



Sol-gel Synthesis of Cerium-doped TiO₂ Nanoparticles for the Photocatalytic Degradation of Rhodamine B and Eosin Y under UV Light

R. Deepha and V. Senthilnathan*

Department of Physics, Chikkanna Government Arts College, Tirupur, TN, India

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*zndl.doeo.na.vasu@gmail.com



ABSTRACT

The sol-gel process was used to develop Ce-doped TiO₂ nanoparticles (0.03–0.09 mol% Ce), which were then calcined at 500 °C. The successful incorporation of Ce into the TiO₂ lattice was verified by characterization, resulting in a notable decrease in the band gap from 3.30 to 2.06 eV. Rhodamine B (RhB) and Eosin Yellow (EY) dyes were degraded under UV light to assess the material's photocatalytic activity. With degradation efficiencies of almost 98% for RhB and 91.65% for EY, the Ce-doped TiO₂ showed high performance. Improved light absorption and effective charge-carrier separation have been chosen as the sources of the increased activity. While future research should focus on visible-light photocatalysis, dopant optimization, and practical wastewater treatment applications, these results suggest the potential of Ce-doped TiO₂ for environmental remediation.

Keywords: Ce-doped TiO₂ nanoparticle; Sol-gel method; Photocatalytic; Rhodamine B; Eosin yellow dyes.

1. INTRODUCTION

One of the most important environmental problems throughout the world is the pollution of water by industrial effluents. The textile industries are among the primary industrial sectors contributing to aquatic pollution due to significant volume discharge of dye-containing effluent. These effluents often contain toxic, carcinogenic and non-biodegradable chemical compounds, which significantly affect aquatic ecosystems by decreasing light penetration, suppressing photosynthetic activity and disturbing biological processes. Therefore, extensive research efforts have been undertaken to develop effective and environmentally sustainable systems for the removal of organic contaminants from contaminated water sources (Singh *et al.* 2024). Amongst the several effective oxidation methods, photocatalysis has gained a lot of attention for the degradation of oxidized organic pollutants. Titanium dioxide (TiO₂) is one of the most extensively investigated photocatalysts because of its high photocatalytic efficiency, chemical stability, low cost, non-toxicity and high oxidative potential for mineralization of hazardous organic compounds (Tong *et al.* 2007). Various types of dyes, such as cationic, anionic, azo, direct, sulfur, vat, acidic and basic dyes, are often present in industrial wastewater and have an important role in the degradation of the water quality (Wu *et al.* 2022). However, the wide band-gap energy

(~3.2 eV for anatase) of pure TiO₂ limits its application in the UV region for photo-activation and quick recombination of photo-generated electron-hole pairs, resulting in low photocatalytic efficiency. Such constraints have been circumvented via methods of modification. Among the doping approaches, elemental doping is one of the most efficient methods to improve the optical and photocatalytic properties of TiO₂. Sol-gel, hydrothermal, co-precipitation and impregnation procedures have been applied for doping of TiO₂ nanoparticles (Nasir *et al.* 2012). One of them is the sol-gel approach, which has an important advantage, since the precursor species are mixed at the molecular level, which provides chemical homogeneity, high purity, regulated particle size distribution and more efficient outcomes of dopant incorporation (Meditana *et al.* 2022). Doping TiO₂ with non-metals has proved successful in reducing the band gap in the region of visible light absorption. However, doping metal ions can form defect states for charge separation and reduce the recombination of electrons and holes (Garg *et al.* 2019). Rare earth elements have garnered great interest as doping elements because of the advantageous electronic topologies of the partially filled 4f orbitals and empty 5d orbitals for interfacial charge transfer and increase of photocatalytic activity (Xu *et al.* 2006). Cerium (Ce) is a rare earth element and a very efficient dopant since its mixed oxidation states (Ce³⁺ /Ce⁴⁺) can develop electron trapping sites, resulting in higher charge carrier

separation and less recombination loss while maintaining the TiO₂ crystal structure (Adrián *et al.* 2009).

The method of synthesis is an important element determining the final form and the catalytic activity of the molecule. The hydrothermal, co-precipitation and impregnation synthesis processes are the most common methods utilized for the formation of doped TiO₂ materials (Nasir *et al.* 2012; Apostolova *et al.* 2023). Nevertheless, there are many unique advantages to the sol-gel technique. It allows doping of dopant ions on a molecular scale in a stable environment, which yields high-purity materials with precise control of particle size and very high chemical homogeneity (Miditana *et al.* 2022). Given the wide range of publications dealing with modified TiO₂ photocatalysts, there is still a clear gap in the research on the specific structural, optical and catalytic effects of low-concentration cerium doping generated exactly using the sol-gel method. Most of the current research works with high dopant concentrations or with catalysts compared to one dye only. However, no systematic studies are present as of now, focusing on and effectively comparing the degradation mechanisms of different dye classifications, e.g., the breakdown of xanthene-based Eosin Yellow (EY) and cationic Rhodamine B (RhB) under perfectly identical experimental parameters. The range of the low-level Ce-doped synthesis to different structures of aquatic pollutants can be observed when comparing the mechanisms (Deepha and Senthilnathan, 2026). To work around the limitations presented by traditional methods, the present methodology is based on a structured morphology of Ce-doped TiO₂ nanoparticles by a highly controlled sol-gel synthesis. The sol-gel approach allows the homogeneous incorporation of cerium directly into the titania framework at a molecular scale. The method uses a controlled low-level doping of cerium to form unique, localized defect sites (oxygen vacancies) and redox couples (Ce³⁺/Ce⁴⁺). When the UV light excites the electrons, the Ce⁴⁺ ions trap them and are reduced to Ce³⁺ for a while. This slows the recombination of charges, allowing enough time for the surface holes to react with water, forming highly reactive hydroxyl radicals. The resulting nanoparticles were determined by XRD, UV-vis spectroscopy, FESEM and EDX in comparison with previous research. To study the wide range of applications, several degradation processes of RhB and EY are analyzed. Furthermore, the proper synthesis here presents a catalyst purity and homogeneity that can be incorporated in thin film fabrication procedures for next-generation applications such as dye-sensitized solar cells (DSSCs), optical sensors and advanced optoelectronic devices when used with wastewater remediation (Senthilnathan and Ganesan, 2010; Parameswari *et al.* 2025).

