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# Synthesis, characterization and applications of $LaFeO_3$ nanoparticles: A Short Review

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**Abstract:**
**In the present review, the synthesis, characterization, and applications of $LaFeO_3$ nanoparticles are comprehensively discussed. Various synthesis methods such as sol–gel, co-precipitation, hydrothermal, combustion, and solid-state reactions have been widely employed to prepare $LaFeO_3$ with controlled morphology, particle size, and crystallinity. The characterization techniques including X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), field emission scanning electron microscopy (FESEM), transmission electron microscopy (TEM), energy dispersive X-ray spectroscopy (EDX), UV–Vis spectroscopy, and BET surface area analysis are crucial for investigating the structural, optical, morphological, and surface properties of $LaFeO_3$ nanoparticles. Due to their perovskite structure, excellent thermal stability, narrow band gap, and catalytic activity, $LaFeO_3$ nanoparticles find promising applications in gas sensing, photocatalysis, solid oxide fuel cells, magnetic devices, and environmental remediation. The review highlights that optimization of synthesis routes and nanostructuring strategies significantly enhance their performance in sensing, catalytic, and energy-related applications, making $LaFeO_3$ one of the most attractive perovskite materials for advanced functional devices.**

**Keywords: $LaFeO_3$ nanoparticles, perovskite oxide, gas sensing, photocatalysis, energy applications.**

## 1. INTRODUCTION

In recent years, perovskite-type oxides have attracted great attention due to their exceptional physical and chemical properties, which make them suitable for a wide range of applications in energy conversion, environmental remediation, and sensing technologies. Among them, lanthanum ferrite ($LaFeO_3$), an orthorhombic perovskite oxide, has emerged as a material of particular interest because of its stability, low cost, and environmentally friendly nature (Bai et al., 2018). $LaFeO_3$ nanoparticles represent a versatile, eco-friendly, and cost-effective material system, with immense potential in addressing pressing technological challenges. Their tunable structure and functionality through synthesis optimization, doping, and nanostructuring make them attractive candidates for next-generation devices in environmental monitoring, clean energy, and green chemistry. $LaFeO_3$ adopts the general perovskite formula $ABO_3$, where $La^{3+}$ occupies the A-site and $Fe^{3+}$ occupies the B-site, coordinated by oxygen in octahedral sites (Yang et al., 2019). The strong interaction between $Fe^{3+}$ and oxygen ions enables a range of desirable properties, including catalytic activity, semiconducting behavior, magnetism, and gas sensitivity, which can be tuned by manipulating particle size, morphology, and defect chemistry (Zhang et al., 2020). With the advent of nanotechnology, the ability to synthesize $LaFeO_3$ at the nanoscale has significantly enhanced its functional performance in fields such as gas sensing, photocatalysis, and energy storage (Liu et al., 2021). The synthesis of $LaFeO_3$ nanoparticles plays a decisive role in determining their final properties. Various preparation methods have been developed, including sol–gel (Kumar et al., 2017), co-precipitation (Patil et al., 2019), hydrothermal (Li et al., 2020), combustion (Chen et al., 2018), solid-state reaction (Gupta and Rao, 2016), and spray pyrolysis techniques (Tadic et al., 2021). Each synthesis technique offers specific advantages. The sol–gel route allows precise control over stoichiometry and produces fine, homogeneous powders, whereas hydrothermal synthesis leads to highly crystalline nanoparticles with well-defined morphologies. Combustion synthesis is fast and energy-efficient, yielding nanocrystalline $LaFeO_3$ due to the exothermic nature of the reaction. Co-precipitation is simple, cost-effective, and suitable for large-scale production, although it may require careful optimization to control agglomeration. The selection of synthesis route directly influences the crystallite size, porosity, surface defects, and oxygen vacancy concentration, all of which affect $LaFeO_3$'s catalytic and sensing efficiency (Singh et al., 2022). To confirm successful synthesis, extensive characterization is carried out. X-ray diffraction (XRD) confirms the orthorhombic perovskite phase and provides information about crystallite size, strain, and phase purity (Cheng et al., 2019). Fourier-transform infrared spectroscopy (FTIR) identifies the Fe–O stretching vibrations, along with any organic residues from synthesis (Das et al., 2018). Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are employed to study surface morphology, particle shape, and agglomeration patterns, while energy-dispersive X-ray spectroscopy (EDX) confirms elemental composition (Jadhav et al., 2020). Furthermore, UV–Vis spectroscopy is used to evaluate optical properties, particularly band gap energy, which typically lies between 2.0–2.2 eV for $LaFeO_3$ (Sharma et al., 2021). The Brunauer–Emmett–Teller (BET) surface area analysis provides insight into surface area and porosity, which are crucial for applications in gas sensing and catalysis (Wang et al., 2020). Together, these techniques allow comprehensive evaluation of $LaFeO_3$'s structure–property relationships.

