IOSR Journal Of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 18, Issue 1 Ser. 1 (Jan – Feb 2026), PP 15-24
www.Iosrjournals.Org

Functional Properties Of Eu-Doped Strontium Ferrite Perovskite Nanomaterials For Magnetic, Catalytic, And Energy Applications

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Abstract:
Eu-doped strontium ferrite perovskite nanomaterials ($Sr_{1-x}Eu_xFeO_3$) have emerged as an important class of functional oxides due to their tunable structural, magnetic, electronic, and catalytic properties. The combination of mixed valence states, oxygen non-stoichiometry, and strong spin–lattice coupling provides a rich platform for engineering material performance for practical applications. This article presents a consolidated overview of recent developments in synthesis, structural evolution, magnetic characteristics, catalytic behavior, and energy-related applications of Eu-doped strontium ferrite perovskite nanomaterials. The influence of Eu substitution on crystal symmetry, defect chemistry, microstructure, band structure, and functional behavior is critically examined. Finally, emerging challenges and opportunities for future research in magnetism, catalysis, and renewable energy technologies are discussed

Keywords: *Eu-doped $SrFeO_3$; Perovskite nanomaterials; Magnetic properties; Catalytic applications; Energy applications.*

Date of Submission: 03-01-2026 Date of Acceptance: 13-01-2026

I. Introduction

Perovskite-structured transition-metal oxides with the general formula ABO_3 (Fig 1) have attracted considerable attention owing to their remarkable structural flexibility and the wide range of electrical, magnetic, catalytic, and optical properties they exhibit. Among these materials, strontium ferrite perovskite ($SrFeO_3$) has emerged as a particularly versatile system due to the coexistence of mixed Fe^{4+}/Fe^{3+} oxidation states, strong Fe–O hybridization, oxygen vacancy ordering, and temperature-dependent metal–insulator transitions. These intrinsic characteristics make $SrFeO_3$ a promising candidate for diverse applications, including magnetic storage devices, heterogeneous catalysis, environmental remediation, and electrochemical energy-conversion technologies. [1,2,3].

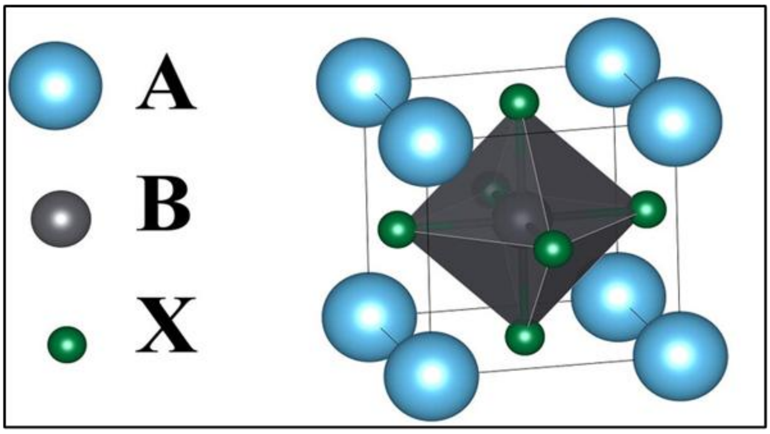

Fig 1: Perovskite Structure

A-site substitution in perovskite oxides provides an effective strategy for tailoring crystal structure, electronic configuration, and defect chemistry. In this context, substitution of trivalent europium (Eu^{3+}) ions at the divalent Sr^{2+} site introduces lattice distortion due to ionic size mismatch and charge imbalance [4]. This imbalance is typically compensated through partial reduction of Fe^{4+} to Fe^{3+}, the formation of oxygen vacancies, and local structural rearrangements that modify Fe–O bond lengths and Fe–O–Fe bond angles. Such structural and electronic perturbations have a pronounced influence on superexchange and double-exchange interactions, charge-transport pathways, and catalytic activity, thereby enabling systematic tuning of functional properties.

Structurally, $SrFeO_3$ generally crystallizes in a nearly cubic perovskite framework; however, deviations from oxygen stoichiometry can induce lattice distortions, driving the structure toward tetragonal or orthorhombic symmetry. The high degree of oxygen non-stoichiometry allows continuous modulation of Fe oxidation states, which in turn enhances both electronic and ionic conduction. Upon Eu substitution, these effects become more prominent, leading to increased defect concentration, altered magnetic interactions, and modified electronic structure.

