

Optimizing Structural, Optical and Photovoltaic Properties of Cobalt Spinel Ferrite with Cerium Substitution: Implications for Next-Generation Solar Cells

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Abstract: The growing demand for sustainable and efficient energy solutions has driven research into advanced materials for next-generation solar cells. This study investigates the effects of cerium (Ce) substitution on the structural, optical, and photovoltaic properties of cobalt spinel ferrite (CoFe_2O_4), a material known for its favorable magnetic and semiconducting properties. The advantages of CoFe_2O_4 for fabricating efficient photovoltaic devices are investigated in this work. Cerium substituted Cobalt ferrites, $\text{Ce}_x\text{CoFe}_{2-x}\text{O}_4$; ($x=0, 0.02, 0.04, 0.06, 0.08, 0.1$) were successfully synthesized using microwave-assisted sol-gel technique. Detailed structural analysis using X-ray diffraction (XRD) and scanning electron microscopy (SEM) revealed changes in crystallite size, lattice parameters, and morphology due to cerium substitution. It is noted that the crystallite size decreases ranging from 24nm to 21nm with Ce concentration having a spinel structure. Optical properties were analyzed through UV-vis spectroscopy, indicating tuning of the bandgap, which is crucial for improving light absorption in the visible region. The results suggest that the CoFe_2O_4 possesses significant photovoltaic property under direct sunlight. The EDAX study confirms the absence of impurities. The bonding Formation of CoFe_2O_4 was

studied by FTIR. The photovoltaic properties were further analysed by current-voltage (I-V) measurements under direct sunlight. The results highlight the potential of Ce-substituted cobalt ferrite as a promising material for improving the efficiency of solar energy devices, paving the way for its application in future photovoltaic technologies.

Keywords: Photovoltaic, solar cell, XRD, sol-gel, ferrite.

1. Introduction

The demand for effective and sustainable photovoltaic materials has increased since the world's shifting towards renewable energy sources as solar energy offers a practical way to fight climate change and energy insufficiency. Cobalt spinel ferrite (CoFe_2O_4) has drawn a lot of interest among the several materials that are researched for solar cell applications because of its useful qualities, which include good magnetic properties, excellent thermal stability, and an appropriate band gap for light absorption¹. However, the performance of CoFe_2O_4 in photovoltaic devices is limited by its inherent constraints, which include low electrical conductivity and menial optical characteristics².

Rare-earth elements have emerged as a key area of study in recent years due to their wide range of applications in solid-state lighting, bio-imaging, and solar cells³⁻⁵. Due to their high light conversion efficiency, silicon-based solar cells are in high demand; nevertheless, the spectrum mismatch between the silicon absorption region and the actual solar radiation prevents them from achieving the intended efficiency^{6,7}. The primary way that energy is lost from Si-solar cells is by thermalisation, which is brought on by the absorption of incident photons with high or low energy. These losses can be reduced by using a layer that either up-converts or down-converts solar cells to increase efficiency. To increase the efficiency of PV cells, a promising method of solar spectrum conversion through the coating of down-converting phosphors has been tried in this work. The process by which high-energy photons are transformed into low-energy photons is known as down-conversion.

Researchers are progressively using rare earth element substitution as a promising tactic to improve the functional characteristics of cobalt spinel ferrite⁸. Cerium (Ce) is notable for its unique electronic configuration, allowing it to exist in multiple oxidation states (Ce^{3+} and Ce^{4+})⁹. This flexibility can produce defect states in the crystal lattice, which are crucial for magnifying the efficiency of solar cells because they boost charge transport and decrease electron-hole recombination. According to previous research, cerium substitution can improve ferrite's optical absorption characteristics

and electrical conductivity, which makes them more suitable for usage in solar energy applications¹⁰.

Although silicon-based solar cells that are sold commercially are effective solar energy converters, efforts have been made to increase their efficiency by considering surface modification, defect control, and device optimisation¹¹. The thermalisation process seems to be the primary cause of the significant radiation loss, hence downshifting is the best way to improve efficiency. In this process, high-energy photons from incident radiation are transformed into low-energy photons. Rare earth elements based on lanthanides are shown to be more effective in the downshift¹².

The fact that commercially available solar cells have strong surface reflection properties is yet another factor that makes surface modification a crucial component. This characteristic causes 30% of incident energy to be reflected, which ultimately reduces the solar cell's efficiency. As a result, efforts were made to increase its efficiency by applying coating materials to the solar cell's surface¹³.

In the proposed work, Ce^{3+} substituted cobalt spinel ferrites were synthesized by a microwave-assisted sol-gel technique using urea as a fuel. The primary goal of this research is to increase solar cell efficiency by coating a thin layer of prepared samples on solar cells by using Dr Blade method. Commercially available silicon solar cells were successfully coated with the as-synthesised material, and the I-V parameters of the coated solar cell were assessed at 38 °C and in direct sunshine using an air mass ratio of 1.5. Under direct solar radiation, the coated solar cell's efficiency increased by 23.01%. These see the application of synthetic material as a viable option for enhancing the efficiency of solar cells.

