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ORIGINAL RESEARCH ARTICLE

Fabrication of dye-sensitized solar cells using $CuO/CdS/Ag_2O$ ternary nanocomposite as a catalyst

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ABSTRACT

In this study, a ternary $CuO/CdS/Ag_2O$ nanocomposite was prepared for the first time to generate DSSCs. The nanocomposite was used as a photoelectrode with two types of dyes (natural and synthetic) serving as absorbing media: a green dye extracted from chard and a yellow dye known as (quinoline yellow E104). The results also showed that the green dye has a higher conversion efficiency (η) in DSSCs than the yellow dye, due to several reasons, including the difference in energy band gap, which is larger for the yellow dye (3.612 eV) than for the green dye (3.19 eV). As a result, more wavelengths of light pass through the cells to be absorbed by the dye, and the absorption of the green dye on the nanomaterial surfaces is increased, leading to higher DSSC efficiency. In addition, the current generated by DSSCs using the synthetic yellow dye is lower than that of DSSCs made with the green dye due to impurities in the natural dye. The absorption spectroscopy also revealed the optical properties of the prepared ternary $CuO/CdS/Ag_2O$ nanocomposite, measuring absorbance versus wavelength and $(\alpha h\upsilon)^2$ versus $h\upsilon$ for $CuO/CdS/Ag_2O$ nanoparticles prepared by the co-precipitation method. The nanocomposite had an energy band gap of (2.63 eV). The ternary nanocomposite was characterized using XRD, SEM, and EDS techniques.

Keywords: Dye-sensitized solar cells; $CuO/CdS/Ag_2O$; ternary nanocomposite

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1. Introduction

Energy powers many aspects of our existence, such as our homes, businesses, transportation, and communication systems, making it the lifeblood of modern civilization. But an over-reliance on fossil fuels has sparked serious geopolitical and environmental issues. The pressing necessity for a worldwide energy transition towards sustainability is highlighted by programs such as Future Earth. In light of the fact that this change is not only a matter of preference but also essential for the planet's future, this study focuses on the obstacles preventing the broad use of renewable energy in sustainable energy transitions [1].

Making the switch to sustainable energy systems is now a worldwide necessity rather than a personal preference. Our capacity to transition from fossil fuels to cleaner, more sustainable energy sources will determine the future of our world. Renewable energy, a key component that provides a route to a cleaner and more sustainable energy future, is at the center of this shift [2].

Recently, a new kind of energy storage device has gained a lot of popularity in a number of industrial-scale areas, including mobile devices, solar energy panels, and abrupt increases in power consumption [3,4]. Its full potential for beneficial uses is limited by its lower energy density when compared to solar cells and batteries. The low energy may be effectively improved by increasing the electrode material capacity and widening the voltage. However, the electrode's low charge-transfer resistance and excellent conductivity allow for an improvement in power density [5,6]. The mechanical properties and stability of an electrode material have a significant impact on performance [7-9].

Intriguing electrode materials for electrochemistry include transition metal oxides. Morphology, specific surface area, and electrical conductivity have a big impact on how much capacitance may be obtained [10]. CuO, CdS, and Ag_2O are examples of transition metal oxides that have higher specific capacitance and energy density [11]. CuO, a recently acquired nontoxic transition metal oxide with a high theoretical capacitance, has garnered significant interest due to its low cost, robust electrochemical reactivity, ecologically friendly properties, and enhanced operating safety [12]. Morphology, specific surface area, and electrical conductivity have a big impact on how much capacitance may be obtained [13].

A combination of CuO/CdS nanocomposites [14] has been employed in photocatalytic applications to enhance light absorption and provide effective charge transport. The highest charge of transition metal sulfide, CdS, has a high optical absorption coefficient because of two-dimensional anisotropy, one of these morphologies' many advantages [15].

According to numerous reports, the formation of binary composites, such as CuO/CdS or CdS/Ag_2O, is to blame for the increase in photocatalytic activity in the visible range [16].

The DSSC concept was created in 1991 by Brian O'Regan and Michael Gratzel utilizing ruthenium dye and mesoporous TiO_2 nanoparticles [17], and the system's maximum photoconversion efficiency is 14.3% [18]. Numerous photovoltaic technologies, their theories of operation, the creation of photovoltaic devices using a range of innovative inorganic nanostructured materials, and the variables that impact DSSC device performance—such as photoconversion efficiency (PCE), short circuit current (J_{sc}), open-circuit voltage (V_{oc}), and fill factor (FF)—are all covered in this review.

