

Research Article

Green-Synthesized Sm³⁺-Doped ZnO Nanoparticles for Multifunctional Applications

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The present study focuses on the green-mediated synthesis of pristine and Sm^{3+} -doped ZnO nanoparticles using *Syzygium cumini* fruit extract. The prepared material was characterized by various characterization techniques. Photocatalytic degradation of a fast orange red (FOR) dye under UV light resulted in 88% degradation, with a minimal decrease (87.90%) observed even after five successive runs, indicating the stability and effectiveness of the catalyst. The enhancement in degradation efficiency is attributed to the incorporation of Sm³⁺ ions into the ZnO lattice. Utilizing the optimized Sm³⁺ (5 mol%)-doped ZnO nanoparticles, cyclic voltammetry (CV) and electrochemical impedance spectra (EIS) were performed on the prepared electrode, demonstrating the excellent CV properties; this enhancement is attributed to the modification of ZnO's redox chemistry and the alteration of charge transfer kinetics at the electrode-electrolyte interface due to the addition of Sm³⁺ into the ZnO structure. The antibacterial activity was performed against two pathogenic strains, i.e., *Escherichia coli* and *Streptococcus aureus*. The obtained results suggest that the prepared material holds great promise for catalytic, energy storage, antibacterial, and other multifunctional applications.

1. Introduction

The rapid growth in nanotechnology has greatly influenced researchers and industries to discover new features of both novel and conventional materials at the nanoscale level [1, 2]. Among various nanomaterials, metal oxides exhibit outstanding electrochemical and antibacterial activity attributed to their ability to finely tune band gaps, actively engage in redox reactions, and display surface reactivity. This inherent capability is pivotal in advancing the fields of energy storage and conversion, enabling the development of pioneering technologies. Moreover, the same features play a crucial role in tailoring metal oxides for specific antibacterial or bioactive functionalities, opening up possibilities for innovative applications in healthcare and material science. Among the various metal oxides, we use zinc oxide nanoparticles as they reflect semiconducting properties at the nano level [3].

ZnO nanoparticles are one of the great potential semiconductor photocatalysts owing to their advanced properties, low cost, abundance, high surface activity, and environmental friendliness. ZnO is a wide-bandgap semiconductor (3.37 eV) with a 60 meV exciton binding energy [4]. There are three unit structures, hexagonal wurtzite, zinc blende, and rock salt in ZnO, among the various structures, and hexagonal wurtzite is the most recognized owing to its superior properties [5].

ZnO replaces TiO₂ in most of the applications. It is a very popular nanomaterial that has been attracting a lot of attention due to its diversity of applications such as gas sensors, biosensors [6], solar cells, organic LEDs [7], batteries, optoelectronic [8], electronic, spintronic [9], photocatalytic [10], antibacterial [11–13], nanomedicine [14], photochemical devices [15], technological, and industrial domain [16]. However, undoped ZnO nanoparticles are affected by photoinduced electron-hole pair recombination and low-light translation efficiency [17].

In addition to this, intensive research is carried out with effective rare earth ion dopants to enrich the photocatalytic degradation of ZnO. It has been reported that Sm³⁺ doping sturdily affects crystal defects, surface morphology, and electrical and optical properties. The dopants diminish the electron-hole pair recombination rate and formation of dopant energy levels within the band gap to expand light absorption capacity [5, 18, 19]. Several chemical and physical methods are used for the fabrication of nanoparticles [20, 21]. Compared to other methods, biomediated procedures are the best possible alternative for fabricating environmentally friendly and nontoxic nanoparticles [22].

In this current work, we presented a simple green synthesis technique to fabricate pristine and Sm³⁺ionsdoped ZnO nanoparticles. Compared with other techniques, this method is simple, fast, inexpensive, green way, and highly competent. The fuel used for the synthesis is easily available as well as renewable in nature. It has various functional biomolecules such as polyphenols, anthocyanins, flavonoids, ellagic acid, gallic acid, tannins, triterpenoids, betulinic acid, and macro biomolecules, act as reducing agents, and also impact the structure properties of the synthesized materials [23-25]. ZnO-based nanomaterials were tested for photocatalytic degradation [26, 27] because it has a wide range of applications (Table 1 Supplementary data) and the main emphasis was exerted on the removal of the fast orange red (FOR) dye from synthetic waste-water [28, 29].