The main objective of this research work is to find a relationship between cerium doping levels and cobalt spinel ferrite's performance in solar cell applications which will provide important new information for sophisticated PV materials, opening the door for more sustainable and efficient solar cells of the future.

2. Experimental and Characterization Details

Cerium-substituted Cobalt Ferrite ($\text{Ce}_x\text{CoFe}_{2-x}\text{O}_4$: with $x = 0, 0.02, 0.04, 0.06, 0.08, 0.10$) was synthesised using a microwave-assisted sol-gel technique using urea as fuel. The stoichiometric proportions of AR grade powder of cobalt nitrate ($\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$), ferric nitrate ($\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$), and cerium nitrate ($\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$) were dissolved in 30ml of distilled water adding the required urea ($\text{CH}_4\text{N}_2\text{O}$) in it as a fuel. The mentioned

compounds were weighed in the required molar proportion using a digital weighing balance. The mixtures of precursors were dissolved in distilled water in a borosil beaker. The beaker-containing solution was introduced into a hot plate magnetic stirrer. The solution was then allowed to form a gel by the slow drying process. Then the formed gel was kept in a microwave oven for instant fire at 600 watts to obtain burnt ash powder. The ash powder is then followed by intermediate grinding in the pestle mortar for 3-4 hrs. The synthesized ferrites were kept in the crucible and sintered at 800°C for 4 hours in a muffle furnace. Then powdered samples were further grinded for another 3 hours to obtain the final product.

The phase recognition of materials was obtained by using X-ray diffraction (XRD) using Cu Ka- radiation in the range of 10 -80° of the 2 θ . The low angle XRD patterns were recorded by Bruker (D8 Advance machine, Germany) x-ray diffractometer using CuK α radiation (1.5418 Å). The spectra were taken at a grazing angle of 1°. The surface morphology of the powder samples was analyzed by Scanning Electron Microscopy (SEM). SEM micrographs were taken with the help of a scanning electron microscope SEM (JEOL, JSM 6390LV) operated at an accelerating voltage of 20KV. An FTIR spectrophotometer (JASCO, 6100-type A) was used to record FTIR spectra in transmission mode throughout the 400–4000 cm⁻¹ range. The optical properties such as band gap and absorbance of the CoFe₂O₄ at various cerium concentrations were investigated from UV-visible spectroscopy. Using a double-beam UV-visible spectrophotometer (Jasco, Japan, Model: V-670), the absorbance spectra were captured. These characterizations were performed at room temperature, *I*–*V* characteristics of the blank and coated solar cell were evaluated under direct sunlight at 38 °C for comparison¹⁴.

3. Results and discussion

3.1 XRD analysis

The XRD pattern of the synthesised Ce substituted CoFe₂O₄ samples calcinated at 800 °C is shown in Figure 3.1. From the XRD pattern, it is observed that the obtained diffraction peaks can be indexed with the spinel face centred cubic symmetry and the crystallographic peaks are well matched to the standard powder diffraction data, JCPDS Card No. 22-1086. The high intensity and sharpness of the obtained peaks indicate good crystallinity. The obtained Miller indices (220), (103), (311), (400), (511), and (440) are substantially indexed with the spinel CoFe₂O₄ structure. Similar results confirming the retention of the spinel structure with rare earth substitution have been reported¹⁵. As the concentration of cerium increases, the diffraction peaks gradually move to lower 2 θ values, indicating an expansion of the

lattice parameter. This is explained by the larger Ce^{3+} ions ($1.03 \text{ \AA}$) replacing the smaller Fe^{3+} ions ($0.64 \text{ \AA}$). Lattice expansion improves electrical conductivity and ionic mobility by lowering electron hopping energy, which is beneficial for solar cell charge transport layers¹⁶.

The crystallite size D was calculated using the Debye-Scherrer equation as follows:

$$D = \frac{0.9 \lambda}{\beta \cos \theta}$$

where λ is the wavelength of the X-ray, β is the Full Width at Half Maximum (FWHM) value of diffraction peaks and θ is the Bragg diffraction angle. The calculated average crystalline size at different cerium concentrations varies from 24.69-21.61 nm and, we found minimal shifts in angles and changes in the intensity as shown in Figure 3.1 According to the Scherrer equation, a decrease in crystallite size is suggested by the broadening of peaks with greater cerium concentrations. For solar cell applications, a larger surface area is provided by smaller crystallite sizes. This increased surface area enhances dye loading in dye-sensitized solar cells (DSSCs), which improves light absorption and energy conversion^{17,18}.

