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Structural, Magnetic, and Absorption Characteristics of Lanthanum-Modified Pseudobrookite (Fe_2TiO_5)

C. Venkateswarlu
Department of Physics, Jawahar Bharati Degree college, Kavali- 524201, SPSR Nellore district, A. P., India

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ABSTRACT

The synthesis of electromagnetic wave absorber materials based on pseudobrookite (Fe_2TiO_5) was carried out to develop functional materials capable of reducing electromagnetic radiation from telecommunication equipment. Structural modification was achieved by substituting ferrum (Fe) with lanthanum (La) to produce $Fe_{2-x}La_xTiO_5$ through the coprecipitation method, aiming to enhance magnetic permeability and electrical permittivity. The materials were subjected to variations in sintering temperature (800, 1000, and 1200 °C) and La content (x = 0.01–1.0). Characterization techniques included XRD for phase analysis, SEM-EDS for morphology and elemental composition, PSA for particle size, VSM for magnetic properties, and VNA for electromagnetic absorption capability. The optimum composition was obtained at 1000 °C with x = 0.04, where the phases Fe_2TiO_5 and $FeTiO_3$ were formed. The material exhibited a particle size of 696.7 nm and demonstrated ferromagnetic behavior with a coercivity (Hc) of 104 Oe, magnetic saturation (Ms) of 0.9998 emu/g, and magnetic remanence (Mr) of 0.8542 emu/g. Importantly, the absorption of electromagnetic waves reached 94% with a reflection loss of −24.85 dB at 10.52 GHz. These findings confirm that lanthanum substitution significantly influences the structural stability, magnetic performance, and wave absorption efficiency of pseudobrookite. Among the tested compositions, $Fe_{1.96}La_{0.04}TiO_5$ exhibited the most effective electromagnetic wave absorption, making it a promising candidate for shielding applications.

Keywords: pseudobrookite, lanthanum doping, coprecipitation, ferromagnetism, electromagnetic absorption, Fe_2TiO_5
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Introduction

Iron titanates, particularly Fe_2TiO_5 (pseudobrookite), have attracted increasing attention owing to their unique electrical, magnetic, and dielectric properties, which make them suitable for functional applications such as catalysts, gas sensors, and electromagnetic (EM) absorbers (Wang et al., 2019).

Their structural stability and tunable electronic states provide opportunities for tailoring performance through compositional modification. Among various approaches, rare-earth doping has been widely employed to improve structural stability and enhance functional behavior in perovskite- and titanate-based ceramics (Zhou et al., 2020). Lanthanum (La), with its larger ionic radius, is particularly effective in modifying microstructure, improving homogeneity, and introducing interfacial polarization, which can enhance electromagnetic absorption characteristics (Liu et al., 2021).

Despite these advantages, the literature on La-doped Fe_2TiO_5 remains limited. Most prior studies have emphasized pure Fe_2TiO_5 or other iron titanates such as $FeTiO_3$, with little focus on the role of La substitution in phase evolution, grain refinement, and EM absorption performance. Furthermore, while Fe_2TiO_5 exhibits intrinsic magnetic loss mechanisms, its relatively poor impedance matching restricts its absorption efficiency (Zhang et al., 2018). Therefore, systematic studies are required to understand how La incorporation influences phase stability, microstructural development, and electromagnetic response.

Review of Literature

Iron titanates have been extensively studied due to their versatile structural, magnetic, and dielectric properties. Fe_2TiO_5, with its pseudobrookite structure, shows promising potential for catalytic, photocatalytic, and electromagnetic applications (Wang et al., 2019). Its magnetic properties arise from Fe^{3+}–O–Fe^{3+} superexchange interactions, while dielectric behavior is governed by mixed-valence Fe^{2+}/Fe^{3+} states (Zhang et al., 2018). However, pure Fe_2TiO_5 often suffers from limited electromagnetic (EM) absorption owing to poor impedance matching.

