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Research Article

CuO/CeO₂ NCs Preparation by PLAL Technique for Solar Cell Application

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ABSTRACT

In this work, using an environmentally friendly and inexpensive method, CuO/CeO₂ NCs were fabricated using the (PLAL)-pulsed laser ablation technique of a piece of CuO/CeO₂ NCs metal immersed in distilled water solution. The NPs were 25-75 nm, and they had an irregular spherical form. The polymeric composite films were prepared using the solution casting technique with equal weight ratios 50:50 wt.% and impregnated. UV-vis spectroscopy was utilized to determine a number of optical parameters, including the absorption coefficient and direct energy gap, absorption and thermal properties, where the results showed an increase in coefficient of Thermal conductivity with an increase in the percentage of CuO/CeO₂ NCs added.

KEYWORDS: CuO/CeO₂ NCs; PLA technique; environmentally friendly; solar cell

INTRODUCTION

They are widely used in fundamental and applied sciences, such as physics, chemistry, and biology, nanoparticles are very significant nowadays. Applications for nanoparticles are numerous and include the development of solar cell and other electrical devices [1-3]. Commercial and research applications in optical sensors, optical switching, color filters, and plasma/photonic systems make CuO/CeO₂ noble metal nanoparticle families vital. CuO/CeO₂ are important noble metal nanoparticle families due to their commercial and scientific applications in optical sensors, optical switching, color filters, and plasma/photonic systems. [4-5]. Research on metal nanoparticle–polymer composites has increased in recent years. An unusual nanocomposite material is made from nano-sized inorganic particles in the polymeric matrix [6]. Due to their optical, electrical, and mechanical characteristics, these nanocomposites are valuable in photo-imaging and patterning, optics, antimicrobial coatings, and solar cell development [7]. Due to their unique chemical and physical properties, nanoparticles (NPs) have attracted experts in physics, biology, chemistry, medicine, materials science, and photonics [8]. As per the findings of the literature search, there are currently no published reports on the production of CuO/CeO₂ nanocomposite. New composite materials that have been functionalized to perform specific and unique activities, such water filtration, have been produced recently by researchers [9]. [10] Examples of these devices are optical and electrochemical ones. These days, cost-effective and sustainable technologies, together with smart technologies, are becoming more and more popular [11]. Scientists have reported that mesoporous materials are used for the detection and extraction of heavy metal ions or trace elements [12-24]. The current study aims to introduce pulsed laser ablation techniques in order to provide spectroscopic examinations for the effect of CuO/CeO₂ dopants generated using these techniques.

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Despite the promising characteristics of CuO and CeO₂ nanoparticles, the synthesis of CuO/CeO₂ nanocomposites and their integration into polymeric matrices remains a challenging area of research. The problem lies in optimizing the synthesis of CuO/CeO₂ nanocomposites using an inexpensive, eco-friendly method, while also understanding the relationship between the nanocomposite concentration and the resulting changes in material properties such as optical energy gap, thermal conductivity, and overall performance. The relevance of CuO/CeO₂ nanoparticles in changing the polymeric matrix for solar cell applications, especially the effect of nanoparticle concentration on material performance, has not been extensively studied.

This study synthesizes CuO/CeO₂ nanocomposites (NCs) utilizing an ecologically friendly and cost-effective PLAL method. The research examines the structural, optical, and thermal characteristics of these nanocomposites, concentrating on how CuO/CeO₂ composition affects polymeric composite films. The study also examines how CuO/CeO₂ nanoparticles affect the polymer matrix's energy gap, thermal conductivity, and optical behavior, with a focus on solar cell applications.

The CuO/CeO₂ nanocomposites (NCs) utilizing the environmentally friendly and cost-effective PLAL method has been synthesized and characterized in this article. CuO/CeO₂ NCs' effects on polymeric composite film structural, optical, and thermal characteristics are studied. We study the energy gap, thermal conductivity, and optical behavior of CuO/CeO₂ NCs by altering concentration. The findings show that adding CuO/CeO₂ NCs to polymer matrices significantly alters these characteristics, which may improve composite performance for solar cells and other optoelectronic devices.