2. Practical part

This work deals with the process of preparation of photocatalyst CuO/CdS/Ag_2O, characterization techniques, and the experimental setup used for the fabrication of solar cells using a triple nanocomposite as a catalyst.

2.1. Chemicals used

[CuO/CdS nanocomposite, Silver nitrate $AgNO_3$, KOH solution, and deionized water].

2.2. Preparation of CuO/ CdS/Ag2O nanocomposites

A method for preparing a ternary CuO/CdS/Ag_2O nanocomposite was proposed in this study. It was prepared using the precipitation method. In the method, previously prepared CuO/CdS nanooxide was used as the main component. Silver oxide nanoparticles were also prepared using the following method: 1 g of CuO/CdS nanoparticles was taken after dissolving 1 g of silver nitrate in 100 ml of deionized water (DIW) and dispersing it. The diluted CuO/CdS nanoparticles were added and mixed for 2 hours at room temperature. Then, 20 ml of KOH solution was added dropwise with continuous stirring for 60 minutes at 80°C. The mixture was then separated and washed thoroughly several times with deionized water and ethyl alcohol and dried in an oven for 5 hours at 85°C.

2.3. Characterization of prepared compounds

2.3.1. XRD analysis

Figure 1 shows the X-ray diffraction (XRD) spectrum of the ternary nanocomposite ($CuO/CdS/Ag_2O$) prepared by the precipitation method. The figure shows the peaks of each nanomaterial prepared within the ternary composite, confirming the crystalline structure of the ternary nanocomposite prepared by this method. Some peaks also overlap. For each material formed in the ternary composite, the magnitude of each peak and the corresponding Miller indices are shown, which were calculated using the Debye-Scherrer relationship.

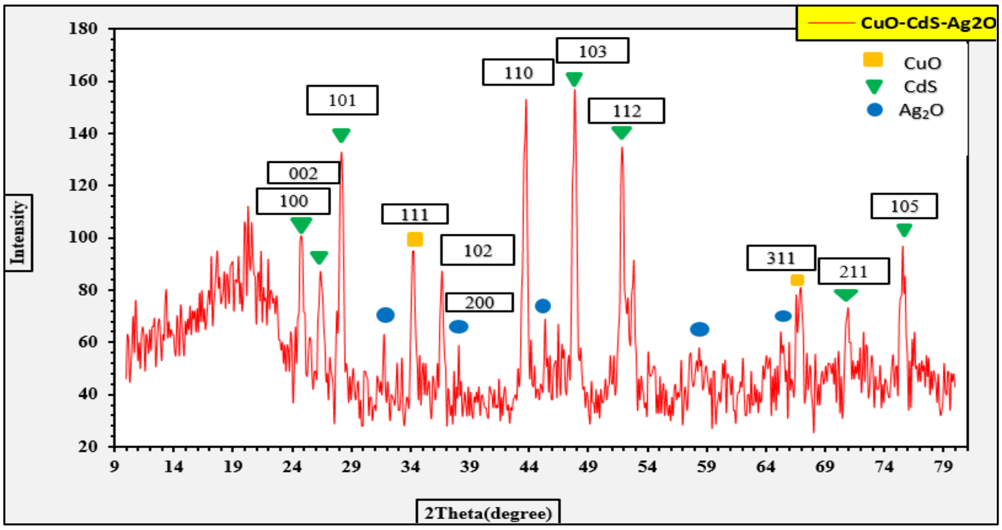

Figure 1. X-Ray Diffraction pattern of $CuO/CdS/Ag_2O$ nanocomposite

2.3.2. FE-SEM analysis

Figure 2 shows the FE-SEM images of the structure of the triple composite $CuO/CdS/Ag_2O$ nanocomposites. The average diameter of the nanoparticles was calculated at (43.15-60.22) nm, where the size of the nanoparticles ranges between (41.40-75.16) nm. The pictures also show the shape and size of the nanoparticles and the way they are collected, as they exhibit a spherical shape and rod-like structures.