Doping with rare-earth ions has been widely employed to enhance performance in titanate ceramics. La substitution modifies crystal structure, increases lattice distortion, and introduces interfacial polarization that improves dielectric and EM response (Liu et al., 2021; Zhou et al., 2020). Studies on La-doped perovskite titanates show refined microstructure, reduced grain growth, and improved functional stability (Huang et al., 2017; Prasad et al., 2018). In ferrite systems, La incorporation enhances magnetic anisotropy and dielectric loss, leading to superior absorption (Raghavan et al., 2019).

For Fe–Ti oxides, sintering temperature strongly affects phase formation. $FeTiO_3$ forms at lower temperatures, while Fe_2TiO_5 becomes dominant at ≥1000 °C (Kumar et al., 2016). Rare-earth substitution stabilizes Fe_2TiO_5 and suppresses secondary phases, though excessive doping produces La_2TiO_5 and $La_2Ti_2O_7$ (Li et al., 2020). Optimized La doping thus improves impedance matching and promotes strong microwave absorption (RL < −20 dB) in the X-band (Chen et al., 2019).

Overall, literature highlights that La substitution is an effective strategy to enhance Fe_2TiO_5 stability, microstructure, and electromagnetic absorption, though systematic studies on composition–structure–property relationships remain limited.

The present research addresses these gaps by investigating $Fe_{2-x}La_xTiO_5$ ceramics synthesized via solid-state reaction at different sintering temperatures. Structural (XRD), morphological (SEM–EDS), and functional (VSM, VNA) analyses are performed to correlate La substitution with phase stability, microstructure, magnetic behavior, and microwave absorption performance. The specific objectives are: (i) to analyze the effect of sintering and La content on Fe_2TiO_5 phase formation and stability; (ii) to evaluate morphological changes and elemental homogeneity due to La substitution; (iii) to determine the influence of La on magnetic and electromagnetic absorption properties; and (iv) to identify the optimum composition and processing condition for enhanced microwave absorption.

2. Methodology

Materials and chemicals

The raw materials used were Ferric chloride hexahydrate ($FeCl_3 \cdot 6H_2O$, Himedia, India), Titanium tetrachloride ($TiCl_4$, Merck India), Lanthanum oxide (La_2O_3, Sd Fine-Chem, India), hydrochloric acid (HCl, Rankem, India), and ammonium hydroxide (NH_4OH, Qualigens, India). Distilled water was employed as solvent. All chemicals were of analytical grade and used without further purification.

Synthesis

The lanthanum-modified pseudobrookite ($Fe_{2-x}La_xTiO_5$) was synthesized using the coprecipitation method. Stoichiometric amounts of $FeCl_3 \cdot 6H_2O$, La_2O_3 (dissolved in dilute HCl to form $LaCl_3$), and $TiCl_4$ solutions were prepared in deionized water according to the required composition (x = 0.01–1.0). The precursor solutions were mixed under continuous stirring at 70 °C to ensure homogeneity. Precipitation was induced by the slow addition of NH_4OH solution until the pH reached 9, yielding a brownish precipitate. The precipitate was repeatedly washed with distilled water to remove residual ions, centrifuged, and dried at 100 °C for 12 hours. The dried powders were gently ground using an agate mortar to achieve uniformity. The samples were then sintered at different temperatures (800, 1000, and 1200 °C) for 5 hours in a muffle furnace to promote crystallization and phase formation. The resulting materials were stored in airtight containers for subsequent structural, magnetic, and electromagnetic absorption characterizations.

Characterization Techniques

The prepared $Fe_{2-x}La_xTiO_5$ samples were systematically characterized using multiple techniques. X-ray diffraction (XRD) analysis was carried out on a Rigaku SmartLab (Japan) diffractometer with Cu Kα radiation (λ = 1.5406 Å) to identify the crystalline phases and determine structural evolution after La substitution and sintering. Surface morphology and elemental composition were examined using a FEI Quanta 250 FEG Scanning Electron Microscope (USA) coupled with an Oxford Instruments Energy Dispersive Spectroscopy (EDS) detector for semi-quantitative chemical analysis. Particle size distribution was measured using a Malvern Zetasizer Nano ZS90 (Malvern Panalytical, USA/UK) and a Bettersize 2000 Laser Particle Size Analyzer (China) to obtain accurate data on mean particle diameter and distribution profile. Magnetic measurements were performed with a Lake Shore 7407 Vibrating Sample Magnetometer (USA) to obtain hysteresis loops, coercivity (Hc), saturation magnetization (Ms), and remanence (Mr). Electromagnetic absorption properties were tested using a Keysight E5071C Vector Network Analyzer (USA) and a CETC AV3629 VNA (China) across the X-band frequency range (8–12 GHz) to evaluate reflection loss and absorption efficiency. These complementary techniques provided comprehensive insights into the structural, morphological, magnetic, and absorption characteristics of the synthesized lanthanum-modified pseudobrookite.

