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REGULAR ARTICLE

Investigation of Cadmium Oxide Nanoparticles Under the Attenuation of Acoustic Shockwaves

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Nanomaterials have gained significant attention due to their size-dependent physical and chemical properties, which differ markedly from bulk materials. Their high surface-to-volume ratio enables control over particle size, morphology, and surface characteristics, enhancing performance in applications such as optoelectronics, photovoltaics, catalysis, energy storage, and biomedicine. Among them, transition metal oxide nanoparticles are particularly important due to their chemical stability, tunable band structure, and versatile properties. Although cadmium oxide (CdO) nanoparticles have been widely studied for synthesis and basic characterization, their behavior under acoustic shockwave loading remains insufficiently explored. Existing literature lacks a systematic understanding of structural and optical modifications induced by shockwaves and their underlying mechanisms. This study addresses these gaps by investigating the synthesis, structural, and optical properties of CdO nanoparticles subjected to acoustic shockwave loading. The work includes synthesis methodology, shockwave treatment, and characterization using PXRD for crystal structure, photoluminescence for optical properties, and SEM for morphology and particle size distribution, providing insight into shock-induced modifications.

Keywords: Cadmium Oxide Nanoparticles, Acoustic Shockwave Attenuation, Nanomaterial Synthesis, Powder X-ray Diffraction, Photoluminescence Analysis, Scanning Electron Microscopy.

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1. INTRODUCTION

Nanomaterials have attracted attention due to size-dependent physical and chemical properties distinct from bulk materials. Their tunable size, morphology, and surface characteristics enable applications in optoelectronics, photovoltaics, catalysis, energy storage, and biomedicine. Transition metal oxide nanomaterials are particularly studied for their chemical stability and tunable band structures [1]. Cadmium oxide (CdO), an II-VI semiconductor with a cubic rock-salt structure, exhibits n-type conductivity [2]. Its properties are governed by intrinsic defects such as oxygen vacancies and cadmium interstitials, resulting in high carrier concentration. CdO typically shows a direct band gap of ~2.2 eV, with high conductivity and optical transparency. Its optical and electronic properties depend on crystallite size, lattice strain, and defect states, which can be tuned via synthesis conditions [3]. CdO nanostructures are widely used in gas sensors, solar cells, phototransistors, transparent conducting oxides, and supercapacitors due to high surface area and improved charge transport [4, 5]. Among synthesis methods, co-precipitation is simple and cost-effective [6]. Studying nanomaterials under shockwave loading is crucial, as extreme conditions can induce structural changes or stability depending on material properties [7]. Therefore, investigating the response of CdO nanomaterials under shockwave conditions is critical for evaluating their structural stability and potential applicability in high-energy environments. The present work focuses on the synthesis of CdO nanoparticles via a simple chemical co-precipitation method followed by structural and optical characterization. Furthermore, the effect of dynamic shockwave exposure on the structural stability and physical properties of CdO nanoparticles is systematically investigated to understand their behavior under extreme conditions.

2. MATERIALS AND METHODS

2.1 Synthesis and Acoustic Shockwave Treatment of CdO Nanoparticles

CdO nanoparticles were synthesized via a co-precipitation method using cadmium nitrate tetrahydrate and deionized water at ~ 25 °C. Aqueous ammonia was added to achieve a pH of ~ 8, leading to the formation of cadmium hydroxide precipitate, which was then centrifuged, washed, and dried. The nanoparticles underwent acoustic shockwave treatment in a semi-automated Reddy shock tube, using Mach 1.5 shockwaves produced by compressed air [8]. Three samples were tested: one control and two subjected to 200 and 400 shock pulses.