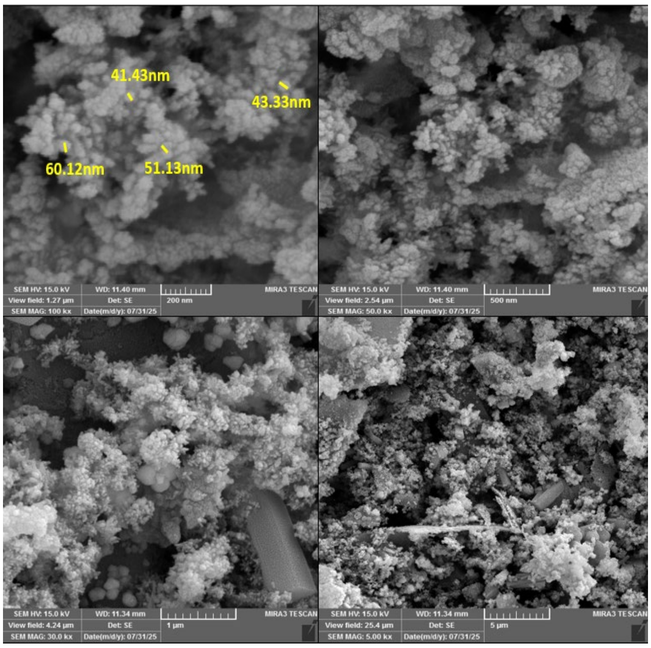

Figure 2. FE-SEM image of ($CuO/CdS/Ag_2O$) nanocomposite (200 nm, 500nm,1 µm, 5µm)

2.3.3. Energy-dispersive spectroscopy (EDS) analysis

EDS analysis is a valuable method for estimating the proportion of elements in compounds (Quantitative Analysis). The intensity of the X-ray signals is related to the abundance of each element. By measuring the intensities, EDS can provide a quantitative analysis of the elemental composition.

Figure 2-3 show the proportions of the elements that make up the ternary nanocomposite $CuO/CdS/Ag_2O$ prepared in the study, where the percentage of oxygen appears high due to its entry into the composition of both the composition of the CuO and Ag_2O nanoparticles, as well as the difference in the proportions and quantities of the elements depending on the method and conditions of the reaction that forms the ternary compound that is prepared for the first time.

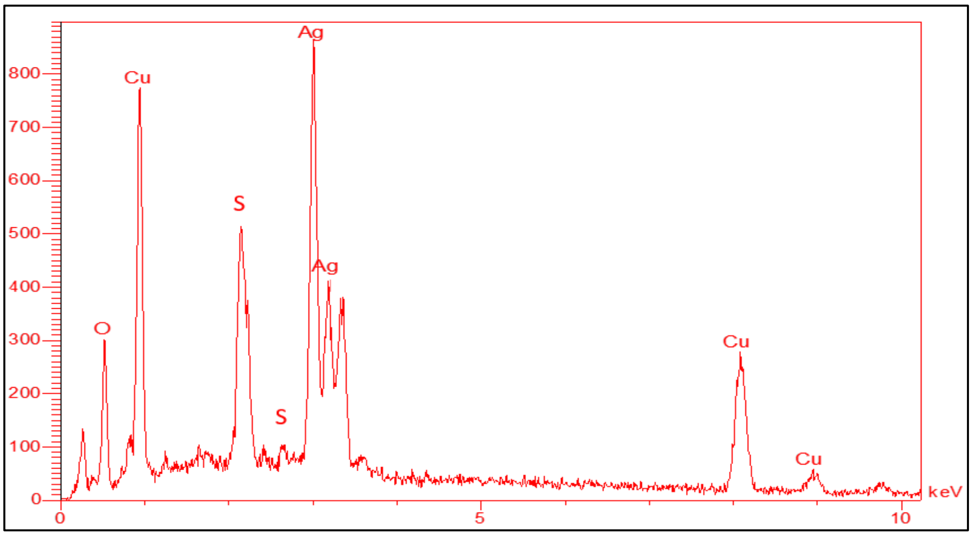

Figure 3. EDS spectrum of (CuO/**CdS/Ag₂O)** nanocomposite

Table 1. Elemental ratios of A: **($CuO/CdS/Ag_2O$)** nanocomposite

Element	Mass (%)	Atom(%)
Copper	33.85	19.21
Oxygen	11.36	29.35
Cadmium	14.16	27.52
Sulfur	12.08	17.27
Silver	27.58	6.65
Total	99.03	100