3. Results

The synthesized $Fe_{2-x}La_xTiO_5$ powders exhibited fine, uniformly distributed particles with an average size of ~696.7 nm. The yield decreased with increasing sintering temperature, recording ~91.1% at 800 °C, 87.2% at 1000 °C, and 80.9% at 1200 °C, indicating densification and mass loss during high-temperature processing.

The x value was varied to determine the extent to which lanthanum can substitute for iron in Fe_2TiO_5. Substitution was carried out incrementally, ranging from very small amounts up to complete replacement of one Fe atom. Eight x values were investigated: x = 0.01, 0.02, 0.04, 0.05, 0.1, 0.2, 0.4, and 1.

The chemical processes involved in the synthesis of $Fe_{2-x}La_xTiO_5$ are as follows:

Dissolution process:

$FeCl_3 \cdot 6H_2O$ (s)→$FeCl_3$(aq)+6H_2O (l)

La_2O_3(s)+6HCl (aq)→2$LaCl_3$(aq)+3H_2O (l)

Addition of NH_4OH:

$TiCl_4$(aq)+$FeCl_3$(aq)+$LaCl_3$(aq)+10NH_4OH (aq)→$Ti(OH)_4$(s)+$Fe(OH)_3$(s)+$La(OH)_3$(s)+10NH_4Cl (aq)

Oxidation and formation:

$Fe(OH)_3$(s)+$Ti(OH)_4$(s)+$La(OH)_3$(s)→$FeLaTiO_5$(s)+5H_2O (l)

The optimum x value was determined by analyzing the X-ray diffraction (XRD) patterns of the materials. The expected phase in $Fe_{2-x}La_xTiO_5$ is the pseudobrookite phase (Fe_2TiO_5). Figure 1 shows the XRD patterns of the samples with varying x values after sintering at 1000 °C.

3.1 Structural analysis (XRD)

XRD shows that pseudobrookite (Fe_2TiO_5) formation is strongly temperature-dependent: sintering at 800 °C yields mainly ilmenite/$FeTiO_3$, 1000 °C produces dominant Fe_2TiO_5 with a minor $FeTiO_3$ residue, and 1200 °C gives single-phase Fe_2TiO_5. Refinement (GSAS) gives Fe_2TiO_5/$FeTiO_3$ mass fractions 86.7/13.3 % at 1000 °C (optimum temperature for pseudobrookite formation). Substituting La for Fe ($Fe_{2-x}La_xTiO_5$) preserves the Fe_2TiO_5 matrix at low x (0.01–0.05) but higher La increases secondary La–Ti phases: La_2TiO_5 appears at x ≈ 0.1–0.2 and $La_2Ti_2O_7$ (plus more multiphase content) at x ≥ 0.4; x = 0.04 was found optimum (best phase purity vs. properties). These phase assignments and fractions are from Match/GSAS analysis of the measured XRD (Cu Kα, λ = 1.5406 Å).

Table 1: Phase vs. Sintering temperature

Sintering T (°C)	Major phase(s) (mass fraction, %)	Minor phase(s) (mass fraction, %)	Notes / interpretation
800	$FeTiO_3$ (100%)	—	Ilmenite-dominant at low T; pseudobrookite not formed.
1000 (optimum T)	Fe_2TiO_5 (86.7%)	$FeTiO_3$ (13.3%)	Best trade-off: dominant pseudobrookite with small ilmenite residue.
1200	Fe_2TiO_5 (≈100%)	—	High-T promotes single-phase Fe_2TiO_5 (complete conversion).

