SONOCHEMICAL SYNTHESIS AND CHARACTERIZATION OF $LA_2ZR_2O_7:EU^{3+}$ LUMINESCENT MATERIALS FOR ENHANCED PHOTOANODES IN DYE-SENSITIZED SOLAR CELLS

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Abstract

The growing use of fossil fuels has led to rising global temperatures and increased interest in renewable energy, particularly solar energy. Dye-sensitized solar cells (DSSCs) offer a low-cost alternative, with their performance strongly influenced by the photoanode. This study focuses on synthesizing europium-doped lanthanum zirconate ($La_2Zr_2O_7:Eu^{3+}$) via solid-state reaction and incorporating it into SnO_2-based photoanodes. The material's downconversion luminescence enhanced light absorption, resulting in improved DSSC performance as confirmed by J–V measurements. These results highlight the potential of luminescent additives in advancing solar cell efficiency.

Keywords: DSSC, photoanode, luminescence, $La_2Zr_2O_7:Eu^{3+}$, SnO_2, downconversion

1. Introduction

The search for efficient materials for photoanodes in dye-sensitized solar cells (DSSCs) has significantly increased, aiming to enhance light absorption and the energy conversion efficiency of the devices. Tin dioxide (SnO_2) is one of the promising semiconductors due to its high electron mobility and chemical stability. However, further improvements can be achieved through the incorporation of luminescent compounds, such as europium-doped lanthanum zirconate ($La_2Zr_2O_7:Eu^{3+}$), which exhibits properties capable of converting unused wavelengths into light useful for the solar cell (Maaouni et al., 2024). Additionally, the application of spectral conversion strategies, such as luminescent down-shifting of the incident light, has proven effective in optimizing photovoltaic performance (Klampaftis et al., 2009). These combined approaches have the potential to significantly boost DSSC efficiency, especially when associated with composite films that promote enhanced absorption and efficient charge transport. Traditional metal oxides such as TiO_2 and SnO_2 are widely used, but modifications to their structure and composition are essential to further improve device efficiency.

2. Methodology

In this study, $La_2Zr_2O_7$ doped with Eu^{3+} was synthesized via solid-state reaction using stoichiometric amounts of La_2O_3, ZrO_2, and Eu_2O_3. The resulting powder was thermally treated and characterized through X-ray diffraction (XRD), UV-Vis spectroscopy, photoluminescence (PL), and scanning electron microscopy (SEM). Composite films of SnO_2 + $La_2Zr_2O_7:Eu^{3+}$ were prepared following a synthesis route involving (a) $La_2Zr_2O_7$ production via solid-state reaction, (b) europium (Eu^{3+}) doping tests, and (c) deposition of the composite films, as illustrated in Figure 1. This procedure enabled the formation of uniform and homogeneous surfaces suitable for effective dye anchoring.

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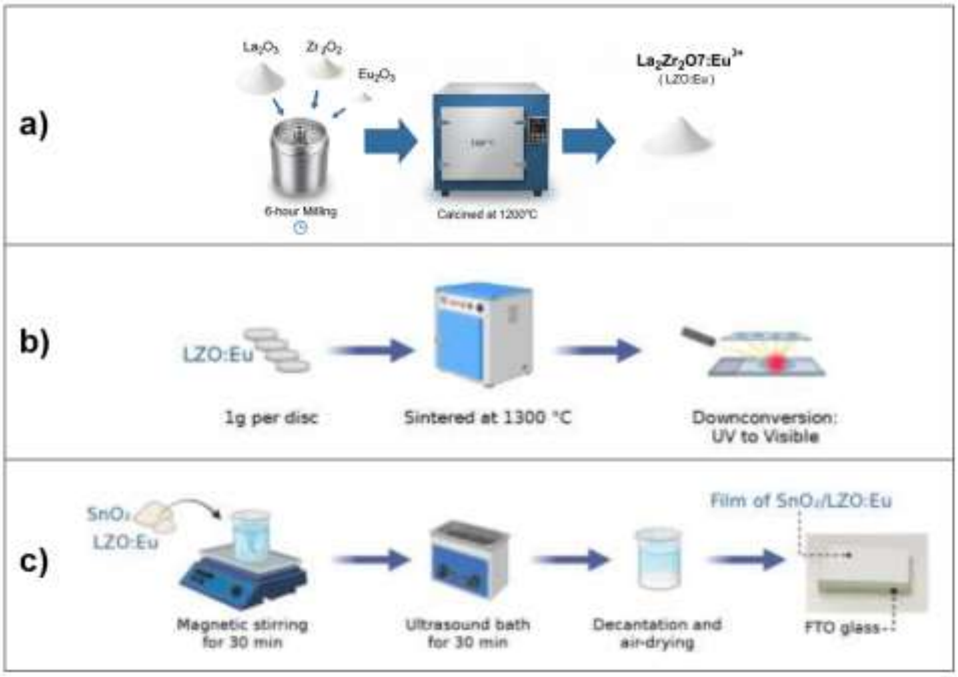

Figure 1: (a) Synthesis of $La_2Zr_2O_7$ via solid-state reaction, (b) Eu^{3+} doping tests, and (c) preparation of composite films.

