

# The Effect of Doping by Nano-Cerium Oxide on the Structural and Optical Properties of Nano-Magnesium Oxide using Pulsed Laser Deposition Technique

<sup>1</sup>Yaqutah D. Suleiman,<sup>2</sup>Niran F. Abdul Jabbar

<sup>1,2</sup>Department of Physics, College of Education for Pure Sciences, Tikrit University, Tikrit, Iraq.

## Article Info

### Article history:

Received: 19, 05, 2025

Revised: 22, 07, 2025

Accepted: 25, 08, 2025

Published: 30, 09, 2025

### Keywords:

Energy Gap  
Hydraulic Piston  
Laser  
PLD  
Transmittance

## ABSTRACT

Pure nano-magnesium oxide (MgO) layers with bombardment spacings of (0.5, 1, and 1.5 cm) and doped with nano-cerium oxide (CeO<sub>2</sub>) at three percentages (0.1, 0.2, and 0.3%) with a spacing of 1 cm were prepared using PLD. Initial samples were prepared by mixing the raw powders and pressing them in a hydraulic press with a diameter of 10 mm at a pressure of 5 tons for 10 minutes. They were then placed in a laser device for fragmentation and deposition on glass substrates. The structural and optical properties of the deposited films were studied. XRD results indicated that the resulting phase of MgO and CeO was cubic, while the composite of both materials after doping was Mg,CeO<sub>3</sub> with a monoclinic crystal system. The optical results showed that the energy gap increased continuously with each nano addition, and the highest energy gap was reached at the ratio of 0.3% CeO<sub>2</sub>, amounting to 3.807 eV, while the transmittance values were 80%, and the absorbance decreased slightly at the same addition ratios.

*This is an open access article under the CC BY license.*



## Corresponding Author:

**Yaqutah D. Suleiman**

Department of Physics, College of Education for Pure Sciences, Tikrit University, Tikrit, Iraq.

Email: [yd230081pep@st.tu.edu.iq](mailto:yd230081pep@st.tu.edu.iq)



## 1. INTRODUCTION

Thin film deposition is one of the most prominent methods known in materials technology for improving certain physical, chemical, and mechanical properties of surfaces, to suit the requirements of specific precision and industrial applications[1]. Most modern technological applications, such as some smartphones, environmental sensors, and electrochemical catalysts, rely primarily on thin layers whose composition, thickness, and physical properties are precisely controlled[2]. This progress has opened up vast and exciting prospects for the development of materials with enhanced properties such as corrosion resistance, optical and thermal transparency, electrical conductivity or insulation, and biocompatibility in some medical applications[3]. These thin films are widely used in solar cells to improve light absorption efficiency, in layered mirrors to increase reflectivity and refraction, and in thin-film electronic chips to provide insulating or conducting junctions[4]. Thin films also play an important role in optical applications such as multilayer lenses, some optical filters, and laser components[5]. Optimal performance requires precise control of the nanostructure and surface properties and increased productivity[6].

In the industrial field, thin films have proven their ability to increase the corrosion and heat resistance of metals and alloys, extending the operating life of devices and components used in harsh environments, such as power plants or precision aerospace industries[7]. This technology is particularly important when depositing metal oxides such as magnesium oxide and cerium oxide, known for their insulating, anti-reflective, and corrosion-resistant properties, in thin films. These oxides are excellent candidates for developing protective or active coatings in optical and electronic devices, especially when their properties are enhanced by the addition of doped or semi-modified materials precisely at the atomic or nanoscale level[8]. Pulsed laser deposition (PLD) is one of the most widely used and accurate thin-film deposition techniques, offering a high degree of control over the compositional and structural properties of the deposited layers[9].

This technology relies on the use of a high-energy pulsed laser, often an excimer laser or Nd:YAG laser, to generate plasma from the surface of the target material. This plasma is then deposited onto the surface of the target substrate (such as glass, silicon, or metal). This method is well-known for its ability to deposit multiple materials, even those with high melting points or materials of different components, without any significant differences in their chemical composition[6]. One of the most notable advantages of PLD is that it maintains the same element concentration in the original compound during the transition from the target to the substrate, making it ideal for the deposition of complex materials such as binary oxides, complex compounds, and hybrids. This method also allows for the deposition of thin films with thicknesses ranging from a few nanometers to a few microns with high precision and good speed[10]. Deposition parameters such as pulse energy, pulse rate, substrate temperature, chamber pressure, and the distance between the substrate and the laser nozzle are controlled to achieve the desired crystal structure. PLD has proven its excellence in the deposition of magnesium oxides (MgO) and cerium oxides (CeO<sub>2</sub>), yielding composites with high homogeneity, distinct crystal structure, and high transparency. These composites are ideally suited for applications such as optical coatings, lenses, spectral filters, and nanocomponents in photovoltaic devices. The addition of cerium oxide as a dopant to the MgO structure improves the electrical and optical properties of the laser-generated layers and enhances their chemical, thermal, and environmental resistance. This makes this MgO:CeO<sub>2</sub> composite system increasingly valuable in research related to sensing, advanced optics, resistive memory technologies, and most optical applications in solar cells[11].

This research aims to study the effect of doping with cerium oxide (CeO<sub>2</sub>) and magnesium oxide (MgO) on some structural and optical properties of thin films deposited on glass by pulsed laser deposition (PLD) technique, by analyzing the crystal structure using X-ray diffraction (XRD) and calculating the optical enhancement through transmittance and energy gap measurements.