ZnO nanoparticles doped with Sm³⁺ ions were confirmed as promising extremely active photocatalyst under UV illumination because of the reduction of the band gap, improved charge separation between electrons and holes, stability, and increased light absorption capacity [30, 31]. The electrochemical behaviour of the Sm3+ ion-doped ZnO was investigated for sensing paracetamol. Paracetamol, also known as acetaminophen, is an electrochemically active molecule that has been broadly tested in various templetes. Paracetamol is the main ingredient in cold and flu medication; however, it does have some potential disadvantages and limitations; overdose of paracetamol can lead to severe complications such as liver damage or liver failure and also causes side effects in some individuals such as gastrointestinal issues, skin rashes, hives, difficulty in breathing, and allergic reactions. The sensors revealed significant selectivity, duplicability, and sensitivity that could be stretched to sense paracetamol in various samples.

The present study focuses on synthesizing and characterizing Sm³⁺-doped ZnO nanoparticles through a green combustion technique using Syzygium cumini fruit extract for multifunctional applications. The study specifically focuses on elucidating the photocatalytic degradation efficiency of a fast orange red (FOR) dye under UV light exposure, assessing the electrochemical properties of Sm^{3+} doped ZnO electrodes via cyclic voltammetry (CV), and evaluating the antibacterial activity against pathogenic strains, namely Escherichia coli and Streptococcus aureus. The novelty of the present work lies in the preparation of materials for multifunctional applications with green and environmentally friendly approach. It demonstrates potential applications in catalysis, supercapacitors, batteries, sensors, and antibacterial activities, and this broad range of functionalities enhances the materials utility and widens its scope for practical applications.

2. Experimental Setup

2.1. Materials. Samarium (III) nitrate hexahydrate $(Sm(NO_3)_3.6H_2O, 99.99\%)$ and zinc nitrate hexahydrate $(Zn(NO_3)_2.6H_2O, 99.99\%)$ of analytical grade were supplied by Hi-Media Chemical Company (India). Reagent-grade dye (fast orange red) (\geq 99.8%) was supplied by Merck (Germany). Distilled water and fresh *Syzygium cumini* (Jamun fruit) are collected from the botanical garden near the Dayananda Sagar Academy of Technology and Management located at Udayapura, Bengaluru.

2.2. Preparation of Fruit Extract. Fresh Syzygium cumini fruit was collected from the botanical garden. These fruits were washed twice thoroughly using running tap water and then again washed with distilled water dried in air. The washed portions are chopped into fine pieces and the pulp of the fruit is separated from the seeds. 100 gm of the chopped pulp is taken and crushed using pestle and mortar, and juice is extracted by filtering.

2.3. Synthesis of ZnO:Sm³⁺ (1-7 mol%) Nanoparticles Using Jamun Fruit Extract as Fuel. The fabrication process of Sm³⁺-doped ZnO nanoparticles is illustrated in Figure 1. A similar procedure for the biosynthesis of undoped ZnO NPs was described elsewhere. Briefly, the stoichiometric ratio of Sm(NO₃)₃.6H₂O and Zn(NO₃)₂.6H₂O were taken in Becher containing 10 ml of distilled water and 7 ml of fruit extract. The uncovered Becher was shaken for 15 min using a magnetic stirrer and kept at 450°C in Muffle Furnace for 30 min. The sample is calcined at the temperature of 550°C for 3 hr. The obtained white solid was cooled down, pulverized, and then stored in a desiccator for further experiments, and the corresponding procedure is illustrated in Figure 1. Undoped ZnO NPs were also prepared by the above mentioned procedure. Sm-doped ZnO with different mol% Sm³⁺ doping concentrations ranging from 1 to 7 mol % were denoted by ZnO: 1 mol %Sm³⁺, ZnO: 3 mol %Sm³⁺, Zno: 5 mol% Sm³⁺, and ZnO:7 mol %Sm³⁺, respectively [32].



FIGURE 1: Schematic diagram of general plan and preparation of pristine and Sm³⁺-doped ZnO nanoparticles.

