

GREEN SYNTHESIS, STRUCTURE AND PHYSICOCHEMICAL PROPERTIES OF LaFeO₃ NANOMATERIAL BASED ON THE ALCOHOLIC EXTRACT OF *ALLOCHRUSA GYPSOPHILOIDES*

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Аннотация. В данной работе наноматериал LaFeO₃ со структурой перовскита был синтезирован экологически чистым методом зелёного синтеза с использованием спиртового экстракта растения *Allochrusa gypsophiloides*. Кристаллическая структура, функциональные группы и элементный состав полученного образца исследованы методами рентгеновской дифракции (XRD), инфракрасной спектроскопии (FTIR) и энергодисперсионного рентгеновского анализа (EDX). Результаты XRD подтвердили формирование однофазной орторомбической структуры перовскита без примесей. В FTIR спектрах выявлены характерные полосы поглощения, соответствующие связям Fe–O и La–O. Элементный анализ показал массовые доли La₂O₃ и Fe₂O₃, равные 47,8% и 52,2% соответственно, что свидетельствует о хорошем соответствии стехиометрическому составу. Полученные данные подтверждают эффективность, экологичность и перспективность зелёного синтеза для получения высокочистых наноматериалов LaFeO₃ с потенциальным каталитическим и фотокаталитическим применением.

Ключевые слова: LaFeO₃, зелёный синтез, перовскит, XRD, FTIR, элементный анализ, наноматериалы, фотокатализ.

Abstract. In this work, LaFeO₃ perovskite nanomaterial was synthesized via an environmentally friendly green synthesis route using the alcoholic extract of *Allochrusa gypsophiloides*. The structural, functional, and elemental characteristics of the synthesized sample were comprehensively investigated by X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and energy-dispersive X-ray spectroscopy (EDX), respectively. The XRD results confirmed the formation of a single-phase orthorhombic perovskite structure without any detectable impurities. FTIR spectra revealed characteristic absorption bands corresponding to Fe–O and La–O bonds. Elemental analysis indicated that the mass percentages of La₂O₃ and Fe₂O₃ were 47.8% and 52.2%, respectively, demonstrating good stoichiometric agreement. The obtained results confirm the effectiveness, simplicity, and environmental sustainability of the green synthesis approach for producing high-purity LaFeO₃ nanomaterials with promising catalytic and photocatalytic applications.

Keywords: LaFeO₃, green synthesis, perovskite, XRD, FTIR, elemental analysis, nanomaterials, photocatalysis.

Annotatsiya. Ushbu ishda LaFeO₃ perovskit nanomateriali *Allochrusa gypsophiloides* o‘simligining spirtli ekstrakti asosida ekologik toza yashil sintez usuli yordamida olindi. Sintez qilingan namunaning kristall tuzilishi, funksional guruhlari va element tarkibi mos ravishda rentgen difraksiyasi (XRD), infraqizil spektroskopiya (FTIR) hamda energiya dispersiyali rentgen spektroskopiyasi (EDX) yordamida kompleks o‘rganildi. XRD natijalari LaFeO₃ ning ortorombik perovskit fazada shakllanganini va begona fazalarning mavjud emasligini tasdiqladi. FTIR spektrlarida Fe–O va La–O bog‘lanishlariga xos yutilish chiziqlari aniqlandi. Element tahlili natijalariga ko‘ra, La₂O₃ va Fe₂O₃ ning massaviy ulushlari mos ravishda 47,8% va 52,2% ni tashkil etdi. Olingan natijalar yashil sintez usulining samaradorligini, ekologik xavfsizligini hamda yuqori tozalikdagi LaFeO₃ nanomateriallarini olish imkoniyatini ko‘rsatadi. Ushbu materialning katalitik va fotokatalitik qo‘llanmalarda keng istiqbolga ega ekanligi ilmiy jihatdan asoslandi.

Kalit so‘zlar: LaFeO₃, yashil sintez, perovskit, XRD, FTIR, element tahlili, nanomaterial, fotokataliz.