2.2 Structural, Optical, Morphological, and Elemental Characterization

The synthesized control and shock-treated CdO nanoparticles were comprehensively characterized using PXRD, UV–Visible spectroscopy, photoluminescence (PL), scanning electron microscopy (SEM), and energy dispersive X-ray analysis (EDAX). The crystallographic structure and phase purity were examined using PXRD (Bruker D8 Advance, CuKα

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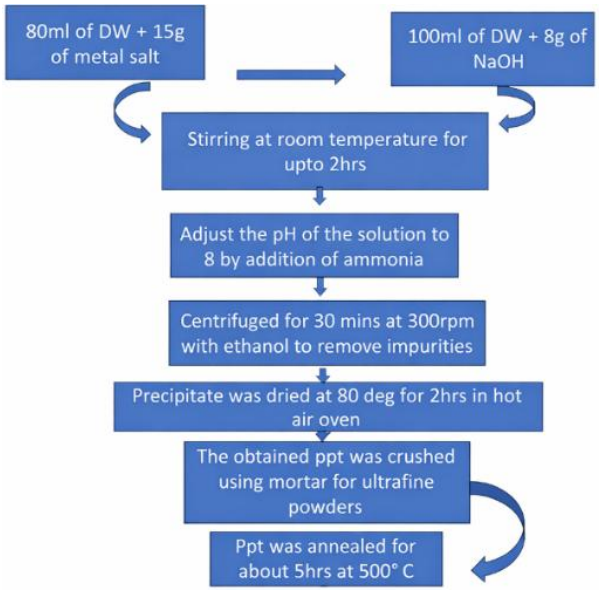

Fig. 1 – Synthesis of CdO

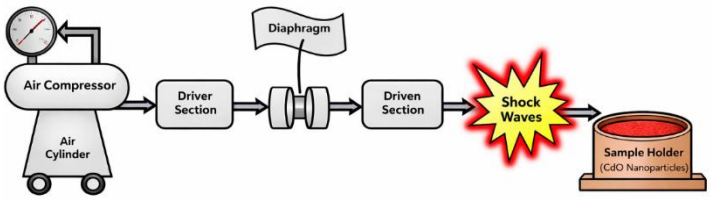

Fig. 2 – Schematic representation of semi-automated shock tube

radiation, $\lambda = 1.5406$ Å) operated at 40 kV and 40 mA over a 2θ range of 20°-80°. The diffraction peaks corresponding to the (111), (200), (220), (221), (311), (400), and (420) planes matched well with standard JCPDS data (78-1125), confirming a face-centered cubic (*fcc*) structure with high crystallinity and phase purity. No secondary phases were observed in either control or shock-treated samples (50-200 pulses), indicating structural stability under shock loading, although slight peak variations suggested changes in crystallite size, strain, or defect density. Optical properties were investigated using UV-Visible spectroscopy in the 200-800 nm range. The CdO powders were dispersed in a solvent, ultrasonicated, and analyzed using a quartz cuvette. The optical band gap (E_g) was determined using the Tauc relation:

$$(\alpha h\nu)_n = A(h\nu - E_g)$$

where α is the absorption coefficient, $h\nu$ is the photon energy, E_g is the optical band gap, A is a constant, and n depends on the nature of the electronic transition. For direct allowed transitions, the value of $n = 2$ was considered.

Band gap values were determined from $(\alpha h\nu)^2$ vs. $h\nu$ plots, with variations in absorption edge attributed to structural changes, defect states, and possible quantum confinement. Photoluminescence (PL) analysis using a Shimadzu RF-6000 revealed both band-edge and defect-related emissions, with shifts indicating changes in defect density and recombination behavior. SEM (TESCAN VEGA 3) showed particle distribution, agglomeration, and shock-induced morphological changes. EDAX confirmed Cd and O as primary elements, validating purity and stoichiometry, with minor peaks due to instrumental artifacts. Overall, CdO nanoparticles maintain structural integrity while exhibiting tunable optical and morphological properties under shock treatment.

