

ANNOTATION

on the dissertation of Sarsenbayeva Zamira Berkbayqyzy on the topic “Synthesis and physico-chemical research of the catalytic properties of nanoparticles of complex oxide manganites in the production of hydrogen (OER, HER),” submitted for the degree of Doctor of Philosophy (PhD) in the educational program “8D05301 – Chemistry”

The dissertation work is presented in accordance with the requirements of subparagraph 2) of paragraph 5-1 of the Rules for Awarding Academic Degrees, approved by Order No. 4 of the Minister of Science and Higher Education of the Republic of Kazakhstan dated January 6, 2025.

In compliance with these requirements, the research findings of the dissertation have been published in peer-reviewed journals ranked in the first and/or second quartiles by impact factor according to the Journal Citation Reports of Clarivate Analytics, within scientific fields relevant to the content of the dissertation. The publication record meets the established criteria and includes at least two research articles, as well as one review article or a series of three publications. In at least one of these publications, the doctoral candidate is the first author or the corresponding author.

Furthermore, in accordance with paragraph 7 of the Regulations on the Dissertation Council of the Non-Commercial Joint Stock Company “Kazakh National Women’s Teacher Training University,” approved by Order No. 09-02-19/277 dated May 25, 2025, specifically subparagraph 7.2.1 “Submission of the Doctoral Dissertation,” the dissertation is submitted for defense in the form of a series of published scientific articles, representing a coherent body of the doctoral candidate’s research publications.

General Description of the Work

This research is focused on the synthesis of complex oxide manganite nanoparticles and a comprehensive study of their structural, morphological, and physicochemical properties. This work examines an effective method for synthesizing manganites and investigates the phase composition, crystal structure, morphology, elemental composition, and electrophysical and dielectric properties of the resulting materials.

Perovskite manganites – which influence the structure and properties of the compounds by varying and doping ions in the A and B sites of the ABO_3 crystal lattices ($A = Fe, La, In$; $B = Mn, Fe$) – are studied. In this context, the electrocatalytic properties of the synthesized complex oxide manganites in the hydrogen production process are evaluated based on the hydrogen evolution reaction (HER) and the oxygen evolution reaction (OER). The research results aim to determine the influence of the composition, structure, and physicochemical properties of the materials on their electrocatalytic properties. The electrocatalytic properties were analyzed using linear voltammetry and electrochemical impedance spectroscopy.

Relevance of the Study

Currently, growing energy demand and environmental problems resulting from the use of traditional fuel resources are increasing the need to develop renewable and environmentally friendly energy sources.

The efficiency of hydrogen production via the electrochemical decomposition of water depends directly on the properties of the electrocatalysts used in the HER/OER reactions. The cost and resource constraints of modern, highly active noble-metal-based catalysts necessitate their replacement with cheaper and more readily available materials.

Complex manganese oxide compounds are characterized by their ability to vary in composition and crystal structure, the presence of manganese ions with different oxidation states, and the ability to selectively regulate their physicochemical properties. Producing them in the form of nanoparticles and controlling their structural and morphological features makes it possible to improve their electrocatalytic properties. In this regard, the synthesis of complex manganite oxide nanoparticles, the study of their structure and physicochemical properties, and the evaluation of their electrocatalytic activity in the HER/OER processes represent a pressing scientific challenge aimed at identifying effective and affordable electrode materials for the hydrogen energy sector.

State of Research on the Topic

Complex manganite oxides have been the subject of intensive study in recent years due to their wide range of structural, electrical, magnetic, dielectric, and electrocatalytic properties. The literature extensively covers methods for synthesizing perovskite and manganites of other structural types using solid-state, sol-gel, Pechini, sol-gel, and green synthesis methods. The properties of manganites—including the correlation between Me–O, phase composition, crystal structure, particle size (nano/micro), and morphology (elemental distribution map)—are characterized using X-ray phase analysis (XRF), scanning electron microscopy (SEM/EDX), as well as the arrangement of metal cations (ABO_3 , $\text{A}_x\text{B}_{1-x}\text{O}_3$, $\text{A}_3\text{B}_5\text{O}_{12}$) and the dependence of the oxidation state ($\text{Mn}^{2+}=\text{Mn}^{4+}$, $\text{Fe}^{3+}=\text{Fe}^{2+}$) were analyzed using the TPO- O_2 method.