2. EXPERIMENTAL

2.1 Materials

All chemicals used in this research were analytical grade and did not require further purification. Cerium nitrate (over 99%) served as the Ce dopant, and titanium (IV) isopropoxide (97%) was used as the precursor. Both were purchased from Sigma-Aldrich Merck in Bangalore. Synthesis and photocatalytic analysis took place in standard double-distilled water. Rhodamine B and Eosin Yellow were selected as model organic pollutants to test photocatalytic activity.

2.2 Sol-gel Synthesis of Pure TiO₂ Nanoparticles

Initially, 40 mL of ethanol and 29.606 mL of titanium (IV) isopropoxide (TTIP) at 1 mol% were added dropwise to the solvent, which was then stirred for 10 minutes. The solution was then stirred vigorously for an additional 10 minutes. The hydrolysis and condensation reactions required for the synthesis of the TiO₂ sol were initiated by gradually adding 10 mL of distilled water. To enable controlled nucleation and particle formation, the reaction system was kept at 60 °C. To control the reaction timings and stabilise the sol, hydrochloric acid (HCl) was subsequently added dropwise over two hours while continuously stirred. The slow addition of HCl produced a homogeneous milky-white sol, and the pH was raised to about 3 to promote the formation of a stable gel structure. The resulting sol was aged for 10 hours. The aged gel was then dried at 100 °C to remove any remaining solvents and moisture, forming a xerogel. The dried material was then finely ground and calcined at 500 °C for 3 hours in a muffle furnace to remove organic residues and encourage the crystallization of the TiO₂ phase. The calcined product was then crushed to obtain phase-pure TiO₂ nanoparticles for more structural, morphological, optical, and photocatalytic studies (Singh *et al.* 2024).

2.3 Sol-gel Synthesis of Ce-doped TiO₂ Nanoparticles

The formed TiO₂ sol was mixed with aqueous cerium nitrate precursor solutions at concentrations of 0.03, 0.05, 0.07, and 0.09 mol% while continuously stirred with a magnetic stirrer. To promote efficient dopant dispersion and enable homogeneous incorporation of Ce ions into the TiO₂ substrate, the reaction mixture was maintained at 60 °C for 2 hours. To improve polycondensation properties and structural stability, the resulting gel was aged for 12 hours. To obtain a clear gel, any remaining byproducts and unreacted species were then thoroughly washed with acetone and distilled water. After the purified gel was dried at 100 °C to form a xerogel, it was finely powdered and calcined at 500 °C for 3 hours in a muffle furnace to promote the formation of the Ce-doped TiO₂ phase and

induce crystallization. The calcined material was ground into evenly doped Ce-TiO₂ nanoparticles for further structural, morphological, optical, and photocatalytic characterization after it had completely cooled to room temperature (Mirghani *et al.* 2022).

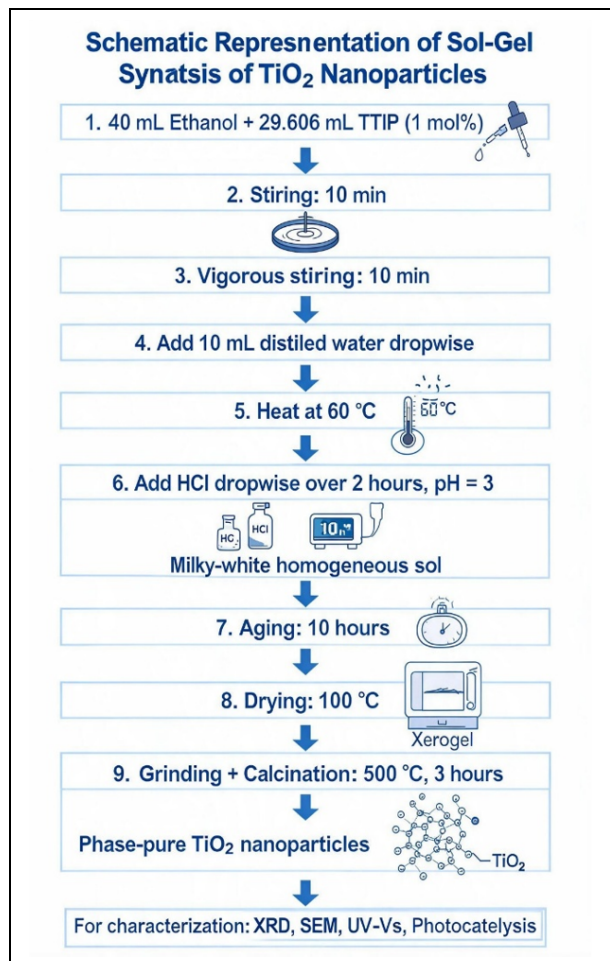


Fig. 1: Schematic representation of the sol-gel synthesis of TiO₂ nanoparticles

2.4 Characterisation Analysis

X-ray diffraction (XRD) with Cu K α radiation was applied to analyze the phases and crystal structure of pure and Ce-doped TiO₂ nanoparticles. Researchers measured the crystallite size and verified phase purity using the diffraction patterns. It evaluated surface characteristics and particle distribution with field-emission scanning electron microscopy (FESEM). Using FESEM, energy-dispersive X-ray spectroscopy (EDAX) confirmed the presence of elements and enabled us to measure the integrated amount of Ce. UV-visible absorption spectra were measured from 200 to 800 nm using a UV-visible spectrophotometer. Band gap energies were determined from Tauc plots using absorption data. The optical properties of pure TiO₂ and Ce-doped TiO₂ will be examined to understand how the addition of Ce affects light absorption.