3. RESULTS AND DISCUSSION

3.1 Structural Stability of CdO Nanoparticles (PXRD Analysis)

PXRD patterns confirm that both control and shock-treated CdO nanoparticles retain characteristic peaks of a face-centered cubic (*fcc*) structure, corresponding to the (111), (200), and (220) planes. This indicates preservation of the fundamental crystal framework without phase transformation or structural degradation after acoustic shock-wave exposure. Similar observations have been reported, where CdO maintained dominant FCC peaks with slight intensity variations due to lattice strain and defect formation [9]. Absence of secondary phase peaks were detected, confirming phase purity under shock conditions. A slight shift in diffraction peaks toward higher 2θ values was observed in shock-treated samples, suggesting lattice contraction caused by compressive stress and induced microstrain, leading to reduced interplanar spacing [10]. Crystallite size decreased from 58.1 nm (control) to ~ 53.9 nm (200 pulses), indicating defect generation and fragmentation of crystalline domains. This trend agrees with earlier reports linking external stimuli to size reduction via strain accumulation and structural rearrangement [11]. Overall, CdO nanoparticles demonstrated high structural stability with minor microstructural modifications under shock loading.

Table 1 – PXRD parameters of unshocked and shocked CdO NPs

No of shock pulses	Average crystallite size (nm)	Microstrain	*d*-spacing (Å)
0 shock	58.1nm	2.07	1.9581
50 shock	57.9 nm	1.99	1.9578
100 shock	56.9nm	1.85	1.9565
150 shock	54.0 nm	1.76	1.9559
200 shock	53.9 nm	1.69	1.9511

Previous static compression studies indicated that CdO in the B1 phase remains stable up to ~ 84.4 GPa, with transition to the B2 phase initiating near 90.06 GPa and completing around 102.5 GPa [12]. Since the shock pressures applied in this study are much lower, the absence of any phase transition aligns with the expected structural stability of cubic CdO. However, shock and static compression differ fundamentally and need to be compared cautiously. The crystallite size, estimated using the Debye-Scherrer equation, decreased from 58.1 nm (control) to 53.9 nm (200 shocks), suggesting shock-induced defects, microstrain, and fragmentation of crystalline domains.

The GIXRD (Grazing Incidence X-Ray Diffraction) pattern of the CdO deposit shows characteristic reflections con-

sistent with cubic CdO, confirming phase retention after deposition. However, the peaks are broader, less intense, and accompanied by a diffuse background hump (20°-40°),