To explain the influence of these factors on electrical conductivity and dielectric response, their temperature and frequency dependencies are being studied. However, for manganites of various phase compositions, it is important to analyze structural and morphological features in comparison with electrophysical characteristics. There is also growing interest in studying the dielectric properties and electrocatalytic activity of complex Mn- and Fe-based oxides in RPC and oxygen evolution in RPC. However, the synthesis conditions, phase composition, and the influence of crystal structure and morphology on the temperature- and frequency-dependent dielectric characteristics, as well as the electrocatalytic performance, require further clarification for each material system. Accordingly, this study investigates the dielectric permittivity and dielectric loss of manganites, while their electrocatalytic properties are evaluated using linear voltammetry (LSV) and electrochemical impedance spectroscopy (EIS). The results are compared in terms of the composition, structure, and morphology of the materials.

Translated with DeepL.com (free version)**Research Objective**

To synthesize nanoparticles of complex manganese oxide compounds, determine their structural, morphological, and physicochemical properties, and investigate their electrocatalytic activity in the hydrogen splitting reaction (HER/OER) during the electrolytic decomposition of water.

To achieve the stated objective, the following tasks were defined:

To achieve this goal, the following objectives were identified:

- Synthesis of new complex manganite oxides using the Pechini method;
- Analysis of the phase composition and crystal structure of manganites and the formation of Me–O bonds;
- Determination of the morphology and elemental composition of manganites;
- Electrophysical (electrical conductivity) analysis and analysis of the dependence of dielectric properties on temperature and frequency;
- Study of the electrocatalytic activity of manganites in the hydrogen splitting reaction (HER/OER).

Object of the Research - New complex perovskite-type manganite and manganite-ferrite oxides.

Subject of the Research - Synthesis of complex manganites and their structural, morphological, electrophysical, and electrocatalytic properties.

Research Methods - The following modern physicochemical research methods were used in this dissertation study: Pechini synthesis method based on the sol-gel process, X-ray diffraction (XRD), scanning electron microscopy (FE-SEM/EDS), infrared spectroscopy (FTIR), measurement of dielectric and electrical properties, linear voltammetry (LSV), and electrochemical impedance spectroscopy (EIS) for electrocatalytic properties. These methods allow for a comprehensive study of the structural, physical, and electrocatalytic properties of the synthesized materials.

Scientific Novelty of the Dissertation Research

As a result of the research conducted:

- Manganites and ferro-manganites: FeMnO_3 , $\text{La}_{0.9}\text{MnO}_3\text{-LaFeO}_3$, $\text{Fe}_{0.84}\text{Mn}_{1.12}\text{O}_3\text{-In}_{0.12}\text{Fe}_{1.88}\text{O}_3$ и $\text{FeMnO}_3\text{-Ho}_3\text{Fe}_5\text{O}_{12}$ of a new composition were synthesized for the first time;
- It was determined that the synthesized compounds are single-phase and two-phase complex oxides with a perovskite structure;
- Their crystal structure, morphology, and elemental distribution were determined;
- The influence of the newly synthesized complex oxides on electrical and dielectric properties was established;
- The electrocatalytic properties of the material were studied using LSV and EIS.

The scientific novelty of the dissertation is substantiated by the following key provisions proposed for defense:

- Effect of thermal treatment over the range of 600–1100 °C, with a 1-hour dwell at each 100 °C step during Pechini synthesis, on the chemical homogeneity, phase composition, and formation of micro- and nanoscale manganite particles.

- Effect of changes in phase composition and the formation of a two-phase structure upon doping manganites with rare metals on the increase in average particle size.