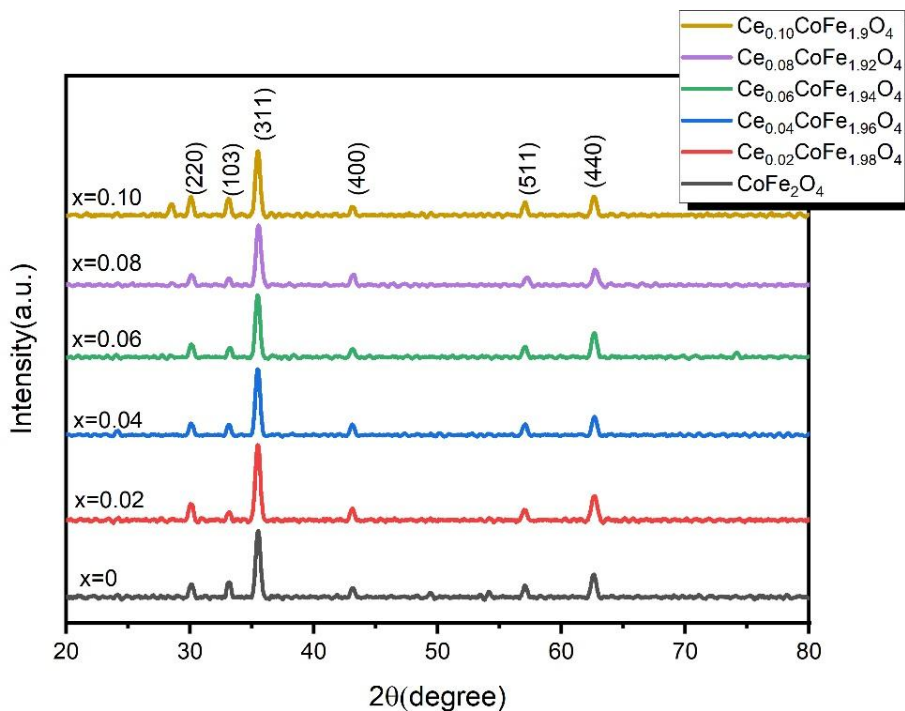


Figure 3.1: XRD pattern of cerium substituted cobalt spinel ferrite

Table 1: The change in values of lattice constant, crystallite size, d-spacing, dislocation density and strain with cerium concentration.

$\text{Ce}_x\text{CoFe}_{2-x}\text{O}_4$	Lattice Constant (a) (Å)	D (Crystallite Size) (nm)	d-spacing (Å)	Dislocation Density (ρ) ($\times 10^{-3} \text{ nm}^{-2}$)	Strain (ϵ) ($\times 10^{-3}$)
CoFe_2O_4	8.3798	24.691	2.5266	1.640	2.7
$\text{Ce}_{0.02}\text{CoFe}_{1.98}\text{O}_4$	8.3847	22.140	2.5281	2.040	2.8
$\text{Ce}_{0.04}\text{CoFe}_{1.96}\text{O}_4$	8.3855	22.400	2.5283	1.992	2.7
$\text{Ce}_{0.06}\text{CoFe}_{1.94}\text{O}_4$	8.3867	23.038	2.5287	1.886	2.6
$\text{Ce}_{0.08}\text{CoFe}_{1.92}\text{O}_4$	8.3706	21.107	2.5238	2.244	2.8
$\text{Ce}_{0.10}\text{CoFe}_{1.90}\text{O}_4$	8.3847	21.617	2.5281	2.139	2.7

3.2. Sem analysis

Figure 3.2(a) and (b) show the scanning electron microscopy (SEM) micrographs of Ce-substituted CoFe_2O_4 . It is observed that the particles have self-assembled into an agglomerated structure with average particle sizes of the samples at $x=0$ and $x=0.02$ and centred around 45 and 25 nm, respectively. The particles are well interconnected, offering an improved surface area and mass transport property. The particles appear to be heavily aggregated. The main reason for this phenomenon is the high surface activity and strong magnetism of CoFe_2O_4 nanoparticles, consequently making it difficult to disperse them uniformly during the SEM sample preparation. The particles are still clearly visible as spheres with a limited diameter distribution, even though their edges are obscured by aggregation.

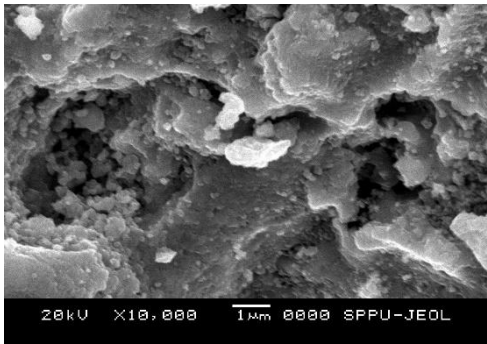


Figure 3.2 (a) Sem image at $x = 0$

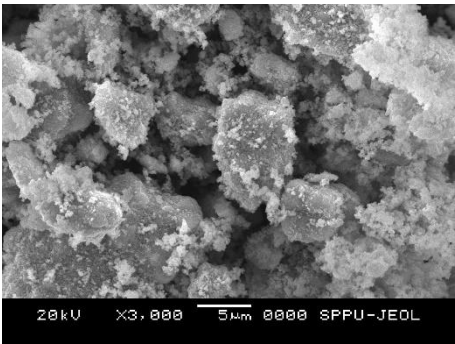


Figure 3.2 (b) Sem image at $x = 0.02$

Although the films consist of particles of slightly varying size the particles are almost spherical Fig. 3.3 reveal the EDS spectra of the synthesized CoFe_2O_4 nanoparticle, the presence of Co, Fe and O peaks confirm the formation of pure CoFe_2O_4 with no other elemental impurity.

