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Research Article

Effect of Multilayers CdS Nanocrystalline Thin Films on the Performance of Dye-Sensitized Solar Cells

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Due to relatively low price and nontoxicity of photovoltaic (PV) systems, dye-sensitized solar cells (DSSCs) recently gained a lot of attention in terms of improving their performance and longevity. Because most of the major elements are impacted by their separate production and layering procedures, the substances in DSSCs are critical to achieving these goals. Methylene blue dye sensitizer-based solar cells were effectively constructed in this work, and DSSC performance was assessed. The morphologies of nanocrystalline CdS thin films were investigated by the FE-SEM machine, and then XRD patterns of 1 layer, 2 layers, and 3 layers of nanocrystalline CdS thin films were analyzed. The thicknesses of the prepared samples were about 391 nm, 457 nm, and 912 nm for 1, 2, and 3 layers of nanocrystalline CdS thin film, respectively. J-V characteristics of the multilayer CdS thin films have been studied under a 100 mW/cm^2 sunlight source. The experimental results revealed that the highest power conversion efficiency of a 3 layer porous-nanowall CdS/MB device was about 0.47%.

1. Introduction

A few years ago, precisely in 2015, the researchers began to take an interest towards alternative materials to become the photoanode instead of ZnO and TiO_2 used in dye-sensitized solar cells (DSSCs) [1–3]. The highest efficiency was obtained from inexpensive materials, porous CdS as a photoelectrode only, and ease of manufacture of the DSSC device at about 1.25% [4]. In many studies CdS was deposited onto the surface of ZnO or TiO_2 as a second layer to enhance the efficiency of DSSC [5–10]. DSSC based on nanostructures cadmium sulfide (CdS) as a photoanode (window layer) attracts a lot of attention as a result of various properties, including its ease of preparation methods [11–14], direct bandgap [15], good thermal stability [16], high electronic mobility [17], and piezoelectric properties [18]. Many researchers were produced CdS with different nanostructures such as porous [19], nanowire [20], nanorods [21], nanoflower [22], and nanoribbons [23]. In addition, cadmium sulfide is a widely studied material for several applications such as solar cells [24], photocatalysis [25], and gas sensors [26]. However, DSSC is one of the most promising solutions in the field of renewable energy instead of fossil fuels. In this study, for the first time, porous and nanowall CdS thin films have been used as a photoanode combination with methylene blue dye (active layer) to fabricate a DSSC device.

2. Synthesis of the DSSC Device

The assembly of a DSSC was divided into three stages as follows: First, cadmium nitrate (4.3 mM) was dissolved in deionized water D.W (100 ml) as a source of Cd^{+2}. Then, ammonium acetate (0.015 M) was added to the solution to control the synthesis process, and 1.5 ml) of ammonia

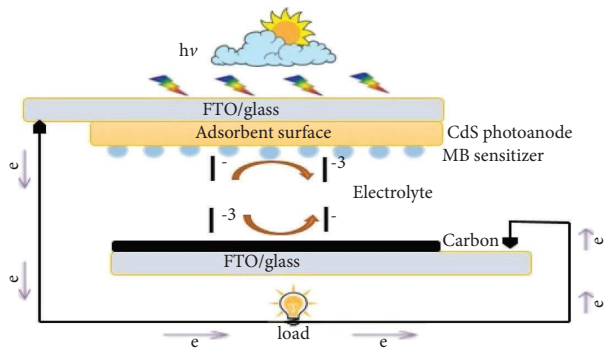

Figure 1: Schematic diagram of operation DSSC.