2.5 The Photocatalytic Process

2.5.1 Choosing the Model Pollutant

The photocatalytic efficiency of Ce-doped TiO₂ nanoparticles in degrading RhB and EY dyes was evaluated under ultraviolet (UV) light.

2.5.2 Photocatalytic Degradation Procedure

100 mg of each dye should be dissolved in 1L of double-distilled water to obtain a 100 mg/L stock solution. 100 mL of the dye solution and 100 mg of the photocatalyst must be combined in a cylindrical glass reactor for the photocatalytic analysis. Before turning on the light, let the mixture mix in the dark for half an hour using a magnetic stirrer until it is uniformly mixed. This enables the dye and catalyst to find a balance between adsorption and emission. A 15 W lamp placed 5 cm above the reactor was used to perform photocatalytic degradation in UV light. During the experiment, constant stirring was used to catalyst dispersion. 3–5 mL samples were collected at specific times and allowed to settle. A UV-Visible spectrophotometer (Cary 8454, Agilent, Singapore) was used to measure the residual dye concentration in the clear solution obtained (Kannan *et al.* 2025). For RhB and EY, absorbance measurements were made at 554 nm and 519 nm, respectively.

2.5.3 Calculating Degradation Efficiency

The efficiency of photocatalytic degradation has been calculated by applying the following method:

$$\text{Degradation efficiency (\%)} = [(C_0 - C_t)/C_0] \times 100 \dots (1)$$

where C_0 represents the initial concentration of dye, and C_t represents the concentration of the dye at irradiation time t .

3. RESULTS AND DISCUSSION

3.1 Structural Analysis

Table 1. XRD analysis of pure and Ce-doped TiO₂ nanoparticle

S. No.	Sample Name	Crystalline Sizes D(nm)	Dislocation Density x 10 ¹⁵	Lattice Strain x 10 ³
1	TiO ₂	26.6	0.037594	0.2135
2	TCe _{0.03%}	25.5	0.039216	0.2199
3	TCe _{0.05%}	24.3	0.041152	0.2762
4	TCe _{0.07%}	19.09	0.052383	0.2909
5	TCe _{0.09%}	13.7	0.072993	0.4193

The crystal structure, phase composition, and crystallinity of pure and Ce-doped TiO₂ nanoparticles

were analyzed using X-ray diffraction (XRD). A Cu K α radiation source ($\lambda = 1.5406 \text{ \AA}$) was used on a Pro Penalty CAL diffractometer to record the diffraction patterns. Figure 2 shows the XRD characteristics of pure TiO $_2$ and Ce-doped TiO $_2$ samples containing 0.03, 0.05, 0.07, and 0.09 mol% Ce. All samples showed prominent diffraction peaks that corresponded to the crystallographic planes (110), (101), (004), (200), (105), (116), and (204). The formation of the tetragonal rutile phase of TiO $_2$ is confirmed by the strong agreement between the diffraction peaks and the standard JCPDS Card No. 78-2486 (Choudhury *et al.* 2012).

Using Scherrer's formula,

$$D = K\lambda / \beta \cos\theta \quad \dots (2)$$

The crystallite size was calculated. In this formula, λ stands for the X-ray beam's wavelength, θ represents the diffraction angle, D is the crystallite size, K is the shape factor, and β is the full width at half maximum of the peak. As the cerium concentration increased from 0.03%, 0.05%, 0.07%, and 0.09 mol%, the crystalline sizes decreased to 26.6, 25.5, 24.3, 19.09, and 13.7 nm (Yan *et al.* 2012).

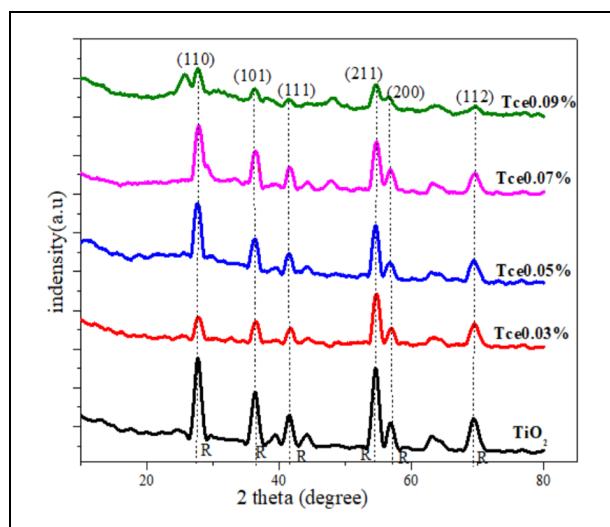


Fig. 2: XRD analysis of pure TiO $_2$ and Ce-doped TiO $_2$

The Ce ions were successfully incorporated into the TiO $_2$ crystal lattice, as shown by the stable increase in lattice strain seen in the Ce-doped TiO $_2$ samples. Because

Ce $^{3+}$ /Ce $^{2+}$ and Ti $^{4+}$ ions have different ionic radii, partial substitution of Ce ions for Ti sites produces physical defects and lattice distortions, which raise a microstrain in the crystal structure. With increasing Ce content, the predicted lattice strain values increased from 0.2135 for pure TiO $_2$ to 0.2199, 0.2762, 0.2909, and 0.4193 for Ce-doped TiO $_2$ samples, showing a gradual modification of the lattice structure (Choudhury *et al.* 2012).

