

Role of Cr-Zn in Structural, Optical, Electrical and Magnetic Properties of CdO Nanoparticles Synthesized by Hydrothermal Method

Emratul Jannat Swapna

Jahangirnagar University

Taskira Islam Hoimontee

Saga University

Sanjida Khanom Bonna

Jahangirnagar University

Md. Golam Sayed

University of Dhaka

M. Rokonzaman Ripon

Bangladesh University of Engineering and Technology

Md. Tachadduk Saber

Jahangirnagar University

M.K. Alam

Bangladesh University of Engineering and Technology

Jahirul Islam Khandaker Khandaker

jahir-nanophysics@juniv.edu

Jahangirnagar University

Article

Keywords: Hydrothermal method, X-ray diffraction, UV, FTIR, PPMS-VSM, Dielectric loss, EDX

Posted Date: July 23rd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10306725/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Role of Cr-Zn in Structural, Optical, Electrical and Magnetic Properties of CdO Nanoparticles Synthesized by Hydrothermal Method.

Emratul Jannat Swapna^a, Taskira Islam Hoimontee^b, Sanjida khanom Bonna^a, Md. Golam Sayed^c, M. Rokonzaman Ripon^d, Md. Tachadduk Saber^a, M.K. Alam^d, Jahirul Islam Khandaker^{a*}

^a, Department of Physics, Jahangirnagar University, Dhaka-1342, Bangladesh

^b, Graduate School of Science and Engineering, Saga University, Saga 840-8502, Japan

^cDepartment of Physics, University of Dhaka, Dhaka -1000, Bangladesh

^d, Department of Physics, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

Corresponding author: jahir-nanophysics@juniv.edu

Abstract: CdO nanoparticle and chromium–Zinc codoped CdO nanoparticles were synthesized by Hydrothermal method with a calcination temperature of 400°C and various analytical techniques were employed to examine their physical, optical and magnetic and electric properties. The X-ray diffraction (XRD) pattern of CdO NPs indicate the cubical structure, with a prominent peak is observed at (111) plane. The Debye-Scherer method has been used to calculate average crystallite size and strain. The lowest crystallite size 27.86 nm was found for Cr doping. UV–visible spectroscopy (300–900 nm) was prepared CdO NPs. From the absorbance curve, it was observed that the absorbance increases gradually up to a certain corresponding wavelength at around 265 nm, followed by an exponential decrease at higher wavelengths and the highest band gap was 5.57 eV, which was found for increasing of Cr doping. Fourier transform infrared spectroscopy (FTIR) verifies the existence of Cd–O and O–C–O vibrations in the sample. Both pure and Cr/Zn-doped CdO nanoparticles revealed the ferromagnetic behaviour by vibrating sample magnetometer (PPMS-VSM) wherein the increasing doping percentage of Cr ($Cd_{0.90}Zn_{0.025}Cr_{0.075}O$) enhanced the ferromagnetic characteristics. The tangent loss ($\tan\delta$) displayed a sharp decline followed by a minor increase in the samples with zinc concentration $x=0.1$.

Keywords: Hydrothermal method, X-ray diffraction, UV, FTIR, PPMS-VSM, Dielectric loss, EDX.

1. Introduction

Cadmium oxide is regarded as a transparent conducting oxide (TCOs). It is an n-type semiconductor in the transition group II–IV, exhibiting a direct bandgap ranging from 2.2 to 2.7 eV at room temperature [1]. Its electrical resistivity is minimal, falling from 10^{-2} to 10^{-4} Ω -cm, and its electrical conductivity is uplifted because to oxygen vacancies and cadmium interstitial. Moreover, among several metal oxide, CdO nanostructures have a lot of attention due to their affordability, chemical stability, and non-toxicity [2]. They possess a significant linear refractive index value, enhanced electrical conductivity, substantial carrier concentration, and upgraded transparency in the visible portion of the electromagnetic spectrum [1]. Cadmium oxide nanoparticles have attracted a lot of attention in recent years and are still being considered for use in a number of possible applications, including gas sensors, optoelectronics, solar cell fabrication, phototransistors, and photodiode applications.

However, the application of CdO is limited by the decrease in photoactivity by the fast recombination of photo-induced electron and hole pairs [3]. But, CdO with metal ions may alter its characteristics including band gap value, its surface and optical characteristics and can increase its antibacterial effectiveness[4]. Due to its favourable electrical characteristics, ease of doping, abundance in nature, and strong chemical stability doping these days researchers are paying close attention to cadmium oxide. By adding metal ions to the CdO host at specific concentrations, the optical, electrical, magnetical characteristics of the CdO nanoparticles may be adjusted.

To enhance the optical properties of the pure CdO crystal, a number of studies have been documented on Zn, Ba, and anion doped CdO nanostructures that modify its crystalline structure [5]. Various transition/rare earth metals, like as indium (In), tin (Sn), aluminium (Al), copper (Cu), fluorine (F), zinc (Zn), magnesium (Mg), iron (Fe), lanthanum (La), cerium (Ce), gadolinium (Gd), and many more, can be doped into cadmium oxide to alter its optical and electrical characteristics [6]. According to the literature review, if the dopant's ionic radii are at least as high as those of Cd^{2+} , the optical characteristics of cadmium oxide can be improved. It has been discovered that the ionic radii of the transition metal zinc are 0.074 nm and Chromium are 0.061 nm which are only slightly smaller than those of cadmium, which are 0.095 nm. The electrical and optical features of cadmium oxide are improved because chromium and zinc's tiny ionic radii allow it to easily penetrate through the crystal lattice structure [6]. It is therefore possible that Cr doping could result in certain encouraging physical characteristics of CdO nanostructures. Based on past

research on doping CdO nanostructures, Cr may improve the electrical conductivity. Furthermore, it could potentially raise the optical band gap of CdO metal oxides. Based on the theory, doping with Cr ions, which share the same coordination number as Cd^{2+} (CN = 6), and has a ionic radii of 0.0615 nm can similarly enhance the conduction properties [7], [8],[9]. In addition, because (Zn) zinc's ionic radii are short, they can readily penetrate the crystal lattice arrangements of cadmium oxide, improving the metal's electrical and optical characteristics. Due to their inability to readily penetrate the host CdO crystal lattice structure, higher radii ions doping causes in structural defects to rise and crystallite size to decrease [6].

CdO can be synthesized by various method, Co-precipitation method [10], Hydrothermal method[11], Sol-Gel method[12], Solvothermal method[13], Green synthesis method[14], Sono-chemical method[1] etc. However, the majority of current techniques struggle to economically and environmentally generate CdO nanoparticles on a big scale: Using cadmium metal as the raw ingredients, the manufacturing processes were hazardous or complex, or even the final goods were unclean [15]. But a microwave-assisted Hydrothermal process that is effective for the controlled fabrication of nanostructures. Additionally, it offers more benefits than other methods like melt mixing, laser ablation, electric arc deposition, and ion implantation, comprising a substantially greater surface area, controllable particle size, low temperature technique, narrow particle size distribution, high purity, and cost-effectiveness.