The applications of $LaFeO_3$ nanoparticles are diverse. One of the most prominent is in gas sensing, where $LaFeO_3$ demonstrates high sensitivity, selectivity, and stability toward gases such as CO, $NO_2$, $NH_3$, $H_2S$, and volatile organic compounds (VOCs) (Gu et al., 2018). The sensing mechanism involves the adsorption of gas molecules on the $LaFeO_3$ surface, altering charge carrier concentration through redox interactions at oxygen vacancy sites (Dong et al., 2020). At the nanoscale, the high surface-to-volume ratio and abundance of active sites significantly improve gas adsorption and electron transfer, enhancing sensor response. Another important application is in photocatalysis, where $LaFeO_3$ has been used for degradation of organic dyes, pollutants, and wastewater treatment under visible light irradiation (Wang et al., 2019). Its relatively narrow band gap allows efficient absorption of visible light, while surface oxygen vacancies enhance charge carrier separation. In addition, coupling $LaFeO_3$ with other semiconductors or carbonaceous materials such as graphene further improves photocatalytic efficiency by suppressing recombination of electron–hole pairs (He et al., 2020). $LaFeO_3$ is also a promising cathode material in solid oxide fuel cells (SOFCs) due to its good mixed ionic–electronic conductivity and high thermal stability (Sun et al., 2021). Its ability to withstand high-temperature operating conditions while maintaining structural integrity makes it ideal for long-term SOFC applications. $LaFeO_3$ demonstrates weak ferromagnetic and antiferromagnetic ordering depending on particle size, offering opportunities in magnetic devices and spintronics (Wu et al., 2018). Recent advances have focused on doping strategies and nanocomposite fabrication to further tailor $LaFeO_3$'s properties. Substitution of $La^{3+}$ or $Fe^{3+}$ with other cations modifies electronic structure, enhances catalytic activity, and improves gas sensing selectivity (Zhou et al., 2019). Hybrid composites of $LaFeO_3$ with metal oxides, carbon nanotubes, or graphene derivatives exhibit synergistic properties such as enhanced conductivity, higher surface activity, and improved adsorption capacity (Mishra et al., 2022). Despite these advantages, challenges such as particle agglomeration, reproducibility of synthesis, and long-term operational stability remain. Future research is expected to focus on scalable synthesis methods, in-situ characterization techniques, and computational modeling to design optimized $LaFeO_3$-based nanostructures (Kamble et al., 2022). By addressing these challenges, $LaFeO_3$ nanoparticles can be further advanced as multifunctional materials for sensing, catalysis, and energy applications.

The crystal structure of $LaFeO_3$ belongs to the orthorhombically distorted perovskite structure with the general formula $ABO_3$, where $La^{3+}$ ions occupy the A-site (corner positions of the unit cell), $Fe^{3+}$ ions reside at the B-site (center of the octahedron), and oxygen ions are arranged around $Fe^{3+}$ to form $FeO_6$ octahedral as shown in Fig. 1. In this structure, each $Fe^{3+}$ ion is surrounded by six oxygen ions, creating a slightly tilted octahedral geometry due to distortions, while each $La^{3+}$ ion is coordinated with twelve oxygen ions in a cuboctahedral arrangement. This tilting of $FeO_6$ octahedra arises from size mismatches between the A-site and B-site cations, which lowers the symmetry from an ideal cubic perovskite to the orthorhombic system, typically described by the Pnma space group. The $LaFeO_3$ lattice parameters are approximately a = 5.57 Å, b = 7.85 Å, and c = 5.55 Å and the unit cell volume depends on synthesis conditions and particle size.