3.2 FESEM with EDAX Analysis

The FESEM micrographs and EDX analysis of pure and Ce-doped TiO $_2$ nanoparticles with Ce concentrations of 0.03, 0.05, 0.07, and 0.09 mol% are shown in Figure 3. The nanoparticles produced have mostly spherical-to-polyhedral morphologies, a fairly uniform particle distribution, and mild agglomeration, according to the FESEM images. The strong interparticle interactions and high surface energy typically associated with nanoscale TiO $_2$ materials could cause the observed agglomeration. Particle size gradually decreases as Ce concentration increases, according to quantitative analysis of the FESEM images. For pure TiO $_2$, the estimated average particle sizes were about 40 nm; for 0.03, 0.05, 0.07, and 0.09 mol% Ce-doped TiO $_2$, they were 36 nm, 33 nm, 28 nm, and 25 nm, respectively. This decrease in particle size shows that during calcination, Ce ions successfully prevent grain growth. By limiting crystal growth and promoting the formation of finer nanoparticles, Ce–O–Ti connections on the particle surface may act as grain-growth suppressors.

Additionally, the specific surface area and the size of active surface sites rise as particle size decreases. Smaller particle sizes and better dispersion enable greater dye adsorption and more effective interaction between the catalyst surface and incident UV rays. Additionally, the doped materials' rough, porous surface provides more reactive sites for photocatalytic reactions. The efficient incorporation of cerium into the TiO $_2$ matrix without the introduction of large impurities is demonstrated by Figure 4, represent the EDAX spectra, which reveal the existence of Ti, O, and Ce. The photocatalytic degradation effectiveness of the Ce-doped TiO $_2$ nanoparticles is greatly increased by the combined effects of decreased particle size, increased surface area, better surface roughness, and homogeneous Ce distribution (Challagulla *et al.* 2017).

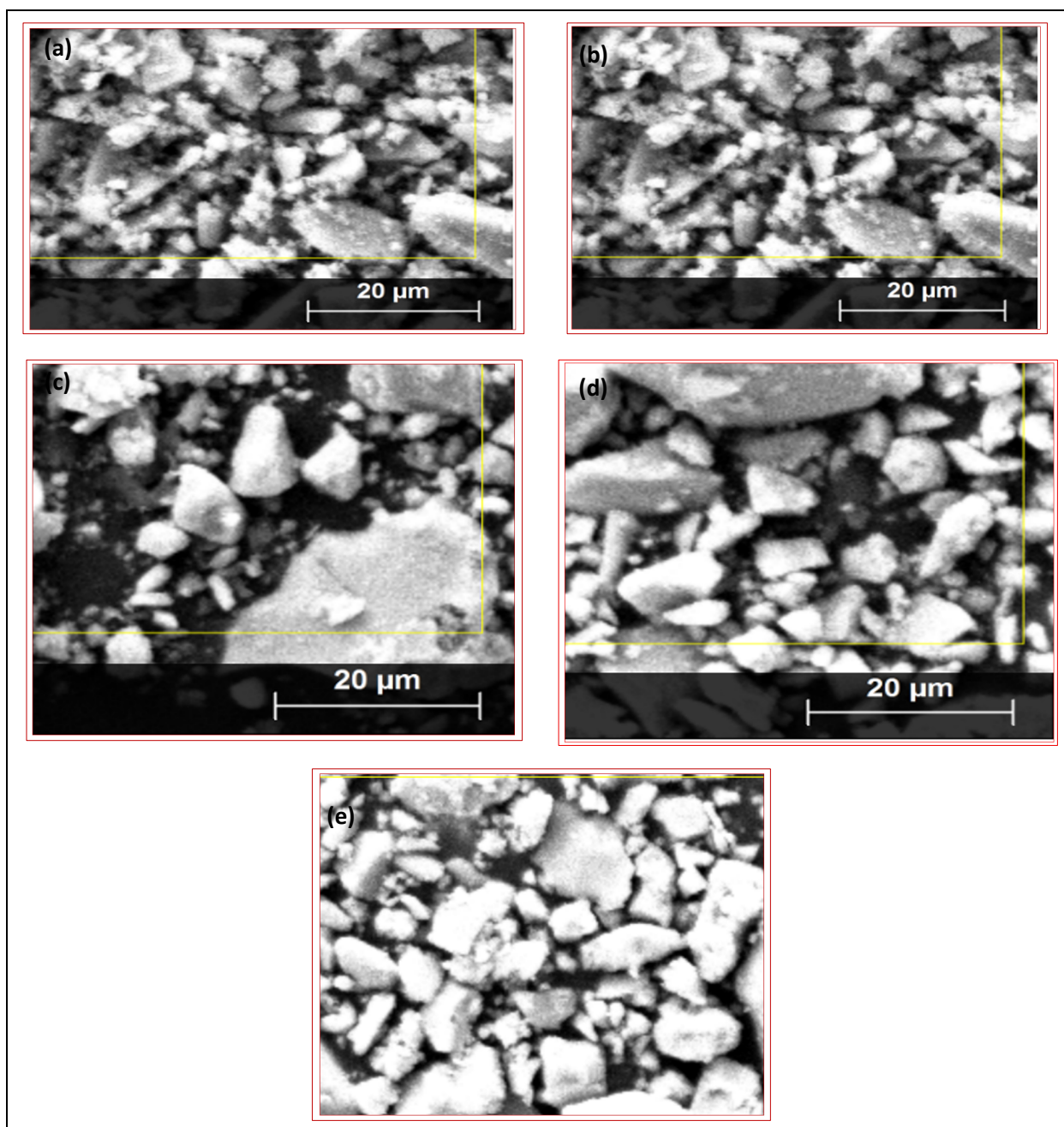


Fig 3: The FESEM images of (a)TiO₂, (B) TCe0.03%, (c) TCe0.05%, (d)TCe0.07% and (e)TCe0.09%

An efficient analytical method for determining the elemental composition of materials, both qualitatively and quantitatively, is energy-dispersive X-ray spectroscopy (EDAX). To provide localised elemental information from specific areas of the sample surface, it is frequently combined with Field Emission Scanning Electron Microscopy (FESEM). The EDX method works by identifying characteristic X-rays emitted by the specimen when exposed to a focused electron beam. A detailed analysis of the material's chemical properties and elemental distribution is made possible by detecting and measuring the elements present in it using the energies and intensities of these X-rays.