EXPERIMENTAL

MATERIALS

In this experiment, a 99.9 copper, cerium metal plate (8.5×3.3×0.3 mm, 0.8 gm) was used. The composite sample also included two polymers: CMC carboxymethyl cellulose polymer, a white powder [25].

PREPARATION OF CuO/CeO₂ NPS

This work used a liquid pulse laser ablation technique (PLAL) to manufacture gold nanoparticles (CuO/CeO₂) for a piece of high-purity metal. The metal was washed with liquid ethanol and water several times to remove impurities, then irradiated with a Nd:YAG device at 1064nm, 10Hz, 300 pulses, and 200 mj.

Polymer are dissolved separately in a solution of pure distilled water (DW), then the quantity is mixed with equal weights (50%: 50wt) and stirred for an hour with a magnetic mixer at a temperature of 50 degrees Celsius, then different volume ratios of (CuO/CeO₂ NPs) are added to the mixture for each energy (10 mL) and continue stirring for another hour until the mixture is homogeneous and its color changes from transparent to pink by increasing the content of CuO/CeO₂ nanoparticles inside the matrix (Cellulose) [26].

CHARACTERIZATION TECHNIQUES

The surface morphology of gold nanoparticles (CuO/CeO₂ NPs) was investigated by scanning electron microscopy (SEM) to analyze laser-ablated nanoparticle size and form. Magnification of 15.00,20.00kx and UV-vis absorbance spectra were measured for the polymeric nanocomposite samples and it was measured within a range of wavelengths from 190-1200 nm.

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RESULT AND DISCUSSION

XRD

X-diffraction The Shimadzu-6000 X-ray diffraction apparatus was used to analyze materials at a wavelength of 1.54060 \AA and an effort difference of 40 KV. Fig. 1 shows the (XRD) for CuO-CeO₂ NCs synthesized via the chemical method at (200) °C [14]. CuO-CeO₂ NCs have distinctive peaks at angles according to XRD ($2\theta = 29.5, 35.43^\circ, 39.04^\circ, 49.20^\circ, 62.55^\circ$) at the crystal planes (311) and (110) , respectively , Which refers to obtaining CuO-CeO₂ NCs of cubic crystal structure with and The dimensions ($a=b=c=4.0589 \text{ \AA}$) and crystal angles ($\alpha=\beta=\gamma=90^\circ$) match the standard card (JCPDS 34-0394) [27].