In the current investigation the surface area, pore size, morphology, crystal arrangement, optical, electrical and surface properties of the produced Cr-Zn Co doped CdO NPs using Hydrothermal approach were characterized using different analysis techniques including X-ray diffraction (XRD) and Fourier Transform Infrared Spectroscopy measurements (FTIR), Ultra- violet ray Spectroscopy (UV), Dielectric measurements by Impedance Analyzer, EDX assures the existence of elements, whereas the magnetic properties were tasted using a vibrating sample magnetometer (VSM) at room temperature.

2. Materials and methods

2.1 Materials

Chemicals: Commercially available, analytical-grade precursors, high-purity, including $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$, $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$, and ZnCl_2 were used. In addition, solutions of pH 4, pH 7, and pH 10, ethanol, acetone, and sodium hydroxide (NaOH) were used in the experiments.

2.2 Preparation method of $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$

At first in a beaker 2.36 g of $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ was added 50 ml of distilled water to make solution A. In another beaker 0.8 g of NaOH was added to a mixture of 50 ml of distilled water and 50 ml of ethanol to make solution B. Following that, solution A and solution B were combined dropwise while being continuously stirred. By the help of magnetic stirrer, the two solutions were mixed properly. By controlling the heat treatment of magnetic stirrer during the operation, after approximately one or a half hour a white milky solution was produced.

The resulting mixture was moved to a Teflon beaker and stainless-steel autoclave and eventually placed in an oven for hydrothermal process at 150°C for 22 h. The obtained precipitate was collected, washed several times with deionized water, and dried at 100°C for 12 h. Finally, the product was kept in thermal calcination at 400°C for 6 h to prepare the crystalline $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$ nanoparticles. To prepare 4gm Cr/Zn co-doped CdO, the precursor's solutions having some percentage of $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ and ZnCl_2 in place of $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ respectively in distilled water. The synthesized materials consisted of pure CdO (CD-1) and five Zn/Cr co-doped variants with compositions $\text{Cd}_{0.90}\text{Zn}_{0.10}\text{Cr}_{0.0}\text{O}$ (CD-2), $\text{Cd}_{0.90}\text{Zn}_{0.0}\text{Cr}_{0.10}\text{O}$ (CD-3), $\text{Cd}_{0.90}\text{Zn}_{0.025}\text{Cr}_{0.075}\text{O}$ (CD-4), $\text{Cd}_{0.90}\text{Zn}_{0.05}\text{Cr}_{0.05}\text{O}$ (CD-5), and $\text{Cd}_{0.90}\text{Zn}_{0.075}\text{Cr}_{0.025}\text{O}$ (CD-6), maintaining a constant cadmium content while changing the zinc-to-chromium ratio.

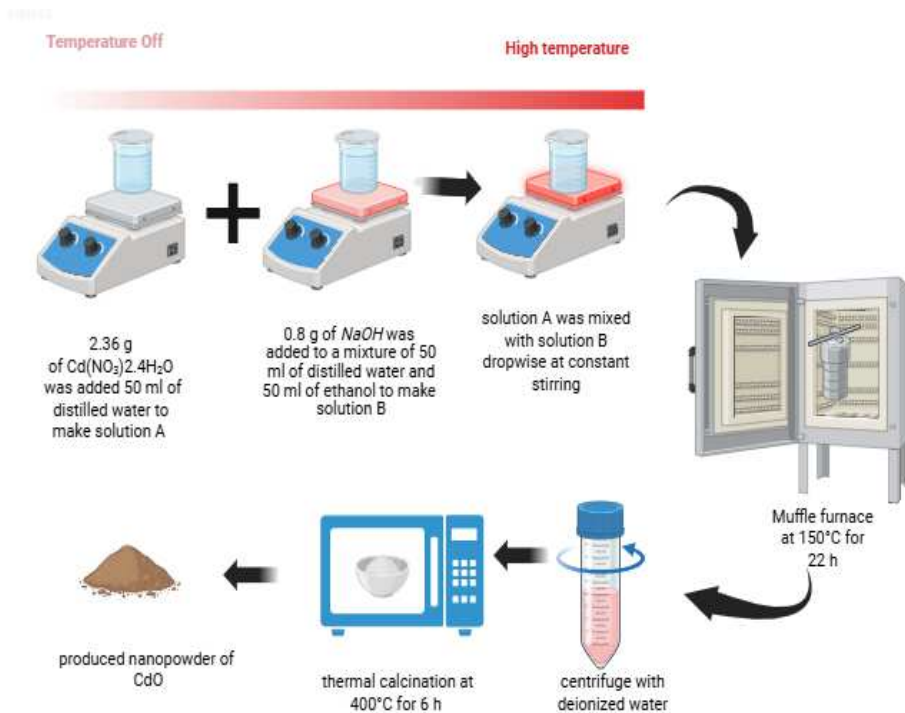


Figure 1: Diagrammatic representation of the Cr, Zn co-doped CdO production process.

3. Results and discussion

3.1 X-ray diffraction analysis of $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$

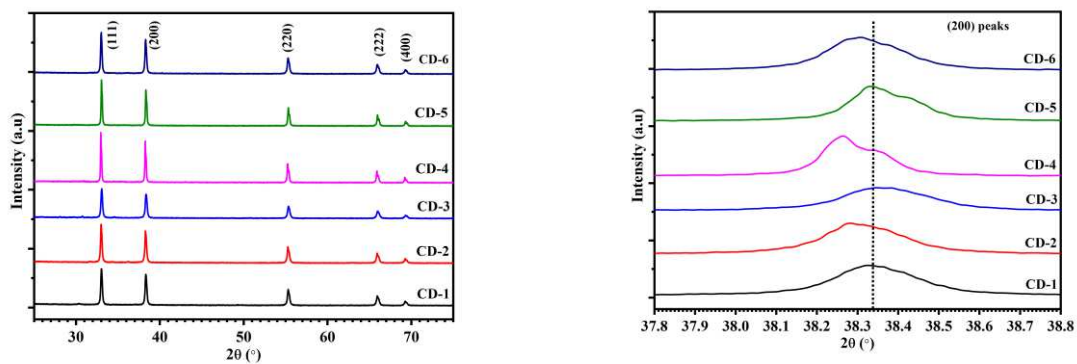


Figure 1: XRD patterns of synthesized $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$.

Error! Reference source not found.:

Shows the variation in different parameters as a function of dopant

The X-ray diffraction method was used to study the desired sample's structure and morphology. Figure 2 shows the XRD patterns of the synthesized $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$. It shows that the diffracted

peaks located at $2\theta = 33.02^\circ$, 38.38° , 55.36° , 65.90° and 69.26° are linked to the plans of the miller (111), (200), (220), (222), and (400) respectively, which are consistent with (JCPD Card No; 96-900-6674, cubic symmetry Fm-3 m) [16]. The prepared samples are all cubic in shape and feature an orientation plane (111). XRD patterns of as-grown CdO and Cr/Zn co-doped CdO NPs show that Cr/Zn ions are effectively substituted or incorporated into the CdO host lattice when there is no additional peak caused by impurity or dopant oxide. This also verifies that Zn or Cr ions have no effect on the lattice structure of cadmium oxide [16], [6]. X-ray diffraction patterns revealed distinctive peak shifts due to doping. For better understanding, we examined the (200) diffraction peak in details, as illustrated in 3. The pristine CdO exhibited a characteristic (200) peak at 38.34° . The position of the (2 0 0) peak in Cr-doped CdO is somewhat higher than in pure CdO as seen in Figure 3. This change could result from Cr ions occupying the Cd sites [17], [18]. When the sample was fully doped with Zn, the peak shifted to the left side. However, when the sample was double doped with Cr-Zn, then there were two peaks at the (hkl) value (200). This phenomenon provides compelling evidence for successful co-doping of both Zn and Cr into the CdO crystal structure. Table 1 summarizes the key structural parameters derived from XRD analysis, including lattice parameters, crystallite size, x-ray density, bulk density, and porosity [19] for all synthesized samples calculated using equations from the literature [20]. The Debye-Scherer method was used to determine the average crystallite size of CdO nanoparticles based on their position, incoming radiation, and Full Wave Half Maximum (FWHM). There is a correlation between average crystallite grain size and When

$$D = k \lambda / \beta \cos \theta \dots (1)$$

where λ is proportional to the wavelength of the (CuK α) radiation, k is the particle form factor (0.94), θ is the Braggs diffraction angle, and the full width at half maximum of the pattern peaks is given in radians ($\lambda = 1.5405 \text{ \AA}$) [21].