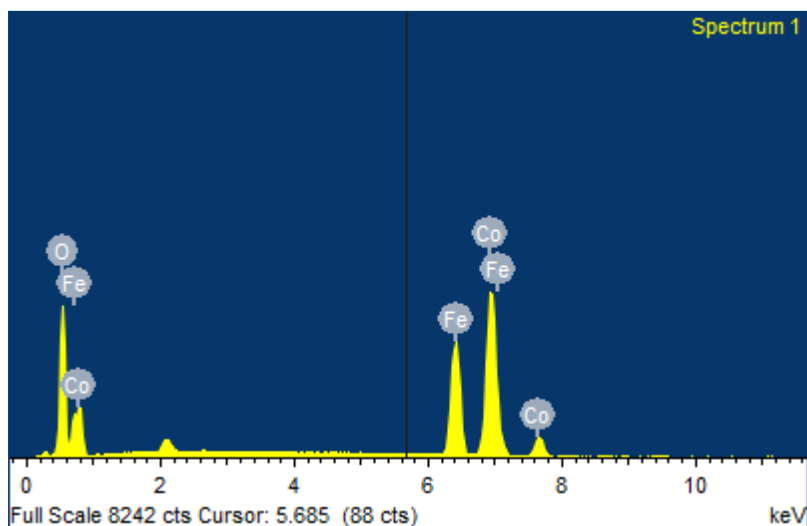


Figure 3.3: EDS spectra of the synthesized CoFe_2O_4 nanoparticle

3.3. UV Analysis

UV–visible absorption spectroscopy was used to investigate the optical properties of transition metal spinel ferrite nanostructures. Figure 3.4(a) shows the absorption profile of cerium-substituted CoFe_2O_4 . In the UV-Vis spectrum, the absorption edge gradually shifts toward longer wavelengths (redshift) as the cerium concentration increases. The UV-Vis absorption spectra of CoFe_2O_4 and cerium-doped CoFe_2O_4 samples exhibited strong absorption in the UV and visible regions, characteristic of ferrite materials. The strong absorbance in the visible region (400–800 nm) suggests that the material efficiently captures solar radiation within this range. Materials with such characteristics are desirable for solar cell absorber layers¹⁹. Cerium alters the electrical structure, most likely by adding intermediate energy levels to the bandgap, as seen by the gradual increase in absorbance with cerium substitution. Findings with rare-earth-doped ferrites, where rare-earth ions enhance light absorption by generating defect levels, are in line with this phenomenon²⁰. A redshift was shown by the absorption edge shifting towards longer wavelengths with cerium substitution. Cerium doping-induced alterations in the electronic structure, including bandgap modifications and localised states in the forbidden gap, are responsible for this shift.

For each sample, the optical bandgap (E_g) was determined using the Tauc plot method. The samples' Tauc plot displays a bandgap between 1.12 to 1.54 eV, which is within the optimal range of 1.1 to 1.5 eV for single-junction solar cells.