Recent advances in nanostructuring strategies have further expanded the functional potential of Eu-doped $SrFeO_3$. At the nanoscale, enhanced surface area, increased density of active sites, and size-dependent effects significantly improve magnetic, catalytic, and energy-related performance compared to bulk counterparts [5]. In view of these developments, the present article consolidates and critically discusses reported studies on Eu-doped strontium ferrite perovskite nanomaterials, with particular emphasis on their structural evolution, magnetic behaviour, and applicability in magnetic, catalytic, and energy-related technologies

II. Methodology Overview

The methodology adopted in the reported studies on Eu-doped $SrFeO_3$ perovskite nanomaterials generally comprises two main components, as illustrated in the Figure 2. The first part involves the synthesis of Eu-substituted $SrFeO_3$ samples using various chemical routes, with particular emphasis on achieving phase purity, uniform dopant distribution, and controlled nanoscale features. The second part focuses on the systematic characterization of the synthesized materials to examine the effects of Eu doping on their structural, morphological, and magnetic properties [6]. These characterization results provide critical insights into how Eu substitution modifies lattice distortion, defect chemistry, and magnetic interactions in $SrFeO_3$ perovskites, thereby enabling their optimization for potential applications in spintronics, energy storage and conversion devices, magnetic sensing, and other multifunctional technological applications.

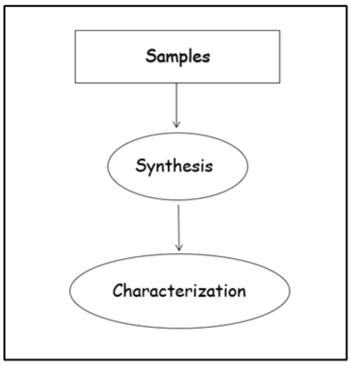

Fig 2: Flowchart of Methodology

(A) Synthesis Approaches

Several chemical and physical synthesis methods have been employed for the preparation of Eu-doped $SrFeO_3$ perovskite nanomaterials, each of which strongly influences crystallite size, morphology, defect concentration, and functional properties [7,8]. Broadly, these synthesis routes can be classified into top-down and bottom-up approaches as shown in the Figure 3

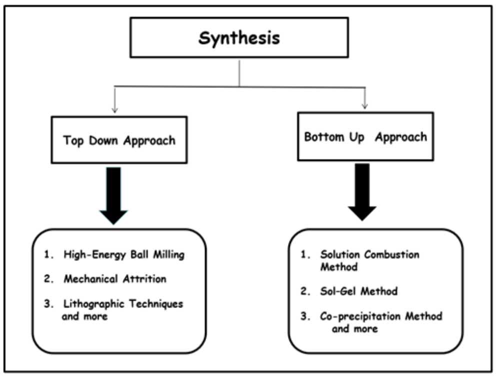

Fig 3: Synthesis Approaches

(1) Top-Down Approaches

Top-down approaches (Fig 4) involve the physical breakdown of bulk materials into nanoscale dimensions. These methods are relatively simple and scalable; however, they often result in a broad particle size distribution, irregular particle morphology, and the introduction of strain-induced defects. Prolonged mechanical processing may also lead to contamination from the milling media and a partial loss of crystallinity, which can adversely affect the magnetic and electronic properties of $SrFeO_3$-based perovskites. Consequently, top-down approaches are less frequently employed when precise control over structural and functional properties is required. Some commonly used top-down methods are briefly described below.

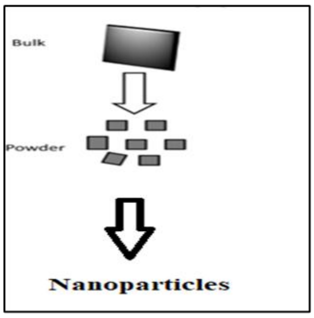

Fig 4: Top-Down Approaches

(i) High-Energy Ball Milling

High-energy ball milling is a mechanical technique in which bulk precursor materials are repeatedly fractured and cold-welded to obtain nanoscale particles. Although this method is simple and scalable, it often produces particles with a wide size distribution and induces lattice strain, which can affect crystallinity and magnetic properties.