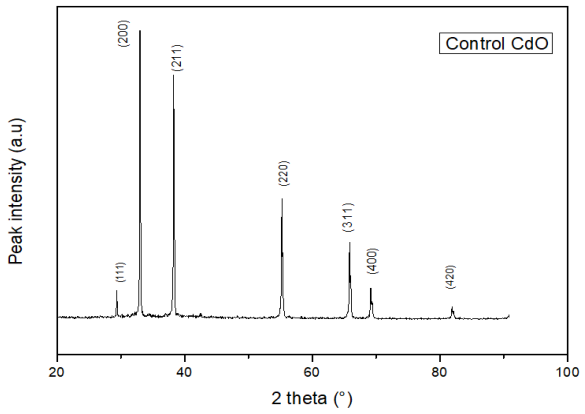

Fig. 3 – PXRD pattern of control CdO NPs

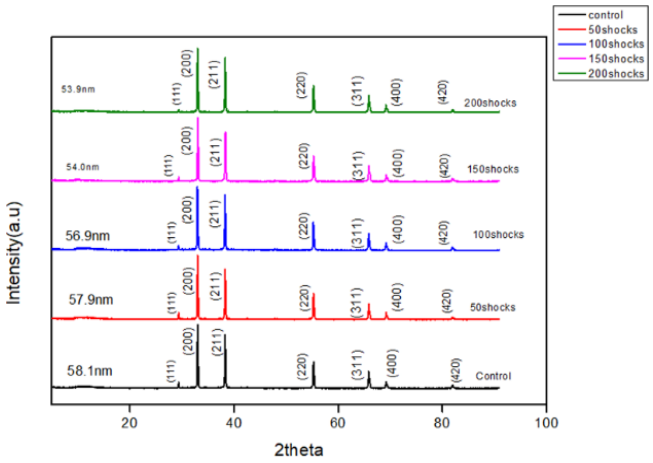

Fig. 4 – PXRD of control and shocked CdO NPs

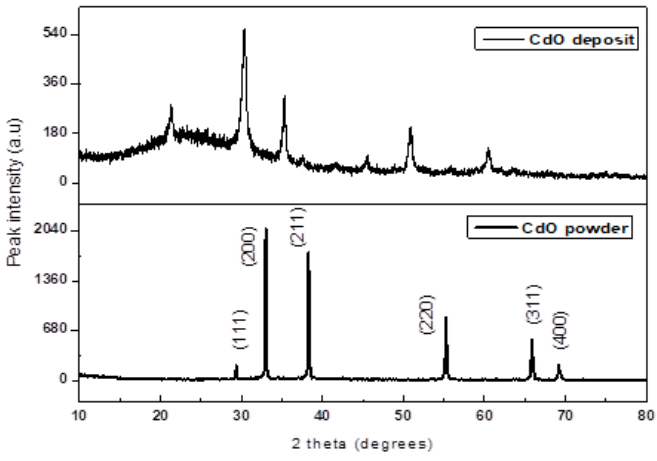

Fig. 5 – XRD of CdO powder and deposit

typical of electrophoretically deposited thin films. The grazing-incidence mode enhances surface sensitivity while revealing the nanocrystalline and partially disordered nature of the film. Similar trends, including peak broadening and reduced intensity due to small crystallite size and low density, have been reported [13]. The results suggest smaller crystallites, lattice strain, and possible surface roughness or residual porosity in the deposited layer.

3.2 UV-Vis Analysis

UV-Visible spectra showed an absorption edge near 240 nm for both control and shock-treated CdO nanoparticles, indicating band-to-band transitions. The control sample exhibits a band gap of ~ 3.22 eV, slightly higher than bulk CdO, likely due to nanoscale effects and defects. With increasing shock pulses, the band gap decreases marginally to ~ 3.16 eV [14], suggesting lattice strain, defect redistribution, or minor structural distortions. Similar band gap variations have been reported in semiconductor nanomaterials under mechanical or high-pressure conditions.

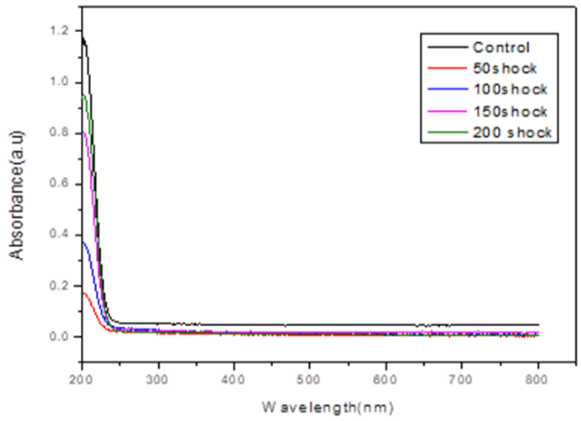

Fig. 6 – UV-Vis absorption spectra of control and shock-treated CdO NPs

Band gap energy was calculated using the following relation,

$$E_g = \frac{hc}{\lambda} = \frac{1240}{240} = 3.22eV$$

$$E_g = 3.22 \text{ eV}$$

For an absorption edge at 240 nm, the control CdO shows a band gap of ~ 3.22 eV, while shock-treated samples exhibit slight variations (3.20-3.16 eV for 50-200 pulses). These changes may arise from lattice strain and defect states. The values align with reported nanocrystalline CdO, suggesting potential optoelectronic applicability [15].

3.3 Photoluminescence Studies

The photoluminescence spectra of control and shock-treated CdO nanoparticles showed emission peaks at ~ 320, 360, 420, and 460 nm. UV emissions arose from near-band-edge (excited) recombination, while visible emissions are