2.3.4. Optical properties

Optical Properties: The absorption spectroscopy reveals the optical properties of the prepared ternary nanocomposite ($CuO/CdS/Ag_2O$), as shown in **Figure 2-4**. The figure shows the absorbance versus wavelength and $(\alpha h\upsilon)^2$ versus $h\upsilon$ for $CuO/CdS/Ag_2O$ nanoparticles prepared by the precipitation method. Since each of the main components has known band gaps: CuO (1.2-2.70 eV), CdS (2.42 eV), and Ag_2O (1.2-3.4 eV), the energy band gap value of the composite is expected to be between or within the range of these individual values for the components and may be affected by the specific ratios and interactions within the nanocomposite. The energy band gap value of the ternary nanocomposite was calculated to be (2.63 eV).

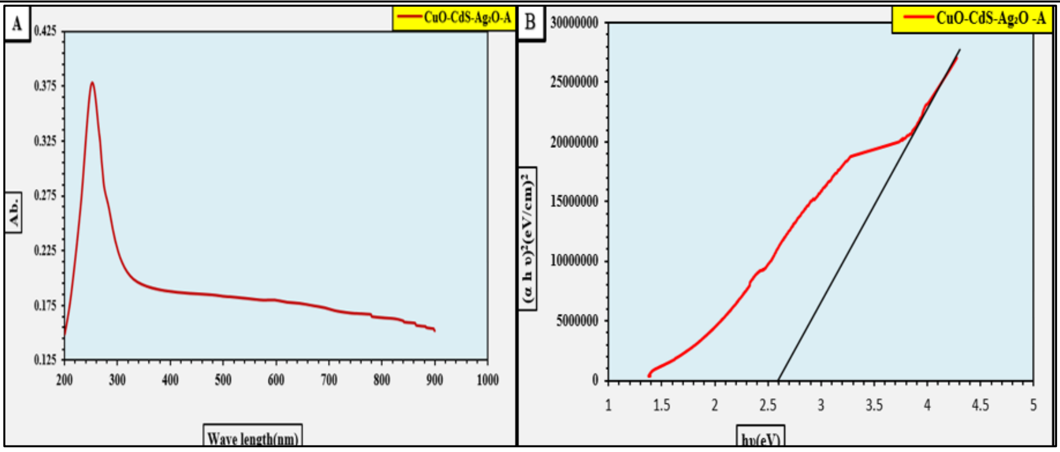

Figure 4. A) The absorbance spectrum B) the E_g optical energy band gap of $CuO/CdS/Ag_2O$

3. Applications of prepared nanocatalysts

The nanomaterials prepared in this study were applied in a practical application. The goal was to compare the efficiency of these nanomaterials with dye-sensitized FTO solar cells with a natural green dye (chard dye) and with an Industrial yellow dye (Quinoline yellow E104).

3.1. Fabrication of dye-sensitized solar cells

DSSCs were fabricated using the nanocomposites prepared in the study ($CuO/CdS/Ag_2O$) and used as photoelectrodes with two dyes (natural and synthetic): a green dye (chard) and a yellow dye (quinoline yellow E104) as absorbers. **Figure 4-1** shows the I-V and η characteristics of the DSSCs prepared using the nanosurface and the dyes mentioned above. The results showed that the efficiency of the DSSCs prepared with the green dye was better in terms of conversion efficiency (η) compared to the yellow dye, as shown in **Table 4-1** and **Figure 4-1**.

There are several reasons, including the difference in energy band gap, which is larger for the yellow dye (3.612 eV) than for the green dye (3.19 eV). As a result, more wavelengths of light pass through the cells to be absorbed by the dye [19], as shown in **Figure 4-2**. Second, the absorption of the green dye on the surfaces of the nanomaterials increases, leading to an increase in the efficiency of the DSSC cells. In addition, the current generated by DSSCs with the synthetic yellow dye is lower than that of DSSCs made with the green dye due to the high concentration of natural dye impurities [20]. Furthermore, the lower value obtained for the synthetic DSSCs is also due to the lower intensity of the light source used (22.53 mW/cm²).