3.3 Optical Properties (UV–visible Spectroscopy)

UV–visible absorption spectra of pure TiO₂ and Ce-doped TiO₂ nanoparticles were recorded in the 200–800 nm wavelength range to study the optical characteristics of the formed materials. In the ultraviolet, both samples exhibited a pronounced absorption edge matching the fundamental band-to-band electronic transition of TiO₂. The absorption edge, characteristic of wide-band-gap semiconductor materials, was observed between 328 and 369 nm. This absorption characteristic indicates the absence of notable impurity phases and confirms the successful production of

crystalline TiO₂. Additionally, the measured absorption characteristics suggest that the inclusion of Ce affects

TiO₂'s optical response, potentially enhancing its photocatalytic efficiency and light absorption ability.

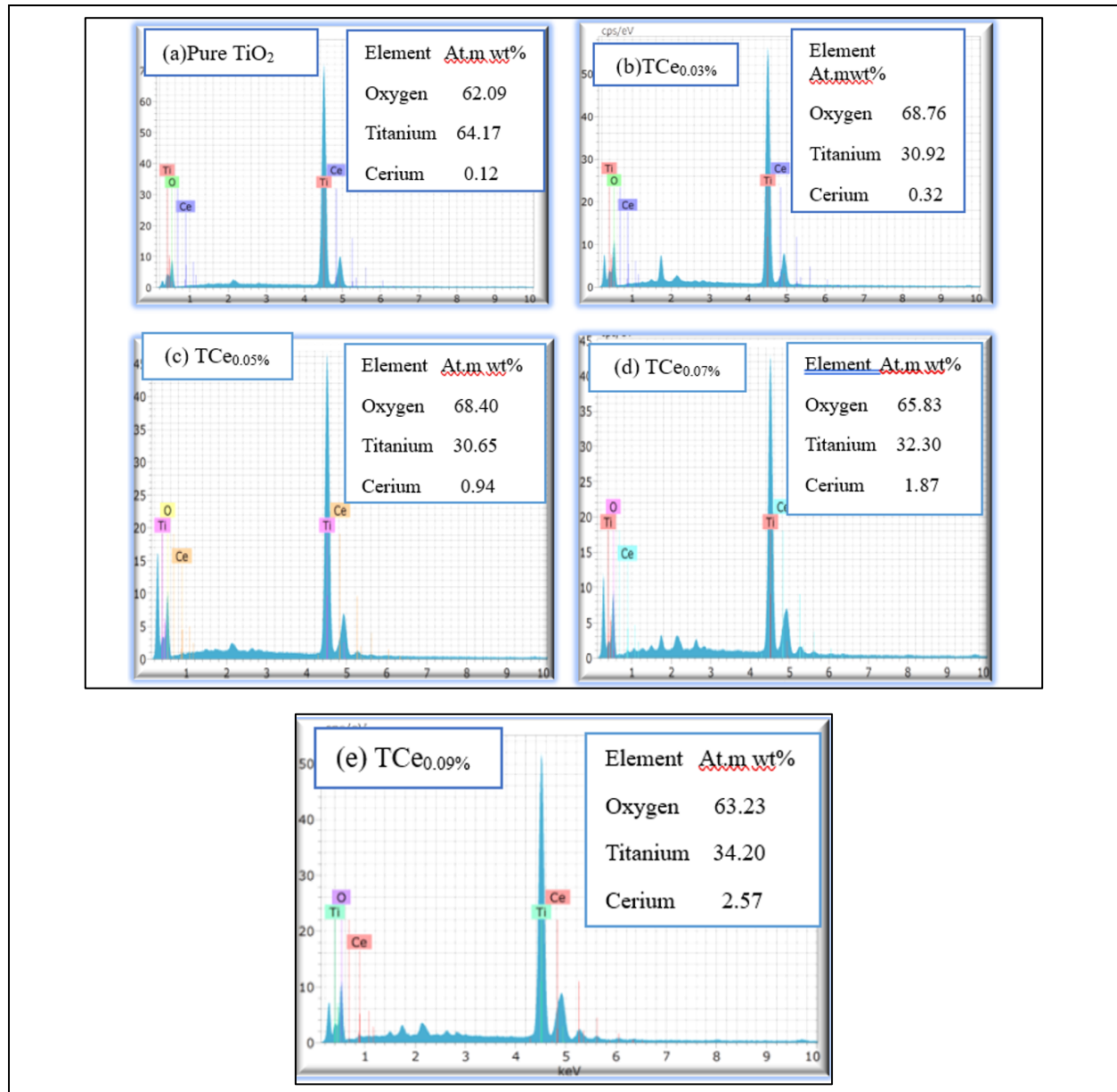


Fig. 4: EDAX and atomic weight% of (a)TiO₂, (B) TCe_{0.03%}, (c) TCe_{0.05%}, (d)TCe_{0.07%} and (e)TCe_{0.09%}

The ultraviolet (UV) absorption coefficient (α) and the optical band gap for each pure and Ce-doped TiO₂ nanoparticle were measured via vis absorption studies. The absorption coefficient has been calculated using the following formula:

$$\alpha = 2.303 A/d \quad \dots (3)$$

where A is the absorbance of the sample and d is the path of light length. Furthermore, the optical band gap energy of both pure TiO₂ and Ce-doped TiO₂ was measured using Tauc plots. The interaction between photon energy and the absorption coefficient is as follows:

$$(\alpha h\nu)^2 = A(h\nu - E_g) \quad \dots (4)$$

where A is a parameter related to the effective mass connected to the valence and conduction bands, ν is the incident photon frequency, α is the absorption coefficient, and h is Planck's constant (6.626×10^{-31} Js). The band gap energy was calculated from the linear region of the $(\alpha h\nu)^2$ vs $h\nu$ plot. These Tauc plots were used to determine the band gap values for both pure and Ce-doped TiO₂ nanoparticles. The band gap values of pure and Ce-doped TiO₂ nanoparticles were determined. Table 2 shows the optical band-gap energies of pure and Ce-doped TiO₂ nanoparticles, which were calculated from the UV-visible absorption spectra. When Ce-doped