XRD analysis was conducted to confirm the crystalline structure and phase identity of the synthesized material (Fig. 2), revealing well-defined diffraction peaks corresponding to the $La_2Zr_2O_7$ phase, with no secondary phases detected.

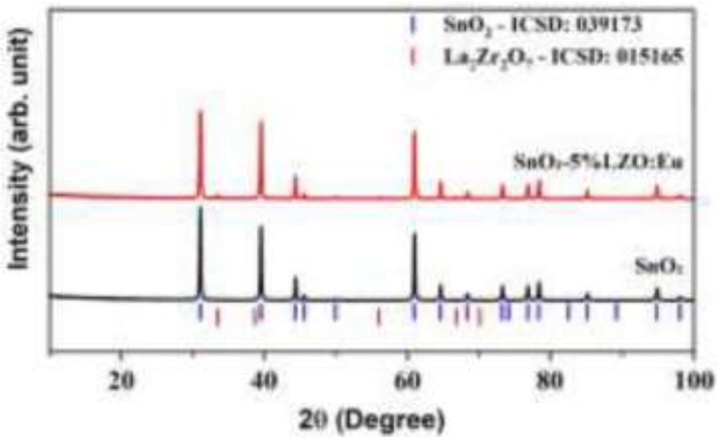

Figure 1: (a) Synthesis of $La_2Zr_2O_7$ via solid-state reaction, (b) Eu^{3+} doping tests, and (c) preparation of composite films.

Additionally, SEM imaging (Fig. 3) revealed that the films exhibit a porous microstructure, which is favorable for dye molecule anchoring and facilitates electrolyte infiltration, improving overall charge transport in the DSSC.

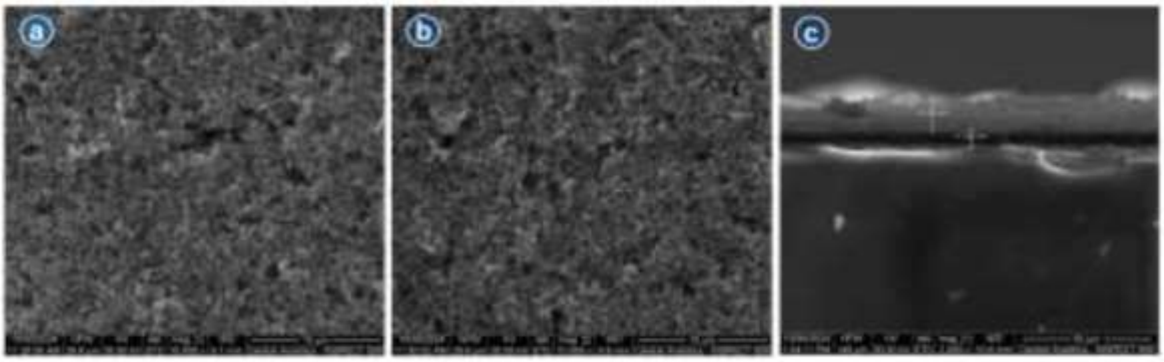

Figure 3: SEM images: (a) pure SnO_2, (b) SnO_2/LZO:Eu, (c) cross-section with film thickness.

These photoanodes were sensitized with an organic dye and assembled into DSSCs. Device performance was evaluated under simulated solar radiation using a potentiostat (Autolab PGSTAT302N) under AM 1.5G conditions.

3. Results and Discussion

The $La_2Zr_2O_7:Eu^{3+}$ compound exhibited strong red luminescence through downconversion, converting UV light into visible wavelengths better absorbed by the dye (Klampaftis et al., 2009). SnO_2 + $La_2Zr_2O_7:Eu^{3+}$ composite films showed enhanced visible light absorption and porous morphology, improving dye loading and charge transport (Anuja et al., 2025; Kumar et al., 2022; Mokrushin et al., 2022). Photovoltaic tests revealed increased current density and efficiency, highlighting the material's role in both spectral conversion and structural enhancement (Maaouni et al., 2024; Demir et al., 2024).