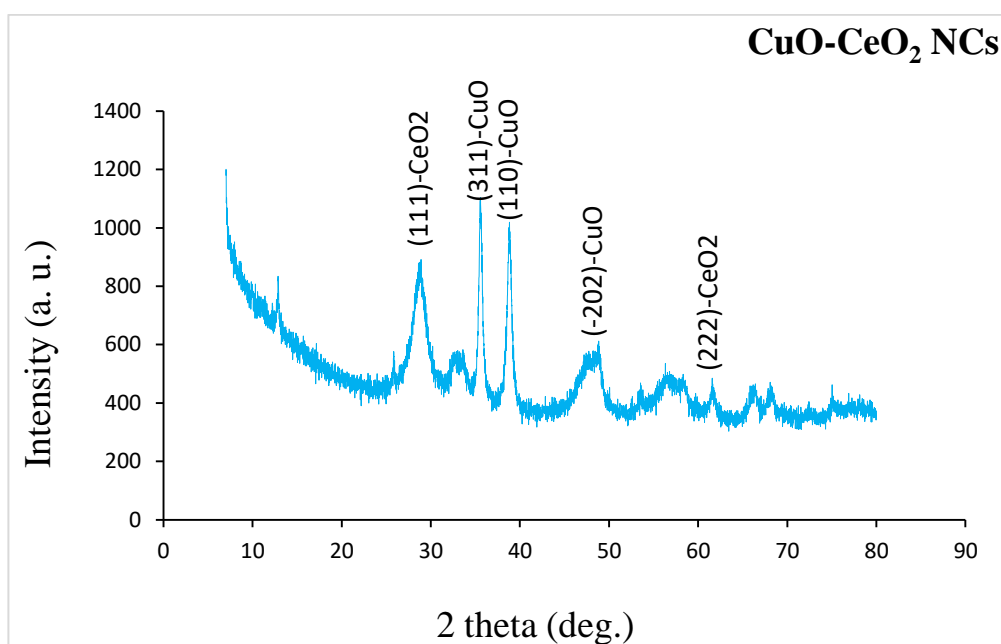


Fig. 1. (XRD) pattern for CuO-CeO₂ NCs sample

Average crystalline size calculation was done using Debye-Scherrer formula for CuO-CeO₂ NCs preparation using the chemical method using the cellulose extract to be equal to (10 -25 nm) , Table 1 show the values of some crystalline parameters extracted from the X-ray Diffraction test for CuO-CeO₂ NCs preparation using the chemical method using cellulose extract [28]. Higher temperatures increase crystalline growth and size.

Table 1. XRD parameters for CuO-CeO₂ NCs sample

2θ (deg) Practical	2θ (deg) Standard	FWHM (deg)	Crystalline size (nm)	dhkl (°A) Practical	dhkl (°A) Standard	(hkl)
29.29	29.29	0.41014	16.700	2.7428	2.35	(111)
35.43	35.43	0.89139	10.630	2.3235	2.03	(311)
39.04	39.04	0.296656	25.360	1.6344	1.44	(110)
49.20	49.20	0.68069	9.0640	1.5261	1.23	(-202)
62.55	63.00	0.285543	27.087	1.5432	1.24	(222)

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FE-SEM OF CuO/CeO₂ NCs

The particle size, and morphological were characterization via FE-SEM equipped FE-SEM images of CuO/CeO₂ NCs preparation using the chemical method using the cellulose extract, as shown in fig. A, B, C, D, E, and G, respectively, from fig. it has been shown that the formation of CuO/CeO₂ NCs. CuO/CeO₂ NCs have rod, and spherical shape in most samples [29]. The Aggregation is not noticeable and with increasing the temperature leads to increases the average size 34 to 56 nm and the spherical nanoparticles of CuO/CeO₂ NCs. This is consistent with XRD assay; at higher energies the particles were more crystallized.

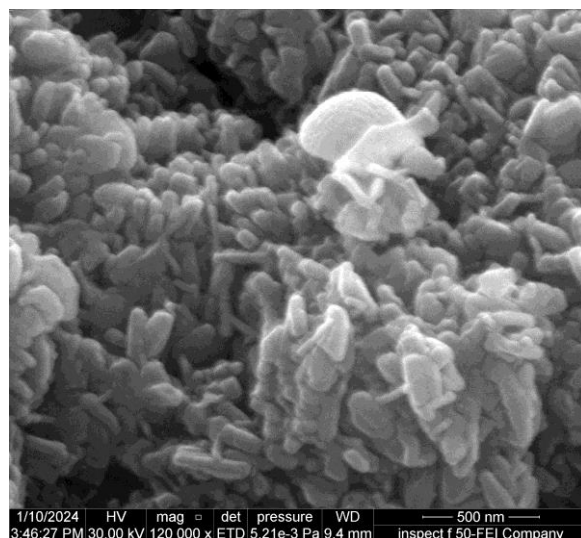


Fig. 2. FE-SEM images of CuO/CeO₂ NCs preparation using the chemical method using the cellulose extract

EDX

Table 1 and Fig. 3 present the elemental composition of the CuO/CeO₂ nanocomposites, as revealed by EDX analysis, confirms the presence of oxygen (O), copper (Cu), and cerium (Ce) as the primary constituents. Oxygen, with a weight percentage of 27.01% and an atomic percentage of 63.58%, is the most abundant element in atomic terms, reflecting its critical role in forming the oxide phases (CuO and CeO₂). Copper exhibits the highest weight percentage of 51.86%, corresponding to an atomic percentage of 30.74%, indicating its dominant contribution to the nanocomposite structure, particularly in the CuO phase. Cerium, with a weight percentage of 21.13% and an atomic percentage of 5.68%, signifies its role in the CeO₂ phase, which provides catalytic and electronic properties. These values collectively confirm the successful integration of the CuO and CeO₂ phases, essential for the functional performance of the nanocomposites in solar cell applications. The observed elemental ratios align well with the stoichiometric expectations for CuO/CeO₂ nanocomposites, validating the material's composition.