(ii) Mechanical Attrition

Mechanical attrition involves prolonged grinding of bulk materials under controlled conditions to reduce particle size. This method can generate nanocrystalline powders; however, it frequently introduces structural defects and contamination from the milling media, limiting its suitability for high-purity perovskite oxides.

(iii) Lithographic Techniques

Lithographic methods enable patterning of materials at the micro- and nanoscale, primarily for thin-film applications. While these techniques provide excellent dimensional control, they are costly, complex, and not suitable for large-scale powder synthesis of $SrFeO_3$-based nanomaterials.

(2) Bottom-Up Approaches

Bottom-up approaches (Fig 5) involve the controlled assembly of atoms, ions, or molecular precursors to form nanostructured materials. These methods offer superior control over composition, crystallite size, morphology, and dopant distribution compared to top-down techniques. By carefully tuning synthesis parameters such as precursor concentration, reaction temperature, pH, and calcination conditions, bottom-up approaches enable the formation of phase-pure perovskite nanomaterials with tailored defect chemistry and oxygen vacancy concentration. As a result, these methods are particularly effective for optimizing the magnetic, catalytic, and energy-related properties of $SrFeO_3$ based perovskites. Consequently, bottom-up approaches are widely preferred for the synthesis of Eu-doped strontium ferrite nanomaterials. Some commonly employed bottom-up methods are outlined below.

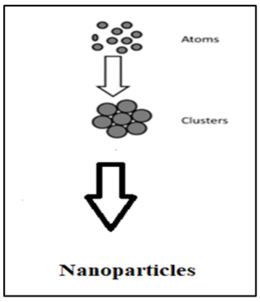

Fig 5: Bottom-Up Approach

(i) Solution Combustion Method

The solution combustion method involves a self-sustained exothermic reaction between metal nitrates and organic fuels, producing fine, porous nanoparticles within a short reaction time. This technique offers excellent dopant homogeneity, high surface area, and controlled oxygen vacancy formation, making it highly suitable for Eu-doped $SrFeO_3$ nanomaterials.

(ii) Sol–Gel Method

In the sol–gel process, metal precursors undergo hydrolysis and condensation reactions to form a homogeneous gel, which upon calcination yields nanocrystalline powders. This method provides precise control over stoichiometry, particle size, and chemical uniformity, though it typically requires longer processing times.

(iii) Hydrothermal / Solvothermal Method

Hydrothermal and solvothermal synthesis involves crystallization under high temperature and pressure in aqueous or organic solvents. These methods enable the growth of well-defined nanostructures with high crystallinity and controlled morphology at relatively low temperatures.

(iv) Co-precipitation Method

Co-precipitation involves the simultaneous precipitation of metal ions from solution, followed by thermal treatment to form the perovskite phase. This method is simple and cost-effective, but careful control of pH and calcination conditions is required to achieve phase purity.

(v) Solid-State Reaction Method

The solid-state reaction method uses high-temperature calcination of mixed oxide or carbonate precursors to form the desired perovskite phase. While it is straightforward and scalable, it generally produces larger grain sizes and lower surface area compared to wet-chemical routes.

In view of the focus on magnetic, catalytic, and energy applications, the solution combustion method is particularly suitable for the present study. This technique enables the rapid synthesis of Eu-doped strontium ferrite perovskite nanomaterials with fine crystallite size, high surface area, and uniform Eu incorporation, all of which are crucial for optimizing magnetic interactions, catalytic activity, and electrochemical performance. Moreover, the inherent generation of oxygen vacancies during the combustion process plays a key role in enhancing redox behaviour and functional efficiency across these application domains

(B) Characterisation Techniques

The characterization of Eu-doped $SrFeO_3$ perovskite nanomaterials reported in the literature commonly employs X-ray diffraction (XRD), field-emission scanning electron microscopy (FESEM), energy-dispersive X-ray spectroscopy (EDX), X-ray photoelectron spectroscopy (XPS), and transmission electron microscopy (TEM/HRTEM) to examine structural, morphological, compositional, and microstructural features, while the magnetic behaviour is typically investigated using vibrating sample magnetometer (VSM) measurements [9.10.11]. The overall synthesis and characterization strategy adopted in these studies is schematically illustrated in the following Figure 6