Table 1: Several parameters of $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$ nanoparticles.

Samples	Lattice parameters	Crystal size D	x-ray density	bulk density,	Porosity
	a=c		ρ_x	ρ_b	
	Å		gm/cc	gm/cc	
CD-1	5.1018	31.57	12.84408	0.897	93.01624
CD-2	4.69763	43.05	15.85009	0.7231	95.43788
CD-3	5.02895	27.86	12.7752	1.066	91.65571
CD-4	4.69486	59.24	15.74528	0.976	93.80132
CD-5	4.6921	52.64	15.81753	0.939	94.06355
CD-6	4.69763	36.43	15.80589	0.8641	94.53305

The corresponding raw XRD data are provided as **Supplementary Data S1**

3.2 Fourier-transform infrared spectroscopy (FTIR) analysis of $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$

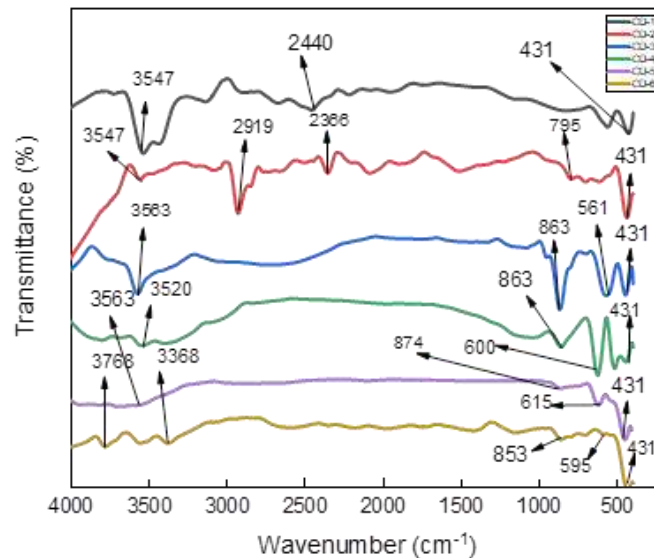


Figure 4: FTIR spectra of the synthesized $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$.

Fourier Transform Infrared (FTIR) Spectroscopy study of pure CdO and $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$ nanoparticles was performed to study the compositional characteristics of $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$ in the frequency range of $400\text{--}4000\text{ cm}^{-1}$ are shown in Figure 4. The pure CdO sample (CD-1) exhibits characteristic absorption bands at 431 cm^{-1} , 2440 cm^{-1} , and 3547 cm^{-1} . Here, observed vibrational bands for (431 cm^{-1}) are characteristic of Cd-O stretching vibrations, [22] C-H bending,[23] and hydroxyl (-OH) stretching modes[24] respectively. After Zn doping (CD-2), the characteristic band at 431 cm^{-1} corresponding to the Cd-O stretching vibration, a new band at 795 cm^{-1} was observed that can be assigned to Zn-O stretching vibrations [25], [26]. Similarly, the Cr-doped sample (CD-3) exhibits a distinctive band at 561 cm^{-1} attributed to Cr-O vibrations [27], along with bands at 863 cm^{-1} (C-H) and 3563 cm^{-1} (-OH). CD-4 displays bands at 431 cm^{-1} (Cd-O), 600 cm^{-1} (Cr-O), 863 cm^{-1} (Zn-O), and 3520 cm^{-1} (-OH). CD-5 shows bands at 431 cm^{-1} (Cd-O), 651 cm^{-1} (Cr-O), 874 cm^{-1} (Zn-O), and 3563 cm^{-1} (-OH). CD-6 exhibits bands at 431 cm^{-1} (Cd-O), 595 cm^{-1} (Cr-O), 853 cm^{-1} (Zn-O), and hydroxyl bands at 3368 cm^{-1} and 3768 cm^{-1} . The metal-oxygen stretching of CdO is responsible for the distinctive bands in the $400\text{--}700\text{ cm}^{-1}$ range [22].

Table 2: The functional group of Cr-Zn co-doped CdO

Wavenumber cm^{-1}	Functional Groups and Vibrational Modes					
	CD-1	CD-2	CD-3	CD-4	CD-5	CD-6
~ 431	(Cd-O) stretching	(Cd-O) stretching	(Cd-O) stretching	(Cd-O) stretching	(Cd-O) stretching	(Cd-O) stretching
500-650			(Cr-O) bending	(Cr-O) bending	(Cr-O) bending	(Cr-O) bending
700-890		(Zn-O) bending	(Zn-O) bending	(Zn-O) bending	(Zn-O) bending	(Zn-O) bending
2000-3000	(C-H)	(C-H)	(C-H)	(C-H)	(C-H)	(C-H)
3000-4000	(-OH)	(-OH)	(-OH)	(-OH)	(-OH)	(-OH)

The corresponding raw XRD data are provided as **Supplementary Data S2**

3.3 UV–Vis spectral analysis

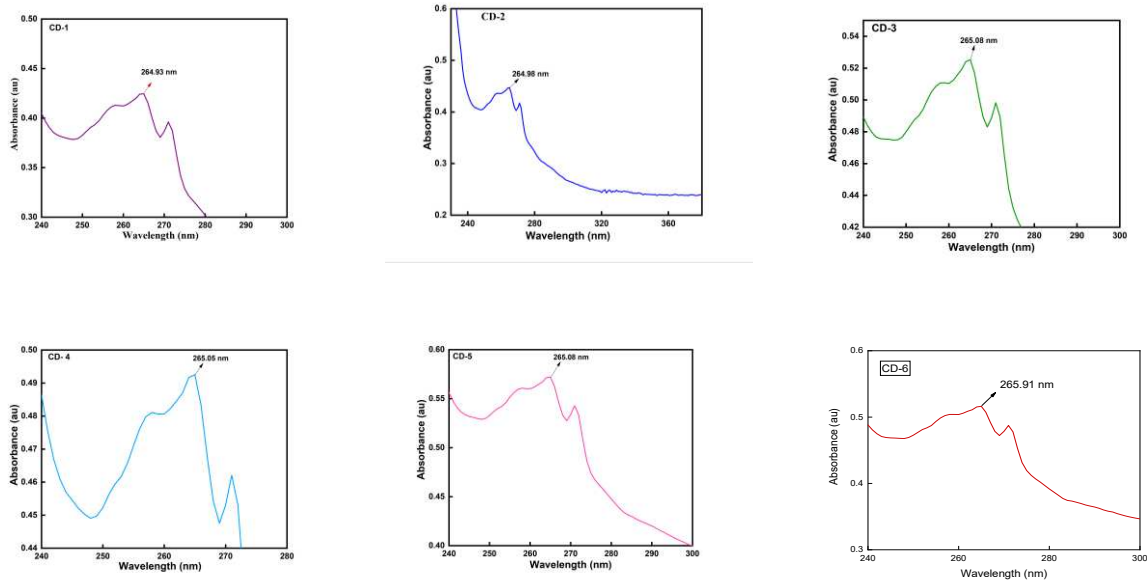


Figure 5: UV–Vis absorption spectra of the synthesized $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$.