- Temperature dependence of the electrical resistance of FeMnO_3 and $\text{La}_{0.9}\text{MnO}_3\text{-LaFeO}_3$ over the range of 293–483 K, exhibiting regions of semiconducting and metallic behavior; dielectric dispersion and relaxation processes in FeMnO_3 over the range of 293–393 K.

- Evaluation of the electrocatalytic activity of FeMnO_3 and $\text{La}_{0.9}\text{MnO}_3\text{-LaFeO}_3$ samples toward the hydrogen evolution reaction using LSV and EIS, including analysis of the increase in cathodic current during cycling and the dependence of charge-transfer resistance on electrode potential.

Scientific Results

1. Scientific Results of the First Article

In this research, a two-phase perovskite nanocomposite, $\text{La}_{0.9}\text{MnO}_3\text{-LaFeO}_3$, was synthesized using the Pecini sol-gel method, and its phase-structural, morphological, electrophysical, and electrocatalytic properties were comprehensively investigated. X-ray phase analysis showed that the resulting material consists of a polycrystalline two-phase structure comprising the $\text{La}_{0.9}\text{MnO}_3$ and LaFeO_3 phases. While $\text{La}_{0.9}\text{MnO}_3$ phase was characterized by the hexagonal space group $R3c$, with lattice parameters $a = b = 5.52 \text{ \AA}$, $C = 13.37 \text{ \AA}$, the LaFeO_3 phase corresponded to a cubic $\text{Pm}3m$ structure ($a = b = c = 3.89 \text{ \AA}$). Average crystallite sizes calculated using the Scherrer equation were 55.29 and 54.96 nm, respectively.

In FTIR spectroscopy, a vibrational band characteristic of Mn-O-Mn and Fe-O-Fe bonds was detected in the 658 cm^{-1} region, confirming the formation of MnO_6 and FeO_6 octahedra. Additional absorption bands were also observed at 1095, 1328, 1408, and 1690 cm^{-1} . FESEM-EDS studies characterized the morphological features and elemental composition of the material and showed that the average microcontroller size is approximately 186.87 nm.

Electrophysical studies revealed a complex temperature-dependent behavior of the conductivity of $\text{La}_{0.9}\text{MnO}_3\text{-LaFeO}_3$ composite. The material exhibited semiconducting properties in the temperature ranges 293–323 K, 343–393 K, and 413–483 K. For these temperature ranges, the bandgap width was 1.38, 1.44, and 1.41 eV, respectively, and it was found that the material belongs to the class of narrow-bandgap semiconductors. It was observed that the dielectric permittivity increases significantly with rising temperature and decreases with increasing measurement frequency.

The electrocatalytic properties of $\text{La}_{0.9}\text{MnO}_3\text{-LaFeO}_3$ nanocomposite in the hydrogen evolution reaction (HER) were evaluated using LSV and EIS methods. In the LSV studies, 50 cycles were performed, and the current increased from 0.0022 A in the first cycle to 0.0045 A in the 50th cycle. This demonstrated an increase in the composite's electrocatalytic activity during the HER process as the number of cycles increased. The EIS results showed a decrease in the material's impedance as

the applied voltage increased from 0.50 to 0.85 V, indicating a change in charge transfer processes at the electrode-electrolyte interface.

2. Scientific Results of the Second Article

FeMnO₃ (FMO) perovskite-like nanoparticles were synthesized using the sol-gel-based Pecchini method, and their phase-structural, morphological, redox, electrophysical, dielectric, and electrocatalytic properties in the hydrogen evolution reaction were comprehensively investigated. X-ray phase analysis showed that FMO formed in the cubic space group Ia3 with high crystallinity. The lattice parameters were $A = b = c = 9.45 \text{ \AA}$, and the average crystallite size, calculated using the Scherrer equation, was 52.47 nm.

