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RESEARCH PAPER

Photocatalytic Activity to Remove the Effect of Methylene Blue Dye by Using CdS Nanocrystalline under Visible Light

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ABSTRACT

Porous CdS nanocrystalline thin film was synthesized via chemical bath deposition. The XRD (X-ray diffraction) pattern of the porous shows the cubic structure. FESEM (Field emission scanning electron microscopy) analysis shows that the surface of Cadmium sulfide (CdS) is a porous shape. The EDX (energy dispersive X-ray spectroscopy) Technique assures the presence of Cd and S elements in the sample. To determine the band gap energy of porous CdS, UV-visible absorption spectra were analyzed, revealing an estimated value of approximately 2.39 eV. Subsequently, the photocatalytic degradation of methylene blue was using porous CdS as the catalyst. This degradation process took place under visible light irradiation from a 200-W xenon lamp. The utilization of porous CdS in this photocatalytic reaction demonstrates its potential as an effective catalyst for the degradation of methylene blue, a commonly used dye in various industries. To our knowledge, there is no previous study about porous CdS acting as catalysis to remove methylene blue dye. In seven hours, porous CdS removed 72% of methylene blue.

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INTRODUCTION

Photocatalysis is a highly effective process utilized in the treatment of colored dye wastewater. It involves the utilization of a semiconductor material that absorbs light energy equal to or greater than its band gap. This absorption triggers the excitation of valence band electrons, causing them to move to the conduction band. As a result, electron-hole pairs are formed, which play a crucial role in generating free radicals within the system. These free radicals, including hydroxyl (•OH), exhibit exceptional oxidizing capabilities, particularly when it comes to organic materials. Consequently, these radicals facilitate the degradation of pollutants present in the wastewater, contributing to the overall decoloration process [1]. The textile, paper, and certain industrial processes generate large quantities of colored dye wastewater that is both highly toxic and resistant to biodegradation. When

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this wastewater is discharged into natural water runoff, it poses a significant threat to the entire ecosystem by interfering with the photosynthetic activity of aquatic plants. Over the past few decades, researchers and scientists have dedicated their efforts to developing a range of physical, chemical, and biological techniques to tackle the decoloration of dye effluents. However, it is crucial to acknowledge that conventional treatments, including coagulation, flocculation, absorption, adsorption, ultrafiltration, reverse osmosis, and membrane technologies, primarily concentrate on transferring or moving organic compounds from one phase to another. Although conventional methods can reduce the visible presence of colored dyes in wastewater, they do not adequately address the toxicity and non-biodegradability of the pollutants. As a result, there is a need for further advancements and innovations to develop sustainable and efficient solutions that can effectively degrade or remove colored dyes from wastewater. These advancements are crucial to ensure the protection and preservation of the ecosystem [2-6]. Traditional methods just concentrate organic substances or move them through one state to the next. Although disruptive methods like chemical oxidation and advanced oxidation processes (AOPs) could be able to solve such issues, they still have high prices and insufficient deterioration [7]. Among AOPs, Since visible light is the predominant component of both indoor illumination and the solar spectrum, photocatalysis under visible-light irradiation is without a doubt one of the most successful and inexpensive approaches [5]. Cadmium sulfide (CdS) in a nanosize is considered one of the best photocatalytic because of characteristics like inexpensive price, high stability, safety, and great photoactivity [8,9]. absorption of light by a semiconductor material occurs when the energy of the incident light is greater than or equal to the band gap, valence electrons in the ground