The optical properties of generated CdO nanoparticles have been examined using UV-Vis spectroscopy. The UV–Vis absorption spectra of pure CdO and Zn/Cr co-doped CdO are shown in Figure 5. From the spectra, the absorption peaks were observed at 264.93 nm, 264.98 nm, 265.08 nm, 265.05 nm, 265.08 nm, and 265.98 nm for CD-1, CD-2, CD-3, CD-4, CD-5, and CD-6 respectively. This suggests that as Zn concentration rises, the band gap energy decreases. The observed absorption peaks positions show good agreement with previously reported values in the literature [28], confirming the expected optical behaviour of the synthesized materials. From the absorbance curve, it is observed that the absorbance increases gradually up to a certain corresponding wavelength at around 265 nm, followed by an exponential decrease at higher wavelengths. These properties ensure us the absorbance of CdO nanostructured particles, which show some wonderful optical properties. The Tauc relation can be used to determine the optical band gap (E_g) by utilizing the relationship between the optical absorption coefficient (α) and the incident photon energy ($h\nu$).

$$(\alpha h\nu)^2 = A (h\nu - E_g)$$

Where, A is a constant and n is the exponential coefficient dependent on the nature of the transition. Figure 6 shows the Tauc's plot (plot of $(\alpha h\nu)^2$ vs. $h\nu$) for pure CdO and Zn/Cr co-doped CdO. The Tauc's plot was used to calculate the samples' optical bandgap value by extending the linear part

of the curves to the energy axis [29]. The obtained bandgap values were around 5.58 eV, 5.36 eV, 5.57 eV, 5.42 eV, and 5.50 eV for sample CD-1, CD-2, CD-3, CD-4, CD-5, and CD-6 respectively. The band gap measurement of the samples indicates that when the doping percentage of Zn increases the band gap decreases. Strong quantum confinements and an increase in their surface area to volume ratio are the causes of the band gap decrease [30],[31], while increasing Cr doping concentration leads to bandgap widening due to Burstein-Moss effect [32].

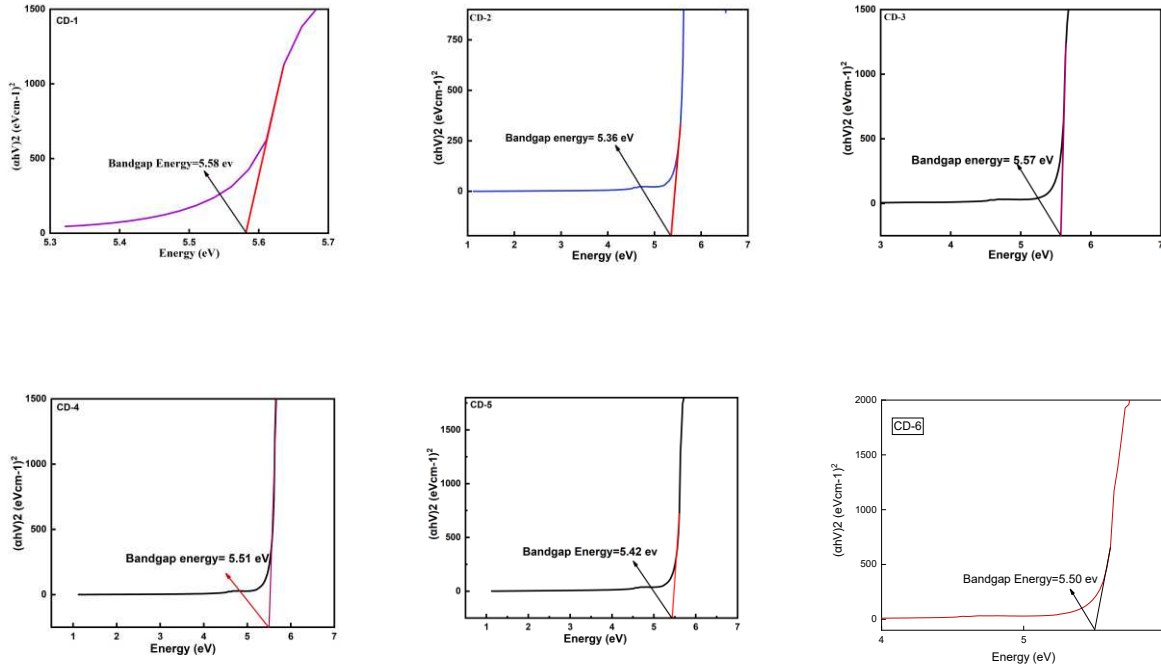


Figure 6: Tauc plots of $\text{Cd}_{1-X-Y}\text{Zn}_X\text{Cr}_Y\text{O}$ nanoparticles for the estimation of optical band gap energy.

Table 3: The Band-gap Energy of Cr-Zn co-doped CdO

Sample name	Absorbance	Band-gap Energy
	(nm)	(eV)
CD-1	264.93	5.58
CD-2	264.98	5.36
CD-3	265.08	5.57
CD-4	265.05	5.51

CD-5	265.08	5.42
CD-6	265.91	5.50

The corresponding raw XRD data are provided as **Supplementary Data S3**

3.4 Magnetic Properties (VSM Analysis)

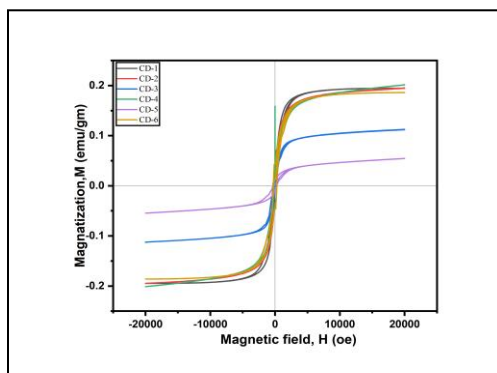


Figure 7 : M-H hysteresis loop of (a) CdO (b) $\text{Cd}_{0.90}\text{Zn}_{0.10}\text{Cr}_{0.0}\text{O}$ (CD-2) (c) $\text{Cd}_{0.90}\text{Zn}_{0.0}\text{Cr}_{0.10}\text{O}$ (CD-3), (d) $\text{Cd}_{0.90}\text{Zn}_{0.025}\text{Cr}_{0.075}\text{O}$ (CD-4) (e) $\text{Cd}_{0.90}\text{Zn}_{0.05}\text{Cr}_{0.05}\text{O}$ (CD-5) and (f) $\text{Cd}_{0.90}\text{Zn}_{0.075}\text{Cr}_{0.025}\text{O}$ (CD-6).