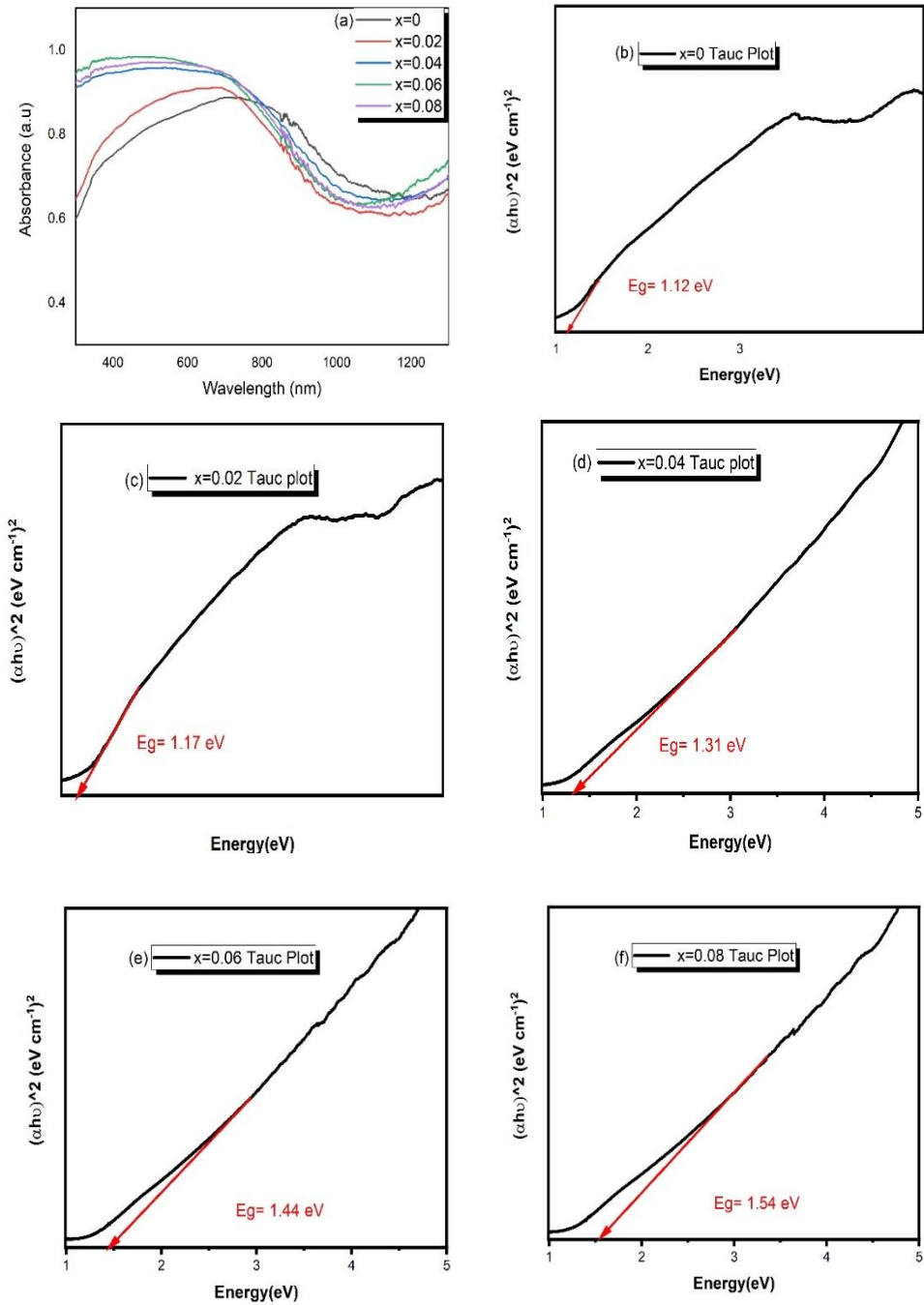


Figure 3.4 (a) Absorption spectra of cerium substituted cobalt spinel ferrite, Tauc plot at (b) x = 0, (c) x = 0.02, (d) x = 0.04, (e) x = 0.06, (f) x = 0.08.

This range optimises the trade-off between photon absorption and thermalisation losses, as described by Shockley and Queisser's efficiency limit (Shockley & Queisser, 1961). The bandgap of the undoped CoFe_2O_4 was around 1.12 eV, which is in line with values reported in the literature for spinel ferrites. The bandgap was systematically raised by the cerium substitution, reaching 1.54 eV at the maximum doping concentration. Fig 3.4 (b), (c),(d),(e),(f) shows the change in bandgap values with concentration of cerium.

Due to the introduction of localised states or changes to the electrical environment surrounding cobalt ions, cerium substitution may result in minor bandgap alterations. This impact is consistent with earlier research on ferrites rare-earth replacement²¹. The material's absorption across the visible and NIR regions indicates suitability as an active layer for solar cells. For example, tandem solar cells could benefit from combining this material with others to optimize light harvesting across the solar spectrum²⁰.

Table 2: The changes in bandgap with concentration of Cerium.

Cerium Concentration	Absorption Edge Shift	Bandgap (E _g) (eV)	Remarks
x = 0.00	No significant shift	1.12	Original CoFe_2O_4 with no cerium substitution.
x = 0.02	Slight redshift	1.17	Minor redshift due to initial cerium substitution.
x = 0.04	Moderate redshift	1.31	Noticeable redshift with increased cerium concentration.
x = 0.06	Notable redshift	1.44	Significant redshift with enhanced absorption in the visible region.
x = 0.08	Strong redshift	1.54	Maximum redshift, indicating substantial changes in electronic structure.

3.4 FTIR analysis

Fig. 3.5 shows the FTIR spectra of Ce doped CoFe_2O_4 prepared by microwave-assisted sol-gel method using urea as fuel and sintered at 800° C recorded between 4000 cm^{-1} and 400 cm^{-1} . The O–H stretching vibrations interacting through H bonds are observed at 3393 cm^{-1} , 2927 cm^{-1} and the absorption band present at about 1647 cm^{-1} is due to the bending of the absorbed water molecules. The absorption band at 1120 cm^{-1} is the characteristic of the cobalt ferrite system, possibly due to the residual FeOOH . The presence of spinel ferrite is demonstrated by the absorption bands at roughly 635 cm^{-1} , which are caused by the stretching vibrations of

metal oxide in the octahedral group complex Co(II)–O2 of the cobalt ferrite phase.

Fading and diminishing of the absorption band at 1647 cm^{-1} may be due to the desorption of water molecules after 0.06% Conc. Also, the characteristic 1120 cm^{-1} peak reappears after 0.08% Conc. This is due to the restructuring and affixing of the dopant % in the spinel structure with decreased strain.