## 2. EXPERIMENTAL PART AND RAW MATERIALS

The white nano magnesium oxide powder with a purity of 99.9% and a nano particle size of 30nm, produced by SkySpring Nanomaterials, Inc., USA, was used. The nano cerium oxide powder with a purity of 99.5% and a nano particle size of 30±5nm, produced by Changsha Santech Co., China, was used. The pure nano magnesium oxide powder was pressed in a Chinese SHOP PRESS hydraulic press at a pressure of 5 tons and a time of 10 minutes per press with a die diameter of 10mm, as shown in Figure (1). The nano cerium powder was added at weight ratios of (0.1, 0.2, 0.3%) to the pure magnesium oxide, and the pressing process was carried out under the same conditions. The thickness of the resulting samples became (0.5 cm) and they can be bombarded by the pulsed laser deposition (PLD) method. The laser type was (Nidemum Yak) with an energy of 700 mJ and a frequency of 6 Hz for a period of 17 minutes. Figure (2) shows the shape of the samples after the laser bombardment process. The deposition process was carried out on high-purity glass substrates free of contaminants that affect the results. The samples resulting from the deposition are ready for thermal annealing at 300°C for a period of one hour so that the glass substrates are ready for structural and optical tests.



Figure 1. The mold used in the pressing process.



Figure 2. The compressed after the pulsed laser deposition process.

### 3. MEASUREMENTS

#### 3.1. X-ray Diffraction Test

X-ray diffraction is a test used to identify the reactants within a coating layer sprayed onto substrates. The phases formed, along with Miller's coefficients and the type of materials present in each coating, can be identified. The test was conducted using an Aeris Research device manufactured by Malvern Panalytical, a Dutch company. The tube used was a Cu( $k\alpha$ ) tube, and the test was conducted at room temperature.

#### 3.2. Optical Properties tests

Optical measurements were performed using a UV-Visible-NIR spectrophotometer manufactured by Shimadzu, Japan. This device covers the wavelength range from 300 to 900 nm and uses a two-beam system. The optical measurements included the determination of absorbance and transmittance within the mentioned wavelength range, which helps in studying the optical properties of films prepared using nano-titanium oxide by the chemical-thermal deposition method and analyzing the effects of thermal and compositional treatments [12]. Transmittance (T) is defined as the ratio of the intensity of the transmitted beam ( $I_t$ ) to the intensity of the incident beam (I) and is written in the following formula [13]:

$$T = \frac{I_t}{I_o} \quad (1)$$

Reflectivity I is defined as the ratio of the intensity of the reflected ray ( $I_r$ ) to the intensity of the incident ray (I) and is written in the following formula [14]:

$$R = \frac{I_r}{I_o} \quad (2)$$

Where  $I_t$ : transmitting light intensity,  $I_r$ : reflected light intensity,  $I_o$ : incident light intensity. Transmittance can be written in terms of reflectivity, absorption coefficient and film thickness [15].

$$T = (1 - R)^2 e^{-\alpha t} \quad (3)$$

There is another relationship between transmittance, absorbance and reflection [16].

$$R + T + A = 1 \quad (4)$$

The relationship between the incident light (I) and the intensity of the transmitted light ( $I_o$ ) can be written using Lambert's law, which is a law for the absorption of radiation. The relationship between the intensity is as in the following equation [17]:

$$I = I_o e^{-\alpha t} \quad (5)$$

Where:  $\alpha$ : is a function of the wavelength and is known as the absorption coefficient and is measured in units of (cm<sup>-1</sup>), and t: the thickness of the film. After simplifying the previous equation, we get [18]:

$$\alpha t = 2.303 \log \frac{I_o}{I} \quad (6)$$

Where ( $\log \frac{I_o}{I}$ ) represents A, which is the absorbance of the thin film, and the intensity of the incident radiation decreases exponentially through the material ( $e^{-\alpha t}$ ), and  $\alpha$  represents the absorption coefficient, which represents the percentage of decrease in radiation energy through the material. Thus, the equation can be written as follows [19]:

$$\alpha = 2.303 \frac{A}{t} \quad (7)$$

## 4. RESULT AND DISCUSSION

### 4.1. X-ray diffraction(XRD) Analysis

When analyzing the X-ray diffraction (XRD) patterns of samples prepared from nano-magnesium oxide doped with nano-cerium oxide at different concentrations (0.1%, 0.2%, 0.3%), and deposited on glass substrates using pulsed laser deposition (PLD) technology. The results revealed a number of important properties, as shown in Figure (3) and Table (1). The X-ray diffraction (XRD) data indicate that the nano-magnesium oxide appears in the cubic phase, which is the known crystalline phase of this element, and is known for its structural stability at medium temperatures [20]. Cerium oxide nanoparticles also exhibited clear peaks consistent with the cubic phase, indicating proper crystallization and crystalline regularity in the composition of these nanoparticles. At 0.1% CeO<sub>2</sub>, the crystalline peaks appeared relatively weak and blunt, indicating poor crystallization and small crystallite size, which may indicate the beginning of the appearance of Ce<sup>4+</sup> ions in the magnesium oxide crystal lattice without the formation of clearly defined new phases[20]. When the concentration was increased to 0.2%, sharper peaks appeared with an increase in peak intensity, particularly at 2θ angles between 30° and 40°, corresponding to the (200), (220), and (311) crystal planes. This reflects an improvement in crystal ordering and an increase in the size of the resulting crystals. As the cerium content increased to 0.3%, the existing peaks became sharper and more intense, with the appearance of other previously invisible phases. Remarkably, the new phases, attributed to the mixed oxide compound MgCeO<sub>3</sub>, were clearly obtained in the monoclinic phase, indicating that the fusion of MgO and CeO<sub>2</sub> at this concentration led to the formation of a new crystalline complex within the composites. This formation of a crystalline phase is considered important for the chemical interaction between the two materials and the formation of a composite phase with some structural properties different from the original compounds [21]. Regarding crystal stresses, some peaks were found at higher ratios with relatively broad peaks, indicating the presence of low crystal stresses (microstresses) resulting from the difference in ionic radii between Mg<sup>4+</sup> and Ce<sup>4+</sup> [22]. The introduction of larger ions leads to a slight expansion of the crystal lattice, generating interfacial distortions. The heat treatment process at 300 °C plays a key role in reorganizing the crystal grains within the film. This improves the clarity of the crystalline peaks and reduces some structural defects. It also helps organize the formed phases and reduce the stresses generated during growth [23]. Overall, this glass-deposited system shows that the addition of nano-cerium oxide with variable ratios of nano-magnesium oxide significantly improves the structural properties and contributes to the formation of cubic and monoclinic crystalline phases. This also improves the crystallization process and enhances the potential of these films in optical and electronic applications, particularly in areas requiring high transmittance, structural regularity, uniformity, and good thermal stability [24].

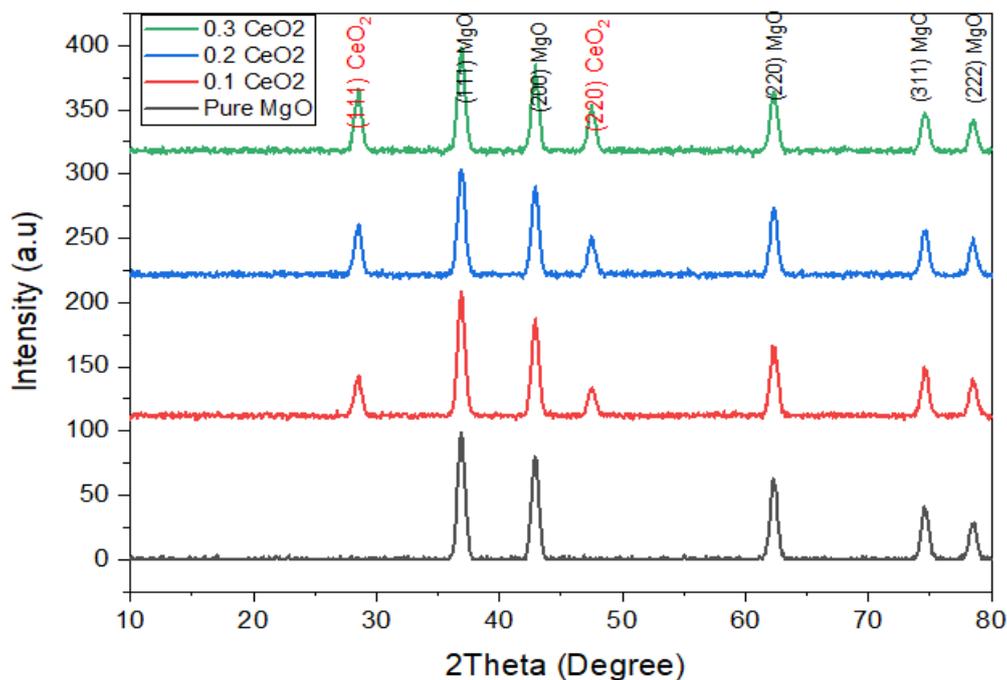


Figure 3. XRD results when adding (0.1, 0.2, 0.3)% of cerium oxide to magnesium oxide after thermal annealing.

Table 1. Parameters of X-ray diffraction results for the (MgO-%CeO<sub>2</sub>) system.

2Theta (deg)	FWHM (deg)	d-spacing (Å)	Crystallite Size (°A)	Theta (deg)	hkl	Material
Pure MgO						
36.837	4.303	2.438	1.16	18.418	(111)	MgO
42.943	6.93	2.095	0.73	21.572	(200)	MgO
62.272	7.21	1.49	0.8	31.136	(220)	MgO
74.605	7.34	1.271	0.86	37.302	(311)	MgO
76.445	7.51	1.259	0.86	37.723	(311)	MgO
Doping CeO <sub>2</sub> =0.1						
28.498	5.661	3.13	1.62	14.249	111)	CeO <sub>2</sub>
36.907	2.856	2.434	3.24	18.453	(111)	MgO
42.933	3.048	2.105	2.24	21.466	(200)	MgO
47.487	5.731	1.913	1.71	23.744	220))	CeO <sub>2</sub>
62.272	4.316	1.49	2.0	31.136	(220)	MgO
74.605	5.45	1.271	1.98	37.302	(311)	MgO
Doping CeO <sub>2</sub> =0.2						
28.548	5.28	3.12	1.73	14.279	111)	CeO <sub>2</sub>
36.957	2.954	2.424	2.56	18.483	(111)	MgO
42.983	4.216	2.095	1.94	21.496	(200)	MgO
47.537	5.491	1.903	1.82	23.774	220)	CeO <sub>2</sub>
62.322	4.497	1.48	2.09	31.166	(220)	MgO
74.655	5.561	1.261	2.07	37.332	(311)	MgO
78.579	5.701	1.207	2.12	39.294	(222)	MgO
Doping : CeO <sub>2</sub> =0.3						
28.498	5.38	3.13	1.63	14.249	111)	CeO <sub>2</sub>
36.907	3.054	2.434	2.46	18.453	(111)	MgO
42.933	4.316	2.105	1.84	21.466	(200)	MgO
47.487	5.591	1.913	1.72	23.744	220)	CeO <sub>2</sub>
62.272	4.597	1.49	1.99	31.136	(220)	MgO
74.605	5.661	1.271	1.97	37.302	(311)	MgO
78.529	5.801	1.217	2.02	39.264	(222)	MgO

