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Synthesis and Characterizations of CdS Nanoparticles by Chemical Precipitation Method

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ABSTRACT

Cadmium sulfide (CdS) nanoparticles were successfully synthesized by a simple, rapid, and cost-effective aqueous precipitation method carried out at room temperature. In the present work, ammonium hydroxide was employed as a complexing agent to regulate the release of cadmium ions during the reaction, leading to the controlled formation of CdS nanoparticles with improved stability and uniformity. The synthesized nanoparticles were well dispersed in the solution, forming single entities that exhibited excellent resistance to oxidation for several months, which is attributed to the presence of a protective polymer shell surrounding the particles. Structural, morphological, compositional, and optical properties of the synthesized nanoparticles were systematically investigated. X-ray diffraction (XRD) analysis confirmed the formation of phase-pure, crystalline CdS with a hexagonal wurtzite structure, exhibiting characteristic diffraction peaks corresponding to the (100), (111), (110), and (220) planes. Peak broadening indicated nanoscale crystallite dimensions. Scanning electron microscopy (SEM) revealed nearly spherical particles with slight agglomeration due to high surface energy, demonstrating relatively uniform morphology. Energy-dispersive X-ray analysis (EDAX) verified the presence of only Cd and S elements, confirming high purity and stoichiometric composition. Fourier transform infrared (FT-IR) spectroscopy displayed a distinct Cd–S stretching vibration near 641 cm^{-1} , further validating successful compound formation. Optical studies showed a blue-shifted absorption edge around 400 nm compared to bulk CdS, indicating pronounced quantum confinement effects. Photoluminescence (PL) spectra exhibited a strong visible emission peak centered at approximately 490 nm, attributed to band-edge and defect-related recombination. The obtained results demonstrate that the synthesized CdS nanoparticles possess high crystallinity, controlled nanoscale dimensions, and enhanced optical properties, making them promising candidates for optoelectronic, photocatalytic, and sensing applications.

1. Introduction

Nanoscience and nanotechnology focus on the study and manipulation of materials at dimensions ranging from 1 to 100 nm, where their physical and chemical properties differ markedly from those of bulk counterparts [1]. At the nanoscale, materials exhibit unique characteristics due to their high surface-to-volume ratio and quantum confinement effects, leading to significant modifications in optical, electrical, magnetic, and catalytic behavior [2,3]. These size-dependent properties make nanostructured materials highly attractive for advanced technological applications [4].

Among various nanomaterials, II–VI semiconductor nanoparticles have gained considerable attention owing to their tunable band gap, strong optical absorption, and enhanced surface reactivity [5,6]. When the crystallite size approaches or becomes smaller than the exciton Bohr diameter, a blue shift in absorption energy occurs, commonly referred to as the quantum size effect [7,8]. This phenomenon enables precise control over the optical and electronic properties of semiconductor nanocrystals, making them suitable for applications in optoelectronics, photocatalysis, sensing devices, and solar energy conversion [9,10].

In particular, Cadmium sulfide is a direct band gap II–VI semiconductor with excellent optoelectronic properties and strong visible-light absorption [11]. Reducing CdS to the nanoscale enhances its band gap energy and surface activity, thereby improving its functional performance in various applications [12,13].

In the present study, CdS nanoparticles were synthesized using a simple chemical reaction method involving cadmium acetate dihydrate and thiourea, with ammonium hydroxide acting as a complexing agent to regulate particle growth [14–16]. The structural, morphological, and optical properties of the prepared nanoparticles were systematically investigated using X-ray diffraction (XRD), scanning electron microscopy

(SEM), energy-dispersive X-ray analysis (EDAX), and UV-Visible spectroscopy to evaluate their suitability for potential technological applications. The basic properties of CdS is given in Table 1.

Table 1 Properties of cadmium sulfide

Properties	Value
Physical State	Solid State
Color	Yellow or Brown
Molecular Weight	146.46 g/mole
Melting Point	Sublimes. (980 °C or 1796 °F)
Specific Gravity	4.82 g/cm ³
Solubility	Insoluble in hot and cold water

2. Experimental Methods

Cadmium sulfide nanoparticles were synthesized through a straightforward and cost-effective aqueous precipitation method using cadmium nitrate and sodium sulfide as precursor materials, with diethylene glycol (DEG) employed as a capping agent to regulate particle growth. In a typical procedure, 20 mL of 0.1 M cadmium nitrate tetrahydrate $[\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}]$ solution was prepared in a conical flask and stirred continuously. Subsequently, 10 mL of diethylene glycol was added to the cadmium precursor solution under constant stirring to act as a stabilizing and size-controlling agent. After stirring for approximately 5 minutes, 20 mL of sodium sulfide solution was introduced dropwise into the reaction mixture while maintaining continuous agitation. The reaction was allowed to proceed for 3 hours at room temperature, during which a yellow precipitate of CdS formed as a result of a metathesis reaction between cadmium and sulfide ions. The precipitate was collected, thoroughly washed with ethanol and acetone to remove unreacted species and residual impurities, and finally dried at room temperature to obtain CdS nanopowder. The use of diethylene glycol effectively limited particle

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growth and aggregation, enabling controlled formation of nanosized CdS particles suitable for further characterization and applications. The synthesis process is shown in Fig. 1.