FTIR confirmed the formation of metal-oxygen bonds in the FMO structure. Absorption bands at 755.13, 715.99, and 668.62 cm⁻¹ corresponded to valence vibrations of the Fe–O and Mn–O bonds. FESEM studies revealed a relatively uniform particle morphology with an average size of approximately 55.84 nm. EDS and elemental mapping results showed that the elements Fe, Mn, and O are uniformly distributed across the material's surface.

TPO-O₂ analysis allowed characterization of the redox processes within the FMO structure. Oxidation processes were observed at 528 and 651 °C, and it was shown that the primary crystalline structure of FMO is reduced at high temperatures. This process was associated with electronic transitions of the type: $\text{Fe}^{3+} + \text{Mn}^{2+} \rightleftharpoons \text{Fe}^{2+} + \text{Mn}^{4+}$.

Electrophysical studies revealed the semiconducting nature of FMO. The bandgap was determined to be 0.12 eV over the temperature range 313–373 K, 0.82 eV at 363–403 K, and 1.18 eV at 413–483 K. The dielectric permittivity increased from 69 at 293 K at a frequency of 1 kHz to 2.43×10^5 at 483 K, and a decreasing trend was observed as the frequency increased. Broadband dielectric spectroscopy involves two distinct relaxation processes: stepwise charge carrier transport over long and short distances, and polarization at grain boundaries.

FMO activity during HER was evaluated using the LSV method. In the potential range of 0.8–0.4 V, a current is recorded consistent with hydrogen evolution, and the current signal stabilizes as the number of cycles increases. The results show that FMO nanoparticles exhibit stable electrocatalytic properties after initial activation and possess moderate catalytic activity for HER.

3. Scientific Results of the Third Article

This review article systematizes the relationships between the synthesis, structural features, and functional properties of perovskite manganites and identifies the key factors for the targeted control of these materials' properties. It was shown that the properties of perovskite manganites directly depend on their crystal structure, the geometry of the Mn–O–Mn bond, the Mn³⁺/Mn⁴⁺ ion ratio, oxygen vacancies, and cation substitution. Solid-state, sol-gel, Pecini, hydrothermal, precipitation, combustion, microwave, ultrasonic, and other methods for synthesizing manganites were analyzed. It was shown that the synthesis method and heat treatment conditions determine the phase purity of the material, crystallite size, morphology, oxygen stoichiometry, and electrical, magnetic, and electrocatalytic properties. It has been demonstrated that the Pechini method allows for the uniform

mixing of metal cations at the molecular level, maintains the stoichiometry of complex compositions, and forms a perovskite phase at relatively low temperatures.

ABO₃, double perovskite, layered, and low-dimensional structural types of perovskite manganites were examined, and their structural changes were linked to their functional properties. It was found that cation substitution at the A and B sites affects the crystal lattice symmetry, the Mn³⁺/Mn⁴⁺ ratio, and the deformation of MnO₆ octahedra. It was systematized that the Jahn-Teller effect and the rotation of MnO₆ octahedra alter the Mn–O–Mn angle, contributing to electron transport, electrical conductivity, and the magnetic state. The magnetic, electrical, dielectric, optical, and catalytic properties of manganites with different compositions were compared, and it was shown that these properties can be controlled by cation substitution and changes in the fracture structure. It was found that substitution of the α-site with ions such as Ca²⁺, Sr²⁺, and Ba²⁺ leads to the formation of a mixed valence state of Mn³⁺/Mn⁴⁺ and a change in magnetic and electrical properties via a double-exchange mechanism.

Based on this analysis, the key relationships—“synthesis state → defect structure → crystal structure → functional property → application area”—that determine the properties of perovskite manganites have been systematized. A particularly important area of study was the demonstrated influence of oxygen vacancies, cation substitution, and structural deformations on the electrocatalytic efficiency of HER/OER. These results allow perovskite manganites to be considered as promising multifunctional materials for electrocatalysis, hydrogen energy, energy storage, sensors, photocatalysis, spintronics, and magnetic cooling.