#### 4.2. Optical Properties Analysis

Figure (4) shows the absorbance curves of CeO<sub>2</sub>-doped MgO films deposited using the PLD technique, showing a clear change depending on the percentage of cerium oxide. At 0.1%, the absorbance appears low and rapidly decreasing, indicating a wide energy gap and a pure crystalline structure [25]. At 0.2%, the absorbance increases and continues towards longer wavelengths, indicating improved crystallinity and the emergence of an additional energy range within the energy gap as a result of doping. At 0.3%, the peak decreases slightly, but the absorption continues to a longer range, indicating a saturation effect and an increase in crystal defect centers [26]. These results demonstrate that controlling the CeO<sub>2</sub> percentage helps modify some of the absorption properties, improving the potential of these films for optical applications such as filters and solar cells [27].

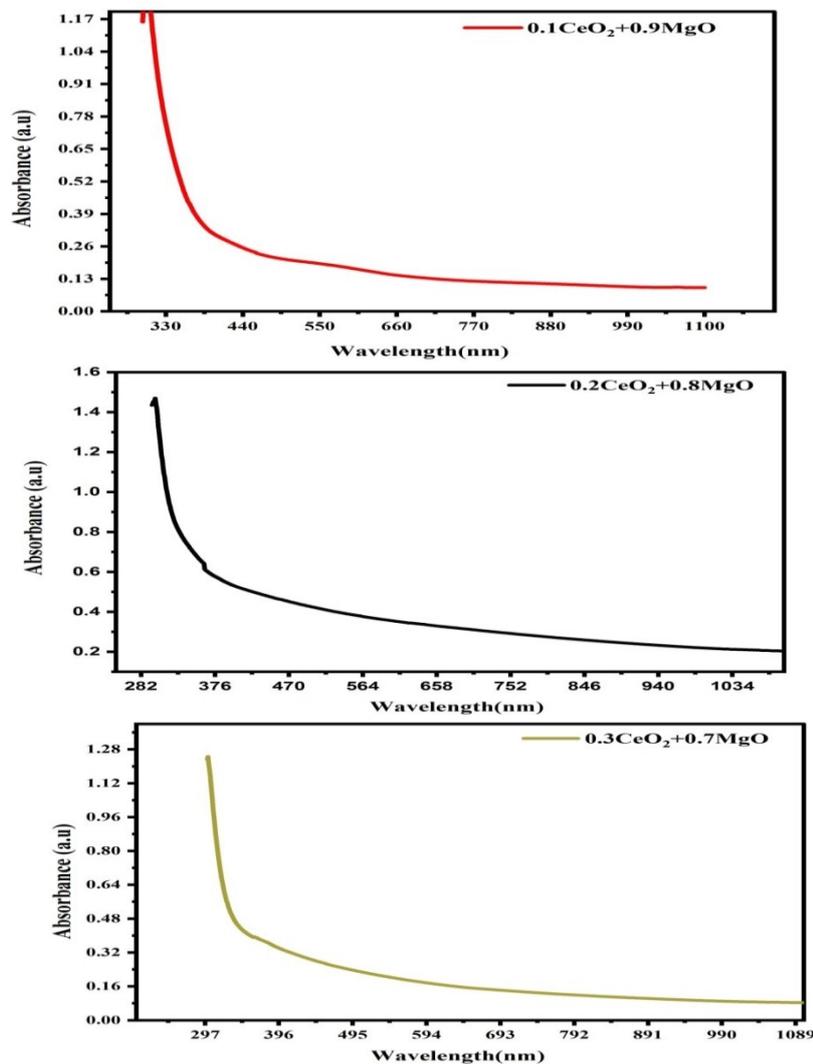


Figure 4. Relationship between absorbance and wavelength of (MgO-%CeO<sub>2</sub>) films

Figure (5) shows the optical transmittance curves of MgO films doped with CeO<sub>2</sub> at different concentrations (0.1, 0.2, 0.3%). The sample with a concentration of 0.1% showed the highest transmittance, reaching more than 80% in the spectral range of more than 1000 nm, indicating that it has a transparent structure with a wide energy gap and low absorbance, a behavior suitable for elements used in optical applications such as spectral windows. When the CeO<sub>2</sub> percentage was increased to 0.2%, the transmittance decreased to less than 65%, indicating an increase in light absorption due to the entry of many defect centers into the crystal lattice, which may cause internal scattering of light or absorption in the visible wavelength range [28]. This reflects a change in the structural composition due to the incorporation of Ce<sup>4+</sup> into the MgO lattice, leading to the emergence of internal energy ranges that reduce transparency [29].