Table 4: Saturation magnetization (M_s), remnant magnetization (M_r), coercivity (H_c) and $\text{SQR} = (M_r/M_s)$ of $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$ nanoparticles.

Sample s	Coercivity y	Saturation Magnetization	Remanent Magnetization	Anisotropy constant,	Squareness
	H_c	$M_s \times 10^{-3}$	$M_r \times 10^{-3}$	$K_a = (M_s \cdot H_c)/2$	M_r/M_s
	(Oe)	(emu/gm)	(emu/gm)		
CD-1	6.6025	195.324	32.433	0.6447	0.1658
CD-2	4.3057	195.322	48.344	0.4206	0.2477
CD-3	7.2083	111.332	8.625	0.4011	0.0768
CD-4	5.5848	200.124	20.338	0.5587	0.1042
CD-5	4.3289	54.756	12.324	0.1185	0.2274
CD-6	1.854	184.623	43.542	0.1711	0.2340

The corresponding raw XRD data are provided as **Supplementary Data S4**

Figure 7 depicts the M-H loops of $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$ NPs. The magnetic parameters such as saturation magnetization (M_s), remanence magnetization (M_r), and coercivity (H_c) of all samples determined by the M-H loops for CD-1, CD-2, CD-3, CD-4, CD-5, and CD-6 are listed in Table 3. The undoped sample (CD-1) exhibits hysteresis with coercivity of 6.6025 Oe and retentivity of $32.433 (\times 10^{-3} \text{emu/g})$ and saturation magnetization of $195.324 (\times 10^{-3} \text{emu/g})$. This provides proof of modest ferromagnetism even though bulk CdO exhibits diamagnetic activity at ambient temperature[33], This can result from the exchange interaction between the oxygen vacancies' localized spin moments [34]. The spontaneous magnetization M_s of the $\text{Cd}_{1-x-y}\text{Zn}_x\text{Cr}_y\text{O}$ nanoparticles is 195.324 for (CD-1), 195.322 for (CD-2), 111.332 for (CD-3), 200.124 for (CD-4), 54.756 for (CD-5), $184.623 (\times 10^{-3} \text{emu/g})$ for (CD-6), respectively. The coercivity H_c is approximately 6.6025 for (CD-1), 4.3057 for (CD-2), 7.2083 for (CD-3), 5.5848 for (CD-4), 4.3289 for (CD-5), 1.854 for (CD-6) Oe. Higher Cr doping has been discovered to boost the ferromagnetic ordering in CdO. Because of the antiferromagnetic coupling between adjacent Cd-Cr and Cr-Cr ions, Cr co-doping reduced the saturation magnetization of the Cr-doped CdO.

The antiferromagnetic ordering of Zn-substituted and Cr-substituted equally nanoparticles is linked to the exchange interactions between Cd ions and O ions [35]. Higher Zn-ion concentrations may therefore have produced a localized antiferromagnetic interaction between the ions, hence decreasing the samples' net magnetization. Additionally, the decrease in magnetization values may have possibly been caused by Zn^{2+} ions replacing Cd^{2+} ions at octahedral locations.[36]

The ratio of remanent magnetization (M_r) to saturation magnetization (M_s) is used to determine the squareness ratio (SQR), which is a measure of the square of the hysteresis loop of pure and doped CdO. The obtained SQR values of $\text{Cd}_{0.90}\text{Zn}_{0.0}\text{Cr}_{0.10}\text{O}$ (CD-3) and $\text{Cd}_{0.90}\text{Zn}_{0.025}\text{Cr}_{0.075}\text{O}$ (CD-4) are 0.0768 and 0.1042 respectively. Its low SQR value and low remanent magnetization make it suitable for use in data storage applications, particularly in read-only and random access memory [37]. They has the characteristics needed for recording media, as well as being utilized as cathode materials in batteries and soft magnetic materials in transformers [38]. For every sample, the computed squareness ratio $\text{SQR}=(M_r/M_s)$ is less than 0.5, indicating the uniaxial magnetic anisotropy caused by internal strains [39]. And SQR values of $\text{Cd}_{0.90}\text{Zn}_{0.10}\text{Cr}_{0.0}\text{O}$ (CD-2) is 0.2477, which is highest.

3.5 Electric Properties

The materials' electrical characteristics are impacted by the presence of oxygen vacancies and mixed valence states. Thus, we investigated the prepared samples' dielectric characteristics. Figure 8 displays the room-temperature dielectric patterns of $\text{Cd}_{1-X-Y}\text{Zn}_X\text{Cr}_Y\text{O}$ nanoparticles.

3.5.1 Dielectric constant:

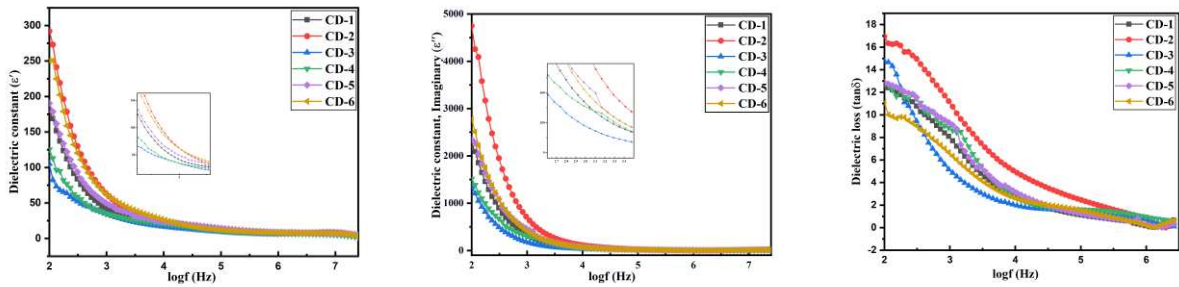


Figure 8 : The room-temperature dielectric patterns of (a) CdO (b) $\text{Cd}_{0.90}\text{Zn}_{0.10}\text{Cr}_{0.00}\text{O}$ (CD-2) (c) $\text{Cd}_{0.90}\text{Zn}_{0.00}\text{Cr}_{0.10}\text{O}$ (CD-3), (d) $\text{Cd}_{0.90}\text{Zn}_{0.025}\text{Cr}_{0.075}\text{O}$ (CD-4) (e) $\text{Cd}_{0.90}\text{Zn}_{0.05}\text{Cr}_{0.05}\text{O}$ (CD-5) and (f) $\text{Cd}_{0.90}\text{Zn}_{0.075}\text{Cr}_{0.025}\text{O}$ (CD-6).

The corresponding raw XRD data are provided as **Supplementary Data S5**.