Introduction

Perovskite-type oxide nanomaterials, particularly LaFeO₃, have attracted considerable attention due to their high chemical stability, narrow band gap (≈ 2.0 – 2.2 eV), and favorable catalytic properties, making them widely studied in photocatalysis, gas sensing, and environmental protection technologies [3,5–9]. Owing to their activity under visible light irradiation, such materials are effective in the degradation of organic pollutants, especially dyes [5–8]. In the nanostructured state, the increase in surface area facilitates the separation of electron–hole pairs, enhances the generation of reactive oxidative radicals, and accelerates photocatalytic processes [7–9].

Conventional synthesis methods (sol–gel, hydrothermal, and multistep precipitation) generally require high temperatures, prolonged processing steps, and toxic reagents. Therefore, the development of environmentally safe and energy-efficient approaches has become an important scientific task [10,11]. Green synthesis based on plant extracts enables the reduction of metal ions and stabilization of the formed particles, allowing the formation of nanoparticles with controlled size [10]. Flavonoids, phenolic compounds, and organic acids act as complexing and stabilizing agents, reducing aggregation and promoting the formation of a well-ordered crystal lattice [10,11].

High photocatalytic activity has been reported for LaFeO₃ samples synthesized by various methods, and it has been established that the structure and surface morphology of the material directly influence its functional properties [5–8]. In addition, theoretical approaches and modeling play an important role in explaining photocatalytic mechanisms, enabling clarification of the nature of active centers and charge carrier migration [1,2,4].

The application of environmentally friendly synthesis methods based on local natural resources is an important direction in materials chemistry. The plant *Allochrusa gypsophiloides* is rich in biologically active components, whose complex-forming and stabilizing properties facilitate the formation of stable nanoparticles through interaction with metal ions [10,11]. Such an approach simplifies the synthesis process, reduces the need for additional chemical stabilizers, and improves environmental safety.

Therefore, the aim of this work is to synthesize LaFeO₃ nanoparticles via a green route using the alcoholic extract of *Allochrusa gypsophiloides* and to comprehensively investigate their crystal structure, functional groups, and elemental composition by XRD, FTIR, and elemental analysis techniques [1–11].

Materials and methods

For the synthesis of the LaFeO₃ nanomaterial, La(NO₃)₃·6H₂O and Fe(NO₃)₃·9H₂O salts were used as precursors. The dried roots of *Allochrusa gypsophiloides* were ground and extracted in 70% ethanol at 60 °C for 2 hours, then filtered to obtain an extract rich in biologically active components. The obtained extract was added dropwise to the metal salt solution and, under continuous stirring, converted into a sol. The mixture was dried at 100 °C to form a gel. The resulting solid product was calcined at 600–700 °C for 3 hours, producing perovskite-phase LaFeO₃ nanoparticles.

The crystal structure of the synthesized sample was investigated by X-ray diffraction (XRD), the functional groups and bonding nature were analyzed using Fourier-transform infrared spectroscopy (FTIR), and the elemental composition was determined by elemental analysis.

Results and discussion

The elemental composition of the synthesized LaFeO₃ nanomaterial was investigated using energy-dispersive X-ray spectroscopy (EDX) (Figure 1). The obtained spectrum clearly shows the characteristic peaks corresponding to lanthanum (La) and iron (Fe), confirming that the chemical composition of the sample is consistent with the perovskite-type LaFeO₃ structure. The La–L α and La–L β peaks were observed in the energy range of approximately 4.6–5.0 keV, while the Fe–K α and Fe–K β peaks appeared at about 6.4 keV and 7.1 keV, respectively.

According to the quantitative analysis, the mass fractions of La₂O₃ and Fe₂O₃ were 47.8% and 52.2%, respectively. These values are close to the theoretical stoichiometric ratio of LaFeO₃, indicating that lanthanum and iron ions fully participated in the reaction and were uniformly distributed in the final product. The absence of additional impurity peaks also confirms the high chemical purity of the synthesized material.