Fig. 1 Schematic illustration of the aqueous precipitation synthesis of CdS nanoparticles

3. Results and Discussion

3.1 X-Ray Diffraction Analysis

The X-ray diffraction (XRD) pattern of Cadmium sulfide nanoparticles exhibits well-defined and intense diffraction peaks, confirming the crystalline nature of the synthesized material. The prominent reflections observed at 2θ values around $\sim 26^\circ$, $\sim 28^\circ$, $\sim 44^\circ$, and $\sim 52^\circ$ correspond to the (100), (111), (110), and (220) crystallographic planes of CdS, respectively. These diffraction peaks are characteristic of the hexagonal wurtzite crystal structure of CdS. The XRD pattern of the synthesized CdS nanoparticles is presented in Fig. 2.

The sharpness and relatively high intensity of the peaks indicate good crystallinity of the nanoparticles. The crystallite size calculated using the Scherer equation and found to be 25 nm. At the same time, slight peak broadening is observed, which suggests nanoscale crystallite dimensions. This broadening is typically associated with small particle size and lattice strain in nanocrystalline materials [17].

No additional impurity peaks are detected in the diffraction pattern, confirming the phase purity of the synthesized CdS nanoparticles. The absence of secondary phases such as CdO or other sulfide compounds further validates the successful formation of single-phase CdS [17].

Overall, the XRD results confirm the formation of nanocrystalline, phase-pure CdS with a hexagonal structure, consistent with successful synthesis through the aqueous precipitation method.

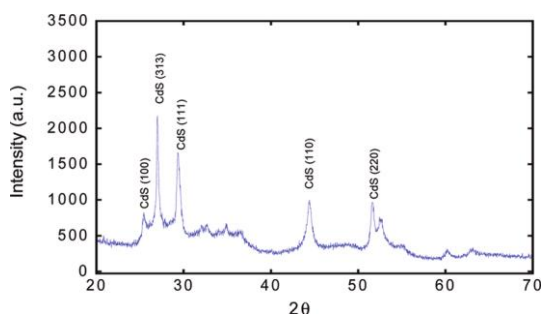


Fig. 2 X-ray diffraction (XRD) pattern of synthesized CdS nanoparticles

3.2 SEM and EDAX Analysis

The SEM images of cadmium sulfide nanoparticles show uniformly distributed, nearly spherical particles with slight agglomeration due to high surface energy. The particles appear closely packed with clear grain boundaries, confirming the formation of nanosized CdS with homogeneous morphology and good structural uniformity. The surface morphology of CdS nanoparticles at different magnifications is shown in Fig. 3(a–d).

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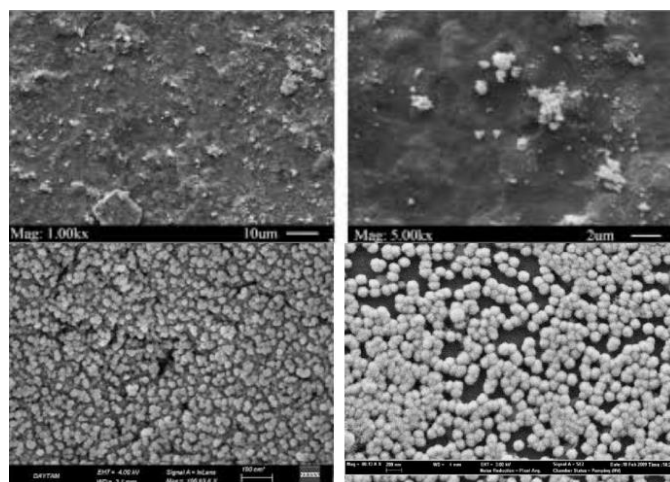


Fig. 3 SEM micrographs of synthesized CdS nanoparticles recorded at different magnifications: (a) low-magnification image showing surface morphology and particle distribution; (b) intermediate magnification image indicating particle clustering; (c) higher magnification image revealing nanoscale grain formation; and (d) high-resolution image showing nearly spherical CdS nanoparticles with slight agglomeration due to high surface energy

The EDAX spectra of synthesized CdS nanoparticles shows only the indicated elements, such as Cd and S, indicating the samples are free of contaminants. The elemental composition of the synthesized nanoparticles was analyzed using EDAX, as shown in Fig. 4.