The dielectric constant is a complicated physical quantity, with ϵ' as the real portion and ϵ'' as the imaginary part ($\epsilon^* = \epsilon' + \epsilon''$). When placed in a fluctuating electric field, the nanoparticles' stored energy is indicated by the real part, while their wasted energy is indicated by the imaginary part. The dispersion at lower frequencies is indicated by the dielectric constant (ϵ'). The dominance of grain borders, as opposed to grains, can be linked to the dielectric dispersion. Koop's theory states that conducting grains are separated by poorly conducting grain borders to form a polycrystalline nanomaterial. [40] Free charges caused by defects (oxygen vacancies) build at the resistive grain borders and travel freely within the grains when exposed to an electric field. This leads to strong interfacial polarization, which in turn causes a high dielectric constant at lower frequencies. At higher frequencies, these polarizations gradually disappear because these charges trail the applied electric field. Higher frequencies result in a constant dielectric constant due to this loss of polarization. [41] According to Table 4, the dielectric constant varies with average grain size Zn-doping and Cr-doping to the CdO lattice. Because the average particle size and the dielectric

constant are directly correlated. However, a thicker grain boundary can be the cause of the decreasing dielectric constant [40]. For both pure and (Zn, Cr) doped CdO samples, the $\epsilon''(f)$ exhibits a peak value at a moderate frequency, and remains nearly a constant at higher frequency. The dielectric constant is found to rise with increasing Cr content. Cr-doping increases defects such vacancies and interstitials as well as the density of free charge carriers. Dielectric constants rise as the density of charge carriers (free charge carriers and vacancies) within the grains increases[42].

3.5.2 Dielectric loss:

Dielectric loss ($\tan\delta$) computations reveal significant loss at lower frequencies (Figure 8). It results from the presence of resistive grain boundaries, which cause high energy to be needed for carrier transport [40]. Nevertheless, dielectric loss is frequency independent at higher frequencies because the electron exchange interaction (hopping) between Cd^{2+} , Cr^{2+} , and Zn^{2+} ions lags behind the alternating applied electric field beyond a certain frequency while the polarization stays constant [43]. Low dielectric constant and dielectric loss are caused by high porosity and low density[44]. At larger Zn contents, dielectric loss may be reduced because impurity phases have good electric insulation.[40]. Because the governing parameters are comparable, the dielectric losses imitate the fluctuation of the dielectric constant with Zn concentration. Nevertheless, in the samples with zinc content $x=0.1$, the loss tangent ($\tan\delta$) showed a sudden fall followed by a little increase (Figure 8). This shows that because of the samples' uneven microstructure, the lag between dipoles and the applied field changed as frequency rose[36]. $\tan\delta$ rises as Cr-doping concentrations rise from $Y=0.025$ to 0.1 . It is a good material for high frequency applications because of its low dielectric constant and dielectric loss at high frequencies.

3.6 EXD Analysis:

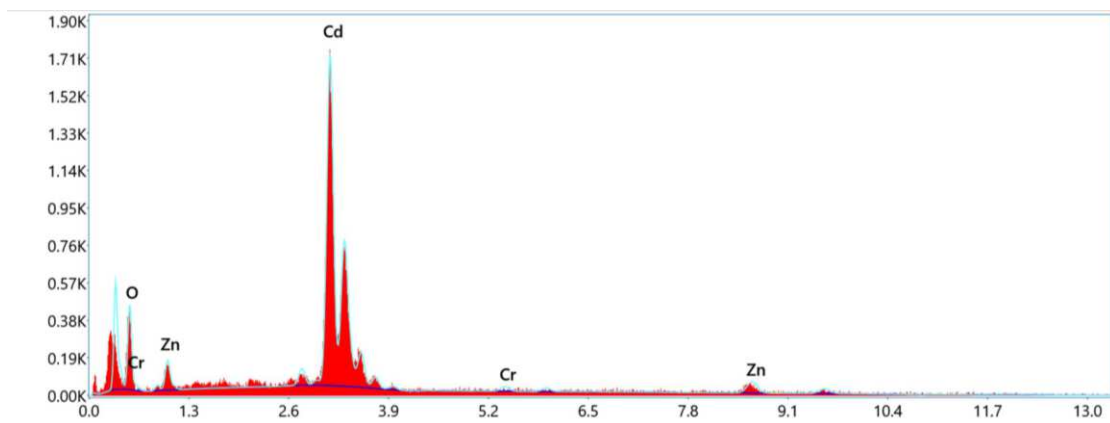


Figure 8: EDX spectra of CdO sample (CD-2)

Table 5: EDX quantitative elemental ratio of CdO sample (CD-2)

Element	Weight%	Atomic %	Net Int.	Error%	R	A	F
O	26.71	70.35	49.72	13.08	0.7746	0.0647	1.0000
Cr	1.06	0.86	6.10	29.39	0.8661	0.8194	1.0448
Zn	6.35	4.09	18.33	12.20	0.9049	0.9479	1.1243
Cd	65.88	24.70	347.24	4.28	0.8395	0.8137	1.0049

4. Conclusion

In this study, Cr-Zn co-doped Cadmium Oxide NPs were synthesized through a simple and cost-effective hydrothermal method. XRD analysis confirmed that the CdO nanoparticles possessed a cubic crystal structure, with crystallite sizes ranging from 27.86 nm to 59.24 nm. The cadmium and hydroxyl functional groups in CdO nanoparticles integrated at several peaks frequency ranges of 400–4000 cm^{-1} are what the title nanoparticles disclosed using Fourier Transform Infrared Spectroscopy. The presence of Cd–O bands at 431 cm^{-1} , Zn–O bands at 795 cm^{-1} , Cr–O vibrations at 863 cm^{-1} and O–C–O band at 1541.72 cm^{-1} , hydroxyl bands at 3368 cm^{-1} and 3768 cm^{-1} has been confirmed by FTIR. From the absorbance curve, it is observed that the absorbance increases gradually up to a certain corresponding wavelength at around 265 nm, followed by an exponential decrease at higher wavelengths. The band gap ranged from 5.36 to 5.57 eV. Strong quantum confinements cause the band gap to narrow as the Zn doping percentage rises, whereas the Burstein-Moss effect causes the bandgap to widen as the concentration of Cr doping rises. The M–H loops were used to determine all samples' magnetic properties, including saturation magnetization (Ms), remanence magnetization (Mr), and coercivity (Hc). The undoped sample (CD-1) exhibits a modest ferromagnetism even though bulk CdO exhibits diamagnetic activity at ambient temperature. The $\epsilon''(f)$ shows a peak value at a modest frequency and stays almost constant at higher frequencies for both pure and (Zn, Cr) doped CdO samples. The dielectric constant is

found to rise with increasing Cr content. For the samples with zinc concentration $x=0.1$, the loss tangent ($\tan\delta$) showed a sudden fall followed by a minor increase. From $Y=0.025$ to 0.1 , $\tan\delta$ increases as Cr-doping concentrations rise.

Credit Authorship and contribution statement:

Jahirul Islam Khandaker- Writing, review and editing, **Sanjida khanom Bonna**- Review and editing, **M. Rokonozzaman**- Writing, Review and editing, **Md. Golam Sayed**- Writing, review and editing, **Md. Tachadduk Saber**- Review and editing, **M.K. Alam**- Writing, review and editing, **Taskira Islam Hoimontee**- Writing, methodology, review and editing. **Emratul Jannat Swapna**- Writing, review and editing, Writing-original draft, Methodology, Investigation, Formal analysis, data collection and curation.

Funding

This research did not receive any specific grant from fundings agencies in the public, commercial or non-profit sectors.

Data Availability

All data generated or analysed during this current study are included in the published article and its supplementary information files.