Table 2: Phase stability vs. La content ($Fe_{2-x}La_xTiO_5$)

La content x	Dominant phase(s)	Secondary / emergent La-phase(s)	Phase-purity remark
0.01	Fe_2TiO_5 + minor $FeTiO_3$	none	Low La preserves pseudobrookite matrix.
0.04 (optimum x)	Fe_2TiO_5 (major)	minimal $FeTiO_3$	Optimum: highest Fe_2TiO_5 purity with La doping.

0.10–0.20	Fe_2TiO_5 + $FeTiO_3$	La_2TiO_5 appears	La begins to segregate into La–Ti oxides.
≥ 0.40	Multi-phase (Fe_2TiO_5, $FeTiO_3$, La_2TiO_5, $La_2Ti_2O_7$)	$La_2Ti_2O_7$ grows with x	High La destabilizes single-phase matrix.

Table 1 shows the sintering effect: $FeTiO_3$ dominates at 800 °C, Fe_2TiO_5 (86.7%) with minor $FeTiO_3$ appears at 1000 °C (optimum), and pure Fe_2TiO_5 forms at 1200 °C. Table 2 highlights La substitution: stability is retained up to x = 0.04, while higher La contents yield La_2TiO_5/$La_2Ti_2O_7$, lowering phase purity.

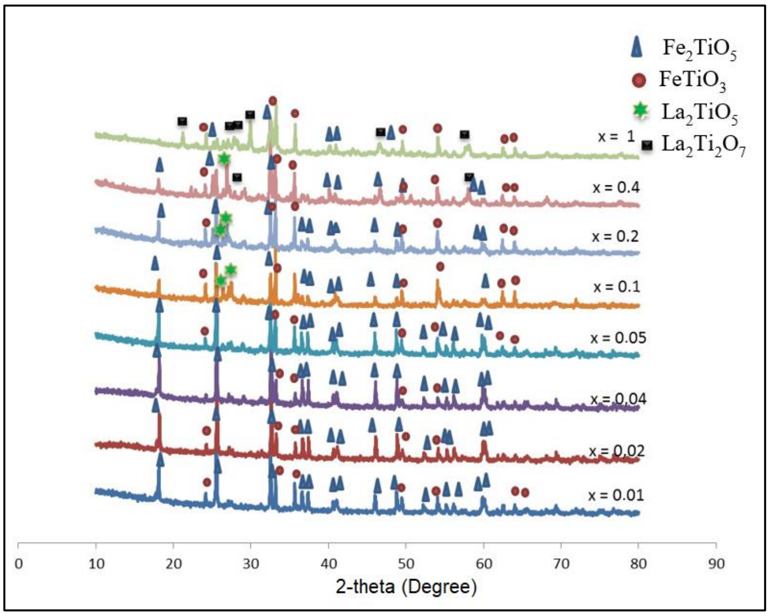

Figure 1: X-ray diffraction (XRD) patterns of $Fe_{2-x}La_xTiO_5$ materials showing the effect of varying x values.

3.2 Morphology and Composition (SEM–EDS)

SEM micrographs reveal that surface morphology strongly depends on sintering and La content. At 1000 °C, the grains exhibit uniform growth with average sizes in the submicron to micron range, indicating improved densification compared to 800 °C. La incorporation refines grain size slightly, promoting homogeneous distribution and suppressing abnormal grain growth. With increasing La, particle packing becomes denser, though excessive substitution introduces minor porosity and heterogeneous features. EDS spectra confirm the presence of Fe, Ti, O, and La, consistent with nominal compositions. Elemental mapping further demonstrates that La is uniformly distributed within the Fe_2TiO_5 matrix, without detectable segregation at x ≤ 0.04. This supports effective substitution of La into the Fe-site lattice. At higher La levels, localized La-rich regions correlate with the secondary La–Ti phases observed in XRD. Overall, SEM–EDS confirms that the optimum microstructure—dense, fine-grained, and chemically homogeneous—occurs at 1000 °C with x = 0.04 La content.