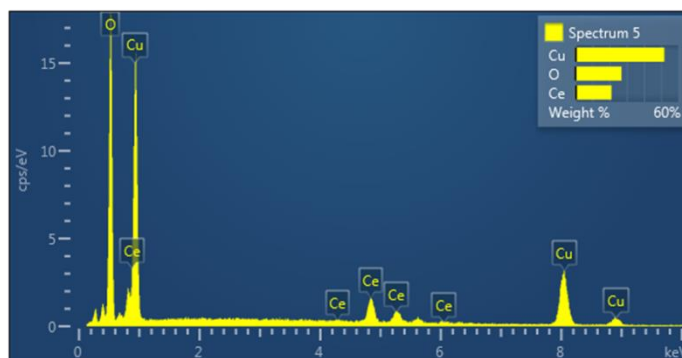


Fig. 3. EDX of CuO/CeO₂ NCs

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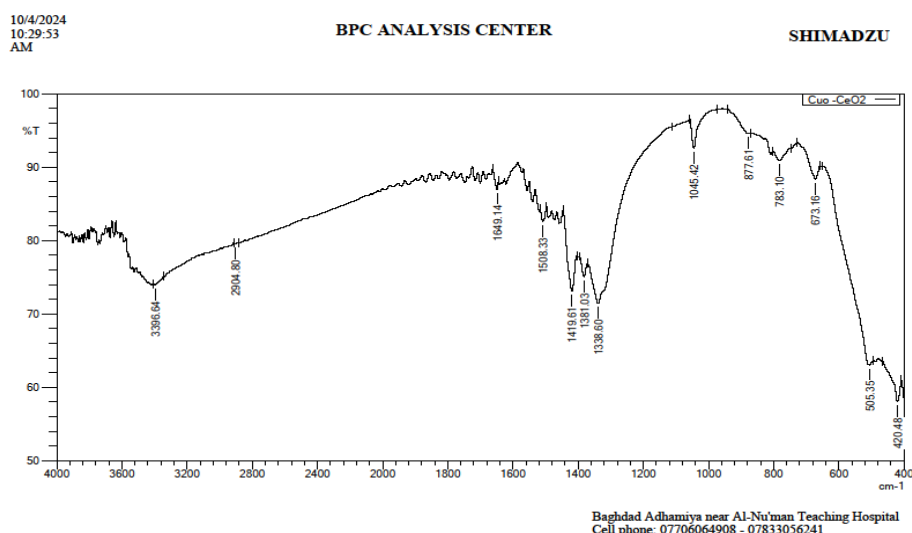
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Table 2. Elemental composition of CuO/CeO₂ nanocomposites analyzed using EDX

Element	Line Type	Apparent Concentration	k Ratio	wt.%	wt.% Sigma	Atomic %	Standard Label	Factory Standard	Standard Calibration Date
O	K series	4.45	0.01497	27.01	0.37	63.58	SiO ₂	Yes	
Cu	L series	2.44	0.02439	51.86	0.53	30.74	Cu	Yes	
Ce	L series	1.52	0.01418	21.13	0.57	5.68	CeO ₂	Yes	
Total				100.00		100.00			