TiO₂ samples showed gradually decreasing band-gap values of 2.59, 2.50, 2.26, and 2.06 eV with increasing Ce concentration, pure TiO₂ showed a band-gap energy of 3.30 eV (Jafari *et al.* 2018; Wenqin *et al.* 2025). The formation of oxygen vacancies, which give intermediate electronic states below the conduction band, and the introduction of Ce-related energy levels within the TiO₂ band structure are responsible for the observed band-gap narrowing. The optical absorption edge is shifted toward longer wavelengths, and the decrease improves the photocatalyst's efficiency in absorbing light at the band-gap energy. Furthermore, Ce³⁺/Ce²⁺ redox couples serve as efficient electron-trapping centres, thereby increasing charge separation and reducing photogenerated electron–hole pair recombination. As a result, more charge carriers are available for photocatalytic processes.

Table 2. Band gap energy of Ce-doped TiO₂ and pure TiO₂

S. No.	Sample Name	Band Gap Energy (eV)
1.	Pure TiO ₂	3.30 eV
2.	TCe _{0.03} %	2.59 eV
3.	TCe _{0.05} %	2.50 eV
4.	TCe _{0.07} %	2.26 eV
5.	TCe _{0.09} %	2.06 Ev

The production of reactive oxygen species such as hydroxyl radicals ($\cdot\text{OH}$) and superoxide radicals ($\cdot\text{O}_2^-$), which are essential for the degradation of organic pollutants, is promoted by the combined effects of band-gap narrowing, enhanced charge-carrier separation, and improved light absorption. As a result, under UV irradiation, the Ce-doped TiO₂ nanoparticles showed improved photocatalytic activity toward the degradation of Rhodamine B (RhB) and Eosin Yellow (EY) dyes, indicating the positive impact of Ce inclusion to improve the photocatalytic efficiency of TiO₂.

3.4 Studies on Rhodamine B and Eosin Yellow Dye Degradation

Figures 5 and 6 represent the full-scan UV–visible absorption spectra of RhB and EY at pH₃ during the photocatalytic experiments. The present research analyzed the efficiency of Ce-doped TiO₂ and pure TiO₂

nanoparticles (TCe_{0.03}, TCe_{0.05}, TCe_{0.07}, and TCe_{0.09}) in degrading Rhodamine B (RhB) and Eosin Yellow (EY) under equivalent ultraviolet (UV) irradiation. The distinctive absorption peaks of the colours gradually diminish as the irradiation period increases from 0 to 90 minutes, indicating the dye molecules' gradual degradation. While EY exhibits its primary absorption at 519 nm, RhB shows strong absorption at 554 nm. RhB is much more exposed to photocatalytic oxidative degradation than EY, as shown by a far sharper decrease in the intensity of the RhB peak. After 90 minutes, RhB degradation efficiency are 86.36% for pure TiO₂, 86.80% for TCe_{0.03}, 92.98% for TCe_{0.05}, 97.75% for TCe_{0.07}, and 98.16% for TCe_{0.09}. The results presented here show that photocatalytic efficiency increases systematically with increasing Ce content, with TCe_{0.09} achieving near-total dye removal (Slimani *et al.* 2023). From the opposite sides, under comparable experimental conditions, EY degradation is significantly reduced. The respective degradation efficiencies are 67.31% for pure TiO₂, 72.65% for TCe_{0.03}, 83.93% for TCe_{0.05}, 84.63% for TCe_{0.07}, and 91.65% for TCe_{0.09}. Under neutral or slightly acidic circumstances, RhB cationic xanthene molecules strongly adsorb onto the negatively charged TiO₂ surface, allowing excellent interfacial charge transfer as well as fast destruction by hydroxyl ($\cdot\text{OH}$) and oxygen (O_2^-) radicals (Maarisetty *et al.* 2019). Because of this, EY breakdown is mostly dependent on direct photocatalytic oxidation rather than on a mixed adsorption and sensitisation mechanism, resulting in much slower degradation rates (Shen *et al.* 2017). By decreasing crystallite size, increasing surface area, boosting visible-light absorption, and inhibiting electron–hole recombination through the reversible Ce³⁺/Ce⁴⁺ redox couple, the addition of Ce to TiO₂ greatly improves the photocatalytic activity of both dyes (Yan *et al.* 2012). Overall, comparative analysis clearly shows that Ce-doped TiO₂ is highly effective at degrading cationic dyes such as Rhodamine B, achieving nearly 98% removal; however, its activity toward anionic dyes such as Eosin Yellow remains comparatively low, with only 91.65% degradation under equivalent ultraviolet (UV) conditions.