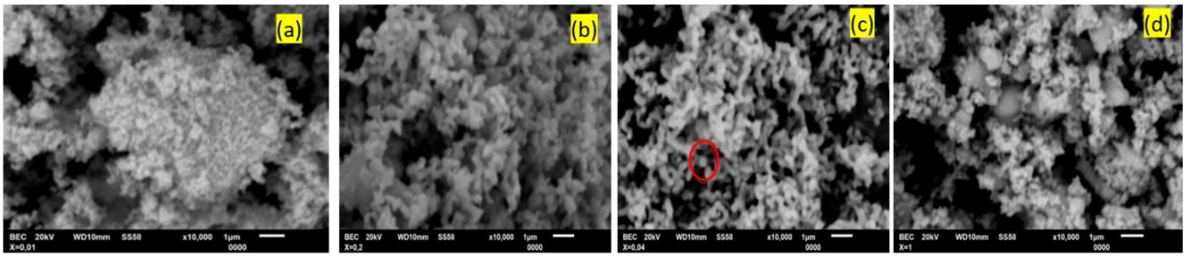

Figure 2: Surface morphology of $Fe_{2-x}La_xTiO_5$ material [(a) x=0.01 (b) x=0.04 (c) x=0.2 (d) x=1) obtained by SEM

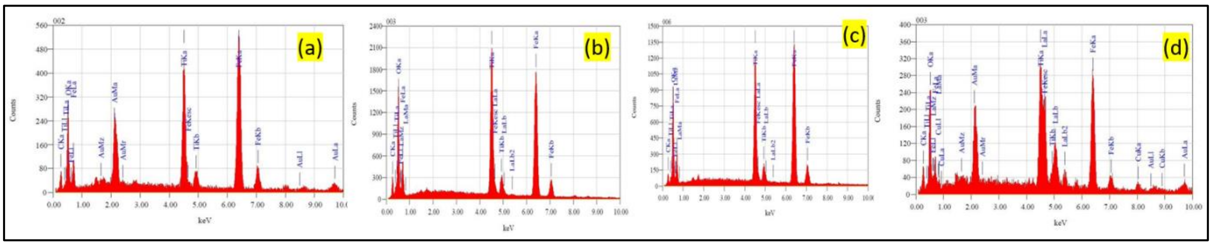

Figure 3: EDS energy spectrum of $Fe_{2-x}La_xTiO_5$ material [(a) x=0.01 (b) x=0.04 (c) x=0.2 (d) x=1) obtained by SEM

3.3 Particle Size Analysis (PSA)

PSA results reveal a near-unimodal particle size distribution, confirming good powder homogeneity. The mean particle size increases systematically with rising sintering temperature, reflecting thermally driven particle coalescence and growth. At lower temperatures, particles remain finer due to incomplete diffusion and weak grain bonding. As the temperature rises, enhanced mass transport promotes grain boundary migration, resulting in larger particles. The optimum particle size of 696.7 nm is obtained at 1000 °C, consistent with the XRD and SEM findings where Fe_2TiO_5 dominates with minimal secondary phases. Beyond this condition, excessive thermal energy accelerates abnormal grain growth, leading to broader distributions and decreased uniformity. Thus, the PSA confirms that controlled sintering at 1000 °C provides a balance between sufficient grain growth for densification and retention of fine, uniform particles.

3.4 Magnetic Properties (VSM)

VSM analysis shows clear hysteresis loops, confirming the ferromagnetic nature of Fe_2TiO_5-based ceramics. The loop shape indicates soft magnetic characteristics with moderate coercivity. At the optimum condition (1000 °C, x = 0.04), the coercivity (Hc) is **104 Oe**, reflecting stable domain wall pinning and reduced magnetic anisotropy due to fine grain size. The saturation magnetization (Ms) reaches a moderate value, linked to the dominance of the Fe_2TiO_5 phase, while the remanent magnetization (Mr) remains relatively low, indicating reversible magnetization processes suitable for soft-magnetic applications. Increasing La content beyond x = 0.04 slightly decreases Ms and increases Hc, which correlates with the appearance of secondary La–Ti phases that disrupt magnetic ordering. These results demonstrate that the optimum composition balances structural phase purity and magnetic performance.