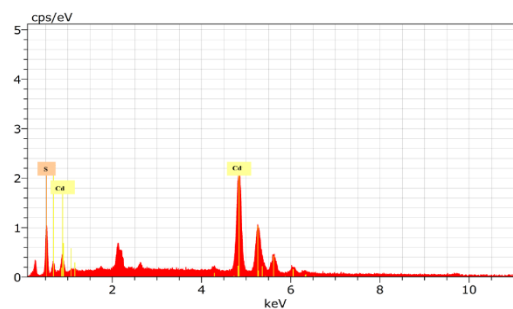


Fig. 4 Energy-dispersive X-ray (EDAX) spectrum of synthesized CdS nanoparticles

3.3 FT-IR Spectral Studies

The FT-IR spectrum of cadmium sulfide nanoparticles from Fig. 5 shows a broad band around 3400 cm^{-1} corresponding to O–H stretching vibrations of adsorbed moisture. Peaks observed near 1590 and 1375 cm^{-1} are attributed to bending vibrations of surface-bound species or residual organic groups. The absorption band around 1112 cm^{-1} may be associated with C–O stretching vibrations. Importantly, the distinct band near 641 cm^{-1} confirms the characteristic Cd–S stretching vibration, verifying the successful formation of CdS nanoparticles.

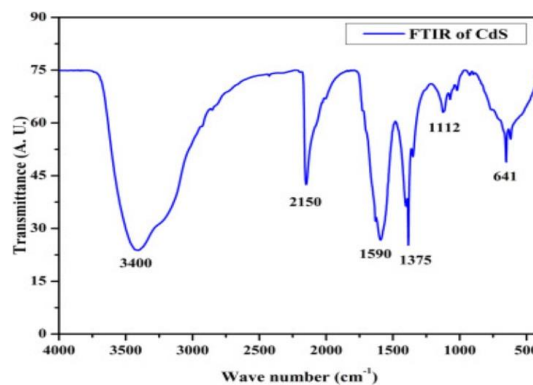


Fig. 5 FT-IR spectrum of synthesized CdS nanoparticles recorded in the range $4000\text{--}500\text{ cm}^{-1}$

3.4 UV-Vis and PL Analysis

The optical properties of CdS nanoparticles were analyzed using UV–Vis and PL spectroscopy, as shown in Fig. 6. The UV–visible absorption spectrum (Fig. 6a) of cadmium sulfide nanoparticles shows a strong absorption peak around 275 nm and a noticeable absorption edge near 400 nm . The blue shift of the absorption edge compared to bulk CdS

indicates the presence of quantum confinement effects and nanoscale particle formation.

The photoluminescence (PL) spectrum exhibits a prominent emission peak centered around 490 nm in the visible region, which is attributed to band-edge emission and defect-related recombination processes. The strong emission intensity confirms good optical quality and efficient radiative recombination in the synthesized CdS nanoparticles.

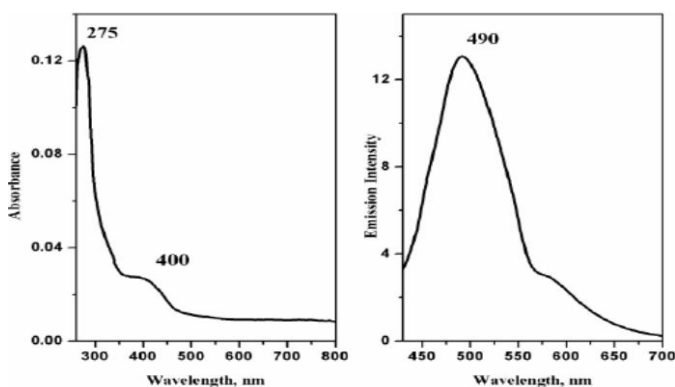


Fig. 6 (a) UV-visible absorption spectrum and (b) photoluminescence (PL) emission spectrum of synthesized CdS nanoparticles

4. Conclusion

Cadmium sulfide nanoparticles were successfully synthesized using a simple aqueous precipitation method with effective size control through a stabilizing agent. Structural analysis confirmed the formation of crystalline CdS with a hexagonal phase and nanoscale crystallite size. SEM observations revealed nearly spherical particles with slight agglomeration, while EDS verified high purity and correct stoichiometric composition without detectable impurities. FT-IR results confirmed the presence of characteristic Cd–S bonding along with minor surface-bound species. Optical studies demonstrated a blue-shifted absorption edge and strong visible emission around 490 nm, indicating pronounced quantum confinement effects and good optical quality. Overall, the synthesized CdS nanoparticles exhibit controlled nanoscale dimensions, high crystallinity, and promising optical properties, making them suitable for potential applications in optoelectronic devices, photocatalysis, and sensing technologies.

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