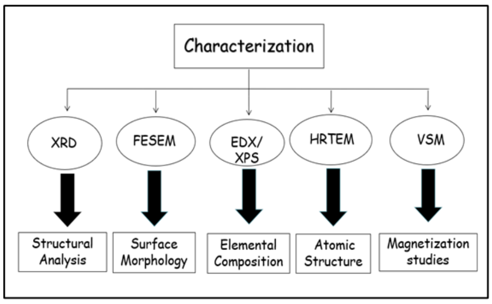

Fig 6: Schematic representation of Characteristic Techniques

(1) Structural Analysis

X-ray diffraction (XRD) studies reported in the literature consistently confirm the formation of phase-pure perovskite structures in Eu-doped $SrFeO_3$ nanomaterials at moderate Eu substitution levels, with no evidence of secondary impurity phases. The diffraction patterns are well indexed to the characteristic reflections of $SrFeO_3$-based perovskites, indicating the successful incorporation of Eu ions into the crystal lattice. Upon Eu doping, a noticeable broadening of diffraction peaks is commonly observed, which is attributed to a reduction in crystallite size and an increase in lattice microstrain. In addition, several studies report slight shifts of diffraction peaks toward higher diffraction angles, suggesting lattice contraction arising from ionic size mismatch and defect-induced structural distortion associated with Eu substitution [12].

To quantitatively distinguish the contributions of crystallite size and lattice strain to peak broadening, Williamson–Hall (W–H) analysis has been widely employed. The W–H plots reveal a systematic decrease in crystallite size along with an increase in microstrain as the Eu concentration increases, corroborating the strain-induced lattice distortion inferred from peak shifts. Furthermore, Rietveld refinement of the XRD data provides detailed structural information, including lattice parameters, unit cell volume, and atomic positions. The refinement results consistently show subtle variations in lattice constants and bond lengths with Eu doping, confirming the successful substitution of Eu^{3+} ions at the Sr^{2+} sites and the associated structural distortion while preserving the perovskite framework.

Raman and Fourier transform infrared (FTIR) spectroscopic investigations further corroborate these structural modifications. Variations in the Fe–O stretching and bending vibrational modes are frequently observed, indicating changes in the local bonding environment. These spectral features reflect lattice distortion, altered Fe–O–Fe connectivity, and the presence of oxygen vacancies induced by Eu incorporation, all of which play a crucial role in governing the magnetic, catalytic, and electronic properties of Eu-doped $SrFeO_3$ perovskite nanomaterials

(2) Morphological analysis

Field-emission scanning electron microscopy (FESEM) studies reported in the literature indicate that the morphology of Eu-doped $SrFeO_3$ perovskite nanomaterials is strongly dependent on the synthesis route and processing conditions. The particles are commonly observed to exhibit spherical or quasi-spherical morphologies, while rod-like structures and agglomerated clusters have also been reported. Such agglomeration is generally attributed to the high surface energy and magnetic interactions inherent to nanoscale ferrite particles. Porous and interconnected morphologies, frequently obtained through wet-chemical synthesis routes, are particularly advantageous for catalytic and energy-related applications, as they provide enhanced surface area, improved mass transport, and increased accessibility of active sites [13]. The schematic representation of Field emission scanning electron microscope (FESEM) is presented in figure 6

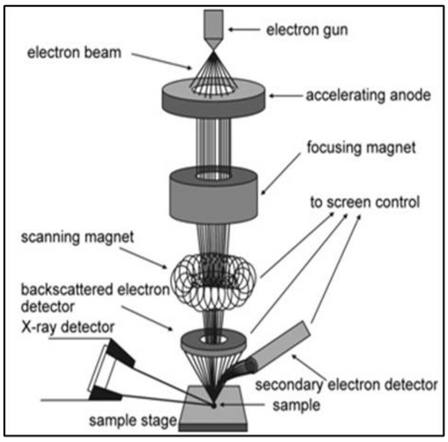

Fig 6: Schematic Representation of FESEM

(3) Compositional Analysis

Energy-dispersive X-ray spectroscopy (EDX) analyses reported in numerous studies confirm the elemental composition of Eu-doped $SrFeO_3$ perovskite nanomaterials and verify the successful incorporation of Eu into the crystal lattice. The EDX spectra typically show the presence of Sr, Fe, O, and Eu without detectable impurity elements, indicating high phase purity. In addition, elemental mapping results consistently demonstrate a homogeneous spatial distribution of Eu throughout the nanomaterials, suggesting uniform dopant incorporation at the microscale [14].