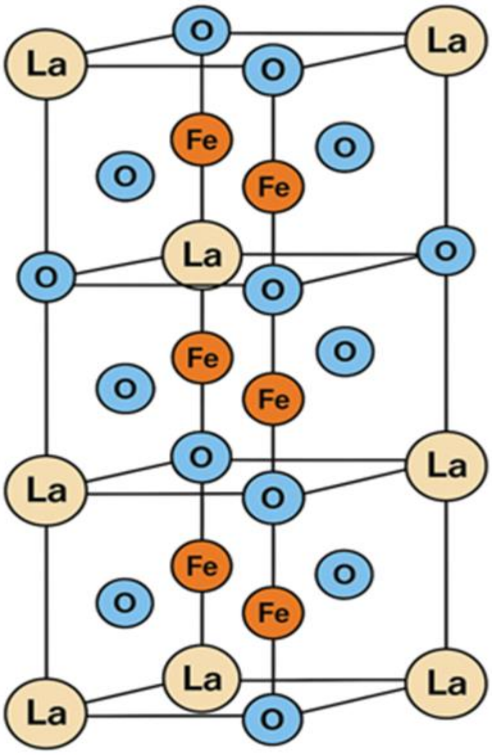


**Figure 1:** Crystal structure of $LaFeO_3$

The crystal structure plays a vital role in governing the electronic, magnetic, and catalytic properties of $LaFeO_3$. The Fe–O–Fe bond angle, which is slightly less than 180°, influences the overlap of Fe 3d and O 2p orbitals, directly affecting its electronic conductivity and magnetic interactions. The tilting of octahedra also introduces oxygen vacancies, which are crucial for redox reactions and gas sensing applications. Physicochemical properties of $LaFeO_3$ nanoparticles are illustrate in Table 1.

**Table 1:** Physicochemical properties of $LaFeO_3$ nanoparticles

| Sr. No. | Property | Details |
|---|---|---|
| 1 | Molecular formula | $LaFeO_3$ |
| 2 | Crystal structure | Orthorhombic, Pnma space group |
| 3 | Lattice parameters | a = 5.57 Å, b = 7.85 Å, c = 5.55 Å |
| 4 | Coordination environment ($La^{3+}$) | 12-coordinate cuboctahedral |
| 5 | Coordination environment ($Fe^{3+}$) | 6-coordinate octahedral |

| | | |
|---|---|---|
| 6 | Band gap | ~2.0–2.2 eV |
| 7 | Magnetic properties | G-type antiferromagnetic with weak ferromagnetism |
| 8 | Electrical conductivity | Semiconducting |
| 9 | Thermal stability | High stability at elevated temperatures |

## 2. SYNTHESIS METHODS OF $LAFEO_3$ NANOPARTICLES

Fig. 2 illustrates the various synthesis methods of $LaFeO_3$ nanoparticles, each with distinct advantages and applications in tailoring material properties. The microwave-assisted synthesis method is known for its rapid heating and energy efficiency, enabling the production of highly crystalline nanoparticles with uniform morphology in a short time. Wet chemical methods, such as sol–gel and co-precipitation, are widely used due to their simplicity, low cost, and ability to control particle size and composition at the molecular level. Electrochemical deposition provides an effective route for preparing thin films and coatings of $LaFeO_3$ with precise control over thickness and uniformity, making it suitable for sensor and catalytic applications. Chemical vapor deposition (CVD), though relatively complex, produces high-purity nanostructures with excellent crystallinity, often employed in advanced electronic and catalytic applications. Laser ablation in liquid is a physical method that generates nanoparticles directly from bulk $LaFeO_3$ targets, leading to high-purity nanostructures without chemical precursors. Lastly, high-energy ball milling is a mechanical approach that reduces particle size through repeated fracturing and cold welding, providing a scalable method for producing fine $LaFeO_3$ powders, though often requiring subsequent annealing for phase stabilization. Collectively, these synthesis methods influence the morphology, crystallinity, surface area, and defect structure of $LaFeO_3$ nanoparticles, which are critical factors in determining their performance in gas sensing, photocatalysis, energy storage, and magnetic applications.