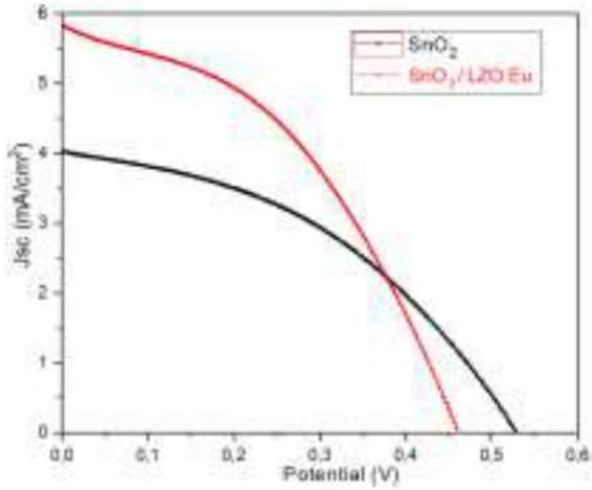

Figure 4: Current density (J–V) curves comparing pure SnO_2 and $SnO_2/La_2Zr_2O_7:Eu^{3+}$ composite photoanodes.

This integration offers a promising approach to improve the performance and stability of DSSCs based on TiO_2 and SnO_2.

4. Conclusion

The $La_2Zr_2O_7:Eu^{3+}$ The integration of $La_2Zr_2O_7:Eu^{3+}$ into SnO_2-based photoanodes represents a promising strategy to improve DSSC performance. The use of a sonochemical deposition method provided uniform and porous films, while the luminescent component enhanced light harvesting. These results reinforce the potential of such composite materials for advancing next-generation solar cell technologies.

5. References

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Appendix: Units and Symbols

This section provides guidance on the use of units and symbols in your paper. Please follow these guidelines.

1. Units

The use of S.I. (Système International d'unités) in papers is mandatory. The following is a discussion of the various S.I. units relevant to solar energy applications.

Energy
The S.I. unit is the joule (J ≡ kg m^2 s^{-2}). The calorie and derivatives, such as the langley (cal cm^{-2}), are not acceptable. No distinction is made between different forms of energy in the S.I. system so that mechanical, electrical and heat energy are all measured in joules. Because the watt-hour is used in many countries for commercial metering of electrical energy, its use is tolerated here as well.

Power
The S.I. unit is the watt (W ≡ kg m^2 s^{-3} ≡ J s^{-1}). The watt will be used to measure power or energy rate for all forms of energy and should be used wherever instantaneous values of energy flow rate are involved. Thus, energy flux density will be expressed as W m^{-2} and heat transfer coefficient as W m^{-2} K^{-1}. Energy rate should not be expressed as J h^{-1}.
When power is integrated for a time period, the result is energy that should be expressed in joules, e.g. an energy rate of 1.2 kW would produce 1.2 kW x 3600 s = 4.3 MJ if maintained for 1 h. It is preferable to say that

Hourly energy = 4.3 MJ

rather than

Energy=4.3 MJ h^{-1}.

Force
The S.I. unit is the Newton (N ≡ kg m s^{-2}). The kilogram weight is not acceptable.

Pressure
The S.I. unit is the Pascal (Pa ≡ N m^{-2} ≡ k^2 m^{-1} s^{-2}). The unit kg cm^{-2} should not be used. It is sometimes practical to use 10^5 Pa = 1 bar = 0.1 MPa. The atmosphere (1 atm = 101.325 kPa) and the bar, if used, should be in parenthesis, after the unit has been first expressed in Pascals. e.g. 1.23 x 10^6 Pa (12.3 atm). Manometric pressures in meters or millimeters are acceptable if one is reporting raw experimental results. Otherwise they should be convened to Pa.

Velocity
Velocity is measured in m s^{-1}. Popular units such as km h^{-1} may be in parentheses afterward.

Volume
Volumes are measured in m^3 or litres (1 litre = 10^{-3} m^3). Abbreviations should not be used for the litre.

2. Flow

In S.I. units, flow should be expressed in kg s^{-1}, m^3 s^{-1}, litre s^{-1}. If non-standard units such as litre min^{-1} or kg h^{-1} must be used, they should be in parentheses afterward.

Temperature
The S.I. unit is the degree Kelvin (K). However, it is also permissible to express temperatures in the degree Celsius (°C). Temperature differences are best expressed in Kelvin (K).
When compound units involving temperature are used, they should be expressed in terms of Kelvin, e.g. specific heat J kg^{-1} K^{-1}.