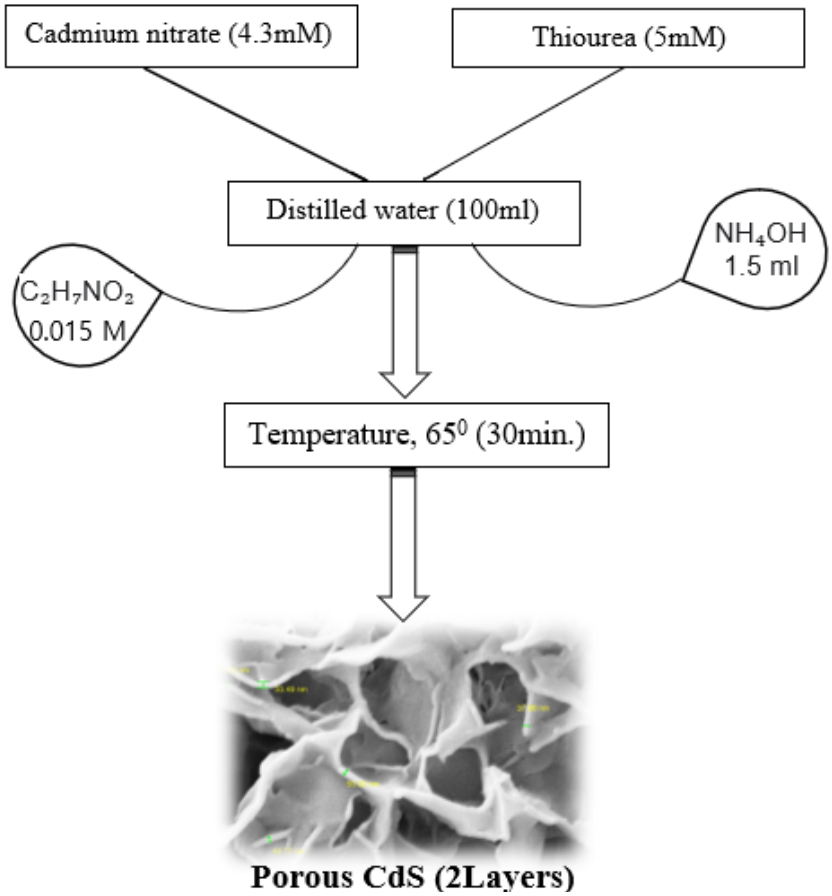

Fig. 1. Flowchart and the preparation steps of porous CdS.

state band are activated and can recombine or dissociate at the material's surface [10,11]. As potential photocatalysts, a variety of materials including TiO_2, ZnO, and SnO_2 have attention to the degradation of organic dye causing water waste [12,13].

This research focuses on using the photocatalytic properties of a porous CdS nanocrystalline thin film, which is irradiated with visible light to oxidatively destroy aqueous source pollutants and highly colored dyes like methylene blue.

MATERIALS AND METHODS

Synthesis of porous CdS nanocrystalline thin film

In brief, Chemical bath deposition was used to create the porous CdS. A suitable amount of Thiourea CH_4N_2S and cadmium nitrate $Cd(NO_3)_2$ were dissolved in 100ml of s distilled water. Then the beaker containing a solution was placed in a hotplate at 70±5°C to deposit a thin film [14]. All procedures are shown in the following flowchart.

RESULTS AND DISCUSSION

Structural Studies

Nondestructively revealing a material's crystal structure, physical properties, and chemical make-up, XRD (X-ray diffraction) analysis is a key technique. Fig. 2 shows the XRD diffractograms obtained for porous CdS nanocrystalline thin film. The main peaks (2 0 0), (2 2 0) and (1 1 1) confirm the cubic structure type. At 2θ~33^0, the (511) plane was discovered to dominate the tiny peak crystalline of sulfur. The other peaks return to a glass substrate [15].

Surface characterizations

Macropores are defined as being larger than 50 nm, micropores are defined as being smaller than 2.0 nm and mesopores are between 2 and 50 nm [16]. Fig. 3 (A) is a FE-SEM micrograph displaying the CdS in a porosity state. It can be seen that CdS was formed in the macropores type with an average distribution porous size between 200-300nm as depicted in (B). The EDX (energy-dispersive x-ray) spectroscopy technique is important to estimate the chemical composition of the material. Fig. 3(C) displays a typical EDX spectrum for a CdS film placed on glass with a high porosity. The results indicate the existence of both Cd and S peaks, with a ratio of 16.3 for Cd to S.