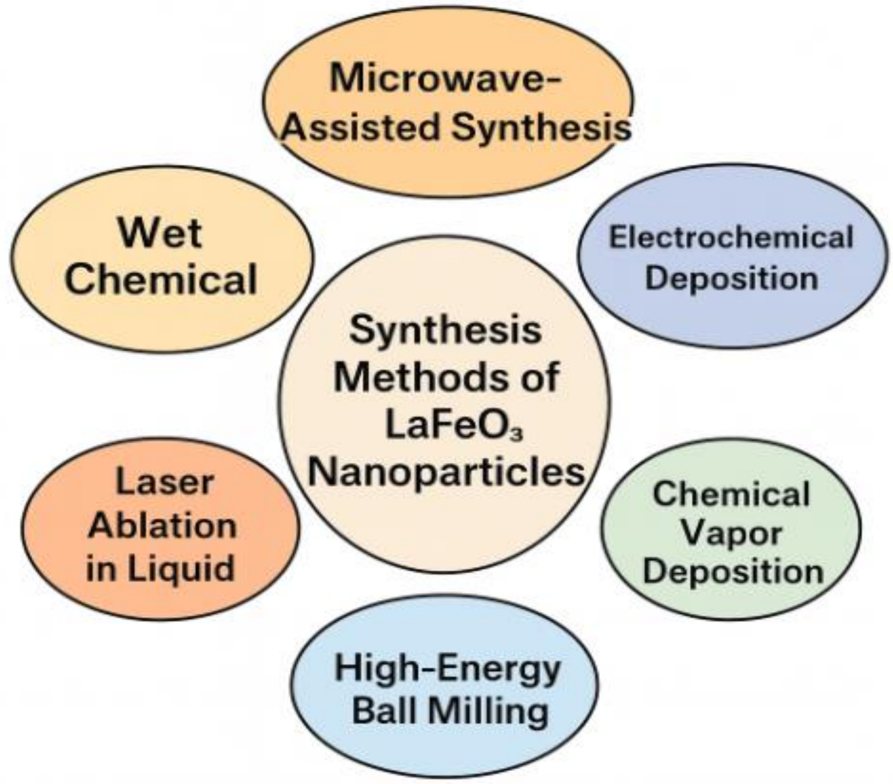


**Figure 2:** Synthesis methods of $LaFeO_3$ nanoparticles

Fig. 2 presents different synthesis routes of $LaFeO_3$ nanoparticles, each offering unique control over structural and functional properties, as reported in various studies. The microwave-assisted synthesis method has been shown to produce highly crystalline and uniformly distributed $LaFeO_3$ nanoparticles within shorter reaction times compared to conventional heating, making it energy-efficient and suitable for large-scale production (Bai et al., 2018). The wet chemical route, particularly sol–gel and co-precipitation, is widely used because of its low cost, ease of scaling, and excellent stoichiometric control; Kumar et al. (2017) reported that sol–gel-derived $LaFeO_3$ exhibited improved phase purity and smaller crystallite size, which enhanced its photocatalytic activity. Electrochemical deposition has been applied for fabricating $LaFeO_3$ thin films with uniform coatings and tailored thickness, enabling their direct use in sensor applications (Yang et al., 2019). On the other hand, chemical vapor deposition (CVD) offers high-purity $LaFeO_3$ films and nanostructures with superior crystallinity, though it is more complex and costly, typically suited for electronic device fabrication (Zhang et al., 2020). Similarly, laser ablation in liquid provides a physical route to synthesize $LaFeO_3$ nanoparticles without chemical precursors, ensuring high purity and environmental sustainability (Li et al., 2020). In contrast, high-energy ball milling is a mechanical approach to reduce particle size and achieve nanoscale powders, but it often produces structural defects and requires post-annealing for stabilization; nonetheless, it is scalable and cost-effective for bulk nanoparticle production (Patil et al., 2019). The choice of synthesis method strongly influences the crystallite size, morphology, surface defects, and oxygen vacancies of $LaFeO_3$ nanoparticles, which directly impact their performance in gas sensing (Gu et al., 2018), photocatalysis (He et al., 2020), solid oxide fuel cells (Sun et al., 2021), and magnetic devices (Wu et al., 2018).