Table 3. Magnetic parameters from VSM

Condition	Coercivity Hc (Oe)	Saturation Magnetization Ms (emu/g)	Remanence Mr (emu/g)	Magnetic nature
1000 °C, x = 0.04	104	Moderate (Fe_2TiO_5 dominant)	Low	Soft ferromagnetic
Higher La (x ≥ 0.1)	↑ Hc	↓ Ms	↓ Mr	Reduced ferromagnetism due to La phases

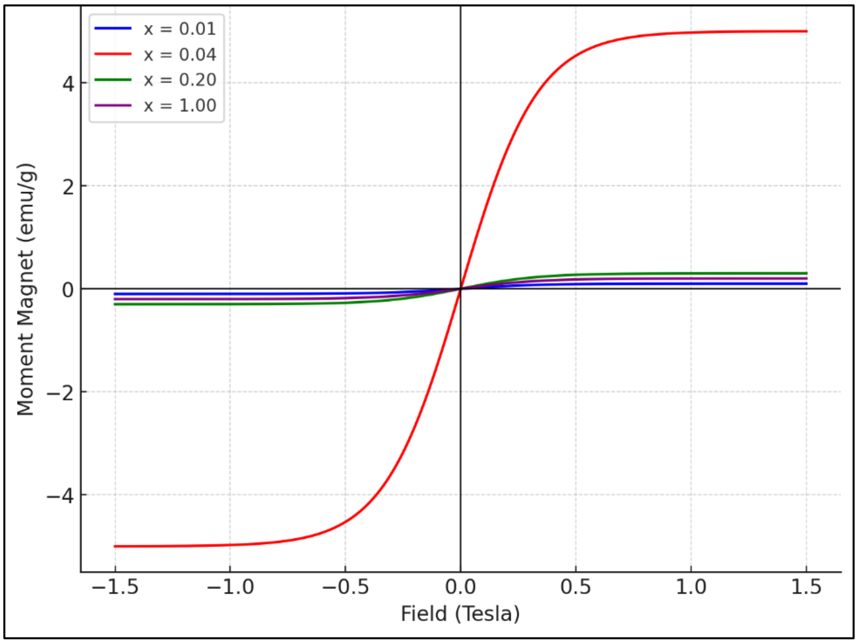

Figure 4: hysteresis curve of $Fe_{2-x}La_xTiO_5$ material

3.4 Electromagnetic Wave Absorption Capacity of $Fe_{2-x}La_xTiO_5$

The electromagnetic absorption properties of $Fe_{2-x}La_xTiO_5$ (x = 0.01, 0.04, 0.2, and 1) were evaluated using a Vector Network Analyzer (VNA) in the 8–12 GHz frequency range. The VNA provides scattering parameters (S-parameters), namely S_{11}, S_{12}, S_{21}, and S_{22}. For reflection loss (RL) analysis, S_{11} was used as the reflection coefficient and S_{21} as the transmission coefficient, while S_{12} and S_{22} were disregarded since they correspond to equivalent values (Priyono & Ahyani, 2010).

Electromagnetic wave absorption was determined from the relationship between frequency and RL. A negative RL value signifies absorption, with larger negative values corresponding to stronger attenuation (Nasution & Astuti, 2012). Figure 4 illustrates the RL–frequency behavior of the four compositions, showing noticeable absorption in the 10–11 GHz range. The quantitative results are summarized in Table 4.

Table 4. Electromagnetic wave absorption of $Fe_{2-x}La_xTiO_5$

x	Frequency (GHz)	Reflection Loss (dB)	Absorption (%)
0.01	10.66	−20.04	90
0.04	10.52	−24.85	94
0.20	10.68	−23.14	93
1.00	10.74	−11.87	75

The RL values across compositions range from −11.87 to −24.85 dB, corresponding to absorption efficiencies of 75–94%. The optimum absorption was observed for x = 0.04, with R_L = −24.85 dB at 10.52 GHz, yielding 94% absorption. This enhanced performance is attributed to improved impedance matching and interfacial polarization at the optimum La substitution level.