X-ray photoelectron spectroscopy (XPS) investigations reported in the literature further provide insight into the surface chemistry and oxidation states of the constituent elements [15]. XPS spectra commonly confirm the coexistence of mixed Fe^{3+}/Fe^{4+} oxidation states and the presence of Eu predominantly in the Eu^{3+} state, consistent with charge compensation mechanisms in the perovskite lattice. Furthermore, analysis of the O 1s core-level spectra frequently reveals contributions associated with lattice oxygen and oxygen vacancies, highlighting the crucial role of defect chemistry in governing the magnetic, catalytic, and electrochemical behaviour of Eu-doped $SrFeO_3$ nanomaterials.

(4) Microstructural Analysis

Transmission electron microscopy (TEM) studies reported in the literature provide valuable insight into the nanoscale microstructure of Eu-doped $SrFeO_3$ perovskite nanomaterials [16]. TEM images commonly reveal the formation of nanocrystalline particles with relatively uniform size distribution, indicating effective control over nucleation and growth during synthesis. Such nanoscale features are particularly beneficial for enhancing surface-dependent properties relevant to catalytic and energy applications.

Selected area electron diffraction (SAED) patterns reported for Eu-doped $SrFeO_3$ typically exhibit well-defined concentric diffraction rings, confirming the polycrystalline nature of the nanomaterials. The diffraction rings are generally indexed to the characteristic planes of the perovskite structure, in good agreement with phase identification obtained from X-ray diffraction. High-resolution TEM (HRTEM) analyses further reveal clear lattice fringes, demonstrating good crystallinity at the nanoscale, with interplanar spacings consistent with reported crystallographic planes of $SrFeO_3$-based perovskites [17,18]. The schematic representation of High-Resolution Transmission Electron Microscope (HRTEM) is presented in figure 7

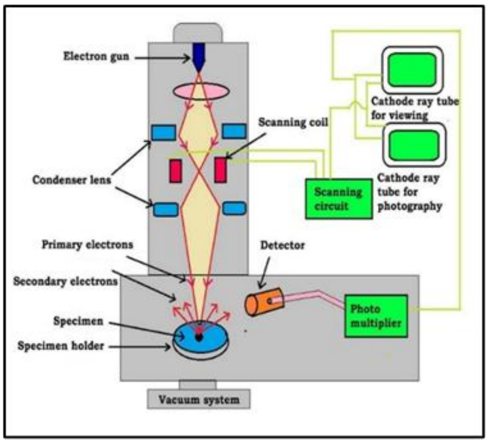

Fig 7: Schematic representation of HRTEM

Overall, microstructural investigations indicate that Eu substitution leads to increased defect concentration, local lattice distortion, and partial disruption of long-range structural ordering. These features are closely associated with the presence of oxygen vacancies and strain induced by Eu incorporation. Such microstructural modifications are widely recognized as key factors influencing magnetic exchange interactions, surface reactivity, and charge transport behaviour, thereby contributing significantly to the enhanced magnetic, catalytic, and energy-related performance of Eu-doped strontium ferrite perovskite nanomaterials.

(5) Magnetic Properties

The magnetic behaviour of Eu-doped $SrFeO_3$ perovskite nanomaterials has been widely investigated in the literature using superconducting quantum interference device (SQUID) and vibrating sample magnetometer (VSM) techniques [19,20,21]. The observed magnetic properties arise primarily from the interactions between mixed-valence Fe^{3+} and Fe^{4+} ions mediated through Fe–O–Fe superexchange and double-exchange mechanisms. Substitution of Eu^{3+} at the Sr^{2+} site introduces lattice distortion, oxygen vacancies, and changes in Fe oxidation states, all of which play a critical role in tailoring the magnetic response of $SrFeO_3$-based perovskites. The nature of MH curve of ferromagnetic material is shown in figure 8

