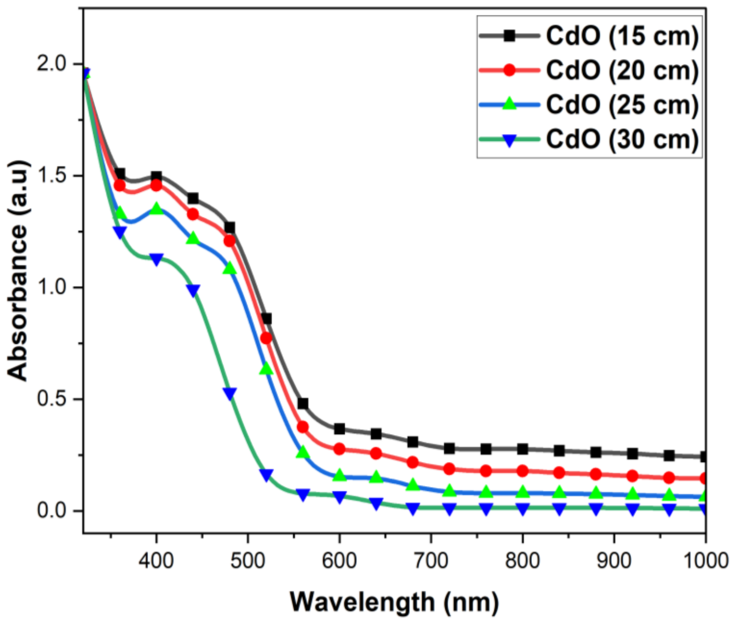

Figure 2. Absorbance spectra of CdO films at different substrate distances (15,20,25 and 30) cm.

The reflectivity of the prepared films was measured using the following relationship (Shujahadeen *et al.,* 2020) :

$R=1-T-A$ **Eqn.1**

Figure 3. represents the three reflectivity as a function of the wavelength. We note when that the wavelength increases the reflectivity decreases. It is noted from the figure that the reflectivity decreases when the distance increases from 15 cm to 30 cm, and the least reflectivity was recorded at 30 cm. The absorption coefficient of prepared films was measured using the following relationships (Abdallh *et al.,* 2013) :

$\alpha= (2.303 * A)/t$ **Eqn.2**

Figure 4. illustrates the absorption coefficients as a function of wavelength. The graphic indicates that the absorption coefficient diminishes as the wavelength increases. The figure indicates that as distance rises, the coefficient of absorption diminishes, with the maximum absorption coefficient seen at 15 cm and the minimum at 30 cm.

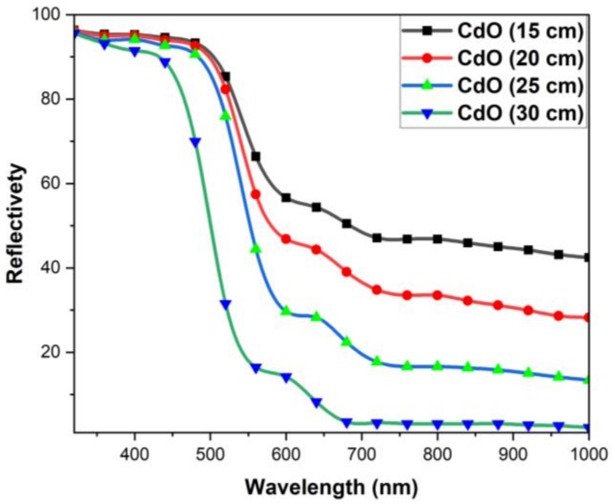

Figure 3. The reflectivity of CdO films at different substrate distances (15,20,25 and 30) cm.

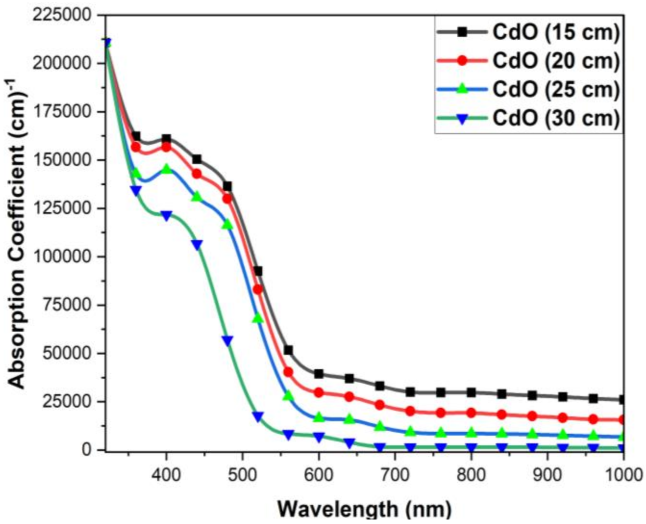

Figure 4. The absorption coefficient of CdO films at different substrate distances (15,20,25 and 30) cm.

To measure the extinction coefficient, the following relationship was used (Ilican *et al.*, 2008):

$K=\alpha\lambda/(4\pi)$ **Eqn.3**

Figure 5. illustrates the extinction coefficient as a function of wavelength. The Figure indicates that the extinction coefficient diminishes as the wavelength of the produced films increases. The figure indicates that the extinction coefficient decreases with increasing distance, peaking at 15 cm and reaching its minimum at 30 cm.