The 0.3% sample exhibits a further increase in transmittance, exceeding 80% at higher wavelengths, with a similar curved shape to the original sample. This behavior may be attributed to the result of atomic arrangement and improved crystal growth after annealing, which reduces defect density and improves film purity. This indicates an optimal doping ratio that improves some optical properties without damaging the structural crystal structure [29]. Overall, these results confirm that CeO<sub>2</sub> doping can modify the optical properties of MgO films, increasing and enhancing their performance, particularly in applications requiring high transmittance and adequate light transmission, such as solar cells, lenses, and optical coatings. Controlling the doping ratio is also essential for achieving improved properties that meet the functional performance requirements of some modern optical devices [30].

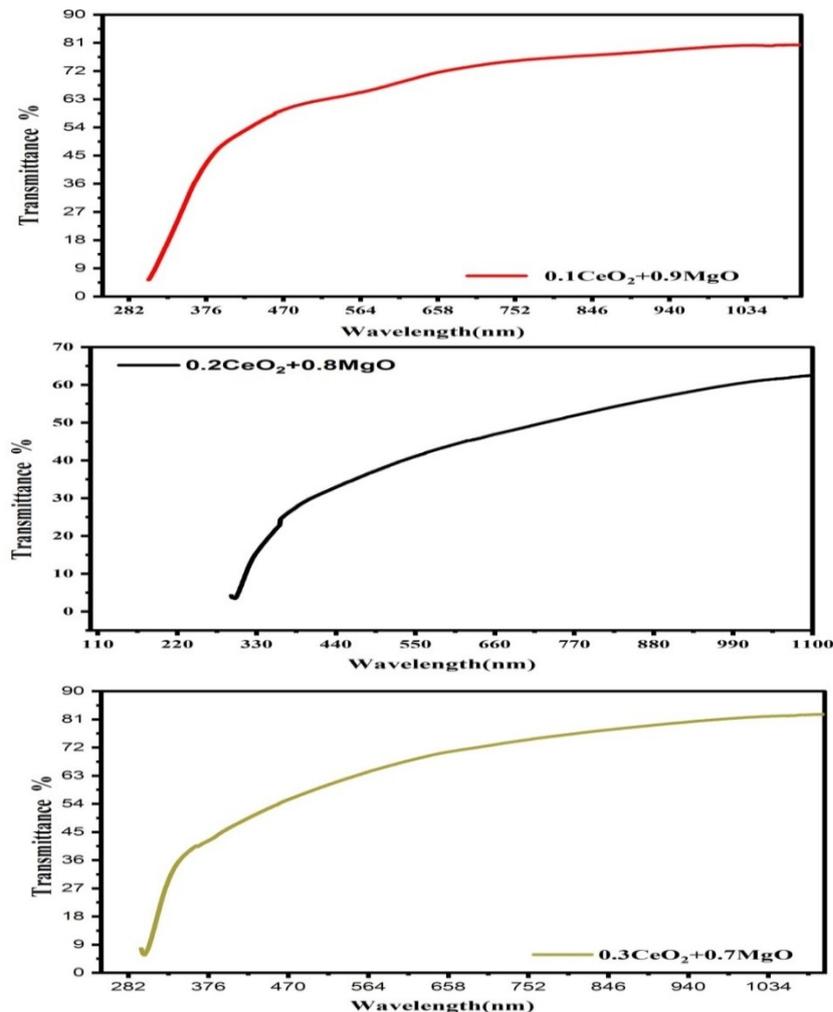


Figure 5. The relationship between transmittance and wavelength for (MgO-%CeO<sub>2</sub>) films.

Figure (6) shows the optical band gap ( $E_g$ ) energy profile of MgO films doped with nano-cerium oxide (CeO<sub>2</sub>) at concentrations of 0.1%, 0.2%, and 0.3%, prepared by pulsed laser deposition and annealed at 300°C for one hour. There is a noticeable change in the optical band gap value with increasing CeO<sub>2</sub> percentages. In the first sample with a concentration of 0.1%, the apparent energy gap from the Tauc curve appeared to be about 3.695 eV, a value close to the known optical band gap of nano-magnesium oxide. This indicates that the low CeO<sub>2</sub> percentage did not significantly alter the electronic arrangement of the MgO lattice, which stabilized at near-constant  $E_g$  values, which is possible at low doping without creating new energy levels within the overall band gap [31]. When the CeO<sub>2</sub> percentage increased to 0.2%, the energy gap increased to 3.790 eV, which is evidence of the beginning of the formation of doping effects on the electron band gap structure. This pattern may be attributed to the presence of larger CeO<sub>2</sub> ions compared to Mg<sub>2</sub>, indicating a slight distortion in the crystal structures and a modification in the density distribution of electronic states, leading to a slight widening of the optical gap [32].