Declaration of competing interest

The authors declare that they have no known competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

Acknowledgement

This work was performed with the assistance of Department of Physics and Wazed Miah Science Research Centre (WMSRC), Jahangirnagar University, Bangladesh. The authors are also thankful to the Materials Science Division, Atomic Energy Centre, Dhaka, Bangladesh. and Bio-inspired Nanomaterials Research Lab, Department of Physics, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh.

References

- [1] M. Abbas, W. Tawfik, and J. Chen, "CdO nanorods and Cd (OH) 2 /Ag core/satellite nanorods: rapid and efficient sonochemical synthesis, characterization and their magnetic properties," *Ultrason. Sonochem.*, vol. 40, pp. 577–582, 2018.
- [2] M. Muraleedharan, H. Singh, S. Suresh, and M. Udayakumar, "Directly absorbing Therminol-Al 2 O 3 nano heat transfer fluid for linear solar concentrating collectors," *Sol. Energy*, vol. 137, pp. 134–142, Nov. 2016, doi: 10.1016/j.solener.2016.08.007.
- [3] R. K. Mandal, P. Saha, and T. P. Majumder, "Structural, optical characterization of the synthesized Fe doped CdO Nano particles, its application as a promising photocatalyst for degradation of the hazardous Methyl violet dye," *Optik*, vol. 246, p. 167795, Nov. 2021, doi: 10.1016/j.ijleo.2021.167795.
- [4] B. Şahin, "Physical properties of nanostructured CdO films from alkaline baths containing saccharin as additive," *Sci. World J.*, vol. 2013, 2013, doi: 10.1155/2013/172052.
- [5] P. Kumar *et al.*, "Optical and surface properties of Zn doped CdO nanorods and antimicrobial applications," *Colloids Surf. Physicochem. Eng. Asp.*, vol. 605, p. 125369, Nov. 2020, doi: 10.1016/j.colsurfa.2020.125369.
- [6] R. Kumari and V. Kumar, "Impact of zinc doping on structural, optical, and electrical properties of CdO films prepared by sol–gel screen printing mechanism," *J. Sol-Gel Sci. Technol.*, vol. 94, no. 3, pp. 648–657, Jun. 2020, doi: 10.1007/s10971-019-05202-0.
- [7] D. İskenderoğlu, H. Güney, and M. E. Güldüren, "Chromium – An effective dopant for engineering the structural and the optical properties of CdO nanostructures grown by SILAR method," *Opt. Mater.*, vol. 115, p. 111067, May 2021, doi: 10.1016/j.optmat.2021.111067.
- [8] N. M. Moussa, F. M. Ebrahim, K. Adly, and M. Y. Hassaan, "Chromium doped ZnO nanoparticles for energy storage, gas and humidity sensing and spin based electronic devices applications," *Opt. Quantum Electron.*, vol. 54, no. 11, p. 683, Sep. 2022, doi: 10.1007/s11082-022-04075-y.
- [9] A. Ahad, J. Podder, T. Saha, and H. N. Das, "Effect of chromium doping on the band gap tuning of titanium dioxide thin films for solar cell applications," *Heliyon*, vol. 10, no. 1, Jan. 2024, doi: 10.1016/j.heliyon.2023.e23096.
- [10] R. Ranjithkumar, A. A. Irudayaraj, G. Jayakumar, A. D. Raj, S. Karthick, and R. Vinayagamorthy, "Synthesis and properties of CdO and Fe doped CdO nanoparticles," *Mater. Today Proc.*, vol. 3, no. 6, pp. 1378–1382, 2016.
- [11] A. K. Barve, S. M. Gadegone, M. R. Lanjewar, and R. B. Lanjewar, "Synthesis and characterization of CdO nanomaterial and their photocatalytic activity," *Int. J. Recent Innov. Trends Comput. Commun.*, vol. 2, no. 9, pp. 2806–2810, 2014.
- [12] S. Sönmezoğlu, T. A. Termeli, S. Akin, and İ. Askeroğlu, "Synthesis and characterization of tellurium-doped CdO nanoparticles thin films by sol–gel method," *J. Sol-Gel Sci. Technol.*, vol. 67, pp. 97–104, 2013.
- [13] K. Kaviyarasu, E. Manikandan, P. Paulraj, S. B. Mohamed, and J. Kennedy, "One dimensional well-aligned CdO nanocrystal by solvothermal method," *J. Alloys Compd.*, vol. 593, pp. 67–70, 2014.
- [14] A. Z. Skheel, M. H. Jaduaa, and A. N. Abd, "Green synthesis of cadmium oxide

nanoparticles for biomedical applications (antibacterial, and anticancer activities),” *Mater. Today Proc.*, vol. 45, pp. 5793–5799, 2021.

[15] Y. Liu, Y. C. Zhang, and M. Zhang, “Green hydrothermal synthesis and characterization of CdO₂ nanoparticles,” *Mater. Lett.*, vol. 64, no. 16, pp. 1779–1781, Aug. 2010, doi: 10.1016/j.matlet.2010.05.047.

[16] T. Munawar *et al.*, “Facile synthesis of Cr-Co co-doped CdO nanowires for photocatalytic, antimicrobial, and supercapacitor applications,” *J. Alloys Compd.*, vol. 885, p. 160885, Dec. 2021, doi: 10.1016/j.jallcom.2021.160885.

[17] Z. Zhang, L. Han, G. Xie, Q. Liao, B. Zhong, and Y. Yu, “Room-temperature ferromagnetic and optical properties of Cr-doped CdS nanoparticles via a solvothermal preparation,” *J. Mater. Sci. Mater. Electron.*, vol. 27, no. 12, pp. 12940–12946, Dec. 2016, doi: 10.1007/s10854-016-5432-2.

[18] Z. Zhang, L. Han, G. Xie, Q. Liao, B. Zhong, and Y. Yu, “Room-temperature ferromagnetic and optical properties of Cr-doped CdS nanoparticles via a solvothermal preparation,” *J. Mater. Sci. Mater. Electron.*, vol. 27, no. 12, pp. 12940–12946, Dec. 2016, doi: 10.1007/s10854-016-5432-2.

[19] R. M. El-Sharkawy, E. A. Allam, A. El-Taher, E. R. Shaaban, and M. E. Mahmoud, “Synergistic effect of nano-bentonite and nanocadmium oxide doping concentrations on assembly, characterization, and enhanced GAMMA-RAYS shielding properties of polypropylene ternary nanocomposites,” *Int. J. Energy Res.*, vol. 45, no. 6, pp. 8942–8959, May 2021, doi: 10.1002/er.6427.

[20] T. Munawar, F. Iqbal, S. Yasmeen, K. Mahmood, and A. Hussain, “Multi metal oxide NiO-CdO-ZnO nanocomposite—synthesis, structural, optical, electrical properties and enhanced sunlight driven photocatalytic activity,” *Ceram. Int.*, vol. 46, no. 2, pp. 2421–2437, Feb. 2020, doi: 10.1016/j.ceramint.2019.09.236.

[21] PG and Research Department of Physics, Thiru. A. Govindasamy Govt. Arts College, Tindivanam - 604 307, Tamil Nadu, India *et al.*, “Synthesis, structural, morphological, functional, optical and particle size enhanced cadmium oxide nanoparticles on electro-chemical applications,” *Dig. J. Nanomater. Biostructures*, vol. 18, no. 1, pp. 83–92, Jan. 2023, doi: 10.15251/DJNB.2023.181.83.