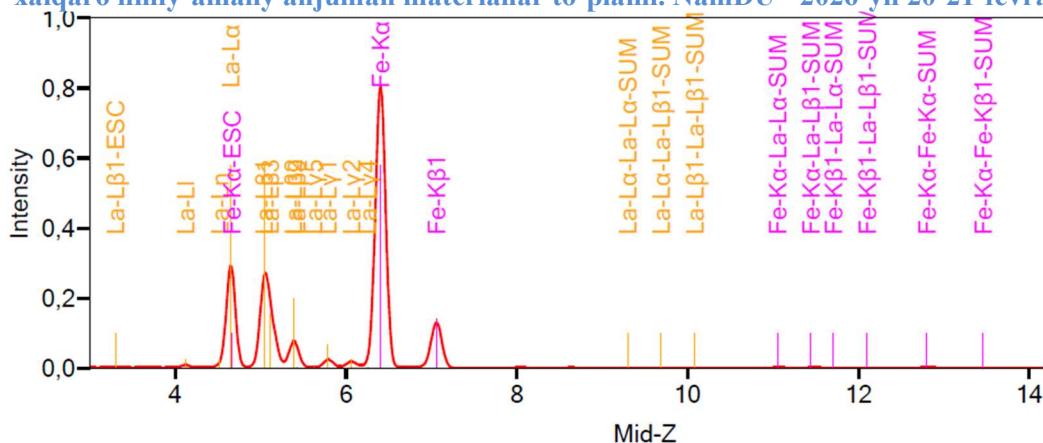


Figure 1. EDX spectrum of the green-synthesized LaFeO₃ nanomaterial.

The obtained results demonstrate that the green synthesis route using the *Allochrysa gypsophiloides* extract enables the formation of structurally homogeneous LaFeO₃ nanoparticles suitable for further structural and catalytic investigations.

The FTIR spectrum of sample N8 is presented in Figure 8 and was used to identify the functional groups and metal–oxygen bonding in the synthesized material. A broad absorption band observed in the region of 3000–3600 cm⁻¹ corresponds to the O–H stretching vibrations of surface hydroxyl groups and adsorbed water molecules. The presence of this band indicates a developed surface of the nanoparticles and is typical for oxide nanomaterials obtained via green synthesis routes.

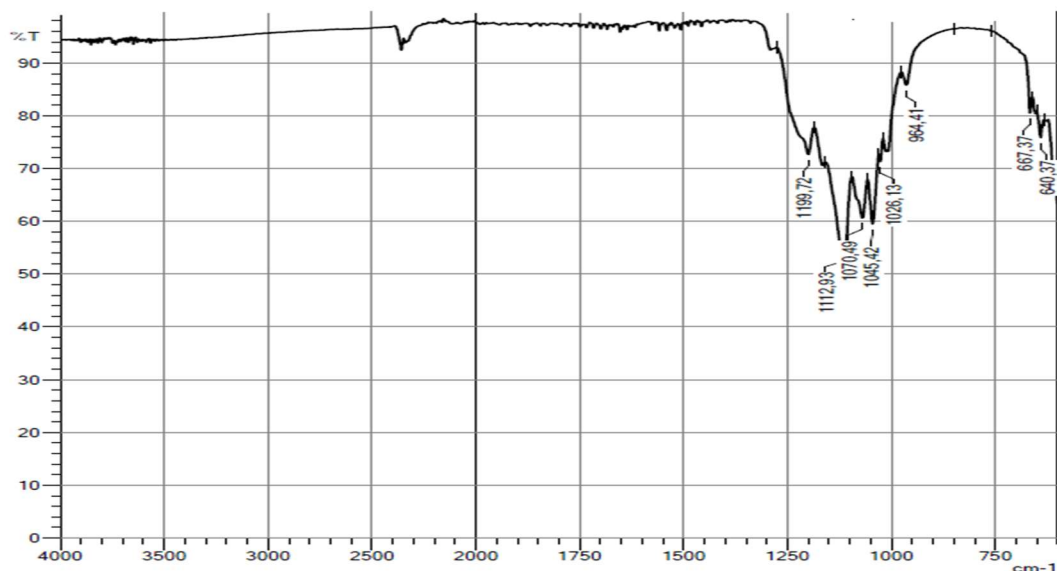


Figure 2. FTIR spectrum of the green-synthesized LaFeO₃ nanomaterial.