2.4. Photocatalytic Experimental Procedure. To investigate the photocatalytic properties of the prepared catalysts, we conducted experiments aimed at the degradation of FOR dye. A 20 ppm solution of FOR in 250 ml of aqueous solution and 60 mg of photocatalysts were placed in a circular glass reactor with a surface area of 176.6 cm^2 . The photocatalytic reaction was initiated under a 125 W mercury vapor lamp, serving as the source of UV light. To activate the photocatalytic process, the solution mixture was thoroughly stirred while exposed to UV light. The irradiation took place by directing UV light directly into the reaction mixture from the top, maintaining a distance of 21 cm, and conducted in an open-air condition [33]. The progress of the reaction was monitored using UV-Vis absorption spectroscopy at room temperature, covering the range of 200-800 nm. A Shimadzu UV-Vis spectrophotometer model 2600 was employed for accurate measurements.

2.5. Fabrication of Working Electrode. In all electrochemical experiments, the carbon paste electrode (CPE) was used as the working electrode. The preparation of the working electrode was as follows: 75%, 15%, and 10% of prepared nanomaterial, graphite powder, and polytetrafluoroethylene, respectively, were mixed thoroughly for about 30 min after which the mixture was inserted into nickel mesh and crushed well at 20 MPa for 5 min to get an electrode. The 0.5 mol KOH is used as an electrolyte and the 1 mol sodium sulfate solution is an electrolyte in EIS studies. The current produced was measured using Ag/AgCl as the reference electrode and platinum wire as the counter electrode.

3. Results and Discussions

To confirm the structure and crystal phase of pristine and doped ZnO nanomaterials, the samples were analyzed by powder X-ray diffractometer. Figure 2 displays the XRD patterns of pristine and doped ZnO. All the obtained peaks and their relative intensities of the prepared samples are well-matched with JCPDS No. 89–1397. The sharp peaks in PXRD indicate the high crystalline nature of prepared materials [34].

The average crystallite size of all the pristine and Sm^{3+} -doped ZnO nanomaterials is estimated using the Scherrer equation (35):

$$\mathbf{D} = \frac{\mathbf{K}\boldsymbol{\lambda}}{\beta\cos\theta},\tag{1}$$

where D = crystallite size, $\lambda = wavelength$ of X-rays, K = Scherrer constant, and $\beta = full-width$ half maximum. Also, the strain in the Sm³⁺-doped ZnO nanomaterials was evaluated using the W-H plots:

$$\beta \cos \theta = \frac{0.9\lambda}{D} + 4\varepsilon \sin \theta.$$
 (2)

Equation (2) indicates a straight line, and the slope and intercept of the line give the strain and crystallite size.

The size-strain plot (SSP) method was used to calculate size-strain parameters. In this method, the crystallite size was described by a Lorentzian function and the strain profile by a Gaussian function [32]. Accordingly, we have

$$\left(\mathbf{d}_{\mathbf{hkl}}\boldsymbol{\beta}_{\mathbf{hkl}}\cos\boldsymbol{\theta}\right)^{2} = \frac{\mathbf{k\lambda}}{\mathbf{D}}\left(\mathbf{d}_{\mathbf{hkl}}\boldsymbol{\beta}_{\mathbf{hkl}}\cos\boldsymbol{\theta}\right) + \left(\frac{\boldsymbol{\varepsilon}}{2}\right)^{2}, \quad (3)$$

where k is a constant that depends on the shape of the particles; for spherical particles, it was given as ~0.9. Similar to the W-H plots, the factor $(d_{hkl} \beta_{hkl} \cos\theta)^2$ was plotted with respect to $(d_{hkl} \beta_{hkl} \cos\theta)$ for all the orientation peaks of ZnO. By linearly fitting the data, the crystallite size and macrostrain was calculated from slope and *y*-intercept of the fitted line. The results obtained from the Scherrer equation, W-H, and size-strain plot method are summarized in



FIGURE 2: PXRD patterns of prepared pristine and (1-7 mol%) Sm³⁺-doped ZnO nanoparticles.