[22] S. Sivakumar, A. Venkatesan, P. Soundhirarajan, and C. P. Khatiwada, “Synthesis, characterizations and anti-bacterial activities of pure and Ag doped CdO nanoparticles by chemical precipitation method,” *Spectrochim. Acta. A. Mol. Biomol. Spectrosc.*, vol. 136, pp. 1751–1759, Feb. 2015, doi: 10.1016/j.saa.2014.10.078.

[23] K. Kaviyarasu, E. Manikandan, P. Paulraj, S. B. Mohamed, and J. Kennedy, “One dimensional well-aligned CdO nanocrystal by solvothermal method,” *J. Alloys Compd.*, vol. 593, pp. 67–70, Apr. 2014, doi: 10.1016/j.jallcom.2014.01.071.

[24] R. K. Mandal, M. D. Purkayastha, and T. Pal Majumder, “Silver modified cadmium oxide – A novel material for enhanced photodegradation of malachite green,” *Optik*, vol. 180, pp. 174–182, Feb. 2019, doi: 10.1016/j.ijleo.2018.11.066.

[25] A. T. Ravichandran, A. Robert Xavier, K. Pushpanathan, B. M. Nagabhushana, and R. Chandramohan, “Structural and optical properties of Zn doped CdO nanoparticles synthesized by chemical precipitation method,” *J. Mater. Sci. Mater. Electron.*, vol. 27, no. 3, pp. 2693–2700, Mar. 2016, doi: 10.1007/s10854-015-4079-8.

[26] V. K. Gupta, A. Fakhri, S. Tahami, and S. Agarwal, “Zn doped CdO nanoparticles: Structural, morphological, optical, photocatalytic and anti-bacterial properties,” *J. Colloid Interface Sci.*, vol. 504, pp. 164–170, Oct. 2017, doi: 10.1016/j.jcis.2017.05.026.

- [27] T. Aswani *et al.*, “Synthesis and spectral characterizations of trivalent ions (Cr³⁺, Fe³⁺) doped CdO nanopowders,” *Spectrochim. Acta. A. Mol. Biomol. Spectrosc.*, vol. 121, pp. 544–550, Mar. 2014, doi: 10.1016/j.saa.2013.11.018.
- [28] A. Khalaf, M. Matar, and W. Abdeen, “Tunable Band Gap and Antiferromagnetic Ordering in Co-doped CdO Nanostructures,” *J. Supercond. Nov. Magn.*, vol. 34, no. 11, pp. 2911–2921, Nov. 2021, doi: 10.1007/s10948-021-05973-0.
- [29] J. Al Boukhari, L. Zeidan, A. Khalaf, and R. Awad, “Synthesis, characterization, optical and magnetic properties of pure and Mn, Fe and Zn doped NiO nanoparticles,” *Chem. Phys.*, vol. 516, pp. 116–124, Jan. 2019, doi: 10.1016/j.chemphys.2018.07.046.
- [30] V. K. Gupta, A. Fakhri, S. Tahami, and S. Agarwal, “Zn doped CdO nanoparticles: Structural, morphological, optical, photocatalytic and anti-bacterial properties,” *J. Colloid Interface Sci.*, vol. 504, pp. 164–170, Oct. 2017, doi: 10.1016/j.jcis.2017.05.026.
- [31] S. George *et al.*, “Role of Fe Doping in Tuning the Band Gap of TiO₂ for the Photo-Oxidation-Induced Cytotoxicity Paradigm,” *J. Am. Chem. Soc.*, vol. 133, no. 29, pp. 11270–11278, Jul. 2011, doi: 10.1021/ja202836s.
- [32] B. Hymavathi, B. R. Kumar, and T. S. Rao, “Structural, Surface Morphological and Optical Properties of Cr Doped CdO Thin Films for Optoelectronic Devices,” *Mater. Today Proc.*, vol. 2, no. 4–5, pp. 1510–1517, 2015, doi: 10.1016/j.matpr.2015.07.077.
- [33] R. Chandiramouli and B. G. Jeyaprakash, “Review of CdO thin films,” *Solid State Sci.*, vol. 16, pp. 102–110, Feb. 2013, doi: 10.1016/j.solidstatesciences.2012.10.017.
- [34] A. Sundaresan, R. Bhargavi, N. Rangarajan, U. Siddesh, and C. N. R. Rao, “Ferromagnetism as a universal feature of nanoparticles of the otherwise nonmagnetic oxides,” *Phys. Rev. B*, vol. 74, no. 16, p. 161306, Oct. 2006, doi: 10.1103/PhysRevB.74.161306.
- [35] Leelavati, R. Kumar, and R. Kumar, “Origin of Ferromagnetism in Cd_{1-x}Mn_xO Nanoparticles,” *J. Supercond. Nov. Magn.*, vol. 35, no. 10, pp. 2851–2858, Oct. 2022, doi: 10.1007/s10948-022-06324-3.
- [36] “Zn doped nano.14-7-25.”
- [37] “Magnetic And Transport Properties Of Conducting polyaniline/nickel Oxide Nanocomposites,” *Adv. Mater. Lett.*, vol. 4, no. 2, pp. 134–140, Feb. 2013, doi: 10.5185/amlett.2012.5348.
- [38] T. Noorunnisha *et al.*, “(Zn + Co) co-doped CdO thin films with improved figure of merit values and ferromagnetic orderings with low squareness ratio well suited for optoelectronic devices and soft magnetic materials applications,” *Appl. Phys. A*, vol. 126, no. 10, p. 762, Oct. 2020, doi: 10.1007/s00339-020-03954-z.
- [39] N. Boudar, B. Mehdaoui, and A. Aatiq, “Structural and Magnetic Properties of the New SrLa₂FeCuSbO₉ Perovskite Phase,” *J. Supercond. Nov. Magn.*, vol. 33, no. 9, pp. 2829–2836, Sep. 2020, doi: 10.1007/s10948-020-05538-7.
- [40] “An approach for correlating the structural and electrical properties of Zr⁴⁺-modified SrBi₄Ti₄O₁₅/SBT ceramic - RSC Advances (RSC Publishing).” Accessed: Mar. 07, 2025. [Online]. Available: <https://pubs.rsc.org/en/content/articlelanding/2017/ra/c7ra00366h>
- [41] S. Suresh, “Studies on the dielectric properties of CdS nanoparticles,” *Appl. Nanosci.*, vol. 4, no. 3, pp. 325–329, Mar. 2014, doi: 10.1007/s13204-013-0209-x.
- [42] “Cr doped nano.14-7-25.”
- [43] S. Kurien, J. Mathew, S. Sebastian, S. N. Potty, and K. C. George, “Dielectric behavior and ac electrical conductivity of nanocrystalline nickel aluminate,” *Mater. Chem. Phys.*, vol. 98, no. 2, pp. 470–476, Aug. 2006, doi: 10.1016/j.matchemphys.2005.08.080.
- [44] “Electrical and magnetic properties of Ni_{0.8}Zn_{0.2}Fe₂O₄/silica composite prepared by

sol-gel method | Journal of Materials Science.” Accessed: Jul. 16, 2025. [Online]. Available: <https://link.springer.com/article/10.1023/B:JMSC.0000017766.07079.80>

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryMaterials.zip.zip](#)