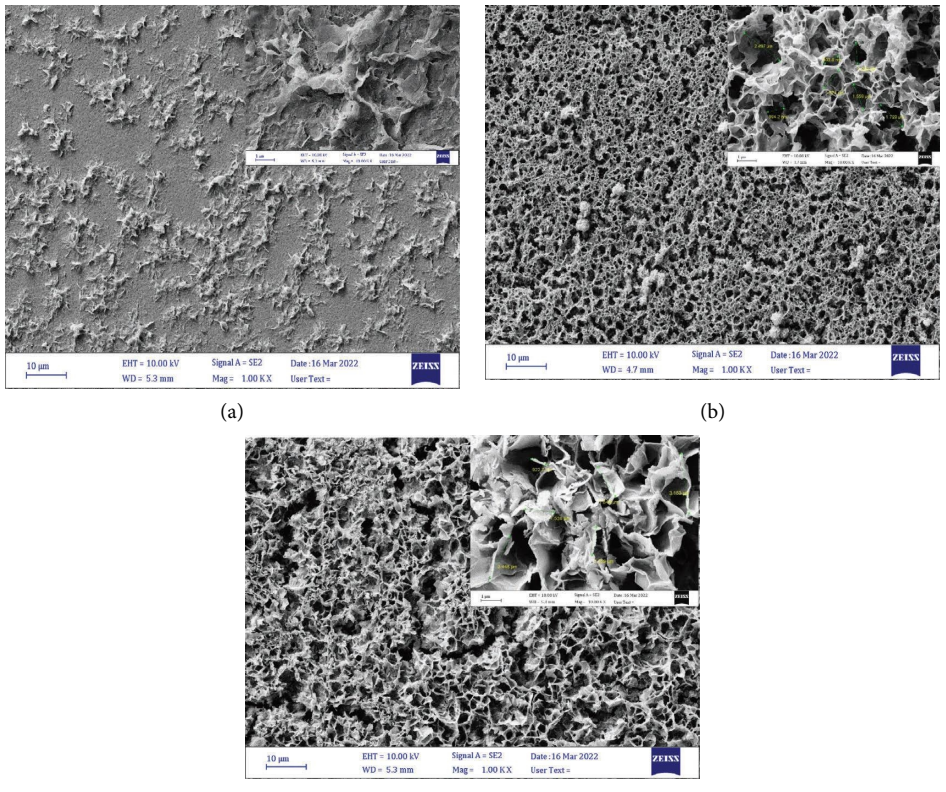

Figure 2: FE-SEM image of nanocrystalline CdS thin film (1 layer, 2 layer, and 3 layer) at 1KX and 10KX magnification.

solution was added to the aqueous solution to raise the pH to 11. Then, thiourea (5 mM) to the mixture was added as a source of S^{-2} under vigorous stirrer at room temperature for 15 minutes. In the next step, a clean FTO/glass substrate was immersed vertically in the mixture and the temperature solution was raised to 65°C for 22 minutes. Porous and porous-nanowall CdS thin films were formed into a substrate FTO/glass as a photoelectrode. This process is repeated three times to obtain three samples with different thicknesses: 1-layer CdS, 2 layers CdS, and 3 layers CdS. All samples were immersed in (0.003 g dissolved in 100 ml of D.W) methylene blue (MB) sensitizer for 24 hours.

Table 1: Standard deviation of CdS thickness.

Samples	Thickness values by SD (nm)
1-layer CdS (seed layer)	—
2-layer CdS (porous)	8.483
3-layer CdS (porous-nanowall)	8.136

The second step was to prepare the electrolyte; 0.15 g of iodine was dissolved in 15 ml of ethylene glycol under stirring. Then, 1 g of potassium iodine was added to increase