Optical properties

Absorbance spectra from 200-800nm for a nanocrystalline porous CdS sheet, as well as

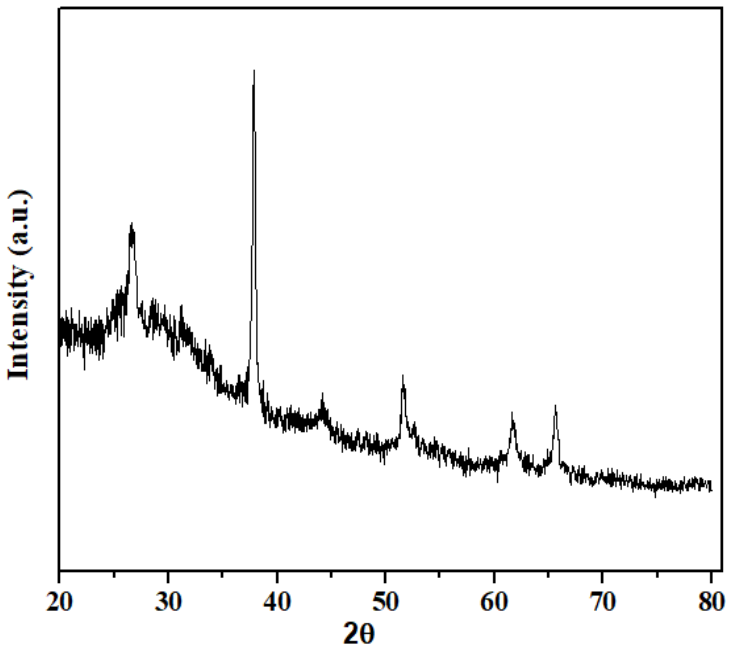

Fig. 2. XRD patterns of porous CdS.