Table 1, and the small variation in the values of *D* may be due to the difference in averaging the particle size distribution. The reduction in crystallite size revealed the large surface to volume ratio which has created more photoexcited electronhole pairs when irradiated by light and enhanced its photocatalytic activity. The conclusion drawn is that the SSP method is more consistent, as it achieves a maximum linear fitting with a greater number of data points closely aligned with the fitted line [36]. The density of X-rays (dX) and specific surface area (S) were calculated using the equations and all the estimated values are depicted in Table 1 [37].

$$dX = \frac{ZM}{Na^3}$$

$$S = \frac{6}{dXD},$$
(4)

where M is the molecular weight, Z is the number of ZnO molecules, and N is Avogadro's number. Also, the comparison of crystallite size with various synthesis route of reported nanomaterials are given in Table 2 (Supplementary data).

$$\varepsilon = \frac{\beta \cos \theta}{4},$$

$$\delta = \frac{1}{D^2}.$$
(5)

The structural morphology of the synthesized nanomaterials was examined through FESEM analysis, and the resulting SEM images are illustrated in Figure 3. The observations from Figure 3 indicates the porous and agglomerated nature of the prepared material and revealed an interconnected network structure with a high rate of agglomeration, and this kind of morphology is attributed to the rapid evolution of gases during the combustion process [20, 38]. The EDAX spectra (Supplementary data) show the elemental composition of the prepared sample. The expected elements such as Zn, O, and Sm³⁺ are detected in the peaks of EDAX spectra. The EDAX spectra reveal the successful incorporation of Sm³⁺ ions in the ZnO lattice [39].

Diffuse reflectance spectroscopy (DRS) serves as a nondestructive and versatile analytical tool, employed to investigate the absorption properties of materials, particularly when they are in powdered or granular form. This technique not only facilitates the exploration of optical characteristics but also provides valuable insights into a broad spectrum of material properties. DRS studies were performed to analyze the optical properties of the synthesized pristine and Sm³⁺doped ZnO, and the recorded diffused reflectance spectrum is shown in Figure 4. The band gap energy of the pristine and Sm³⁺-doped ZnO was calculated from the DRS using the Kubelka–Munk function:

$$\mathbf{F}(\mathbf{R}_{\infty}) = \frac{(\mathbf{1} - \mathbf{R}_{\infty})}{2\mathbf{R}_{\infty}}.$$
 (6)

Here, R_{∞} is the absolute reflectance and *F* (R_{∞}) is the Kubelka–Munk function [40]. The optical band gap values are estimated by plotting the variation of the Kubelka–Munk function with photon energy through the following equation [41, 42].

$$\mathbf{F}(\mathbf{R})\mathbf{h}\mathbf{v} = \mathbf{A}\left(\mathbf{h}\mathbf{v} - \mathbf{E}_{\mathbf{g}}\right)^{\mathbf{n}}.$$
 (7)

Here, "Eg" is the optical band gap energy, $h\nu$ is the incident photon energy, and n is the nature of the sample transition which depends on the type of optical transition triggered by photon absorption. Obtained characteristic Kubelka–Munk plots of the prepared nanomaterial are shown in Figure 5, and the energy gap values for the prepared ZnO samples were found to be in the range of 3.14–3.20 eV, which was lesser than the reported value (~3.3 eV). The reduction in the band gap energy might be owing to ZnO lattice crystal defects and also the presence of excess Zn in interstitial wurtzite lattice.

To investigate the effect of Sm³⁺ in ZnO structure, photocatalytic studies were performed on FOR dye for a total duration of 120 mins with a time interval of 15 mins under UV light. Photocatalytic experiments were performed for the degradation of FOR dye, a 20 ppm of 250 ml aqueous solution of FOR dye, and 60 mg of photocatalysts in 176.6 cm² surface area of a circular glass reactor under a 125 W mercury vapor lamp as a source of UV light operating with an accelerating voltage up to 20 kV using a Tungsten filament. The irradiation was carried out directly focusing UV light into the reaction mixture from the top at a distance of 21 cm in the open-air condition. Also, it was monitored by UV-Vis absorption spectroscopy at RT in the range 200-800 nm using Shimadzu UV-Vis spectrophotometer and the corresponding absorption spectra of Sm³⁺ (5 mol%): ZnO catalyst are presented in Figure 6, and the efficiency of degradation was evaluated by the following equation:

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Nanocomposite	Crystallite size by Scherrer equation (nm)	Crystallite size by WH plots (nm)	Crystallite size by size-strain plots (nm)	Dislocation density (δ)	Strain (E)
ZnO	25.6	44.1	28	0.00140	0.001539
1% Sm ³⁺ : ZnO	25.7	44.3	27	0.00141	0.001527
3% Sm ³⁺ : ZnO	25.9	44.1	28	0.00139	0.001497
5% Sm ³⁺ : ZnO	25.3	44.7	24	0.00141	0.001567
7% Sm ³⁺ : ZnO	25.6	44.3	26	0.00139	0.001539

TABLE 1: Estimated crystallite parameters of prepared materials.



FIGURE 3: FESEM images of Sm³⁺-doped ZnO nanoparticles.



FIGURE 4: DRS spectra of Sm³⁺-doped ZnO nanoparticles.



FIGURE 5: Energy gap spectra of Sm³⁺-doped ZnO nanoparticles.



FIGURE 6: Absorbance spectra of Sm³⁺-doped ZnO nanoparticles.

Degradation efficiency =
$$\frac{C0 - C}{C0} \times 100$$
 %. (8)

The degradation of FOR dye tracks the Langmuir–Hinshelwood first-order kinetics model and can be expressed as ln (C/Co) = -k t, where k is the constant of apparent reaction rate, C₀ is the initial concentration of aqueous dye, t is the reaction time, and C is the concentration of aqueous FOR dye at the reaction time of t. The percentage of FOR dye degradation with Sm³⁺ (1–7 mol%) activated ZnO catalyst is illustrated in Figure 7. Sm³⁺ (5 mol



FIGURE 7: % of degradation and (C/C_0) spectra of Sm³⁺-doped ZnO nanoparticles.

%)-activated ZnO catalyst reveals that 88% of FOR dye was degraded, and the detailed mechanism of photocatalytic degradation process under UV light irradiation is presented [43, 44]. The detailed degradation percentage of FOR dye with Sm³⁺-doped ZnO catalyst under UV light irradiation is given in Table 2, and the comparison study of different dye degradations is given in Table 3 (Supplementary data) [45–47].

During UV irradiation (Figure 8), photons with energy equal to or greater than the bandgap of ZnO are absorbed, promoting electrons from the valence band (VB) to the conduction band (CB). These excited electrons in the CB of ZnO can interact with Sm³⁺ ions present in the ZnO lattice. The Sm³⁺ ions act as electron scavengers, effectively reducing the recombination of the electron-hole pairs that are generated during the excitation process. By minimizing recombination, the presence of Sm³⁺ ions enhances the lifetime and mobility of the photogenerated charge carriers. The reduced recombination rate results in a higher concentration of reactive species, such as O₂⁻ and OH, which are known for their strong oxidative properties. These reactive species are responsible for the degradation of organic compounds, including the fast orange red (FOR) dye, through oxidation processes.

Additionally, the presence of Sm³⁺ ions in the ZnO lattice creates defects, such as oxygen vacancies and interstitial sites, as well as modifies the band structure of ZnO. These modifications can shift the energy levels of the CB and VB, influencing the positions of the redox potentials and the ease with which electrons can be transferred to or from the ZnO surface. As a result, the addition of Sm³⁺ ions not only enhances the generation of reactive species but also affects the overall electronic properties of ZnO, contributing to its improved photocatalytic performance. The Sm²⁺ ions, which are produced from the reduction of Sm³⁺ by the

5 mol% Sm ³⁺ : ZnO								
t	с	c/c_0	$\log c/c_0$	$-\log c/c_0$	%D			
0	20	1	0	0	0			
15	5.22293	0.261146	-0.58312	0.5831	73.8853			
30	5.095541	0.254777	-0.59384	0.5938	74.5222			
45	4.246285	0.212314	-0.67302	0.6730	78.7685			
60	2.972399	0.14862	-0.82792	0.8279	85.1380			
75	2.845011	0.142251	-0.84695	0.8469	85.7749			
90	2.675159	0.133758	-0.87368	0.8736	86.6242			
105	2.420382	0.121019	-0.91715	0.9171	87.8980			
120	2.208068	0.110403	-0.95702	0.9570	88.9596			
Slope = 0.007701			$Rate = 0.017735 min^{-1}$					

TABLE 2: The rate constant and kinetic studies of 20 ppm fast orange red dye in 60 mg Sm³⁺-doped ZnO under UV light.