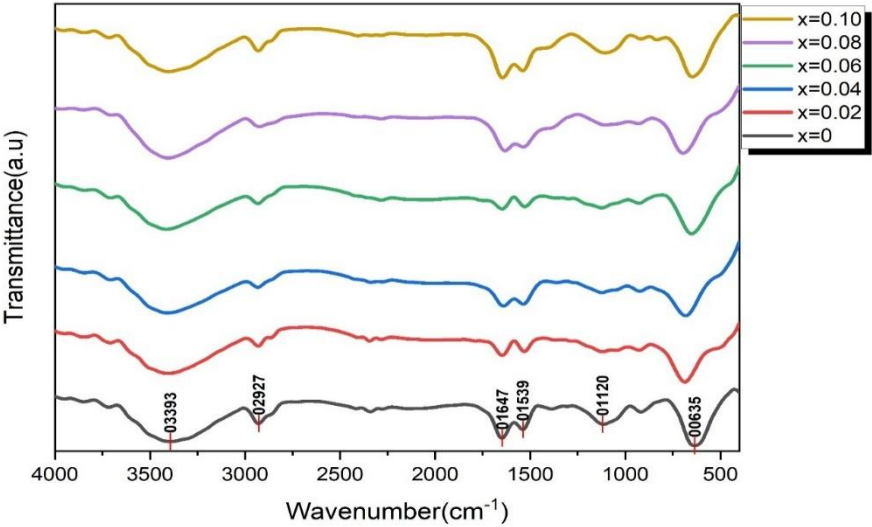


Figure 3.5: FTIR spectra of synthesized cerium substituted cobalt ferrite

3.5. IV characteristics

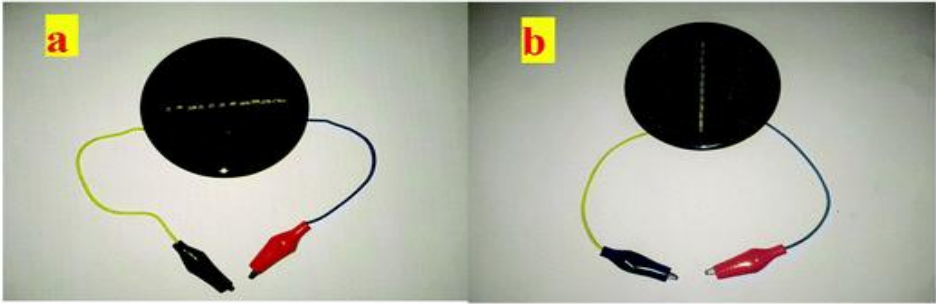


Figure 3.6 (a) Silicon solar cell without coating, (b) Coated silicon solar cell²²

The experiment was performed in open conditions at $38\text{ }^{\circ}\text{C}$ of temperature in the Nagpur Region (21.129516968235478, 79.06755089527041) at 12:30 pm on summer day 21 May 2024 in intense sunlight under constant temperature monitoring using a digital thermometer. The I-V properties of blank silicon solar cells were measured at the same temperature outside in direct sunlight.

This cell is then coated by $\text{Ce}_x\text{CoFe}_{2-x}\text{O}_4$ ($x=0,0.02,0.04,0.06,0.08$) by doctor blade method using terpineol, ethyl cellulose, ethanol, and acetic acid as a combined binder by taking them in a stoichiometric ratio. The blank solar cell and solar cell after being coated looks like this as reported as the synthesized sample is displayed in the Figure 3.6.

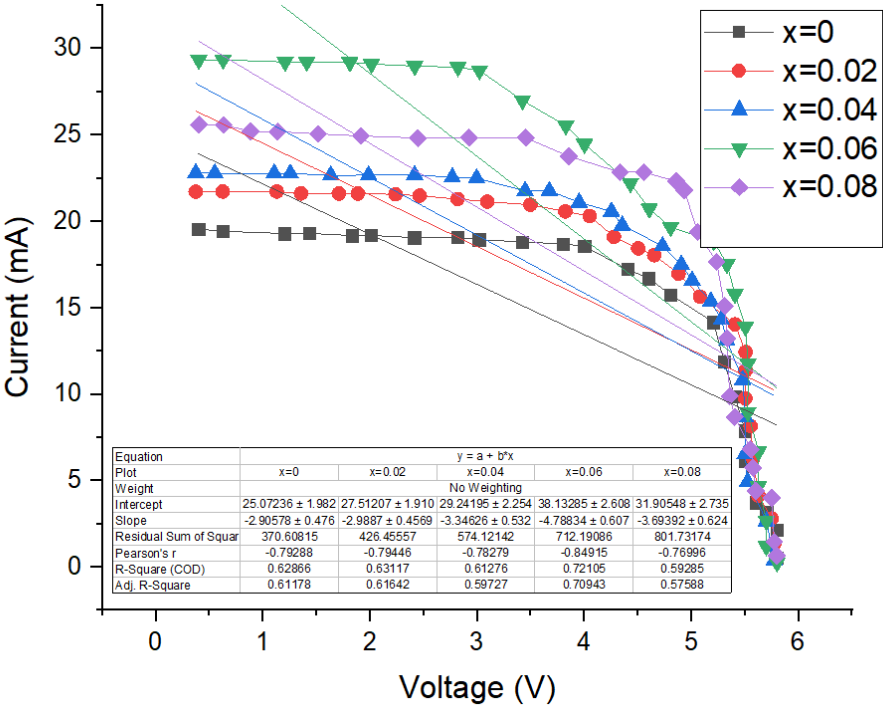


Figure 3.7: The plot of I-V characteristics under direct sunlight at different Ce^{3+} doping %.