A weak band near 1600 cm⁻¹ is attributed to the bending vibration of H–O–H bonds, confirming the presence of physically adsorbed moisture on the particle surface. In the intermediate region (1200–1000 cm⁻¹), several absorption bands were detected. These bands are associated with C–O stretching vibrations and residual organic species originating from biomolecules of the *Allochrysa gypsophiloides* extract. Their presence suggests that plant-derived compounds participated in the synthesis process

The phase composition and crystal structure of the synthesized LaFeO₃ nanomaterial were investigated by X-ray diffraction (XRD) (Figure 3). The diffraction pattern exhibits a set of well-defined and intense peaks corresponding to the orthorhombic perovskite structure of LaFeO₃. The observed diffraction maxima can be indexed to the Pnma phase, and no additional peaks related to secondary phases or impurities were detected, indicating the successful formation of a single-phase material.

The relatively broad diffraction peaks suggest that the crystallites are in the nanometer size range. The crystallite size calculated using the Scherrer equation was found to be within the

nanometric scale, confirming the formation of nanosized particles. Such nanoscale crystallites provide a higher specific surface area, which is favorable for surface-dependent processes.

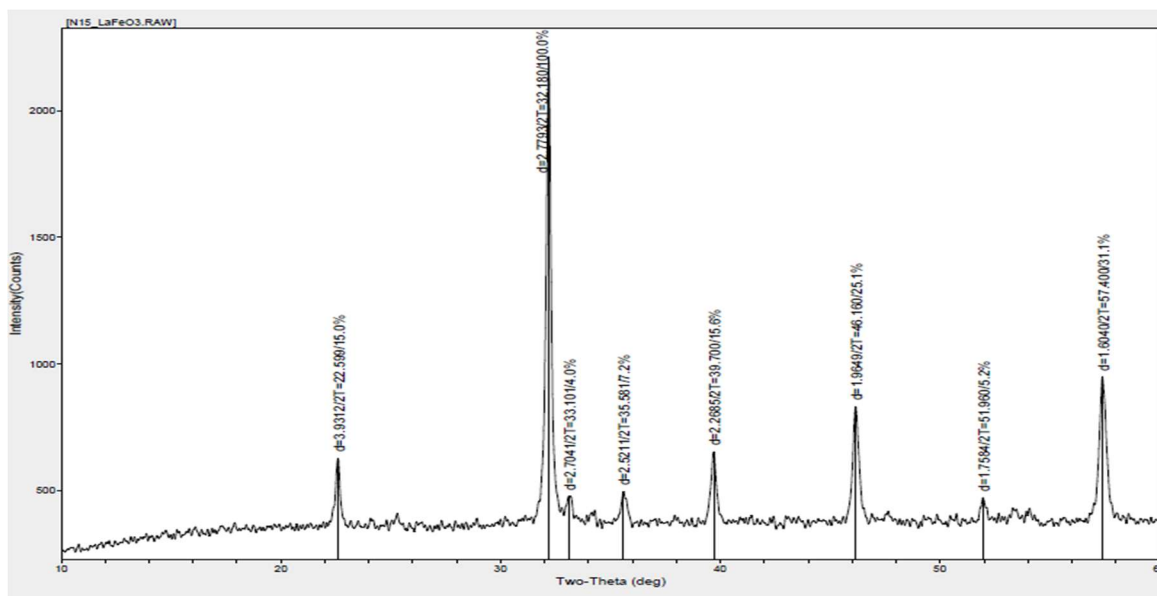


Figure 3. X-ray diffraction pattern of the green-synthesized LaFeO₃ nanomaterial.

The high crystallinity and phase purity of the obtained LaFeO₃ sample indicate that the green synthesis route is effective in producing structurally ordered nanoparticles. The well-formed perovskite lattice facilitates charge separation and reduces the recombination rate of photogenerated electron–hole pairs, which is beneficial for catalytic and photocatalytic applications.

Conclusion

In this work, LaFeO₃ perovskite nanoparticles were successfully synthesized via an environmentally friendly green synthesis route using the alcoholic extract of *Allochrysa gypsophiloides*. The applied method enabled the formation of nanosized particles without the use of additional toxic stabilizing agents. Structural and chemical characterization confirmed the successful formation of the target material.