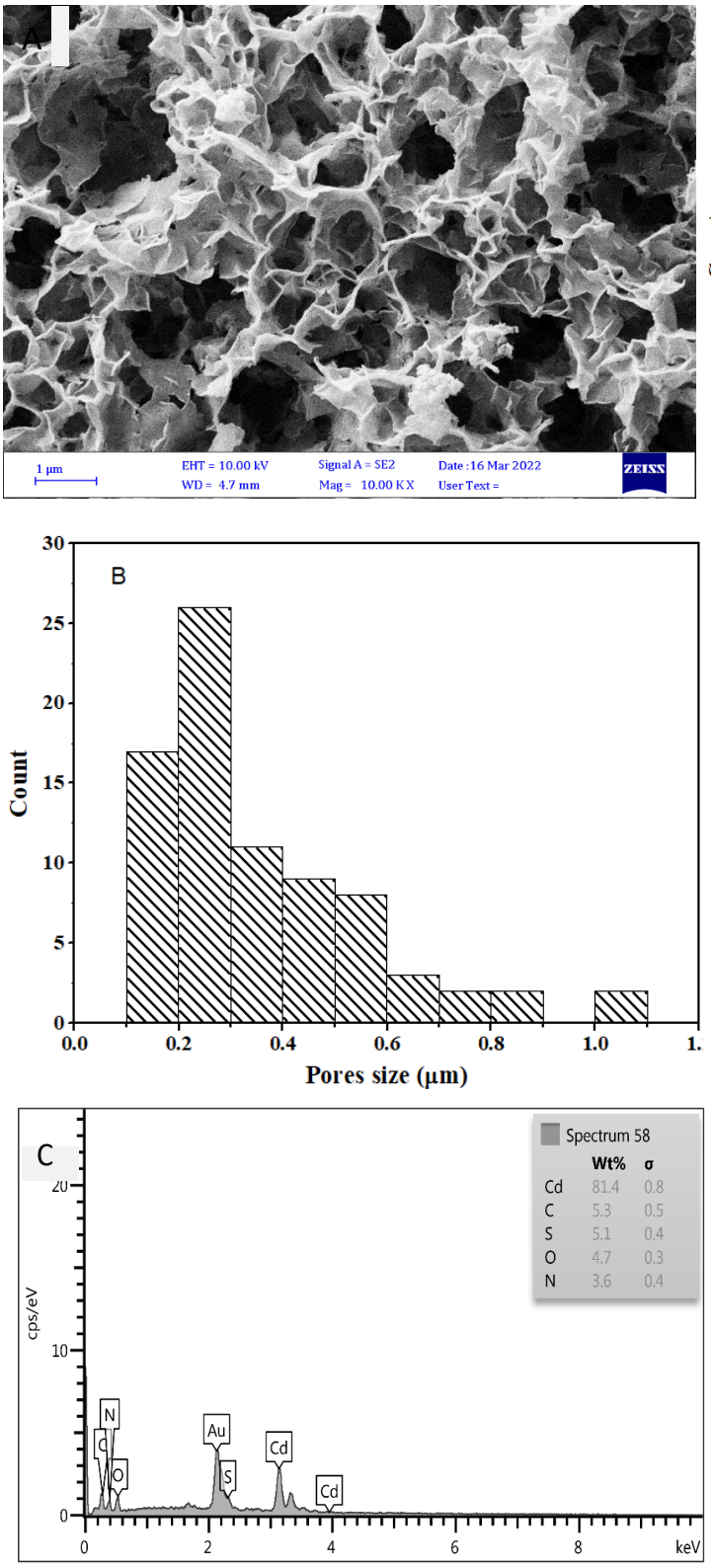

Fig. 3. FE-SEM of porous CdS (A), Distribution porous siz (B) and EDX spectra (C)

methylene blue dye are displayed in Fig. 4(A). By creating a Tauc plot of (hvα)2 versus (hv), and then projecting the linear sections of the curves to the energy axis, the band gap energy (Eg) of porous CdS was derived from the UV-Vis spectra through calculation[17].

$$(\alpha h\nu)^{1/n} = (h\nu - Eg) \quad (1)$$

where, α is denoted by absorption coefficient, The optical band gap of porous CdS is denoted by Eg, hν is the photon energy, and The value of the exponent (n) varies depending on the kind of transition being considered. Fig. 4(B) shows that it determined the energy gap of porous CdS thin films is 2.39eV, There is a redshift from the spectra that can be observed compared with a bulk CdS (2.42 eV).

Photoluminescence (*PL*)

The photoluminescence spectral analysis was used to detect the formation defect of Cd and S [18-20]. The PL spectra of the nanocrystalline CdS thin films are shown in Fig. 5. The figure depicting the two peaks, The first one has its center near 461nm and is associated with emission resulting from the recombination of electron-hole pairs occurring close to the band gap ,whereas the second one has a significant shift towards 620nm. The red band emission may be attributed to the increase in sulfur vacancies [21].