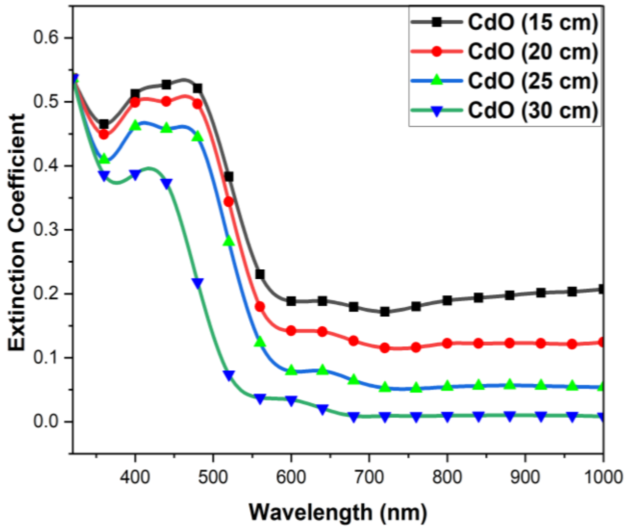

Figure 5. The extinction coefficient of CdO films at different substrate distances (15,20,25 and 30) cm.

Optical band gap, Tauc law expression used to measuring the optical energy gap (Pankove, 1971) :

$(\alpha h\nu)^n=B(h\nu-Eg)$ **Eqn.4**

n=2 denote the parameter for direct and n=1/2 for indirect band gap semiconductors, respectively; hν represents the incident photon energy, α is the absorption coefficient, and B is a constant. The optical energy gap values were measured by plotting the relationship between $(\alpha h\nu)^2$ and photon energy, as illustrated in Figure 6, and drawing a tangent to the linear segment of the curve at $(\alpha h\nu)^2 = 0$. Figure 6 shows that the optical energy gap is 2.226 eV, 2.252 eV, 2.288 eV and 2.499 eV for CdO films at distance 15,20,25 and 30 cm, respectively.

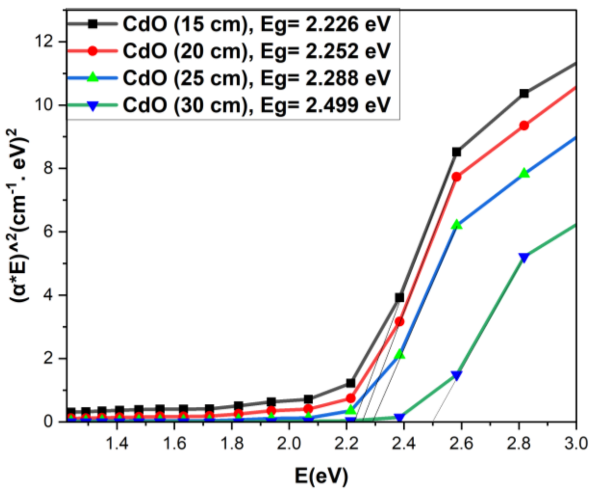

Figure 6. $(\alpha h\nu)^2$ verses *hv* spectra of CdO films at different substrate distances (15,20,25 and 30) cm.

The refractive index of the prepared films was measured using the following relationship (Crawfor, 1987) :

$$n = \{(\frac{1+R}{1-R})^2 - K_o^2 + 1\}^{\frac{1}{2}} + (\frac{1+R}{1-R}) \qquad \textbf{Eqn.4}$$

Figure 7. illustrates the refractive index as a function of wavelength. The refractive index diminishes as the wavelength increases. The graphic indicates that the refractive index diminishes as the distance rises from 15 cm to 30 cm, with the maximum refractive index seen at 15 cm.

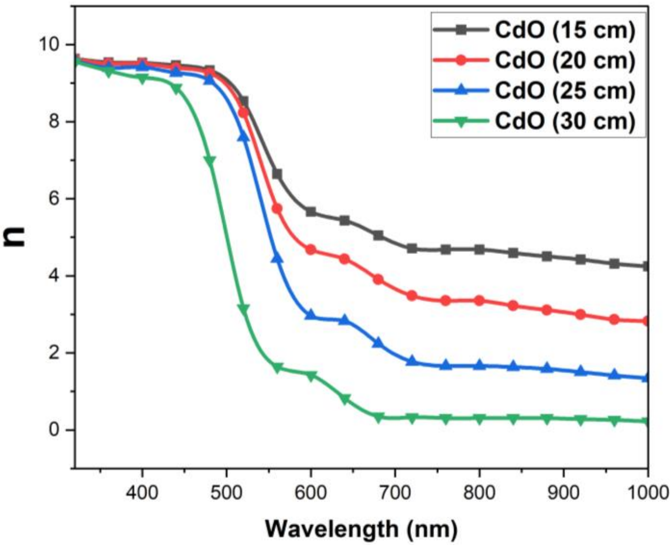

Figure 7. The refractive index of CdO films at different substrate distances (15,20,25 and 30) cm.

Conclusion

In this work, thin film of CdO at different substrate distances (15,20,25,30) cm prepared via spray pyrolysis at moving substrate mode on glass substrates at 200 °C. The effect the distance on the Optical Properties of CdO thin film was studied. UV-VIS spectrophotometer was used to measuring the optical properties. As the distance increases (from 15 cm to 30 cm) the transmittance increases and the films recorded the lowest absorbance at a distance of 30 cm, and the highest absorbance was recorded at a distance of 15 cm. The optical energy gap increased from 2.226 eV for CdO film at distance 15 cm to 2.499 eV for CdO films at 30 cm. Refractive index, extinction coefficient and separation coefficient it was decreased as the distance increases. According to these results, the best distance for CdO films is 30 cm. As the membranes are characterized at a distance of 30 cm by the lowest absorption, highest permeability and highest energy gap value, this membrane can be used at this distance in applications that require the highest permeability and lowest absorption, such as solar cells.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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