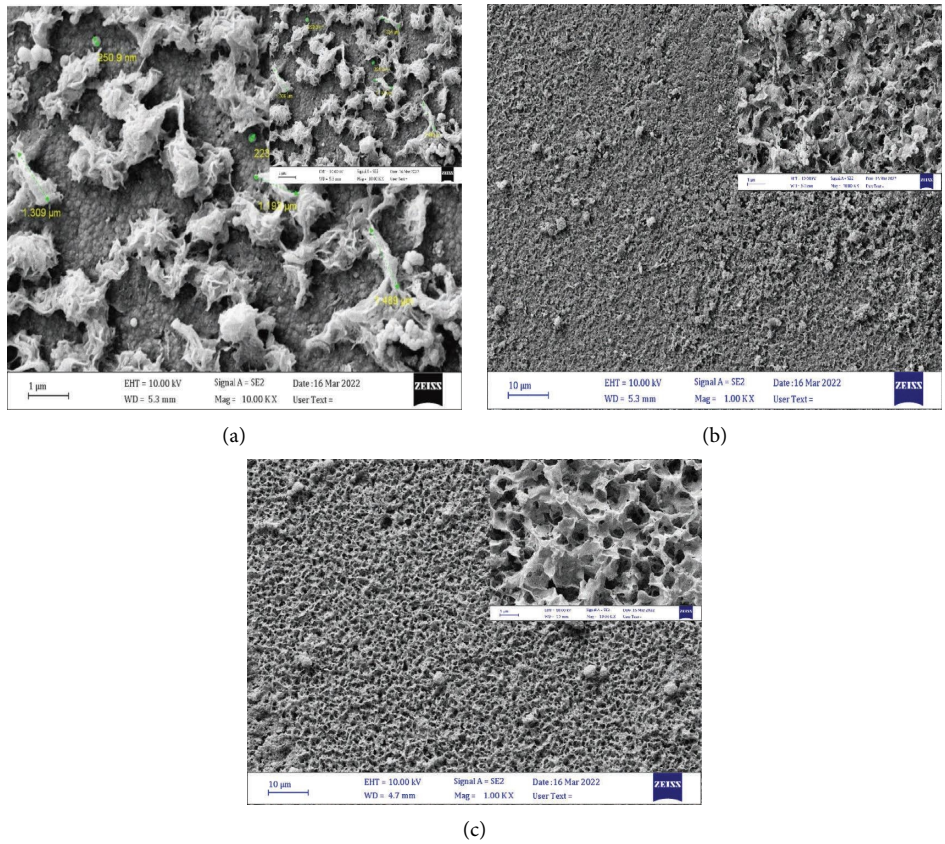

Figure 3: FE-SEM image of (a) CdS (1 layer)/MB, (b) porous CdS (2 layer)/MB, and (c) porous nanowall CdS (3 layer)/MB.

the conductivity. Then, the counter electrode was prepared; 60 mg and 30 mg of carbon black and graphite powder were dissolved in 10 ml of ethylene glycol, respectively. Then, 1 ml of the mixture was cast to the FTO/glass and then annealed at 300°C for 30 minutes. The final step determines the area of an active layer of DSSC by using adhesive tape (0.28 cm^2). Figure 1 shows the whole steps of fabricated DSSC.

3. Results and Discussion

3.1. Morphology. The morphologies of nanocrystalline CdS thin films were investigated by the FE-SEM machine. The most important observation that was diagnosed is the transfer of a surface shape of CdS from thin film to porous and then porous nanowall arrays in the third layers, as shown in Figure 2.

Table 1 shows that the thickness values of porous and porous nanowall-like CdS were calculated using the standard deviation formula (SD) as follows [27]:

$$\mathrm{SD} = \sqrt{\frac{\sum_{i=1}^{n}\left(x^{'} - x_i\right)^2}{n-1}}, \quad (1)$$

where samples are x_1, x_2, …, x_n and n is the sample size.

It is discernible that the standard deviation of the thickness of porous and porous-nanowall CdS thin films decreased with increased layers. Figure 3 shows the adsorption of MB dye at the surface of samples in a unique and homogenous way to capture more energy from sunlight.

3.2. Structural Analysis. Figure 4 shows the XRD patterns of 1 layer, 2 layers, and 3 layers of nanocrystalline CdS thin films. Here, the FTO/glass patterns have been marked as (■). In 1-layer crystalline plane (111) cubic/(002) hexagonal mixed phase of CdS observed at 2θ~26.6° after deposition of 2 layer of CdS, whereas CdS(200)C and CdS(220)C/CdS(110)H, CdS(311)C appears corresponding to 2θ~30°, 44°, and 52°, respectively. The small peak of crystalline Sulfur dominated by the (511) plane was observed at 2θ~33°. All peaks of various thicknesses were matched with a standard data card of CdS (JCPDS card no. 89-0019) [28]. It is difficult to distinguish between cubic and hexagonal phases, but disappearing planes (100) at 2θ~24.9° and (101) at 2θ~28.4° tend to the CdS cubic structure [29, 30]. The plane (111) diffraction peak value shifts slightly towards the higher angle with increasing thickness.