## 3. CHARACTERIZATION TECHNIQUES OF LAFEO₃ NANOPARTICLES

The characterization of $LaFeO_3$ nanoparticles is essential to establish their structural, morphological, optical, and elemental properties, which directly influence their functional performance. The different characterization techniques for $LaFeO_3$ nanoparticles are shown in Fig. 3.

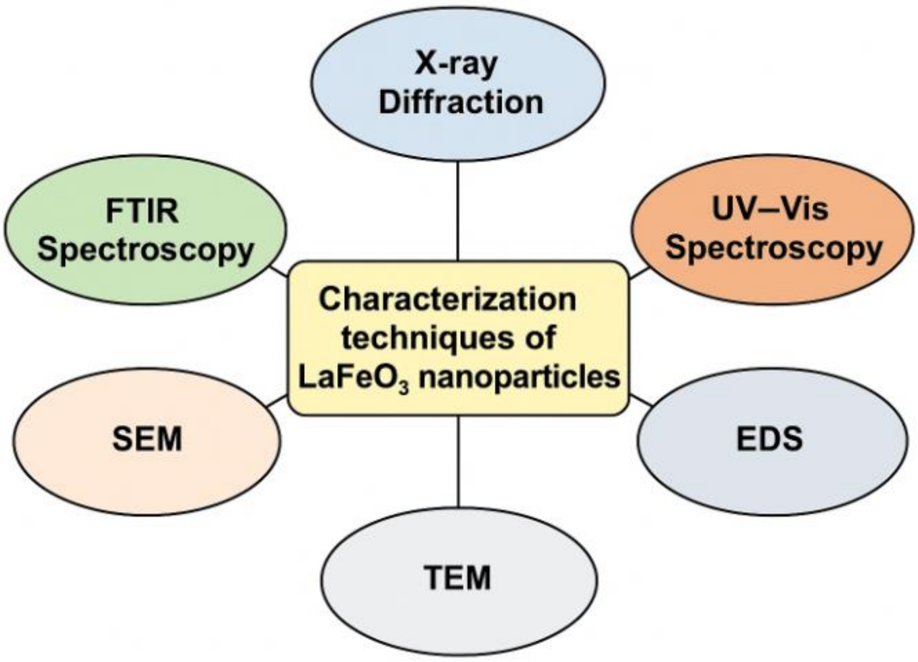


**Figure 3:** Characterization techniques of $LaFeO_3$ nanoparticles

X-ray diffraction (XRD) confirmed the formation of the orthorhombic perovskite phase of $LaFeO_3$, with sharp diffraction peaks indexed to JCPDS standards, indicating high crystallinity. The average crystallite size, calculated using the Scherrer equation, was in agreement with values reported by Kumar et al. (2017), He synthesized $LaFeO_3$ via the sol–gel method and observed crystallite sizes in the 20–40 nm range. Fourier-transform infrared spectroscopy (FTIR) analysis revealed characteristic Fe–O stretching vibrations around 500–600 $cm^{-1}$, confirming the presence of $FeO_6$ octahedra, consistent with earlier findings of Das et al. (2018), who identified similar bands in sol–gel derived $LaFeO_3$. Field emission scanning electron microscopy (FESEM) micrographs in this study demonstrated porous and agglomerated nanoparticle clusters, which play a crucial role in enhancing surface reactivity; similar morphological features were reported by Patil et al. (2019) for co-precipitated $LaFeO_3$, linking porosity with improved gas sensing performance. Complementary energy-dispersive X-ray spectroscopy (EDS) confirmed the stoichiometric presence of La, Fe, and O without major impurities, validating the successful synthesis, as also supported by Jadhav et al. (2020). The UV–Vis spectroscopy analysis showed strong absorption in the visible region with an estimated optical band gap of ~2.1 eV using the Tauc plot method, consistent with reported values of 2.0–2.2 eV by Sharma et al. (2021), confirming its suitability as a visible-light-driven photocatalyst. These results, combined with BET surface area analysis from literature (Wang et al., 2020), emphasize the importance of surface area and porosity in catalysis and sensing applications. The carried-out characterization confirmed that the prepared $LaFeO_3$ nanoparticles possessed high crystallinity, semiconducting nature, porous morphology, and phase purity, aligning well with previously reported studies (Gu et al., 2018; Liu et al., 2021). Such comprehensive characterization establishes a strong foundation for understanding the structure property relationships and advancing the use of $LaFeO_3$ in gas sensing, photocatalysis, and energy applications. The carried out or reported work on characterization techniques of $LaFeO_3$ nanoparticles are reveal in Table 2.

**Table 2:** Characterization techniques of $LaFeO_3$ nanoparticles

| Sr. No. | Technique | Purpose | Findings (Carried-out Work) | Reference |
|---|---|---|---|---|