This widening could be due to the formation of localized energy levels associated with Ce atoms within the crystal lattice, which hinders the transition of electrons between the valence and conduction bands. In the sample with the highest 0.3% CeO<sub>2</sub> content, a high energy gap of 3.807 eV was observed, indicating a double doping effect on the film structure. This demonstrates that a high CeO<sub>2</sub> content enhances the crystal lattice order and reduces the density of electronic defects, which reduces atomic rearrangement centers and increases the purity of the electronic structure [33]. A high  $E_g$  also indicates improved optical properties, as seen in applications requiring a wide band gap, such as ultraviolet optical devices and some optical insulators [34]. The results show that increasing the doping of MgO with cerium oxide leads to a gradual widening of the optical gap, which can be used to improve the performance of films in electronic and optical applications in solar cells, especially in devices that require thermal or electrical stability along with high transmittance in the UV spectrum [35-37].

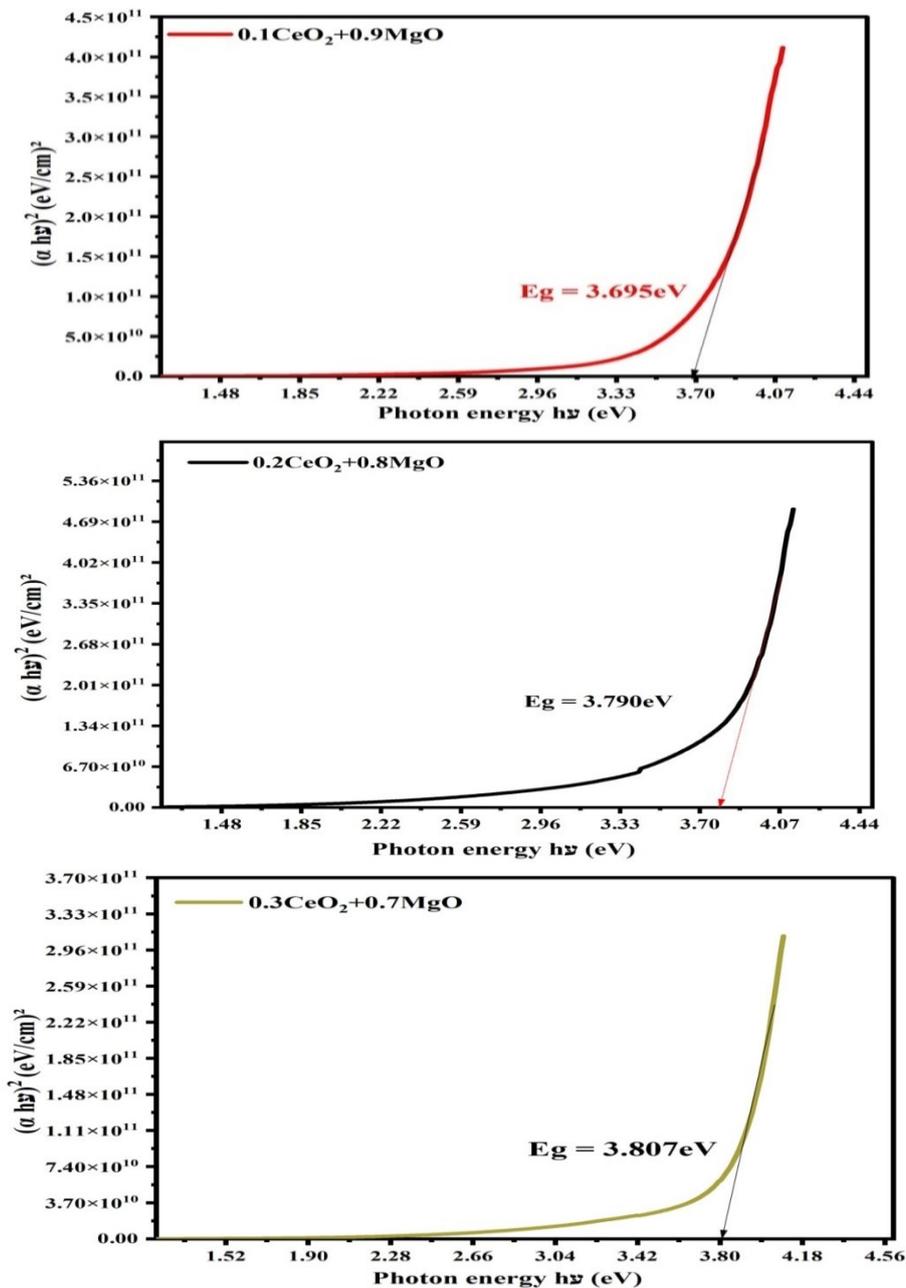


Figure 6. Relationship of energy gap with photon energy for  $(\text{MgO}-\% \text{CeO}_2)$  films after thermal annealing.

## 5. CONCLUSIONS

The final conclusion of the article is the feasibility of applying the deposition method to capsules of the  $(\text{MgO}-\% \text{CeO}_2)$  system using the pulsed laser method, and the possibility of fragmenting its atoms and depositing them on glass substrates in the laboratory. Through X-ray diffraction testing, a new phase was obtained that contributed to improving the optical properties of the material, namely the  $\text{Mg}_2\text{CeO}_3$  phase with a monoclinic crystal system. The results of the optical tests also showed a gradual increase in the energy gap value with each added concentration of nano-cerium oxide up to 0.3%. The transmittance and absorbance results also showed an improvement at the same ideal ratio of 0.3%. Therefore, it is possible to obtain deposited Nano layers with suitable scientific applications in solar cells and gas sensors.