FIGURE 8: Mechanism of degradation of FOR dye under Sm³⁺-doped ZnO nanoparticles.

photogenerated electrons, are less stable and can react with O_2 to promote the generation of O_2^- . This process contributes to the pool of reactive oxygen species available for the photocatalytic degradation reactions. The degradation mechanism for Sm³⁺-doped ZnO is shown in the following equations:

$$ZnO + hv \longrightarrow e^{-} + h^{+}$$

$$O_{2} + e^{-} \longrightarrow O_{2}^{--}$$

$$OH + h + \longrightarrow OH$$

$$O_{2}^{--} + OH + dye \longrightarrow degradation product$$

$$Sm^{3+} + e^{-} \longrightarrow Sm^{2+}$$

$$O_{2} + e^{-} \longrightarrow O_{2}^{--}$$

$$O_{2}^{--} + Sm^{3+} \longrightarrow Sm^{2+}$$

$$Sm^{2+} + O_{2} \longrightarrow Sm^{3+} + O_{2}^{--}.$$
(9)

Furthermore, the half-life was evaluated for the FOR dye degradation of 50%, and the half-life was observed at 9.19 min. These results reveal that the synthesized material is useful for textile dye pollutants degradation and also suitable for the removal of secondary pollutants.

Furthermore, the reusability test was performed to investigate the photostability and reusability of the synthesized catalyst and a negligible decrease in the degradation efficiency was observed even after five successive runs; at the end of the 5th cycle, the decomposition efficiency was found to be 87.90%. It was observed that the physical property of the new and used photocatalyst remains almost same. The well-established stability of the catalyst increases its practical usage as a catalyst in the photodecomposition of dye. Thus, the prepared material was stable and reusable.

Electrochemical studies were performed to examine the electrochemical properties of Sm^{3+} -doped ZnO for battery and supercapacitor applications. The obtained cyclic voltammetry (CV) curve of Sm^{3+} (5 mol%): ZnO electrodes with various scan rates (0.01 V/s–0.05 V/s) are shown in Figure 9. It was noticed that the peaks shift towards positive and negative potential side upon increasing the scan rates which indicates the pseudocapacitive nature of Sm^{3+} : ZnO electrode [48].

To understand the charge transfer resistance, electrochemical impedance studies (EIS) were performed, and the obtained spectra of Sm³⁺(5 mol%): ZnO electrode and the fitted equivalent circuit are seen in Figure 10(a) and 10(b). Z' is the real component, which discloses the ohmic properties, and Z''is the virtual component, which reveals the capacitive properties. The EIS spectra show an elevated arc (semicircle); generally, an arc with larger radius indicates a higher charge transfer resistance [48]. Nyquist plots of pristine and 5 mol% of Sm³⁺-doped ZnO electrodes are presented in Figure 10. The results indicate a semicircle at the higher frequency region and a straight line at the lower frequency region, representing that the electrodes have a superior capacitive behaviour. Pristine ZnO electrode shows semicircle with larger radius which represents the higher charge transfer resistance, and 5 mol% of Sm³⁺-doped ZnO electrode shows semicircle with smaller radius which denotes the smaller charge transfer resistance and thus Sm³⁺(5 mol%)-doped ZnO electrode possesses superior capacitive properties than the pristine and other doped electrodes [49]. This superiority is primarily attributed to the introduction of Sm³⁺ into the ZnO structure. The incorporation of Sm³⁺ serves to modify the redox chemistry of ZnO and brings about alterations in the charge transfer kinetics at the electrode-electrolyte interface. These combined effects contribute synergistically to the superior capacitive performance observed in the Sm³⁺-doped ZnO electrodes.

Also, to assess the applicability of the proposed method as an electrochemical sensor, prepared electrodes were used to sense the paracetamol content in available Dolo-650



FIGURE 9: CV plots of Sm³⁺ (5 mol%)-doped ZnO nanoparticles.