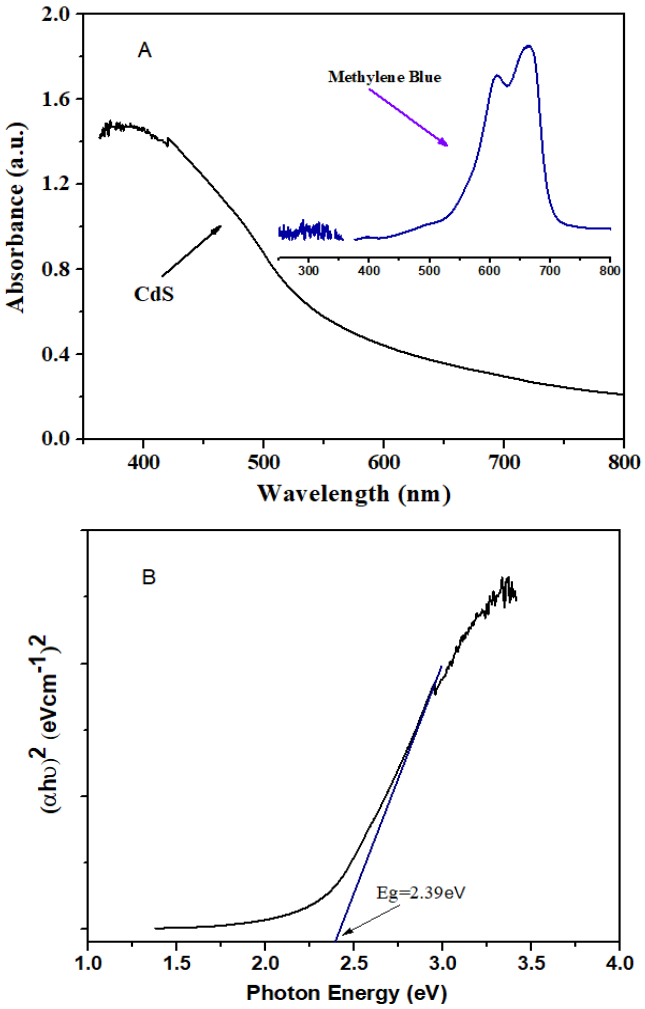

Fig. 4. UV–Vis spectra (A) and Tauc plot of the porous CdS(B).

Photocatalytic activity

In this work, MB (methylene blue) dye was used as a target pollutant to assess the real performance of the as-prepared catalyst porous CdS under visible-light illumination with power 200W (Xenon) as depicted in Fig. 6.

Photocatalytic degradation of MB was studied using UV-Vis spectral analysis scanned in the range of 200-900nm. The sample was centred directly at the circular spot of light for continued times 0-7

$$CdS + h\vartheta \rightarrow h^+ + e^- \quad \text{porous thin film} \tag{2}$$

$$OH^- + h^+ \rightarrow OH^{\cdot} \quad \text{hydroxyl radical} \tag{3}$$

$$O_2 + e^- \rightarrow O_2^{\cdot} \quad \text{superoxide radical} \tag{4}$$

$$MB + OH^{\cdot} \rightarrow (CO_2 + H_2O + NH_4^+ + NO_3^- + SO_4^{2-} + Cl^-) \quad \text{products} \tag{5}$$

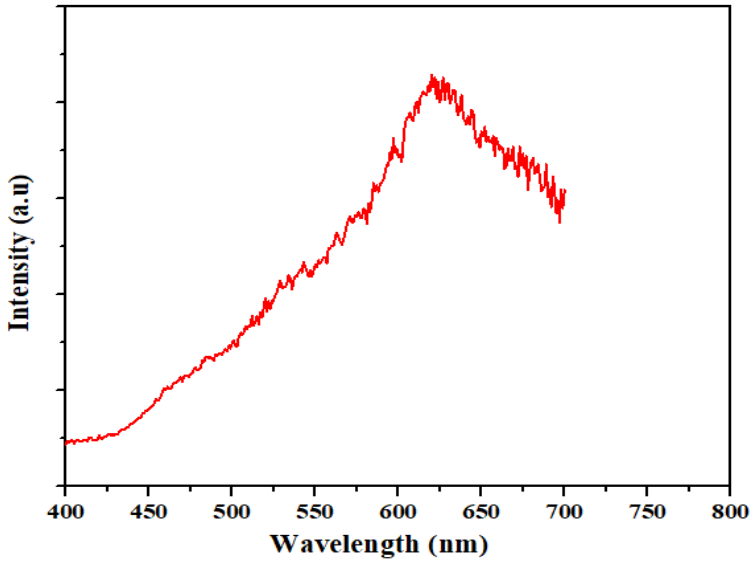

Fig. 5. The PL spectra of the porous CdS.