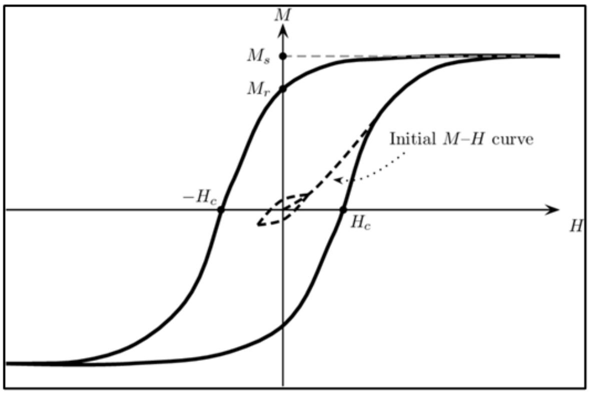

Fig 8: Schematic representation of MH curve of ferromagnetic materials.

Field-dependent magnetization (M–H) curves reported at both low temperature (~5 K) and room temperature (~300 K) reveal a clear dependence of magnetization on Eu concentration. In general, magnetization is consistently higher at 5 K compared to 300 K due to reduced thermal fluctuations and enhanced spin ordering at lower temperatures. At both temperatures, an initial increase in magnetization with increasing Eu doping is commonly observed, which has been attributed to enhanced spin canting, defect-mediated exchange interactions, and the increased contribution of surface and interface spins in nanostructured materials. These effects are further strengthened by Eu-induced lattice distortion and oxygen vacancy formation.

However, beyond an optimum Eu substitution level, further increase in Eu concentration typically leads to a reduction in magnetization at both 5 K and 300 K. This decrease has been widely associated with excessive lattice distortion, an increased proportion of Fe^{3+} ions at the expense of Fe^{4+}, weakening of double-exchange interactions, and possible magnetic dilution effects. Temperature-dependent magnetization measurements, including zero-field-cooled (ZFC) and field-cooled (FC) studies, frequently support these interpretations by revealing changes in magnetic ordering, spin dynamics, and the emergence of surface spin disorder or cluster-glass-like behaviour at higher doping levels.

Overall, the reported magnetic studies highlight the presence of an optimal Eu doping range that maximizes magnetization in $SrFeO_3$ perovskite nanomaterials. The strong temperature dependence, combined with the non-monotonic variation of magnetization with Eu concentration, underscores the complex interplay between structural distortion, defect chemistry, mixed-valence Fe states, and nanoscale effects. These characteristics make Eu-doped strontium ferrite perovskite nanomaterials promising candidates for applications in magnetic sensing, spintronic devices, and multifunctional magnetic systems.

III. Applications

In this article, the magnetic, catalytic, and energy applications of Eu-doped strontium ferrite perovskite nanomaterials are comprehensively discussed. Special emphasis is placed on understanding how Eu-induced structural distortion, defect chemistry, and electronic modifications influence their multifunctional performance across spintronic, catalytic, and energy-related technologies**.**

(A) Magnetic Applications

Eu-doped strontium ferrite perovskite nanomaterials have attracted significant interest for magnetic applications due to their tuneable magnetic behaviour, structural flexibility, and defect-mediated exchange interactions [22,23,24]. Eu substitution at the A-site introduces lattice distortion, oxygen vacancies, and mixed-valence Fe^{3+}/Fe^{4+} states, which collectively modify superexchange and double-exchange interactions within the perovskite lattice. These features enable systematic control of key magnetic parameters such as saturation magnetization, coercivity, magnetic anisotropy, and spin canting, making Eu-doped $SrFeO_3$ a versatile platform for magnetic and spin-based technologies.

(1) Spintronic and Magnetoresistive Devices

Reported studies indicate that Eu-doped $SrFeO_3$ perovskite nanomaterials exhibit weak ferromagnetism and canted antiferromagnetic behaviour, which can be tuned through Eu concentration and nanoscale engineering. The presence of mixed-valence Fe states and oxygen vacancies facilitates spin-polarized charge transport, a key requirement for spintronic and magnetoresistive devices. In addition, Eu-induced lattice distortion enhances spin canting and magnetic anisotropy, enabling potential applications in spin valves, magnetic tunnel junctions, and magnetic logic devices, where controlled spin manipulation is essential.