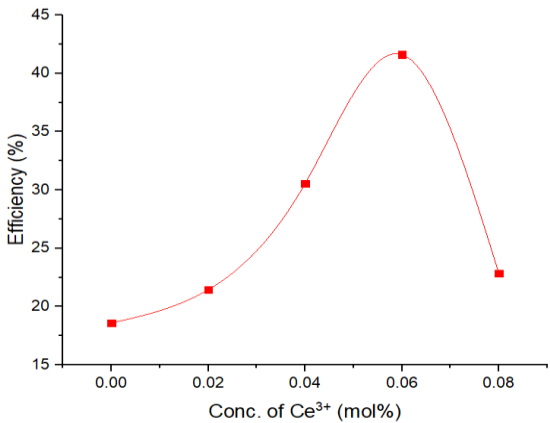


Figure 3.8: Efficiency enhancement by coating of Ce^{3+} doped CoFe_2O_4

The solar cell efficiency enhancement is determined by following the formula;

$$\text{Efficiency \%} = \frac{\text{slope of coated cell}}{\text{slope of without coated cell}} * 100 \%$$

It is observed that maximum solar cell efficiency is enhanced after coating of sample by 23.01% for $x = 0.06$ conc. of Ce^{3+} under direct sunlight.

4. Conclusion

A series of Ce^{3+} substituted cobalt spinel ferrite was synthesized by microwave-assisted sol-gel technique using urea as a fuel. The structural, optical, and photovoltaic properties of the proposed material were characterized using several characterization techniques. The crystalline nature of the proposed phosphor was characterized using XRD, which was then compared with the standard JCPDS Card No. 22-1086 which confirms the cubic spinel crystal structure of $\text{Ce}_x\text{CoFe}_{2-x}\text{O}_4$. XRD profile shows that all peak positions are in good agreement with the standard data. Increasing cerium concentration leads to lattice strain and slight reductions in crystallite size, as evident from peak broadening. The spherical shape and limited size distribution of the particles, despite significant aggregation, are explained by the strong magnetic properties and high surface activity of CoFe_2O_4 . These materials' connected particle structure, which boosts surface area and enhances mass transport properties, makes them suitable for applications needing high reactivity, such as solar cells or catalysis. Furthermore, the elemental purity of the synthesised CoFe_2O_4 is confirmed by the energy-dispersive X-ray spectroscopy (EDS) study. A redshift in the absorption edge with increasing cerium concentration is revealed by UV-visible absorption spectroscopy of cerium-substituted CoFe_2O_4 , suggesting improved optical characteristics brought about by structural changes. The strong absorption in the visible region (400–800 nm) highlights its potential for solar cell applications. Cerium doping introduces intermediate energy levels, which increase light absorption and systematically raise the bandgap from 1.12 eV to 1.54 eV, aligning with the optimal range for single-junction solar cells. These modifications, consistent with prior studies, improve photon capture and energy conversion efficiency, demonstrating the material's suitability for active layers in solar energy devices. Moreover, Ce^{3+} substituted CoFe_2O_4 was coated on solar cells and tested for IV characteristics. Results show enhancement in its efficiency by 23.01% under direct sunlight. Therefore, with all these results, we can conclude that Ce^{3+} substituted CoFe_2O_4 is a

potential candidate for solar cell efficiency enhancement, and a broad spectral converter for next-generation solar cells.