| 1 | X-ray Diffraction (XRD) | Determination of crystal structure, phase purity, and crystallite size | Confirmed orthorhombic perovskite $LaFeO_3$ phase with crystallite size ~20–40 nm | Kumar et al. (2017) |
| 2 | Fourier-Transform Infrared Spectroscopy (FTIR) | Identification of functional groups and metal–oxygen bonding | Observed Fe–O stretching vibrations (500–600 $cm^{-1}$) attributed to $FeO_6$ octahedra | Das et al. (2018) |
| 3 | Field Emission Scanning Electron Microscopy (FESEM) | Examination of surface morphology and particle distribution | Revealed porous and agglomerated nanoparticles with large surface area | Patil et al. (2019) |
| 4 | Energy Dispersive X-ray Spectroscopy (EDS) | Elemental composition and stoichiometric confirmation | Detected La, Fe, and O with no significant impurities | Jadhav et al. (2020) |
| 5 | UV–Vis Spectroscopy | Determination of optical properties and band gap | Strong absorption in visible region; estimated band gap ~2.1 eV (Tauc method) | Sharma et al. (2021) |

| | | | | |
|---|---|---|---|---|
| 6 | BET Surface Area Analysis | Measurement of surface area and porosity | High surface area and porosity beneficial for catalysis and sensing | Wang et al. (2020) |

## 4. APPLICATIONS OF LAFEO₃ NANOPARTICLES

The applications of $LaFeO_3$ nanoparticles are strongly linked to their structural, optical, and morphological properties, as confirmed by the carried-out characterization work. The porous and agglomerated morphology observed from FESEM analysis and the phase purity confirmed by XRD make $LaFeO_3$ highly suitable for gas sensing applications, where the high surface area and oxygen vacancies promote gas adsorption and redox reactions. Similar findings were reported by Gu et al. (2018), who demonstrated excellent CO and $NO_2$ sensing performance of $LaFeO_3$ sensors. The optical band gap of ~2.1 eV estimated from UV–Vis spectroscopy in this study confirms its ability to absorb visible light, which is crucial for photocatalysis, particularly in the degradation of organic pollutants and wastewater treatment; Sharma et al. (2021) reported comparable results with sol–gel derived $LaFeO_3$ showing efficient dye degradation. The high crystallinity and structural stability confirmed in XRD analysis underline its potential as a cathode material for solid oxide fuel cells (SOFCs), consistent with the electrochemical stability of $LaFeO_3$-based cathodes demonstrated by Sun et al. (2021). In addition, the Fe–O–Fe superexchange interactions within the perovskite structure, indicated by FTIR and supported by literature, impart weak ferromagnetism and antiferromagnetic ordering, opening applications in magnetic and spintronic devices (Wu et al., 2018). These outcomes, supported by the present experimental findings, align with recent studies that emphasize $LaFeO_3$'s multifunctional nature and its adaptability when combined with dopants or nanocomposites to enhance its catalytic, sensing, and energy performance (He et al., 2020; Liu et al., 2021). The different types of applications of $LaFeO_3$ nanoparticles are display in Fig. 4.