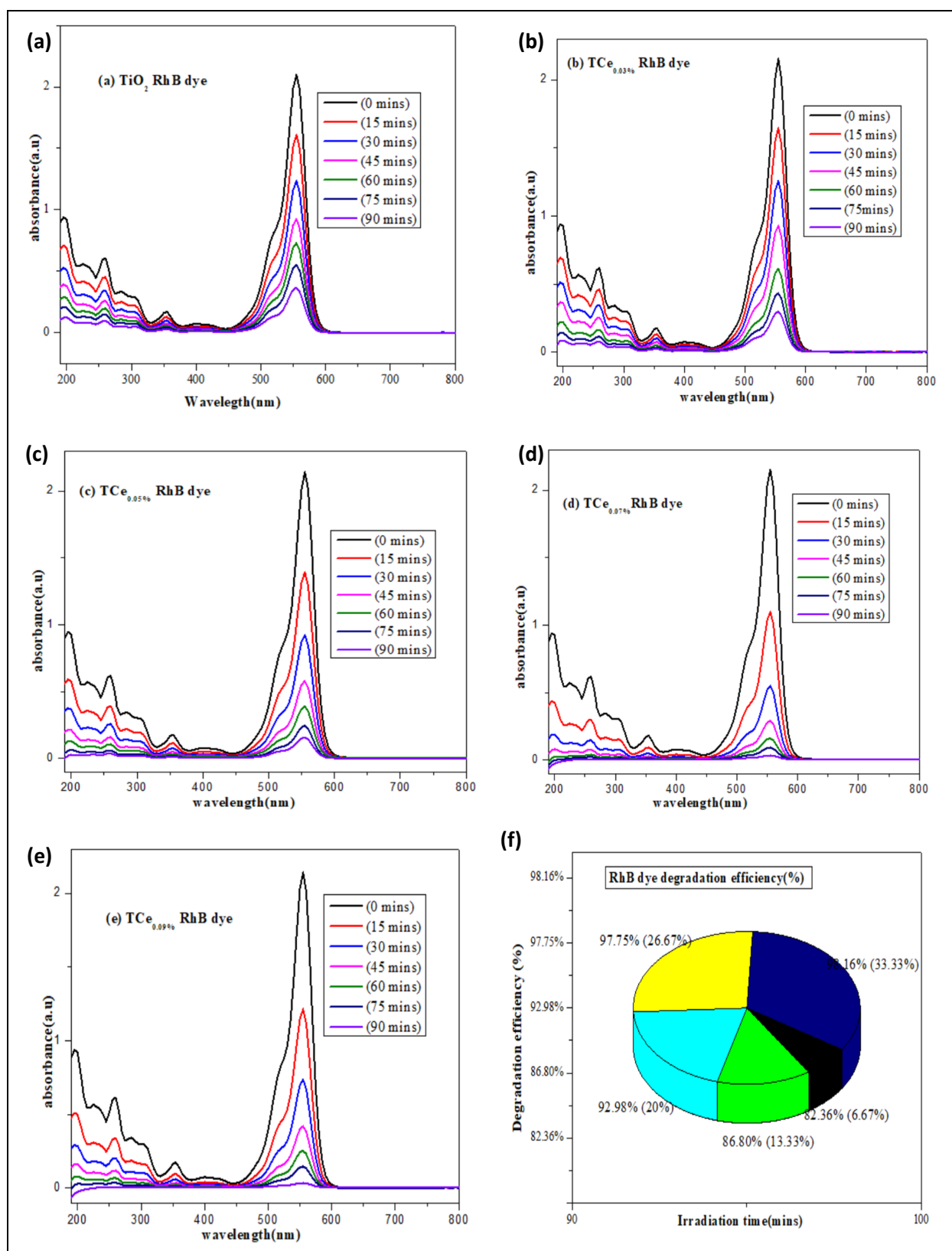


Fig. 5: The time-dependent UV-vis absorption spectra of rhodamine B(RhB) dye degradation