(2) Magnetic Sensors and Actuators

Eu-doped $SrFeO_3$ nanomaterials have also been explored for magnetic sensing applications due to their sensitivity to external magnetic fields and temperature-dependent magnetic behaviour. The tunable coercivity and remanent magnetization, combined with stable magnetic responses over a wide temperature range, make these materials suitable for magnetic field sensors, position sensors, and actuators. Nanoscale dimensions further enhance sensor performance by increasing surface-to-volume ratio and enabling faster magnetic response times [25].

(3) Data Storage and Microwave Devices

The ability to tailor magnetic anisotropy and coercivity through Eu doping and defect engineering has prompted interest in Eu-doped $SrFeO_3$ for magnetic data storage applications. Optimized compositions may offer improved thermal stability and reduced switching fields, which are desirable for high-density magnetic recording media. Additionally, the frequency-dependent magnetic response of these perovskite nanomaterials supports their potential use in microwave and radiofrequency (RF) devices, including absorbers, filters, and electromagnetic interference shielding components.

(4) Biomedical and Multifunctional Magnetic Applications

Beyond conventional magnetic devices, Eu-doped $SrFeO_3$ nanomaterials have been suggested for multifunctional magnetic applications, such as magnetic separation, targeted drug delivery, and magnetic hyperthermia, owing to their tuneable magnetic behaviour and chemical stability. Although further studies are required to address biocompatibility and toxicity, the ability to engineer magnetic response through Eu substitution highlights the broader applicability of these materials.

B Catalytic Applications

Eu-doped strontium ferrite perovskite nanomaterials have been widely recognized as efficient and versatile catalysts owing to their structural flexibility, mixed-valence Fe^{3+}/Fe^{4+} redox chemistry, high oxygen mobility, and defect-rich surfaces [26,27,28]. Eu substitution at the A-site induces lattice distortion and promotes oxygen vacancy formation, which play a crucial role in enhancing surface reactivity, adsorption of reactant molecules, and redox cycling. These characteristics make Eu-doped $SrFeO_3$ perovskite nanomaterials particularly suitable for a variety of catalytic applications related to environmental protection and energy conversion.

(1) Catalytic Oxidation and Environmental Remediation

In heterogeneous catalytic oxidation processes, Eu-doped $SrFeO_3$ nanomaterials have been extensively studied for carbon monoxide (CO) oxidation, volatile organic compound (VOC) degradation, and removal of hazardous pollutants. The enhanced catalytic performance is commonly explained by the Mars–van Krevelen mechanism, wherein lattice oxygen directly participates in oxidation reactions and oxygen vacancies are subsequently replenished from the surrounding atmosphere. The increased concentration of oxygen vacancies and improved oxygen ion mobility resulting from Eu doping significantly lower the activation energy for oxidation reactions. As a result, these materials have shown strong potential for applications in automotive exhaust treatment, indoor and industrial air purification, and wastewater treatment, particularly for the degradation of organic dyes and toxic contaminants.

(2) Electrocatalytic Applications

Beyond conventional heterogeneous catalysis, Eu-doped $SrFeO_3$ perovskite nanomaterials have also emerged as promising electrocatalysts for oxygen-related electrochemical reactions. In particular, they have been explored for the oxygen evolution reaction (OER) and oxygen reduction reaction (ORR), which are critical processes in fuel cells, metal–air batteries, and electrochemical energy-conversion systems [28]. Eu-induced modification of the electronic structure optimizes the adsorption energies of reaction intermediates and enhances charge-transfer kinetics, while mixed-valence Fe states and oxygen vacancies facilitate efficient redox cycling. These attributes position Eu-doped $SrFeO_3$ as a cost-effective and earth-abundant alternative to noble-metal-based catalysts for sustainable catalytic and energy-related technologies.

(3) Photocatalytic and Multifunctional Catalytic Uses

Eu-doped $SrFeO_3$ perovskite nanomaterials have also been reported for photocatalytic applications, including the degradation of organic pollutants and dye molecules under light irradiation. Eu-induced defect states and band-structure modification enhance light absorption and promote charge separation, thereby improving photocatalytic efficiency. Furthermore, the multifunctional nature of these materials allows the integration of catalytic activity with magnetic properties, enabling magnetically recoverable catalysts, which are advantageous for repeated use and catalyst recycling in practical applications.