3.3. Optical Properties. The thicknesses of the prepared samples were about 391 nm, 457 nm, and 912 nm for 1, 2, and 3 layers of CdS nanocrystalline thin film. Figure 5(a) shows the absorption was increasing with CdS thickness because of an increase in crystallinity and the amount of material deposited on the FTO/glass substrate [31]. All the samples are blue-shifted when increasing the thickness of CdS which indicates the formation of particles in the

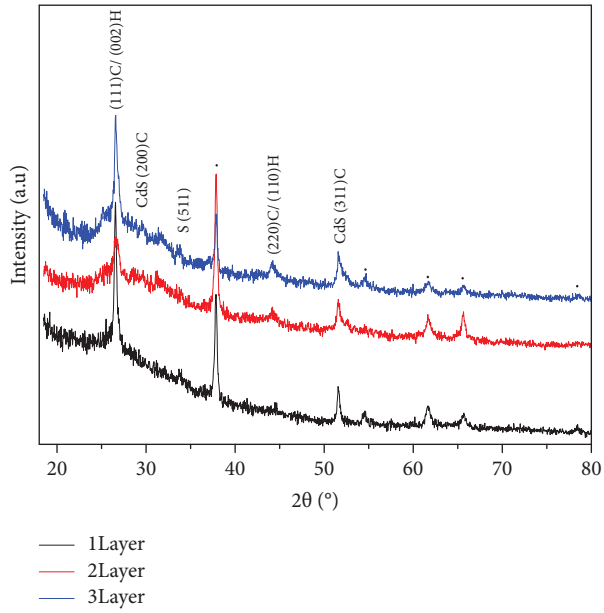

Figure 4: XRD patterns of 1, 2, and 3 layers of nanocrystalline CdS thin films.

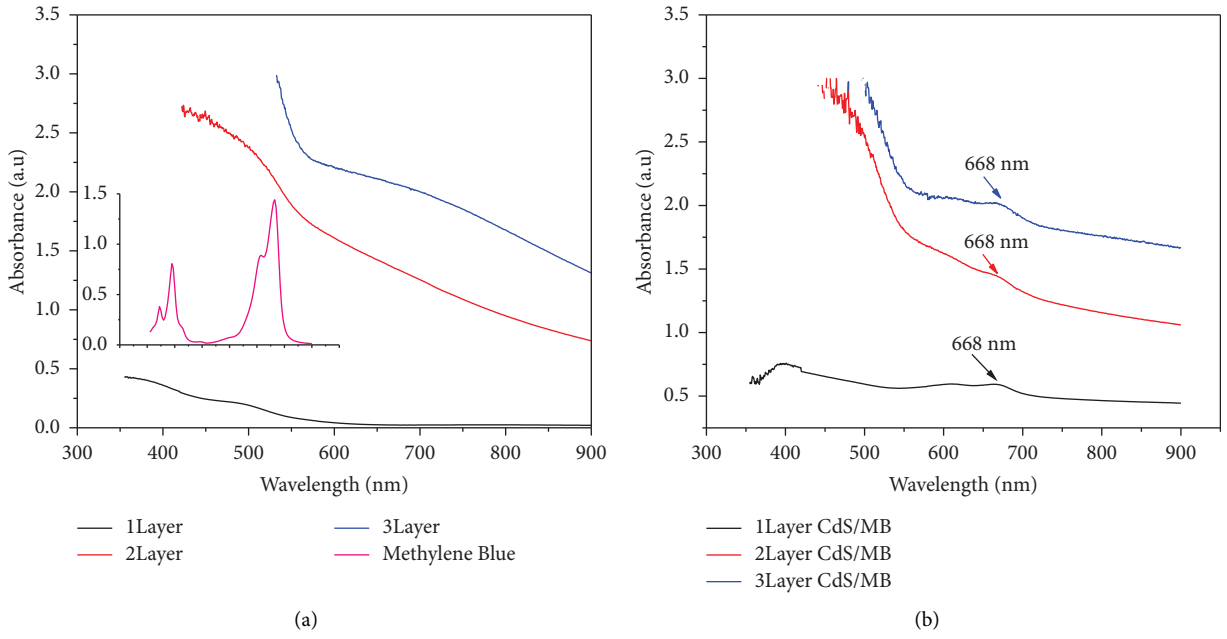

Figure 5: The UV-Vis absorption spectra of (a) only CdS layers and (b) layers CdS/MB.

nanoscale regime. The characteristic wavelength of absorbance exhibited by the MB dye corresponds to $\lambda_{max} = 668$ nm ($\pi - \pi^*$). This result confirms that the sensitizer was adsorbed at the surface of the photoanode CdS, as shown in Figure 5(b). In addition, the absorption coefficient (α) of the prepared samples shows higher values greater than 10^4. This indicates there is a large probability of the allowed direct transition, as shown in Figure 6(a). The optical bandgap has been measured by Tauc's relation $\alpha h\upsilon = A(h\upsilon - Eg)^m$ [32, 33]. It has been observed to increase Eg (2.45, 2.37, and 2.32 eV) with a decrease in the thickness of films [34] (Figure 6(b)).