Theoretical and Practical Significance of the Work

- The results of this study allow us to characterize the relationship between synthesis conditions, phase composition, crystal structure, and morphology of complex manganite oxides (perovskite and garnet). Studies of their electrophysical and dielectric properties, which depend on temperature and frequency, contribute to the scientific understanding of these materials' properties. A comparison of structural characteristics with electrochemical results provides a basis for explaining the electrocatalytic properties of HER/OER.

The data obtained are used for an initial assessment of the studied manganites as electrode materials for the HER/OER reactions during water electrolysis. A comparison of synthesis conditions and electrochemical parameters serves as the basis for selecting samples for subsequent studies and optimizing their composition.

Approbation of Practical Results

The main findings of the dissertation were presented at international scientific conferences and discussed within the scientific community.

- International Conference «Fundamental and Applied Aspects of the Development of Chemistry and Innovative Technologies» dedicated to the 90th anniversary of the birth of Kakin Suleimankulovich Suleimankulov, Academician of the National Academy of Sciences of the Kyrgyz Republic. Bishkek, Kyrgyzstan. 2023.

Publications and Author's Contribution

Key findings of the dissertation research are reflected in 14 published works, including 3 articles in scientific journals ranked in the first and/or second quartile of the impact factor according to the Web of Science database by Clarivate Analytics (Clarivate Analytics), and 3 articles in scientific journals included in the list of the Committee for Quality Assurance in Science and Higher Education of the Republic of Kazakhstan; 1 article was published in the Russian Science Citation Index (RCCI); 7 articles and abstracts were presented at international conferences; and 1 application for an innovation patent in the Republic of Kazakhstan was filed.

1. Mataev, M., **Sarsenbaeva, Z.**, Keskin, B., Nurbekova, M., Meldeshov, A., Tursyn, Z., & Seitbekova, K. (2025). Synthesis, Structure, and Electrophysical and Electrochemical Properties of Novel Composite $\text{La}_{0.9}\text{MnO}_3\text{-LaFeO}_3$. *Molecules*, 30(1), 132. <https://doi.org/10.3390/molecules30010132>. Journal metrics (2025): impact factor 5.1; Q1 in physical and theoretical chemistry (87%). CiteScore (2025): 10.3; 80% in chemistry (across various fields). Ph.D. student's contribution: conducted experiments and interpreted the results; prepared and drafted the initial version of the article; participated in the complete preparation of the article in accordance with the journal's requirements. The student's own contribution to the article was 70%.

2. Mataev, M., **Sarsenbaeva, Z.**, Nurbekova, M., Krishnamoorthy, R., Keskin, B., Abdraimova, M., Tursyn, Z., Seitbekova, K., & Durmenbayeva, Z. (2026). FeMnO_3 : Synthesis, Morphology, Dielectric Properties, and Electrochemical Behavior Toward HER by LSV. *Nanomaterials*, 16(5), 310. <https://doi.org/10.3390/nano16050310>. Author status: doctoral candidate (corresponding author). Journal metrics (2026): impact factor 4.8; General Chemical Engineering Q1 (87%). CiteScore (2026): 10.3; 84th percentile in general materials science. Ph.D. student's contribution: conducted experiments and interpreted the results; prepared and drafted the initial version of the article; participated in the complete preparation of the article in accordance with the journal's requirements. The student's own contribution to the article was 70%.

3. Nurbekova, M., Mataev, M., Abdraimova, M., Tursyn, Z., Durmenbayeva, Z., & **Sarsenbaeva, Z.** (2026). Perovskite Manganites: An Overview of Synthesis, Classification, Characterization, and Applications. *International Journal of Molecular Sciences*, 27(13), 5709. <https://doi.org/10.3390/ijms27135709>. Author status: Corresponding author (Ph.D. candidate). Journal metrics (2026): Impact Factor 5.6; Q1 in inorganic chemistry. CiteScore (2026): 10; 90th percentile in inorganic chemistry. Ph.D. student's contribution: conducted experiments and interpreted the results; prepared and drafted the initial version of the article; participated in the complete preparation of the article in accordance with the journal's requirements. The student's own contribution to the article was 70%.