FIGURE 10: (a) EIS spectra of pristine and Sm³⁺ (5 mol%)-doped ZnO nanoparticles; (b) fitted equivalent circuit for EIS Spectra.

tablets, and the spectra are presented in Figure 11. Paracetamol is an electrochemically active molecule that has been broadly tested in various samples. Several papers have been published on the electroanalytical determination of paracetamol depending on its oxidation behaviour with electrodes such as modified glassy carbon electrodes, graphite electrodes, and gold electrodes [50-54]. Electrochemical techniques are versatile analytical techniques that can solve the problems of pharmaceutical interest. Voltammetry is a convenient electrochemical analytical technique that exhibits high selectivity, sensitivity, and accuracy. Figure 11 shows that observed and modified CV profile with the scan rate 0.05 V/s is surely due to the paracetamol. This demonstration stated that the paracetamol substances in pharmaceutical medicines can be sensed by using the proposed method [55].

The current study employs the gel diffusion method for the antibacterial activity of Sm3+: ZnO (5 mol%) nanoparticles (Figure 12) using pathogenic bacterial strains of Streptococcus aureus and Bacillus subtilis (Gram positive) and Escherichia coli and Pseudomonas aeruginosa (Gram negative) bacteria (Azymes Biosciences Pvt. Ltd., Bengaluru). Different dilution of Sm³⁺: ZnO (5 mol%) of 150, 100, 50, and 25 mg/ml was done by using autoclaved distilled water. Standard antibiotic ciprofloxacin (20 mcg/disc) (Hi-Media, Mumbai, India) and autoclaved distilled water are used as positive and negative control, respectively. Antibacterial activity was done as per the standardized protocol in our lab. After 24-36 hrs, the diameter of the clear zone of inhibition around the discs is measured to assess the antibacterial activity. The results of the antibacterial activity showed a significant zone of inhibition at higher



FIGURE 11: Paracetamol-treated CV plots of Sm³⁺ (5 mol%)-doped ZnO nanoparticles.



FIGURE 12: Antibacterial activities of synthesized material.

concentrations (100 mg/ml) demonstrating efficient antibacterial activity of Sm^{3+} : ZnO (5 mol%). However, these NP's activity is interpreted to be more effective even at lower doses like 25 mg/ml on *E. coli* and *S. aureus*. Even though the mode of action of Sm^{3+} : ZnO (5 mol%) against microbes is not completely understood yet, hypotheses may interfere with microbial multiplication, the ways of inhibition of bacterial growth may be the production of reactive oxygen species which may lead to denaturizing proteins by bonding with the sulfhydryl group or by damaging its genetic material [56] and the comparison study of antibacterial activity with other various materials are given in Table 4 (Supplementary data).

4. Conclusion

In summary, pristine and Sm³⁺ ions-doped ZnO nanomaterial with various dopant concentrations have been fabricated by the green synthesis technique. The predicted XRD graph confirms that the effective integration of Sm³⁺ ions in the lattice of ZnO crystal and FESEM examination of prepared samples evidence the morphology. Photocatalytic activity of the prepared catalyst was performed to degrade fast orange red dye. In the degradation process, it has been noticed that the 5 mol% Sm³⁺-doped ZnO catalyst shows the maximum catalytic activity compared to another prepared catalyst. Optimized Sm³⁺ concentration on ZnO electrode has shown great impact on the electrochemical activities, and this approach was applied to monitor paracetamol and exhibits exceptional response to sense paracetamol. Antibacterial activity analysis demonstrated excellent inhibition by prepared nanomaterials on Gram positive compared to Gram negative. All the obtained results explored that the present material can be highly useful for multifunctional applications such as wastewater purification and decolorsupercapacitor, battery, and antimicrobial ation, applications.

Data Availability

The data used to support the findings of this study can be made available on request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

Table 1 from introduction section, Table 2 from XRD section, Table 3 from photocatalytic section, and Table 4 from antimicrobial section are given in the supplementary file. Figures such as W-H plots, SS plots, EDS analysis, time span of fast orange red dye, reusability test, % of degradation, and (C/C_0) spectra of Sm³⁺-doped ZnO nanoparticles are given in the supplementary files. (*Supplementary Materials*)

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