3.4. J-V Characteristics. Figure 7 illustrates the performance of the multilayer CdS nanocrystalline thin films that have been studied. The parameters fill factor (FF) and efficiency ($\dot{\eta}$) are used to characterize solar cells [35, 36].

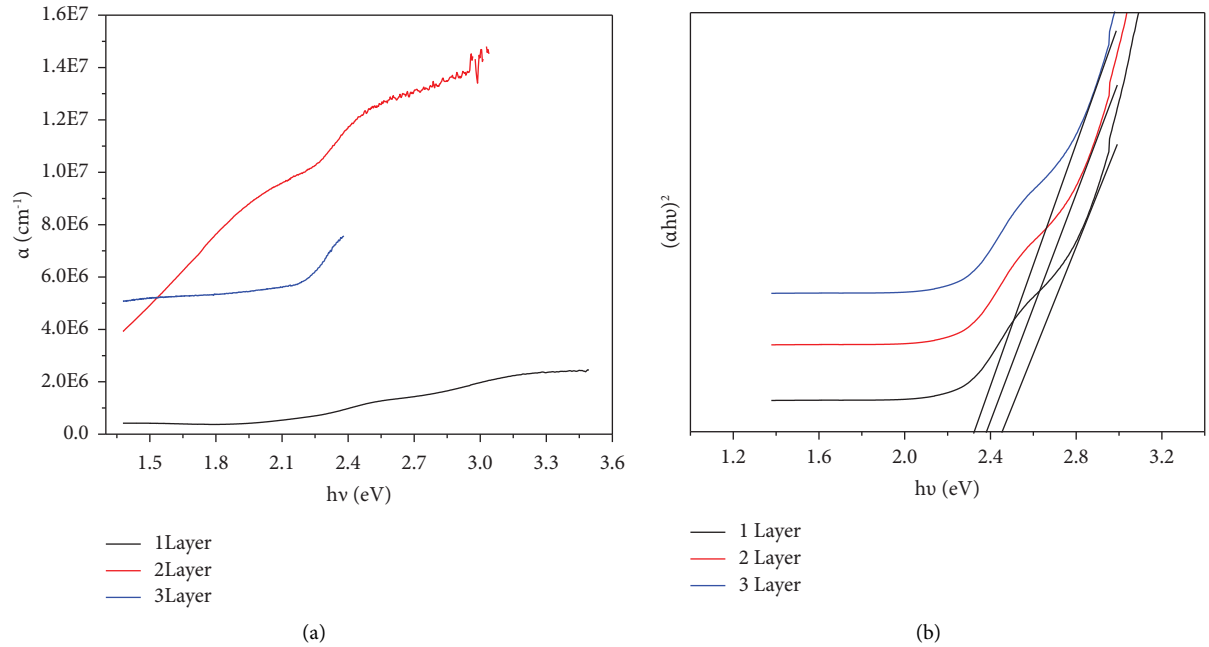

Figure 6: Absorption coefficient (a), and the optical bandgap of 1 layer, 2 layers, and 3 layers (b).