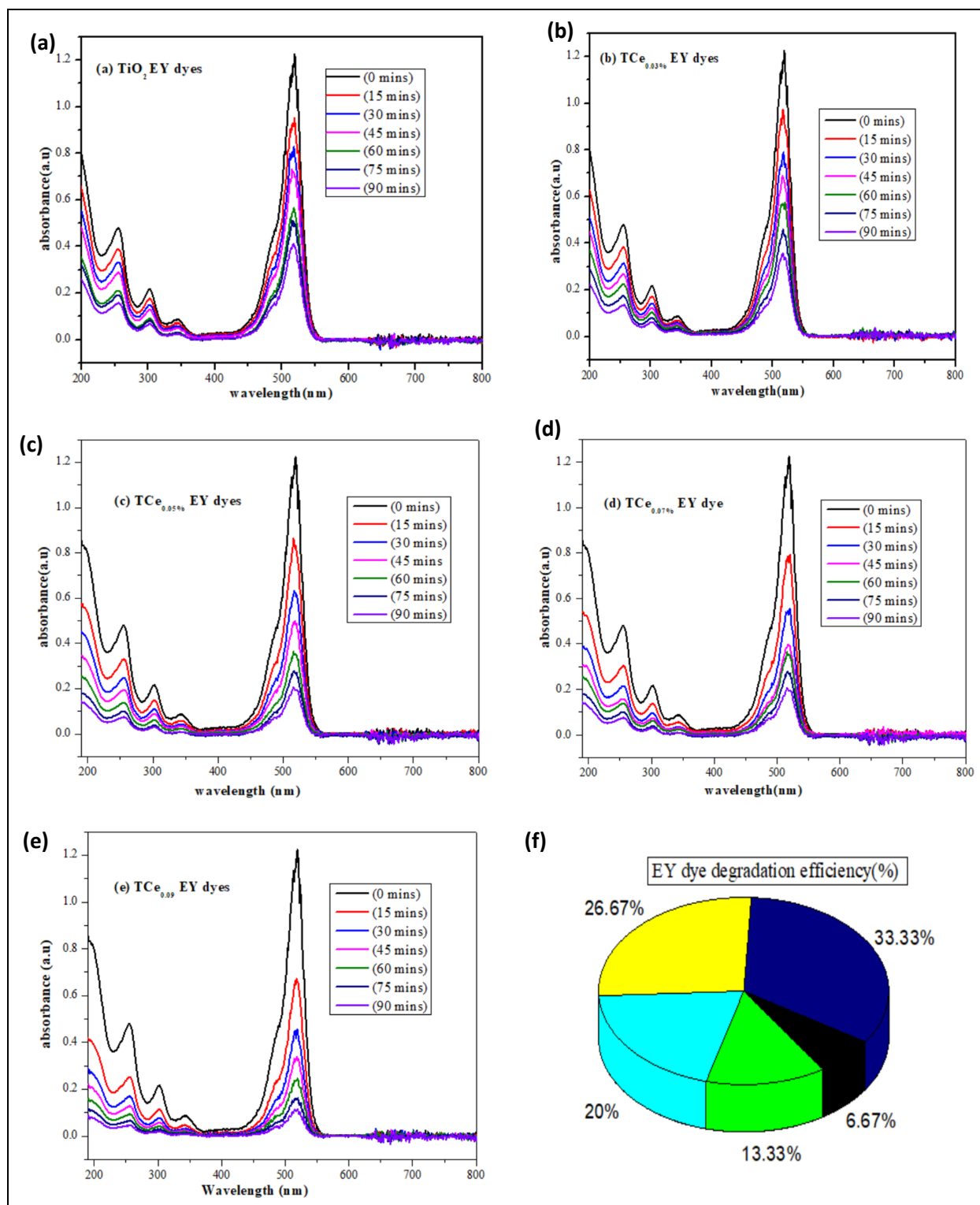


Fig. 6: The time-dependent UV-vis absorption spectra of eosin yellow dye (EY) degradation

3.4.1 Equation for Photocatalytic Reaction

The photodecomposition method of RhB and EY dyes has been reported. Two mechanisms occur in an aqueous solution when TiO_2 particles are present as a photocatalyst: (1) the photocatalytic system, which

would take place when exposed to UV light. (2) the photosensitization process, which typically takes place under visible light irradiation; in this case, the process, TiO_2 , would be activated to generate electrons under UV - O_2 irradiation, thereby driving photodegradation. (Pawar *et al.* 2018)

(1) Photocatalytic: Ce-TiO_2 (system) + $h\nu \rightarrow e^- + h^+$

(2) $\text{Ce}^{4+} \rightarrow \text{Ce}^{3+} + e^-$

(3) Interfacial charge transfer: $e^- (\text{CB Ce}) \rightarrow e^- (\text{CB anatase}) \rightarrow e^- (\text{CB rutile})$

(4) Reduction: $\text{O}_2 + e^- (\text{CB rutile})$

(5) $\text{O}_2^- + \text{organic dye} \rightarrow \text{degradation of dye}$

(6) Interfacial charge transfer: $h^+ (\text{UV rutile}) \rightarrow h^+ (\text{UV Ce})$

(7) Oxidation: $h^+ (\text{UV Ce}) + \text{H}_2\text{O} \rightarrow \text{HO}^\bullet + \text{H}^+$

(8) $\text{HO}^\bullet + \text{Organic dye} \rightarrow \text{degradation of dye}$

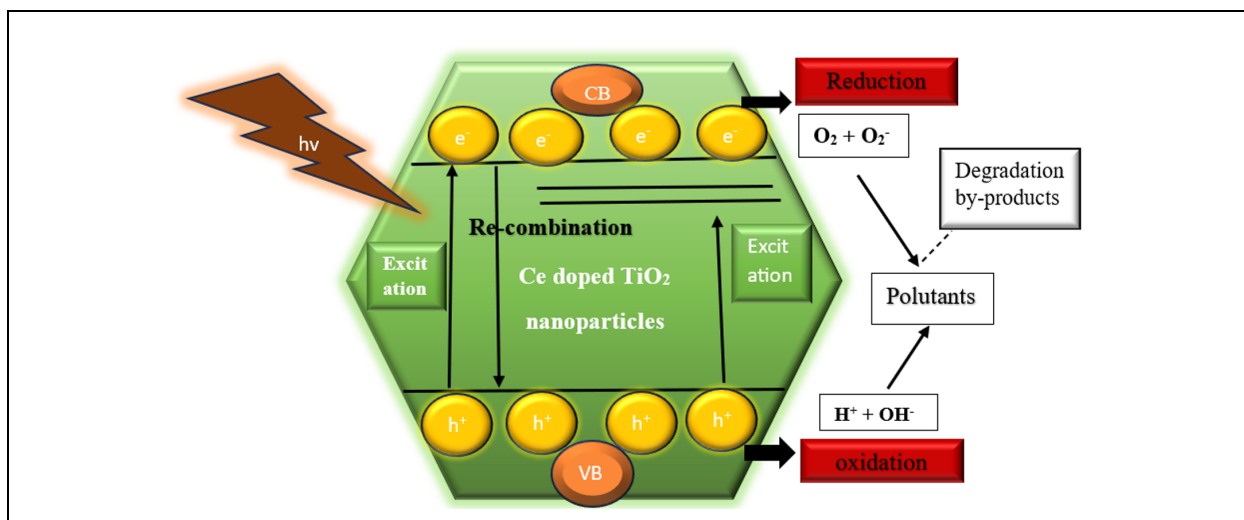


Fig. 7: Photocatalytic process mechanism pathway

4. CONCLUSION

The sol-gel method was successfully used to synthesise Ce-doped TiO_2 nanoparticles. Ce ions were absorbed into the TiO_2 lattice, resulting in decreased crystallite size, increased lattice strain, and band-gap narrowing, as confirmed by structural and optical spectroscopy. Under UV irradiation, the improved Ce-doped TiO_2 indicated excellent photocatalytic performance, degrading Rhodamine B (RhB) by around 98% and Eosin Yellow (EY) by 91.65%. Improved light absorption, effective charge separation, and inhibited electron-hole recombination were identified as the causes of the increased activity. These findings indicate that Ce-doped TiO_2 has the potential to be an effective photocatalyst for wastewater treatment. Future research should focus on treating actual wastewater systems, enhanced characterization, catalyst reusability, and visible-light photocatalysis.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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