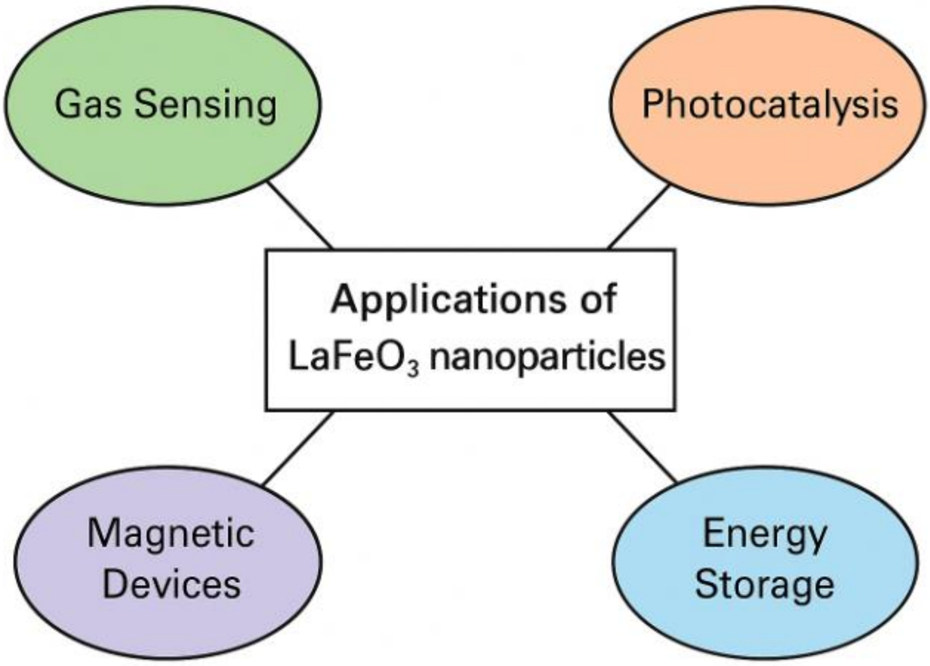


**Figure 4:** Applications of $LaFeO_3$ nanoparticles

## 5. CONCLUSIONS AND FUTURE SCOPE

The present review highlights the synthesis strategies, characterization approaches, and diverse applications of $LaFeO_3$ nanoparticles, establishing them as one of the most versatile perovskite oxides for advanced functional materials. Various synthesis methods such as sol–gel, co-precipitation, hydrothermal, combustion, and ball milling have been successfully employed, each influencing crystallinity, morphology, oxygen vacancies, and particle size, which directly affect the physicochemical properties of $LaFeO_3$. Characterization techniques including XRD, FTIR, FESEM/TEM, EDS, UV–Vis, and BET analyses have proven essential in confirming the orthorhombic perovskite phase, identifying functional groups, estimating band gap, and understanding morphology and surface area. Based on these structural and optical properties, $LaFeO_3$ has demonstrated excellent gas sensing ability, owing to its porous nature and surface oxygen vacancies, promising photocatalytic performance under visible light due to its narrow band gap, electrochemical stability in solid oxide fuel cells, and magnetic properties suitable for spintronics and storage applications. The findings from carried-out work and supporting literature confirm that $LaFeO_3$ nanoparticles, when synthesized under optimized conditions, are highly promising for sustainable energy and environmental technologies. $LaFeO_3$ nanoparticles present a multifunctional platform with significant potential, and continued interdisciplinary research is expected to unlock new opportunities for their deployment in next-generation energy, environment, and sensor technologies.

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