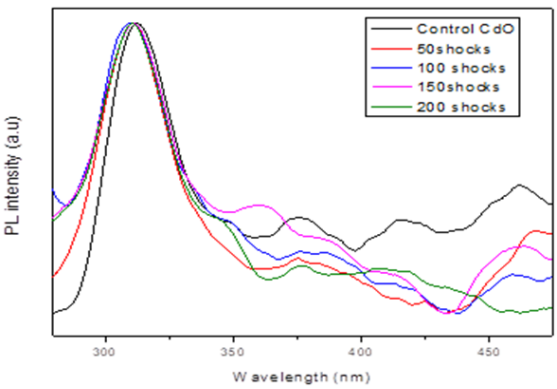

Fig. 7 – PL spectrum of control and shock-treated CdO NPs

linked to non-excited states such as oxygen vacancies and interstitials [16]. A blue shift is observed, attributed to quantum confinement in nanocrystalline CdO. The blue emission results from band-to-band transitions between Cd-3d and O-2p states, along with defect-assisted recombination. Overall, the emission behavior is governed by both intrinsic electronic transitions and defect-mediated processes, influencing peak intensity and position [17].

3.4 Scanning Electron Microscopy

SEM analysis revealed clear morphological differences between control and shock-treated CdO samples. The unshocked sample showed a porous, loosely aggregated structure, while shocked samples exhibited denser packing due to shock-induced compressive stresses, leading to particle rearrangement and reduced voids. Similar densification and agglomeration under external energy inputs have been reported. Partial fragmentation of larger agglomerates into smaller particles was observed, indicating weakening of interparticle bonds under repeated shock exposure. These results confirm morphological compaction without altering the crystal phase.

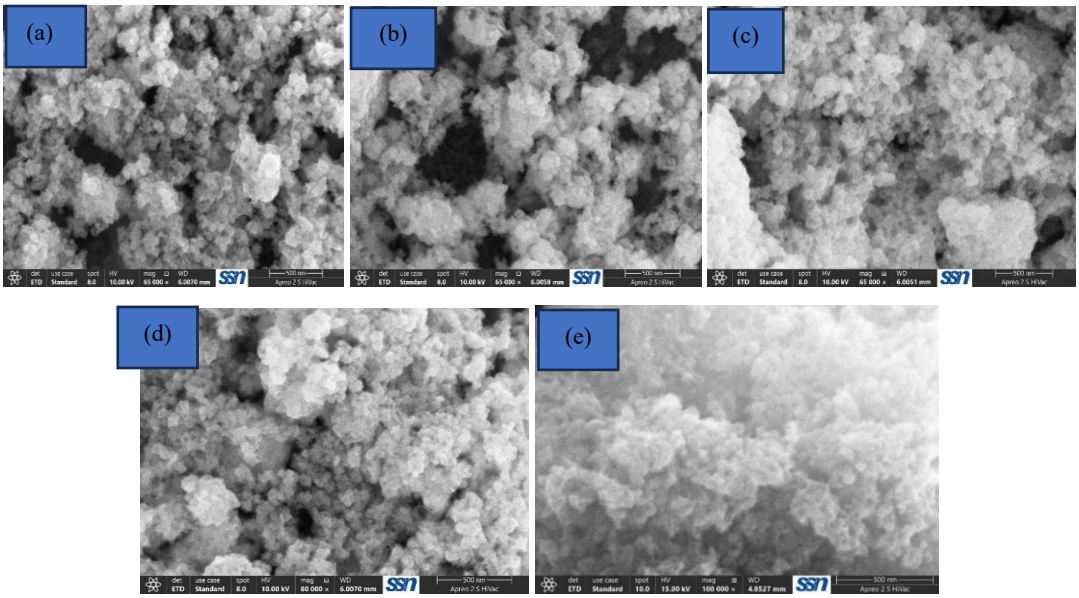

Fig. 8 – SEM images of (a) unshocked, (b) 50 shock, (c) 100 shock, (d) 150shock, (e) 200 shock

3.5 Elemental Composition Analysis (EDAX)

EDAX analysis confirmed the elemental composition of CdO nanoparticles, showing distinct peaks for cadmium (Cd) and oxygen (O). The absence of additional strong peaks indicates high chemical purity of the synthesized samples. Minor peaks observed might be due to background noise or instrumental artifacts rather than actual impurities. Similar artifacts have been reported in characterization studies and attributed to experimental limitations [18]. Thus, EDAX results validated the successful synthesis and compositional integrity of CdO nanoparticles.