(C) Energy Applications

Eu-doped strontium ferrite perovskite nanomaterials have attracted considerable attention in the field of energy technologies due to their mixed ionic–electronic conductivity, tuneable defect chemistry, thermal stability, and redox-active transition-metal centres. Eu substitution at the A-site plays a crucial role in modifying oxygen vacancy concentration, electronic structure, and charge transport behaviour, which are key parameters governing performance in energy-related applications [29,30]. The synergistic effects of lattice distortion, mixed-valence Fe states, and nanoscale features enable Eu-doped $SrFeO_3$ to function effectively in various energy conversion and storage systems.

(1) Solid Oxide Fuel Cells and Oxygen Transport

One of the most prominent energy applications of Eu-doped $SrFeO_3$ perovskite nanomaterials is in solid oxide fuel cells (SOFCs) and oxygen separation membranes. Reported studies indicate that Eu doping enhances oxygen ion mobility and surface oxygen exchange kinetics by increasing oxygen vacancy concentration and modifying Fe–O bond strength. These characteristics make Eu-doped $SrFeO_3$ suitable for use as cathode materials, electrode catalysts, or functional interlayers in SOFCs, where efficient oxygen reduction and transport are essential [31]. In addition, the structural stability of the perovskite framework under high-temperature and reducing environments further supports their applicability in oxygen-permeable membranes and related energy systems.

(2) Electrochemical Energy Storage

Eu-doped $SrFeO_3$ perovskite nanomaterials have also been explored for electrochemical energy storage applications, particularly in supercapacitors and hybrid energy storage devices. The presence of mixed-valence Fe^{3+}/Fe^{4+} redox couples enable reversible Faradaic charge storage, while the nanoscale morphology provides a high surface area for electrolyte interaction. Eu-induced defect engineering and oxygen vacancies facilitate fast ion diffusion and charge-transfer processes, leading to improved specific capacitance, rate capability, and cycling stability. These features make Eu-doped $SrFeO_3$ promising electrode materials for high-power energy storage applications.

(3) Water Splitting and Renewable Energy Conversion

In renewable energy technologies, Eu-doped $SrFeO_3$ perovskite nanomaterials have been investigated for electrochemical and photo-assisted water splitting, where efficient oxygen evolution is a critical requirement. The optimized electronic structure, enhanced oxygen vacancy concentration, and strong redox activity introduced by Eu substitution improve catalytic activity toward oxygen-related reactions. As a result, these materials show potential for use in alkaline water electrolysers and integrated renewable energy systems, contributing to sustainable hydrogen production.

(4) Gas Sensors and Energy Monitoring Devices

In addition to direct energy conversion and storage, Eu-doped $SrFeO_3$ nanomaterials have been applied in gas-sensing devices relevant to energy systems, such as monitoring hydrogen, carbon monoxide, and other fuel-related gases [32]. The sensitivity of electrical conductivity to surface redox reactions and oxygen vacancy concentration enables effective detection and control of gases in fuel cells, combustion systems, and energy storage environments, thereby supporting safer and more efficient energy management.

IV. Conclusion

Eu-doped strontium ferrite perovskite nanomaterials represent a highly versatile and multifunctional oxide system with strong potential for magnetic, catalytic, and energy applications. The incorporation of Eu^{3+} into the $SrFeO_3$ perovskite lattice induces structural distortion, oxygen vacancy formation, and mixed-valence Fe^{3+}/Fe^{4+} states, which collectively govern magnetic exchange interactions, surface reactivity, and charge-transfer behaviour. The reviewed literature clearly demonstrates that controlled Eu substitution enables systematic tuning of magnetic properties such as magnetization, coercivity, and spin dynamics, while simultaneously enhancing catalytic performance in oxidation and electrocatalytic reactions and improving efficiency in energy conversion and storage systems.

Overall, the strong interdependence between crystal structure, defect chemistry, and functional behaviour highlights the importance of optimized composition and nanoscale engineering in this material system. Continued progress in synthesis strategies, advanced characterization, and mechanistic understanding of structure–property–application relationships is expected to further advance the performance of Eu-doped strontium ferrite perovskite nanomaterials. Such developments will support their effective implementation in spintronic devices, environmental and electrocatalytic technologies, and sustainable energy systems, underscoring their significance as promising candidates for next-generation multifunctional materials.

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