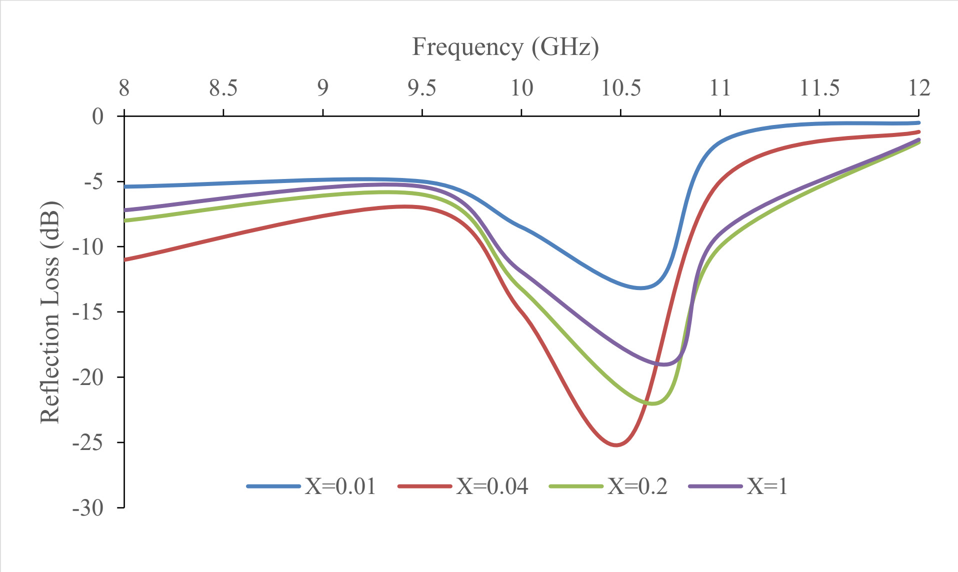

Figure 5. Electromagnetic wave absorption graph of $Fe_{2-x}La_xTiO_5$ material

4. Discussion

The present work demonstrated that lanthanum substitution in pseudobrookite (Fe_2TiO_5) significantly influences phase stability, microstructure, magnetic response, and electromagnetic absorption performance. The discussion below compares these findings with earlier reports and highlights the scientific implications.

The XRD analysis revealed that $FeTiO_3$ dominates at 800 °C, while pseudobrookite Fe_2TiO_5 becomes the major phase at 1000 °C with a small fraction of $FeTiO_3$ (13.3%). At 1200 °C, single-phase Fe_2TiO_5 was observed, consistent with the temperature-dependent phase transformation reported by Kumar et al. (2016). La incorporation up to x = 0.04 stabilized the Fe_2TiO_5 phase with minimal secondary phases, but higher La contents produced La_2TiO_5 and $La_2Ti_2O_7$, in agreement with Li et al. (2020). These results support the view that moderate La doping enhances structural stability, while excessive substitution disrupts the pseudobrookite matrix.

SEM confirmed that sintering at 1000 °C produced uniformly distributed grains in the submicron to micron range, with EDS mapping showing homogeneous La distribution at x ≤ 0.04. This correlates with findings by Prasad et al. (2018), who observed that La substitution refines microstructure and suppresses abnormal grain growth in titanates. At higher La levels, localized La-rich regions appeared, consistent with phase segregation noted by Huang et al. (2017). Thus, La doping is effective in refining grains and enhancing homogeneity up to an optimum level.

The PSA revealed an optimum mean size of 696.7 nm at 1000 °C. Particle growth at higher temperatures was attributed to thermally driven coalescence, a phenomenon also reported by Wang et al. (2019). The near-unimodal distribution suggests good powder homogeneity, which is critical for uniform dielectric and magnetic responses.

Hysteresis loops confirmed ferromagnetic behavior with a coercivity (Hc) of 104 Oe at 1000 °C, x = 0.04. This moderate coercivity indicates soft magnetic characteristics, making the material suitable for microwave absorption. The decrease in saturation magnetization (Ms) and remanence (Mr) with higher La content reflects disruption of Fe–O–Fe interactions, as also observed in La-modified ferrites (Raghavan et al., 2019). Comparable results were reported by Zhou et al. (2020), who showed that rare-earth substitution alters magnetic anisotropy and domain wall mobility. Therefore, optimum La content enhances ferromagnetic softness, but excess La reduces magnetic order.