3. Nomenclature and Symbols

Tables 1-5 list recommended symbols for physical quantities. Obviously, historical usage is of considerable importance in the choice of names and symbols and attempts have been made to reflect this fact in the tables. But conflicts do arise between lists that are derived from different disciplines. Generally, a firm recommendation has been made for each quantity, except for radiation where two options are given in Table 5.
In the recommendations for *material properties* (see Table 1), the emission, absorption, reflection, and transmission of radiation by materials have been described in terms of quantities with suffixes 'ance' rather than 'ivity', which is also sometimes used, depending on the discipline. It is recommended that the suffix 'ance' be used for the following four quantities:

$$\text{emittance } \varepsilon = \frac{E}{E_b}\left(or\ \frac{M_s}{M_{sb}} \right)$$

$$\text{absorptance } \alpha = \frac{\Phi}{\Phi_i}$$

$$\text{reflectance } \rho = \frac{\Phi}{\Phi_i}$$

$$\text{transmittance } \tau = \frac{\Phi}{\Phi_i}$$

where E and ϕ is the radiant flux density that is involved in the particular process. The double use of α for both absorptance and thermal diffusivity is usual, as is the double use of ρ for both reflectance and density. Neither double use should give much concern in practice.

Table 1: Recommended symbols for materials properties

Quantity	Symbol	Unit
Specific heat	c	J kg^{-1} K^{-1}
Thermal conductivity	k	W m^{-1} K^{-1}
Extinction coefficient^{+}	K	m^{-1}
Index of refraction	n	
Absorptance	α	
Thermal diffusivity	α	m^{2} s^{-1}
Specific heat ratio	γ	
Emittance	ε	
Reflectance	ρ	
Density	ρ	kg m^{-3}
Transmittance	τ	

$^{+}$ In meteorology, the *extinction coefficient* is the product of K and the path length and is thus dimensionless.

Table 2: Recommended symbols and sign convention for sun and related angles

Quantity	Symbol	Range and sign convention
Altitude	α	0 to ± 90°
Surface tilt	β	0 to ± 90°; toward the equator is +ive
Azimuth (of surface)	γ	0 to 360°; clockwise from North is +ive
Declination	δ	0 to ± 23.45°
Incidence (on surface)	Θ, i	0 to + 90°
Zenith angle	Θ_z	0 to + 90°
Latitude	Φ	0 to ± 90°; North is +ive
Hour angle	ω	-180° to +180°; solar noon is 0°, afternoon is +ive
Reflection (from surface)	r	0 to + 90°

Table 3: Recommended symbols for miscellaneous quantities

Quantity	Symbol	Unit
Area	A	m^{2}
Heat transfer coefficient	h	W m^{-2} K^{-1}
System mass	m	kg
Air mass (or air mass factor)	M	
Mass flow rate	$\dot{m}$	kg s^{-1}
Heat	Q	J
Heat flow rate	$\dot{Q}$	W
Heat flux	q	W m^{-2}
Temperature	T	K
Overall heat transfer coefficient	U	W m^{-2} K^{-1}
Efficiency	η	
Wavelength	λ	m
Frequency	ν	s^{-1}
Stefan-Boltzmann constant	σ	W m^{-2} K^{-4}
Time	t, τ, Θ	s

Table 4: Recommended subscripts

Quantity	Symbol
Ambient	a
Black-body	b
Beam (direct)	b
Diffuse (scattered)	d
Horizontal	h
Incident	i
Normal	n
Outside atmosphere	o
Reflected	r
Solar	s
Solar constant	sc
Sunrise (sunset)	sr, (ss)
Total of global	t
Thermal	t, th
Useful	u
Spectral	λ

Table 5: Recommended symbols for radiation quantities

	Preferred name	Symbol	Unit
a)	Nonsolar radiation		
	Radiant energy	Q	J
	Radiant flux	Φ	W
	Radiant flux density	Φ	W m^{-2}
	Irradiance	E, H	W m^{-2}
	Radiosity or Radiant exitance	M, J	W m^{-2}
	Radiant emissive power (radiant self-exitance)	Ms, E	W m^{-2}
	Radiant intensity (radiance)	L	W m^{-2} sr^{-1}
	Irradiation or radiant exposure	H	J m^{-2}
b)	Solar radiation		
	Global irradiance or solar flux density	G	W m^{-2}
	Beam irradiance	G_b	W m^{-2}
	Diffuse irradiance	G_d	W m^{-2}
	Global irradiation	H	J m^{-2}
	Beam irradiation	H_b	J m^{-2}
	Diffuse irradiation	H_d	J m^{-2}
c)	Atmospheric radiation		
	Irradiation	$\Phi\downarrow$	W m^{-2}
	Radiosity	$\Phi\uparrow$	W m^{-2}
	Exchange	Φ_N	W m^{-2}