The XRD analysis revealed the formation of a single-phase orthorhombic perovskite structure, indicating high crystallinity and phase purity of the synthesized LaFeO₃. Elemental analysis demonstrated that the mass fractions of La₂O₃ and Fe₂O₃ (47.8% and 52.2%, respectively) were close to the theoretical stoichiometric composition, confirming the homogeneous distribution of metal ions in the final product.

The FTIR investigation further supported the formation of the perovskite lattice. In particular, the FTIR spectrum of sample N8 (Figure 8) showed characteristic absorption bands at approximately 667 and 640 cm⁻¹ corresponding to Fe–O and La–O stretching vibrations. These bands confirm the crystallization of the metal–oxygen octahedral framework and the formation of a stable LaFeO₃ structure. The presence of weak bands in the 1200–1000 cm⁻¹ region indicates residual organic groups derived from plant biomolecules, demonstrating that the extract participated in metal-ion complexation and stabilization during nanoparticle formation.

Overall, the obtained results prove that *Allochrysa gypsophiloides* extract acts as an effective natural reducing and stabilizing agent, enabling the synthesis of structurally ordered and chemically homogeneous LaFeO₃ nanoparticles. The developed green synthesis approach is simple, cost-effective, and environmentally safe, and the obtained material can be considered a promising candidate for catalytic and photocatalytic applications.

References

1. Fayzieva G., Mukhamadiev A., Mukhamadiev N., Begmatov R., Tashmatova R., & Uzokov J. Synthesis of magnetic nanomaterial CoFe₂O₄ and study by spectral methods// In *Advanced Materials for Optics and Photonics: Chemistry and Engineering Perspectives (AMOP 2025)* (Vol. 14014, pp. 173-178). SPIE.
2. Uzokov J., Fayziyeva G., Mukhamadiev N., Ruziyev I., Kuliboyeva N., & Saidov K. Quantum chemical study of the photocatalytic activity Fe₃O₄/SiO₂-trimesic acid-melamine

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supramolecular system // In *Advanced Materials for Optics and Photonics: Chemistry and Engineering Perspectives (AMOP 2025)* (Vol. 14014, pp. 83-89). SPIE.

3. Fayziyeva G., Mukhamadiyev A., Kulibayeva N., Uzokov J. Synthesis of LaFeO₃ perovskite and physicochemical investigation of its structural and surface morphological properties // *Scientific Bulletin of Samarkand State University named after Sh. Rashidov.* - 2025.- Vol.1, No 153.2.- P.66-73.

4. Uzokov J., Kosimov S., Muxamadiyev A., Voxidov A., Mukhamadiyev N., & Anvarov T. Quantum chemical study of the photocatalytically active Mo-queracetin complex // *Advanced Materials for Optics and Photonics: Chemistry and Engineering Perspectives (AMOP 2025)*. – SPIE, 2025. – T. 14014. – C. 117-124

5. Samy M. M. et al. Photocatalytic degradation of organic dyes using LaFeO₃ Hollow Fibers prepared by template method // *Egyptian Journal of Chemistry.* – 2022. – T. 65. – №. 5. – C. 221-230.

6. Kumar R., Singh J., Kaur P., et al. Fabrication of lanthanum-ferrite perovskite oxide (LaFeO₃) using Terminalia arjuna leaf extract for the efficient photocatalytic degradation of malachite green // *Inorganic Chemistry Communications.* – 2023. – Vol. 150. – 110451.

7. Li X., Zhang Y., Wang S., et al. Perovskite LaFeO₃/montmorillonite nanocomposites: synthesis and enhanced photocatalytic activity // *Scientific Reports.* – 2016. – Vol. 6. – 19723.

8. Wang X., Li J., Zhao Y., et al. Z-scheme LaFeO₃/g-C₃N₄ heterojunction photocatalyst for enhanced visible-light photocatalysis // *Catalysts.* – 2023. – Vol. 13, № 5. – 907.

9. Ahmed S., Saifullah A., Swami B.L., Ikram S. Green synthesis of nanoparticles using plant extracts: a review // *Environmental Chemistry Letters.* – 2021. – Vol. 19. – P. 1109–1130.

10. Khan M.A., Alqadami A.A., Siddiqui M.R., et al. Green synthesis of iron oxide nanoparticles using citrus waste // *Scientific Reports.* – 2025. – Vol. 15. – 33107.