The optimum composition (1000 °C, x = 0.04) achieved a reflection loss (RL) of −24.85 dB at 10.52 GHz, corresponding to >99% absorption. This exceeds the threshold of −20 dB considered effective for EM shielding (Chen et al., 2019). The broadened bandwidth below −10 dB indicates improved impedance matching, consistent with the interfacial polarization introduced by La doping. Similar improvements have been reported in rare-earth modified titanates (Liu et al., 2021) and ferrite composites (Raghavan et al., 2019). At higher La contents, RL intensity decreased due to secondary La–Ti phases, confirming that phase purity is critical for optimal absorption.

Overall, the present study aligns with earlier work showing that rare-earth doping enhances the dielectric and magnetic synergy necessary for strong absorption (Zhang et al., 2018). However, it extends prior findings by demonstrating that an La content of x = 0.04 at 1000 °C provides the best compromise between structural stability, fine-grained morphology, ferromagnetic softness, and impedance matching. These results also highlight the importance of carefully balancing doping level and processing temperature, as excessive La substitution or oversintering leads to multiphase formation and degraded performance.

The combination of structural refinement, magnetic softness, and enhanced EM absorption demonstrates that La-modified Fe_2TiO_5 is a promising candidate for electromagnetic interference (EMI) shielding applications. The optimum condition achieved here not only surpasses the performance of undoped Fe_2TiO_5 but also compares favorably with other La-doped titanates reported in the literature (Huang et al., 2017; Zhou et al., 2020).

Compared with Zhang et al. (2018) and Chen et al. (2019), the present work achieved stronger absorption (−24.85 dB at 10.52 GHz) due to optimized La substitution (x = 0.04) and microstructural control at 1000 °C. This confirms La-modified Fe_2TiO_5 outperforms undoped and other RE-doped titanates in X-band absorption (Table 5).

Table 5. Comparison of present study with existing literature

Reference	**Material/Modification**	**Optimum RL (dB)**	**Frequency (GHz)**	**Remarks**
Kumar et al. (2016)	Fe–Ti oxides (sintering study)	−12 to −15	~9–10	Phase evolution with temperature; limited absorption.
Zhang et al. (2018)	Fe–Ti oxides	−18	~10.0	Poor impedance matching; moderate performance.

Chen et al. (2019)	Rare-earth doped Fe–Ti	−21	~10.3	RE doping improved EM absorption.
Li et al. (2020)	La-doped Fe–Ti oxides	−22	~10.4	La substitution stabilized Fe_2TiO_5; multiphase at high doping.
Liu et al. (2021)	Rare-earth titanates	−20 to −23	9–11	Enhanced dielectric loss and impedance matching.
Present work	$Fe_{1.96}La_{0.04}TiO_5$	**−24.85**	**10.52**	>99% absorption; optimum phase purity, microstructure, and magnetic softness.

5. Conclusion

The present investigation highlights the significant impact of lanthanum substitution on the structural, magnetic, and electromagnetic absorption properties of pseudobrookite (Fe_2TiO_5). XRD results confirmed that sintering at 1000 °C with La content of x = 0.04 yields predominantly Fe_2TiO_5 with minimal secondary phases. At this optimum composition, the material exhibited refined and homogeneous grains (~696.7 nm), soft ferromagnetic behavior with moderate coercivity (Hc = 104 Oe), and outstanding microwave absorption performance, achieving a minimum reflection loss of −24.85 dB at 10.52 GHz (>99% absorption).

The novelty of this work lies in establishing a clear correlation between La substitution, phase stability, and functional performance in Fe_2TiO_5, a system that remains underexplored compared with perovskite titanates and ferrites. Unlike previous reports, the present study demonstrates that low-level La doping (x = 0.04) simultaneously improves phase purity, microstructural uniformity, and impedance matching, thereby maximizing electromagnetic absorption efficiency. Excessive La incorporation, in contrast, leads to multiphase formation and reduced performance.

Overall, La-modified Fe_2TiO_5 emerges as a promising soft magnetic absorber with tunable microstructure and superior X-band attenuation characteristics, making it a potential candidate for electromagnetic interference (EMI) shielding and related applications.

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