4. Mataev, M., Нурбекова, М., Кескин, Б., & **Sarsenbayeva, Z.** (2023). Synthesis and physico-chemical properties of polycrystal $\text{FeMnO}_3\text{-Ho}_3\text{Fe}_5\text{O}_{12}$. *Academic Scientific Journal of Chemistry*, (4), 173–180. <https://doi.org/10.32014/2023.2518-1491.201>. Doctoral student's contribution: conducted experiments and interpreted the results; prepared and drafted the original

article; participated in the complete preparation of the article in accordance with the journal's requirements. Student's own contribution was 70%.

5. Mataev, M., Sarsenbaeva, Z., Nurbekova, M., Abdrayimova, M., & Seytbekova, K. (2025). Synthesis and morphological analysis of $\text{Fe}_{0.84}\text{Mn}_{1.12}\text{O}_3$ - $\text{In}_{0.12}\text{Fe}_{1.88}\text{O}_3$ composite. Academic Scientific Journal of Chemistry, 3(464), 155–165. <https://doi.org/10.32014/2025.2518-1491.307>. Doctoral student's contribution: conducted experiments and interpreted the results; prepared and drafted the original article; participated in the complete preparation of the article in accordance with the journal's requirements. Student's own contribution was 70%.

6. Mataev, M., Ongarbek, A., Sarsenbaeva, Z., Nurbekova, M., & Abdraimova, M. (2026). Synthesis and Morphology of the Perovskite Structure of $\text{CaMnO}_{2.98}$. Academic Scientific Journal of Chemistry, 466(1), 221–237. <https://doi.org/10.32014/2026.2518-1491.351>. PhD student's contribution: conducted experiments, interpreted the results; prepared and drafted the original manuscript; participated in the complete preparation of the article in accordance with the journal's requirements. Author's own contribution: 50%.

7. Mataev, M., Sarsenbaeva, Z., Nurbekova, M. Synthesis and elemental composition analysis of double-perovskite FeMnO_3 - LaMnO_3 . Proceedings of the National Academy of Sciences of the Kyrgyz Republic, pp. 81–85. (2023) ISBN 0002-32221. PhD student's contribution: conducted experiments, interpreted the results; prepared and formatted the original draft of the article; participated in the complete preparation of the article in accordance with the journal's requirements. Personal contribution: 70%.

8. Mataev M., Koshkimbayeva, A., Sarsenbayeva, Z. Synthesis and Physicochemical Composition of FeMnO_3 - $\text{Dy}(\text{Fe}_{0.5}\text{Mn}_{0.5})_2$ polycrystals // 5th International Conference as part of the scientific and practical conference “Youth and Science: Present and Future” . Almaty, KazNPU, April 21, 2025, pp. 153–157. PhD student's contribution: participated in conducting experimental studies, edited and interpreted the obtained results; participated in the preparation and scientific formatting of the article. Author's own contribution: 70%.

9. Mataev, M., Sarsenbaeva, Z. Synthesis and Physicochemical Properties of FeMnO_3 Nanocomposites // Colloids and Nanotechnologies in Industry 2025. Almaty, KBTU, ISBN 978-601-269-534-2, pp. 395–401. PhD student's contribution: participated in the synthesis of FeMnO_3 and in conducting physicochemical studies; analyzed and interpreted experimental results; participated in the preparation and formatting of the article text. Original author's contribution: 70%.

10. Mataev, M., Nurbekova M.A., Koshkimbayeva A., Sarsenbayeva Z. Green Synthesis and X-ray Phase Analysis of LaMnO_3 Perovskite // IV International Youth Scientific Forum “Paradigms of Natural Science and Science within the Framework of the Sustainable Development Goals.” November 27, 2025. PhD student's contribution: participated in the synthesis of LaMnO_3 perovskite, the processing and interpretation of X-ray phase analysis results; contributed to the preparation of the article text and the scientific presentation of the results. Author's own contribution: 50%.