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References

1. N. Labchir, A. Hannour, A. Ait Hssi, D. Vincent, K. Abouabassi, A. Ihlal and M. Sajieddine; Synthesis and characterization of CoFe_2O_4 thin films for solar absorber application, *Mater Sci Semicond Process*, 111 (2020).
2. K. L. Routray, S. Saha, D. Behera, N. Tripathy and S. P. Ghosh; High dielectric constant, low loss and efficient visible photoluminescence properties of porous rose- flower shaped CoFe_2O_4 for photovoltaic application, *Mater Lett*, 242 (2019), 62-65.
3. R. Cao, W. Wang, J. Zhang, S. Jiang, Z. Chen, W. Li and X. Yu; Synthesis and luminescence properties of $\text{Li}_2\text{SnO}_3\text{:Mn}^{4+}$ -red-emitting phosphor for solid-state lighting, *J Alloys Compd*, 704 (2017), 124-130.
4. Y. Li, Y. Sun and Y. Zhang; Regional measurements to analyze large-area luminescent solar concentrators, *Renew Energy*, 160 (2020), 127-135.
5. N. Hamon, A. Roux, M. Beyler, J-C Mulatier, C. Andraud, C. Nguyen, M. Maynadier, N. Bettache, A. Duperray, A. Grichine, S. Brasselet, M. Gary-Bobo, O. Maury and R. Tripiet.; Pyclyen-Based Ln(III) Complexes as Highly Luminescent Bioprobes for in Vitro and in Vivo One- And Two-Photon Bioimaging Applications, *J Am Chem Soc*, 142 (2020), 10184-10197.
6. T. G. Allen, J. Bullock, X. Yang, A. Javey and S. De Wolf; Passivating contacts for crystalline silicon solar cells, *Nature Energy*, 4 (2019), 914-928.
7. A. Padhy, B. Vishal, P. Verma, G. Dwivedi and A.K. Behura; Fabrication of parabolic trough hybrid solar PV-T collector using a-Si thin film solar cells in Indian perspective, *Materials Today: Proceedings*, 38 (2020), 56-62.
8. H.Ghorbani, M.Eshraghi, A.A.Sabouri Dodaran, P.Kameli, S. Protasowicki, Camron Johnson, Daryoosh Vashae; Effect of Yb doping on the structural and magnetic properties of cobalt ferrite nanoparticles, (2021).
9. A.Prakash, A.Sagayaraj, R.Jayarajan, D.Aravazhi, S.Sebastian, S. Sylvestre, S. Nyanga, Cliv; Influence of Ce^{3+} (Rare Earth Element) on the Structural, Morphological, Impedance, Binding Energy and Ferrimagnetic Properties of Spinel ZnFe_2O_4 Nanoparticles Fabricated by the Coprecipitation Method: Antibacterial Activity, *Chemistry Africa*, 6 (2022).
10. M. Arslan, Ali Mujtaba, M.I. Khan, Imen kebaili, M.S. Hasan, Wissem Mnif and Zaina Algarni; Investigating the influence of cerium doping on the

- structural, optical and electrical properties of $\text{ZnNiMgFe}_{2-x}\text{Ce}_x\text{O}_4$ soft ferrites, *J Mol Struct*, 1318 (2024), 139237.
11. S. Binetti, M. Acciarri, A. Le Donne, M. Morgano and Y. Jestin; Key success factors and future perspective of silicon-based solar cells, *International Journal of Photoenergy*, 2013.
 12. A. De Vos, A. Szymanska and V. Badescu; Modelling of solar cells with down-conversion of high energy photons, anti-reflection coatings and light trapping, *Energy Convers Manag*, 50 (2009), 328-336.
 13. B. Ashok Kumar, G. Sivasankar, B. Sangeeth Kumar, T. Sundarapandy and M. Kottaisamy; Development of Nano-composite Coating for Silicon Solar Cell Efficiency Improvement, *Materials Today: Proceedings*, 5 (2018), 1759-1765.
 14. A. R. Kadam and S. J. Dhoble; Energy transfer mechanism of $\text{KAlF}_4:\text{Dy}^{3+}$, Eu^{3+} co-activated down-conversion phosphor as spectral converters: An approach towards improving photovoltaic efficiency by downshifting layer, *J Alloys Compd*, 884 (2021).
 15. P. Kumar, P.V. Prasanna, B. Suryanarayana, Vijaya Lakshmi Vemula, D. Jagadeeswa Rao, Susmit Uppugalla and Y. Ramakrishna; Effect of rare earth ions (RE = La, Sm, Nd and Gd) substitution on structural, magnetic properties and dc electrical resistivity of $\text{Co}_{0.5}\text{Ni}_{0.5}\text{Fe}_2\text{O}_4$ ferrite, *Applied Physics A*, 129 (2023).
 16. S. Yasmeen, M. Khan, Z. Gilani and M. Khalid; Fabrication of Cerium Doped Nickel-Cobalt Ferrite by Co-Precipitation Method, *Journal of Materials and Physical Sciences*, 1 (2020), 26-36.
 17. A.L. Patterson; The Scherrer Formula for I-Ray Particle Size Determination. *REVIEW*, 56 (1939).
 18. D. Nan, H. Fan, A. Bolag, W. Liu and T. Bao; Enhanced electrocatalytic properties in dye-sensitized solar cell via Pt/SBA-15 composite with optimized Pt constituent, *Heliyon*, 9, e22403 (2023).
 19. S. O. Kasap; *Principles of Electronic Materials and Devices*, McGraw-Hill, 2006.
 20. M. A. Green; *Solar Cells: Operating Principles, Technology, and System Applications*, Prentice-Hall, 1982.
 21. P. Chand, S. Vaish and P. Kumar; Structural, optical and dielectric properties of transition metal (MFe_2O_4 ; M = Co, Ni and Zn) nanoferrites, *Physica B Condens Matter*, 524 (2017), 53-63.
 22. A. Kadam, R. Kamble, M. Joshi, A. Deshmukh and S. J. Dhoble; Eu (III), Tb (III) activated/ co-activated K_2NaAlF_6 host array: Simultaneous approach for improving photovoltaic efficiency and tricolour emission, *New Journal of Chemistry*, 46 (2021).