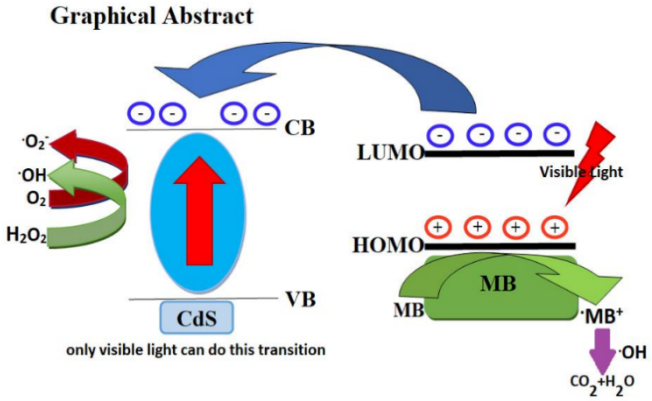

Fig. 6. Schematic diagram of photocatalytic activity

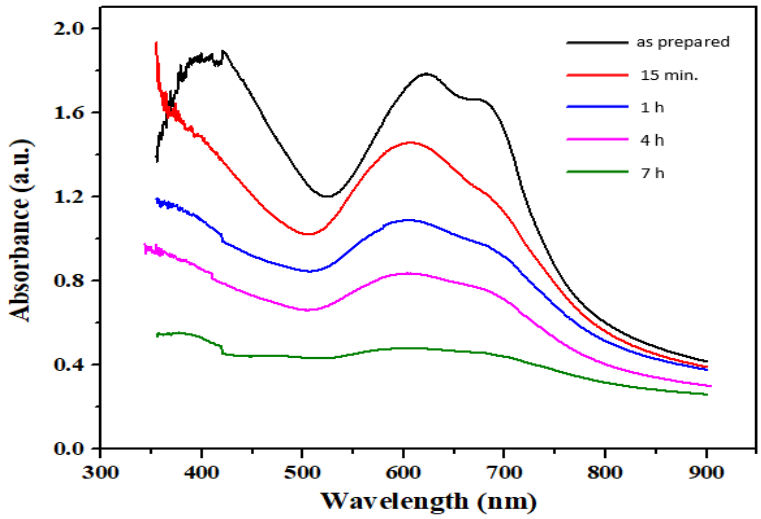

Fig. 7. Photodegradation of MB dye by porous CdS.

hours. Upon photon (hυ) activation of porous CdS, highly reactive electron-hole pairs are released, which can be written as equqtions 2-5 [22,23]

The photodegradation rate estimate using the formula [24]:

$$D(\%) = \frac{A_0 - A}{A_0} \times 100\% \quad (6)$$

where A_o, and A represent the absorbance value before and after exposure, respectively.

Fig. 7 shows that the presence of porous CdS led to the obvious breakdown of MB dye. The degradation rate efficiency has reached 72% after 7h of exposure to visible light.

CONCLUSION

In conclusion, an easy and low-cost method named chemical bath deposition was employed to prepare CdS in form porous. Porous-CdS was confirmed by FE-SEM analysis. The optical bandgap of porous CdS was evaluated using Tauc's relationship and it's about 2.39eV. EDX analysis confirms that the compound form was CdS. The XRD pattern shows a cubic structure for porous CdS. After a continuous illumination period of 7 hours, the photocatalyst porous demonstrated a degradation efficiency of approximately 72%. This indicates that the POROUS photocatalyst effectively facilitated the breakdown and removal of pollutants present in the colored dye wastewater. The high degradation efficiency achieved within this timeframe highlights the effectiveness of the photocatalytic process in treating such wastewater and reducing its environmental impact.

CONFLICT OF INTEREST

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

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