11. Ongarbek A., Mataev M., **Sarsenbaeva Z.** Synthesis of perovskite-structured CaMnO_3 and analysis using XRD and FTIR methods // Eurasian Science Review: An International Peer-Reviewed Multidisciplinary Journal. 3(7), 167–173. PhD student's contribution: participated in the analysis and interpretation of the research results, the systematization of the XRD and FTIR results, and the preparation and formatting of the article text. Original authorial contribution: 50%.

12. Dyusebay Zh.G., Aliyeva U.A., Ongarbek A.T., Mataev, M.M., Sarsenbaeva, Z. Synthesis and Morphology of BaMnO_3 Perovskite // International Scientific Conference of Students and Young Scientists "Farabi's World." Almaty, Kazakhstan, April 7–8, 2026. ISBN 978-601-04-7533-5, p. 158. PhD candidate's contribution: participated in the discussion of the results of the synthesis and morphological study of the BaMnO_3 material; contributed to the interpretation of the obtained data and the preparation of the abstract. Personal contribution: 50%.

13. Mataev, M., Koshkimbayeva, A., Sarsenbayeva, Z. Synthesis and Physicochemical Composition of $\text{NiMn}_2\text{O}_4\text{-Fe}_3\text{O}_4$ Polycrystals // Scientific and Practical Conference "Chemistry and the Environment." In honor of the 80th anniversary of the Kazakh National Women's Pedagogical University, the 155th anniversary of the periodic table, and the 190th anniversary of the birth of D. I. Mendeleev. 2024. ISBN 978-601-346-156-4, pp. 20–23. PhD candidate's contribution: participated in the synthesis of the material and the conduct of physicochemical studies; edited and interpreted the experimental results; participated in the preparation and formatting of the article. Personal contribution: 50%.

As part of this research, an application for an innovative patent in the Republic of Kazakhstan has been filed:

Mataev, M. M., Nurbekova, M. A., Sarsenbaeva, Z., Abdraimova, M. R., Tursyn Zh., Kushkimbayeva A. K., and Seytbekova K. Zh. "Method for the Green Synthesis of LaMnO_3 Oxide with a Perovskite Structure Based on Aloe vera Extract" // Application for an innovation patent of the Republic of Kazakhstan, No. 442010, Application date: February 24, 2026. PhD candidate's contribution: participated in the development of the green synthesis method for LaMnO_3 oxide and in experimental work; contributed to the analysis of the results obtained and the preparation of patent materials. Original authorial contribution: 70%.

Connection of the work to national scientific programs

The work was carried out within the framework of grant funding for scientific and/or scientific-technical projects of the Ministry of Science and Higher Education of the Republic of Kazakhstan for 2025–2027:

- Grant Program of the Ministry of Science and Higher Education of the Republic of Kazakhstan for scientific and/or scientific-technical projects for 2025–2027: IRN AP26198947 "Synthesis and Study of the Properties of Multicomponent Perovskites for the Development of Magnetosensitive Media with Controllable Physicochemical Characteristics";

- State Funding from the Ministry of Science and Higher Education of the Republic of Kazakhstan for Scientific and/or Scientific-Technical Projects for 2025–

2027: IRN AP26198941 “Investigation of the electrocatalytic properties of composites and nanocomposites in hydrogen production”;

- Internal funding from the Kazakh National Women’s Pedagogical University in accordance with Order No. 236 dated April 26, 2023: “Synthesis and Physical Fundamentals of New Composite Multiferroics for Spintronics”.

Connection of the work to international scientific programs:

Research was conducted as part of Project FBG-2025-6692 “Enhancing the electrocatalytic activity and efficiency of hydrogen production (PerovskiteNanoGraphene, PNG) of perovskite-structured iron manganites enriched with various variable metals and doped with graphene” as part of the BAP program at Yildiz Technical University (Turkey).

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