FTIR

The Fourier Transform Infrared (FTIR) spectrum of the CuO/CeO₂ nanocomposites (Fig. 4) reveals the presence of various characteristic peaks, which provide insights into the vibrational modes of the functional groups and chemical bonds within the material. The wavenumber data corresponds to the following observations: 3996.64 cm⁻¹ and 2904.80 cm⁻¹: These high-wavenumber peaks are attributed to O–H stretching vibrations, indicating the presence of hydroxyl groups on the surface of the nanocomposites. Such hydroxyl groups may arise from adsorbed water molecules or surface hydroxylation of the oxides. 1649.14 cm⁻¹: This peak corresponds to the bending vibration of H–O–H, further confirming the presence of adsorbed water molecules in the nanocomposite material. 1508.33 cm⁻¹ and 1419.61 cm⁻¹: These peaks are likely associated with symmetric and asymmetric stretching vibrations of C=O or C–O groups, suggesting the presence of carbonate species adsorbed on the surface of the CeO₂ phase. 1381.03 cm⁻¹ and 1338.60 cm⁻¹: These peaks can also be linked to the stretching vibrations of carbonate ions, which often form due to the interaction of cerium oxide with ambient CO₂. Peak at 1045.42 cm⁻¹ may indicate C–O stretching vibrations from organic residues or surface-modified carbonates. Peaks at 877.61 cm⁻¹ and 783.10 cm⁻¹ indicate significant bonding of cerium oxide in the composite structure, implying Ce–O–C vibrations or metal-oxide bonding interactions. Peaks at 673.16 cm⁻¹ and 505.35 cm⁻¹ indicate the existence of the CuO phase in the nanocomposite material due to Cu–O stretching vibrations. The low-wavenumber peak at 420.48 cm⁻¹ is due to Ce–O stretching vibrations which are typical of the CeO₂ phase.

**Fig. 4. FTIR Analysis of CuO/CeO₂ NCs**

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PL

In Fig. 5, photoluminescence (PL) examination of CuO/CeO₂ nanocomposites under 330 nm excitation with 10–20 nm slits and a 360 nm filter shows two strong emission peaks at 319.07 and 662 nm. These peaks provide insights into the electronic and optical properties of the material. 319.07 nm (1000 intensity): This peak, located in the UV region, is associated with near-band-edge (NBE) emission. It originates from the recombination of excitons (electron-hole pairs) near the conduction and valence band edges, which is characteristic of the CeO₂ phase. The high intensity of this peak indicates strong quantum confinement effects or efficient radiative recombination in the CeO₂ component of the nanocomposites. 662 nm (772.475 intensity): This peak, situated in the visible region, corresponds to defect-related emission. It can be attributed to oxygen vacancies or surface defects within the CuO and CeO₂ phases. Such defect states often act as radiative centers, facilitating emissions in the visible range. The moderate intensity of this peak highlights the presence of structural imperfections, which are typical in oxide nanomaterials and play a crucial role in their optical properties.

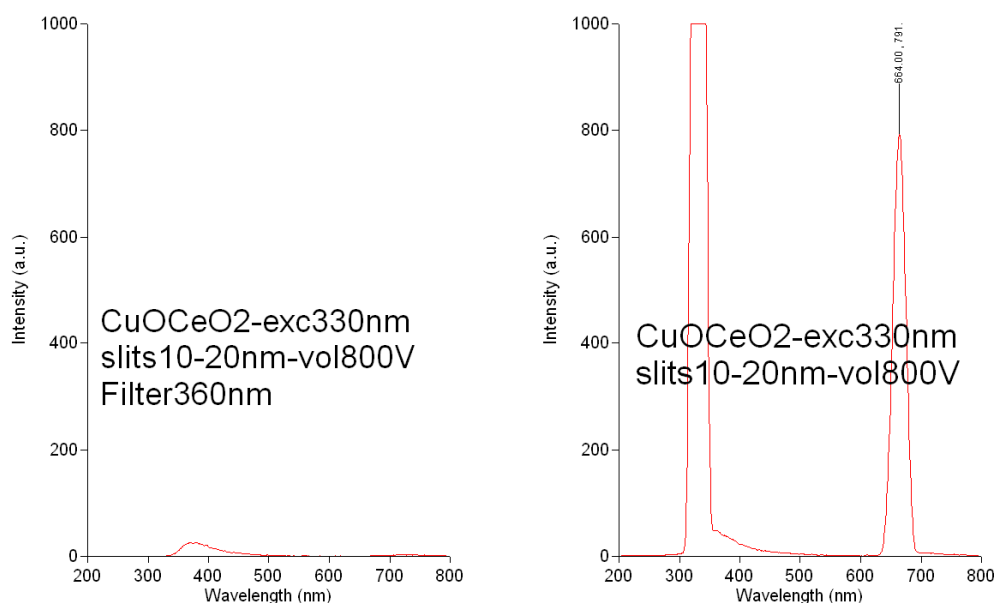


Fig. 5. Photoluminescence (PL) spectrum of CuO/CeO₂ nanocomposites under 330 nm excitation, showing prominent peaks at 319.07 nm (UV emission) and 662 nm (visible emission), corresponding to near-band-edge recombination and defect-related states, respectively