## ACKNOWLEDGEMENTS

I would like to thank all the staff of the Physics Department at Tikrit University.

## REFERENCES

- [1] M. N. Chaudhari, R. B. Ahirrao, and S. D. Bagul, "Thin film deposition methods: a critical review," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 9, no. 6, pp. 5215–5232, 2021.
- [2] E. Nemati, C. Batteate, and M. Jerrett, "Opportunistic environmental sensing with smartphones: a critical review of current literature and applications," *Current Environ. Health Rep.*, vol. 4, pp. 306–318, 2017.
- [3] A. Thakur, A. Kumar, S. Kaya, R. Marzouki, F. Zhang, and L. Guo, "Recent advancements in surface modification, characterization and functionalization for enhancing the biocompatibility and corrosion resistance of biomedical implants," *Coatings*, vol. 12, no. 10, Art. no. 1459, 2022.
- [4] F. J. Haug and C. Ballif, "Light management in thin film silicon solar cells," *Energy Environ. Sci.*, vol. 8, no. 3, pp. 824–837, 2015.
- [5] I. Maitlo, "Optical and Photonic Applications," in *Thin Films and Coatings: Engineering Applications*, Singapore: Springer Nature Singapore, 2025, pp. 123–148.
- [6] J. T. Liberty, A. Anil, S. J. Ijimdiya, M. J. Kwaji, and R. U. Ijimdiya, "Harnessing the potential of nanostructured materials for sustainable development," *Nano-Struct. Nano-Objects*, vol. 38, Art. no. 101216, 2024.
- [7] M. N. Ahmed, N. A. Daham, and S. Y. Darweesh, "Structural and mechanical properties for (Ni-WC) system by using thermal spray," in *AIP Conf. Proc.*, vol. 2885, no. 1, Mar. 2024, Art. no. 020007.
- [8] R. S. Antar, S. Y. Darweesh, and F. W. Ridha, "Production of a double cermet coating to treatment of the turbine blades," *Eng. Res. Express*, vol. 6, no. 1, Art. no. 015407, 2024.
- [9] E. Ahmed, N. J. Hussien, and S. F. M. Yusoff, "Synthesis, characterization, and antibacterial activity of some new metal complexes containing semicarbazide," *Iraqi Journal for Applied Science*, vol. 1, no. 1, pp. 36–49, 2024.
- [10] J. Yu, W. Han, A. A. Suleiman, S. Han, N. Miao, and F. C. C. Ling, "Recent advances on pulsed laser deposition of large-scale thin films," *Small Methods*, vol. 8, no. 7, Art. no. 2301282, 2024.
- [11] H. Y. Jassim and M. A. M. H. Hammadi, "Synthesis, green chemistry method characterization of CuFe<sub>2</sub>O<sub>4</sub> nanocomposite and assessment of its prostate cancer-preventive effects," *Iraqi Journal for Applied Science*, vol. 1, no. 1, pp. 81–87, 2024.
- [12] W. Li et al., "Broadband optical properties of large-area monolayer CVD molybdenum disulfide," *Phys. Rev. B*, vol. 90, no. 19, Art. no. 195434, 2014.
- [13] Y. Matamura, T. Ikenoue, M. Miyake, and T. Hirato, "Mist CVD of vanadium dioxide thin films with excellent thermochromic properties using a water-based precursor solution," *Sol. Energy Mater. Sol. Cells*, vol. 230, Art. no. 111287, 2021.
- [14] V. Sittinger, S. Baron, M. Höfer, M. Armgardt, and T. Harig, "Hot-filament CVD diamond coatings for optical applications," *Surf. Coat. Technol.*, vol. 457, Art. no. 129287, 2023.
- [15] V. Sedov, J. Wei, and V. Ralchenko, "Polycrystalline diamond: recent advances in CVD synthesis and applications," in *Novel Aspects of Diamond II: Science and Technology*, 2024, pp. 101–144.
- [16] N. S. Wilcox et al., "Cardiovascular disease and cancer: shared risk factors and mechanisms," *Nat. Rev. Cardiol.*, vol. 21, no. 9, pp. 617–631, 2024.
- [17] H. Zhang et al., "Measuring the refractive index of highly crystalline monolayer MoS<sub>2</sub> with high confidence," *Sci. Rep.*, vol. 5, Art. no. 8440, 2015.
- [18] L. Jia et al., "Synthesis of 2-inch hexanary medium-entropy alloy monolayer via chemical vapor deposition with superior photoelectric properties," *Adv. Funct. Mater.*, vol. 35, no. 22, Art. no. 2418423, 2025.
- [19] V. M. Pradeepa, K. Kesavan, S. Sarathkumar, and B. Mohanavel, "Coating temperature in CVD technique effects the CZTS thin film characteristics," in *AIP Conf. Proc.*, vol. 2901, no. 1, Dec. 2023, Art. no. 020007.
- [20] S. Mou, J. Ye, R. Zhu, L. Liu, and Y. Li, "Effect of the buffer layers on the performance of Fe(Se,Te) films fabricated on IBAD metal templates by pulsed laser deposition," *J. Supercond. Nov. Magn.*, vol. 36, no. 3, pp. 793–802, 2023.
- [21] N. Kamarulzaman and N. Badar, "Pulsed laser deposition of MgO thin films," *Adv. Mater. Res.*, vol. 545, pp. 38–42, 2012.
- [22] R. A. Ismail, A. M. Mousa, and S. S. Shaker, "Pulsed laser deposition of nanostructured MgO film: effect of laser fluence on the structural and optical properties," *Mater. Res. Express*, vol. 6, no. 7, Art. no. 075007, 2019.
- [23] G. Balakrishnan et al., "Microstructure, optical and dielectric properties of cerium oxide thin films prepared by pulsed laser deposition," *J. Mater. Sci. Mater. Electron.*, vol. 30, pp. 16548–16553, 2019.
- [24] S. H. Humeedi, S. M. Abdulkareem, and S. Y. Darweesh, "The synthetic and mechanical properties of a silica matrix cermet composite," *J. Wuhan Univ. Technol.–Mater. Sci. Ed.*, vol. 37, no. 3, pp. 423–428, 2022.
- [25] A. M. Ibraheem, S. M. A. Allah, and S. Y. Darweesh, "Enhancement the properties of aluminum by adding boron carbide by the powder method," in *J. Phys.: Conf. Ser.*, vol. 1999, no. 1, Art. no. 012074, 2021.
- [26] B. Tatar et al., "Synthesis and optical properties of CeO<sub>2</sub> nanocrystalline films grown by pulsed electron beam deposition," *J. Mater. Sci.*, vol. 43, no. 15, pp. 5102–5108, 2008.
- [27] S. A. Abdulrahman, R. A. Ismail, and M. F. Jawad, "Advancements and challenges in pulsed laser-deposited hydrophobic CeO<sub>2</sub> film for broadband antireflection applications," *J. Opt.*, vol. 53, no. 3, pp. 2745–2756, 2024.
- [28] M. Wang et al., "Controllable fabrication of a super broadband antireflection film: Gd: MgO nanoparticles composite film by pulsed laser deposition method," *Vacuum*, vol. 190, Art. no. 110310, 2021.
- [29] A. S. Karim, Z. N. Majeed, and S. Y. Darweesh, "The effect of nanostructured zirconia reinforcement on the mechanical and structural properties of a copper-based system," in *Mater. Sci. Forum*, vol. 1039, pp. 297–306, Aug. 2021.
- [30] F. T. Ibrahim, "Pulsed-laser deposition of magnesium oxide thin films doped with copper oxide for gas sensing applications," *Iraqi J. Sci. Ind. Res.*, vol. 3, no. 1, 2024.
- [31] N. A. Ghazal, Z. N. Majeed, and S. Y. Darweesh, "The effect of adding different percentages manganese on some mechanical and magnetic properties of composite (Al-Cu)," in *AIP Conf. Proc.*, vol. 2885, no. 1, Mar. 2024, Art. no. 020001.
- [32] C. Mitra et al., "Growth of epitaxial and polycrystalline thin films of the electron doped system La<sub>1-x</sub>Ce<sub>x</sub>MnO<sub>3</sub> through pulsed laser deposition," *J. Appl. Phys.*, vol. 89, no. 1, pp. 524–530, 2001.