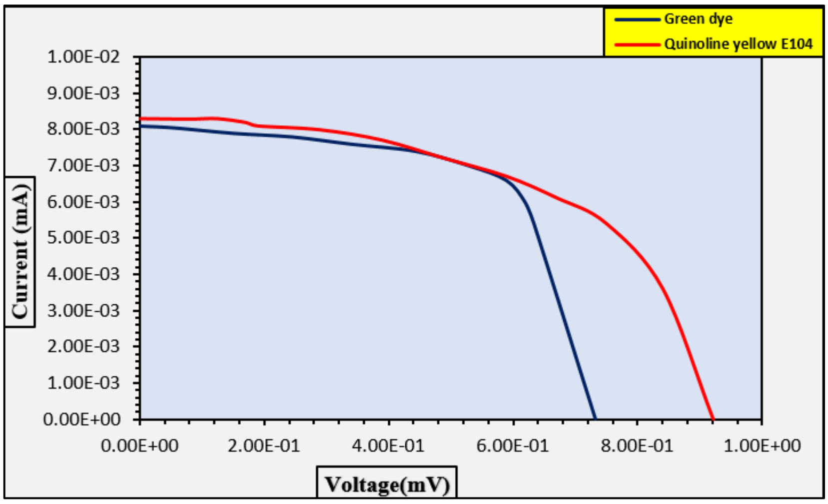

Figure 5. I-V characteristics of prepared DSSCs nanoparticles and Nanocomposite prepared with green dye (*chard*) and yellow dyes

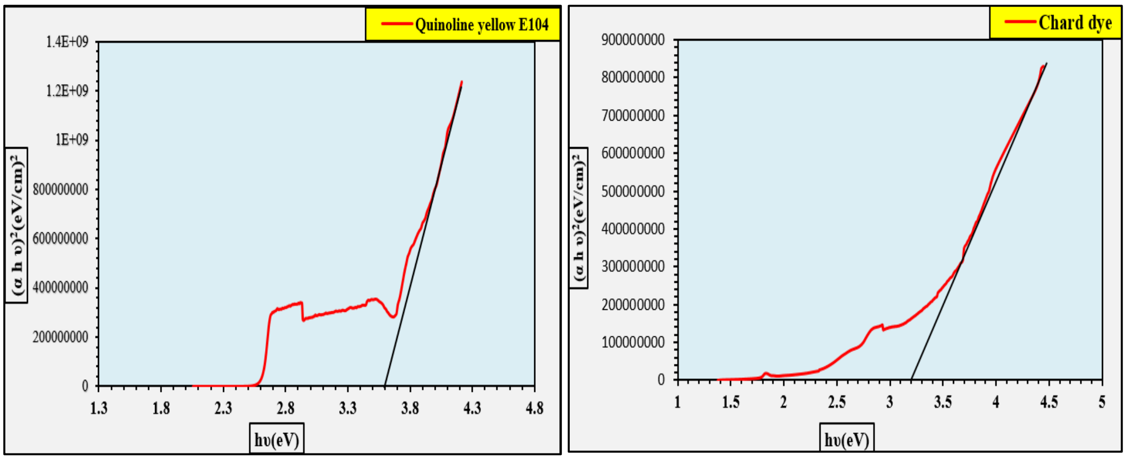

Figure 6. The optical energy band gap Eg for the green and yellow dyes

Table 2. Photo electrochemical parameters of DSSCs (A = 4.5 cm^2) under light intensity (22.53 mW/cm^2)

Catalyst/Dye		ISC (mA)	V_{oc} (V)	Imax (mA)	Vmax (V)	FF	η
$CuO/CdS/Ag_2O$	Yellow dye	0.938	93.75	0.74	84	0.707	0.1381
	Green dye	1.0125	91.5	0.92	74	0.735	0.1513

4. Conclusions

1. Triangular $CuO/CdS/Ag_2O$ nanoparticles were prepared using the precipitation method.
2. The prepared nanoparticles were characterized using various techniques, such as FE-SEM, XRD, and EDX, to study their structure and surface characteristics, as well as their properties and effectiveness.
3. The $CuO/CdS/Ag_2O$ nanoparticles demonstrated high efficiency as a light source in the DSSCS technique using natural and synthetic dyes, with better efficiency with the green dye compared to the yellow dye.

Due to the difference in energy band gaps between natural and synthetic dyes, the application of semiconductors (prepare nanoparticles) on FTO glass plates produces a uniform surface. Furthermore, the deposited graphite provides a more uniform and stable surface than using a candle (flame), which quickly removes the glass surface. Therefore, a permanent pencil is used on the surface of type 10B glass.

Conflict of interest

The authors declare no conflict of interest

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