RAMAN

Fig. 6 presents the Raman analysis of the CuO/CeO₂ nanocomposites reveals a characteristic peak at 475.889 cm⁻¹, with an intensity of 35.639. This peak is significant for understanding the structural and vibrational properties of the material. 475.889 cm⁻¹ Peak: This peak is attributed to the Cu–O stretching vibration in the CuO phase. This peak indicates copper oxide (CuO) inclusion in nanocomposites. Raman peaks in this range are indicative of the CuO monoclinic phase, where lattice vibrations strain the copper-oxygen bond. The intensity suggests intermediate crystallinity and copper oxide.

The peak at 475.889 cm⁻¹ indicates that the CuO phase is well-formed in CuO/CeO₂ nanocomposites, enhancing structural stability. For the nanocomposite to work effectively in catalytic processes and solar cell devices, the CuO lattice must be well-organized. The Raman peak's sharpness and location indicate this.

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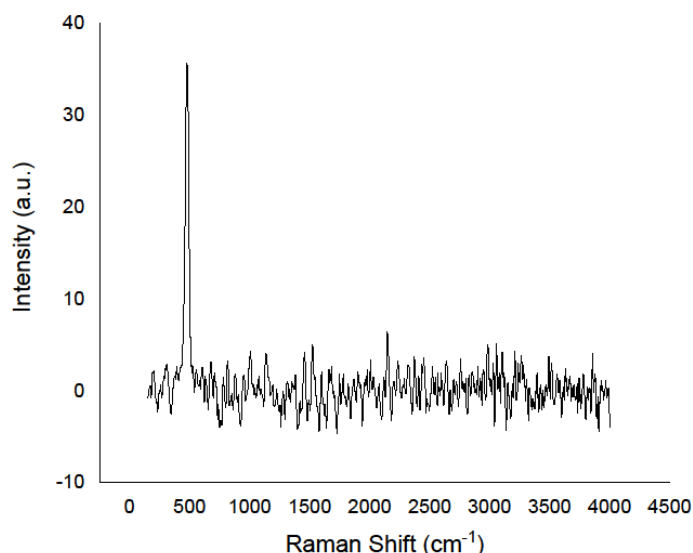


Fig. 6. A peak at 475.889 cm⁻¹ in the Raman spectra of CuO/CeO₂ nanocomposites indicates the existence of the CuO phase due to Cu–O stretching vibrations

CONCLUSION

Different concentrations of CuO/CeO₂ NCs particles were successfully incorporated into the polymer mixture by solution PLA technique, and XRD confirmed the formation of those NCs by showing characteristic diffraction values. It was crystallized at high energies with a cubic structure in FCC phase. The EDX analysis confirms the successful synthesis of CuO/CeO₂ nanocomposites with the expected elemental composition. The high oxygen content reflects the oxide nature of the materials, while the substantial presence of copper and cerium indicates the formation of the CuO and CeO₂ phases, respectively. These findings align with the anticipated composition for solar cell applications, where the complementary properties of CuO and CeO₂ enhance light absorption and charge carrier dynamics. The Raman peak at 475.889 cm⁻¹ in the CuO/CeO₂ nanocomposites confirms the presence of the CuO phase and provides insights into the vibrational characteristics of copper-oxide bonding. This feature supports the structural integrity of the material, making it suitable for applications where both CuO and CeO₂ phases play a role in enhancing material properties such as optical behavior, photocatalytic activity, and solar cell performance. Nanomaterial This leads to potential future applications such as solar cell.

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