- [33] E. J. Salih, S. M. A. Allah, and S. Y. Darweesh, "Study the structural and mechanical properties of the Cu-WC composite," in AIP Conf. Proc., vol. 2398, no. 1, Oct. 2022, Art. no. 020009.
- [34] W. A. Aelawi, S. Alptekin, and M. H. Al-Timimi, "Structural, optical, and electrical properties of nanocrystalline CdS<sub>1-x</sub>CuS<sub>x</sub> thin films," Indian J. Phys., vol. 97, no. 13, pp. 3949–3956, 2023.
- [35] A. T. Shihatha, A. M. Ghelab, and R. A. Munfi, "Theoretical study of electronic structure and optical properties for ZnO thin film," in AIP Conf. Proc., vol. 2398, no. 1, Oct. 2022, Art. no. 020011.
- [36] A. A. Al-Bayati and H. F. Al-Taay, "Enhance the efficiency of ZnO/SnO<sub>2</sub> nanocomposite gas sensor using pulsed laser deposition," J. Opt., pp. 1–11, 2025.
- [37] R. T. Shbeeb and F. A. H. Mutlak, "Silicon photodetectors enhanced by metal oxide semiconductor (MOS) and developed using PLD technique," J. Opt., pp. 1–15, 2025.

## BIOGRAPHIES OF AUTHORS

	<p>Assistant Lecturer Yaqouta Dawood Sulaiman is a lecturer at the Iraqi Ministry of Education, Tikrit, Iraq. She holds a BS in Physics from Tikrit University and an MS in Physics from Tikrit University, Iraq. She is specialized in solid state physics. Her research areas include thin films and gas sensors. She has published numerous scientific papers in local and international conferences and journals. To contact her, please email: <a href="mailto:vd230081pep@st.tu.edu.iq">vd230081pep@st.tu.edu.iq</a>.</p>
	<p>Dr. Niran Fadhil Abduljabbar is a professor at the College of Education for Pure Sciences, Tikrit University, Iraq. He holds a BSc. in Physics from Tikrit University and an MSc. in Physics from Tikrit University, Iraq. He holds a PhD in Physics, specializing in Solid State Physics. His research areas include thin films and gas sensors. He has published numerous scientific papers in local and international conferences and journals. To contact him, please email: <a href="mailto:niran.fadhil64@tu.edu.iq">niran.fadhil64@tu.edu.iq</a>.</p>