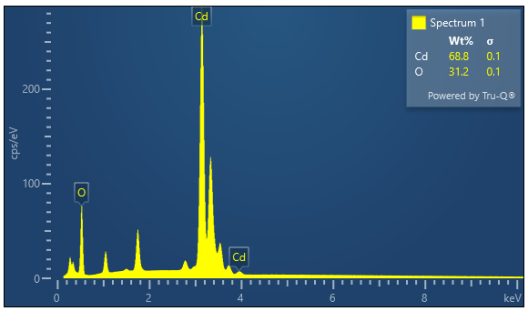

Fig. 9 – EDAX spectrum of CdO NPs

4. STUDY LIMITATIONS

Although the present investigation provides insights into the behavior of CdO nanoparticles under acoustic shockwave exposure, several limitations need to be acknowledged. The study examined a relatively limited range of shock intensities and pulse numbers, which restricts the ability to evaluate the full response of CdO nanoparticles under extreme shock conditions. The shock exposure duration is short and transient, which may limit the extent of structural modification. Furthermore, the present study relies on post-shock characterization techniques, and no in-situ diagnostics were employed to monitor structural evolution during shock propagation. Future studies involving time-resolved measurements or higher shock pressures could provide deeper insight into the dynamic structural response of CdO nanomaterials.

5. CONCLUSION

CdO nanoparticles were subjected to controlled acoustic shockwave treatment to assess structural and optical changes. PXRD confirms retention of the cubic phase, indicating structural stability, while slight crystallite size reduction suggests minor lattice modifications. Optical studies showed a small band gap decrease, and PL results indicate changes in defect-related emissions. SEM analysis revealed particle compaction and rearrangement. Overall, shockwave effectively tunes the structural and optical properties of CdO nanoparticles, highlighting its potential for future technological applications.

DECLARATION OF COMPETING INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

AUTHORSHIP CONTRIBUTION STATEMENT

R. Yoga Indra Eniya: Writing – review & editing, writing – original draft, Methodology, Investigation, Formal analysis, Supervision, Conceptualization, Project administration; K. Vijayakumar: Writing – review & editing, Writing – original draft, Visualization, Investigation, Data curation; B. Vigneashwari: Writing – review & editing, Visualization, Investigation, Resources, Validation.

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Дослідження наночастинок оксиду кадмію в умовах затухання акустичних ударних хвиль

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Наноматеріали привернули значну увагу завдяки своїм фізичним та хімічним властивостям, що залежать від розміру та значно відрізняються від властивостей об'ємних матеріалів. Їхнє високе співвідношення поверхні до об'єму дозволяє контролювати розмір частинок, морфологію та характеристики поверхні, підвищуючи продуктивність у таких сферах застосування, як оптоелектроніка, фотоелектричні прилади, каталіз, накопичення енергії та біомедицина. Серед них наночастинки оксиду перехідних металів є особливо важливими завдяки своїй хімічній стабільності, регульованій зонній структурі та універсальним властивостям. Хоча наночастинки оксиду кадмію (CdO) широко вивчалися, їх поведінка під впливом акустичного ударнохвильового навантаження залишається недостатньо дослідженою. В існуючій літературі бракує систематичного розуміння структурних та оптичних модифікацій, викликаних ударними хвилями, та їхніх основних механізмів. Дане дослідження вивчає синтез, структурні та оптичні властивості наночастинок CdO, що піддаються акустичному ударнохвильовому навантаженню. Робота включає методологію синтезу, ударнохвильову обробку та характеристику за допомогою PXRD для вивчення кристалічної структури, фотолюмінесценції – для визначення оптичних властивостей та SEM – для дослідження морфології і розподілу розмірів частинок, що забезпечує розуміння модифікацій, викликаних ударною хвилею.

Ключові слова: Наночастинки оксиду кадмію, Затухання акустичної ударної хвилі, Синтез наноматеріалів, Порошкова рентгенівська дифракція, Фотолюмінесцентний аналіз, Скануюча електронна мікроскопія.