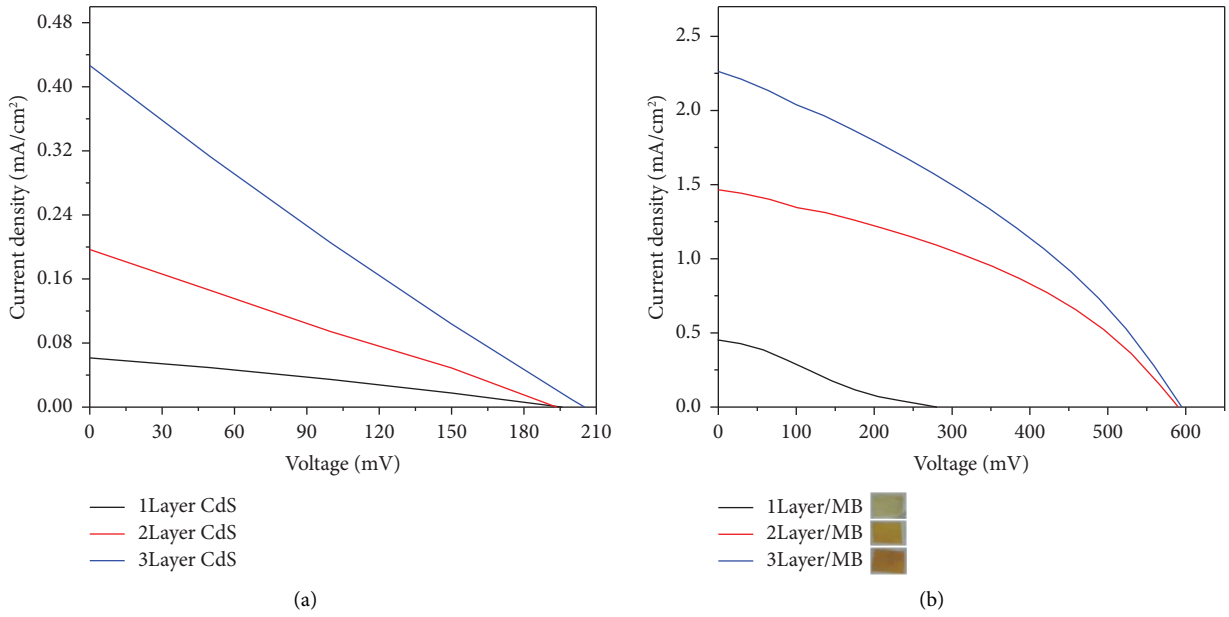

Figure 7: J-V characteristics of (a) CdS without dye and (b) CdS/MB devices.

Table 2: The output of DSSC.

Samples	J_{SC} (mA/cm^2)	V_{OC} (mV)	FF (%)	R_{Sh} (Ω·cm^2)	R_S (Ω·cm^2)	η (%)
1-layer CdS	0.063	189	30	15094	8163	0.003
1-layer CdS/MB	0.350	270	32	2211	115	0.02
2-layer CdS	0.197	193	24	4109	2455	0.009
2-layer CdS/MB	1.470	582	39	5590	298	0.34
3-layer CdS	0.427	205	20	1718	1275	0.018
3-layer CdS/MB	2.270	594	34	4043	302	0.47

$$\eta = \left(\frac{J_m V_m}{P_{in}}\right) \times 100\%,$$
$$\text{FF} = \frac{J_m V_m}{J_{sc} V_{oc}}. \quad (2)$$

The performance of various thicknesses of CdS without a MB sensitizer has been studied, and the short circuit current density J_{SC} increases with increasing the thickness, reaching 0.462 mA/cm^2 with a power conversion efficiency of 0.018% for FTO/3 layer CdS/electrolyte/carbon/FTO device, as shown in Figure 7(a). Gadalla et al. [37] studied the influence of increasing the thickness of CdS thin films on the output photocurrent, and they found that an increment in the photocurrent with increased thickness. Other researchers found the same results by increasing the thickness which agrees with [38–40].

One-layer CdS/MB device shows the lowest J_{SC} (0.35 mA/cm^2), open circuit voltage V_{OC} (270 mV), and the output efficiency η (0.02%), respectively. When increasing the layers to three of CdS nanocrystalline thin films, it has been found enhancement of $J_{SC,}$ V_{OC}, and η reach the highest value due to increased harvesting of adsorption between CdS nanocrystalline thin film and methylene blue dye (2.27 mA/cm^2), (594 mV), and (0.47%), respectively. It can be seen the effect of multilayers and MB sensitizer on the performance of solar cells, and the increment is about 96% (η) with the dye of a 3 layers device. Table 2 shows all the parameters of DSSC devices.

4. Conclusion

Nanostructures of cadmium sulfide were prepared via the chemical bath deposition method, yielding porous and wall morphologies. CdS was used as a window layer, and how complementary its aspects are to improving the layers of DSSC. As revealed by SEM images, as-deposited CdS films possess porous surface morphology. It is difficult to distinguish between cubic and hexagonal phases, but disappearing planes prove the CdS cubic structure. By Tauc's relationship optical bandgap has been measured, and it has been observed to increase with a decrease in the thickness of films. The highest efficiency has been recorded at about 0.47% of 3 layers porous CdS/MB device.

Data Availability

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

The original draft, data analysis, and funding acquisition were performed by Abdullah A. Hussain, Haider Abdulelah, Ali Hussein Amteghy, Raed A. Dheyab, and Ban Hamdan AlMulla.

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