JPPIPA 11(5) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Effect of Doping for Barium M-Hexaferrite Material Composition on Microwave Absorption Effect (A Systematic Review)

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Received: January 07, 2025
Revised: April 06, 2025
Accepted: May 25, 2025
Published: May 31, 2025

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DOI: 10.29303/jppipa.v11i5.11276

Abstract: Research in the field of materials, especially the magnetic properties of materials, continues to increase. This is because Indonesia is one of the countries whose technological developments are developing very rapidly, where the amount of energy use is on a large scale, so that human needs for renewable energy sources must be met properly. This research aims to identify and analyze research trends of doping for barium m-hexaferrite material composition. This research method is descriptive and analytical. The data used in this research was obtained from documents indexed by Google Scholar from 2016-2025 using Publish or Perish and Dimension.ai. Research procedures use PRISMA guidelines. The data identified and analyzed are the type of publication, publication source, and the title of research doping for barium m-hexaferrite material composition that is widely cited. The data analysis method uses bibliometric analysis assisted by VOS viewer software. The results of the analysis show that research trend indexed by Google Scholar from 2016 to 2025 has experienced ups and down. There are many documents in the form of articles, chapters, preprints, monograph, proceeding and edited books that discuss research about doping for barium m-hexaferrite material composition. Key words that are often used in research about it are synthesis, characterization, permanent magnet, etc.

Keywords: Barium m-hexaferrite; Doping; Microwave absorption

Introduction

Natural iron sand is an abundant natural material available in Indonesia. Sand iron compounds contain magnetite (Fe_3O_4), hematite (α-Fe_2O_3) as the main minerals (predominantly compound) and maghemite (γ-Fe_2O_3), silica (SiO_2), alumina (Al_2O_3), rutile (TiO_2), and ilmenite ($FeTiO_3$) as a minor compound. The differences in levels of mineral content due to geological structure and mineralization processes in each region. These minerals have 88% magnetic properties (Susilawati et al., 2019). These minerals have the potential to be developed as an industrial material. For example, magnetite can be used as a base material dry ink (toner) on a copier and laser printer, in industries such as ceramics, catalysts, energy storage, magnetic data storage device, ferrofluids, as well as in medical diagnostics, absorbing radar waves, and microwave absorption (Susilawati et al., 2018).

One of the materials currently drawing attention to the microwave absorbent material is Barium M-hexaferrite ($BaFe_{12}O_{19}$) or better known as BaM. The BaM

How to Cite:
Susilawati, Ardianto, T., Doyan, A., Nisrina, N., Yusoff, W. Y. B. W., & Jaswadi. (2025). Effect of Doping for Barium M-Hexaferrite Material Composition on Microwave Absorption Effect (A Systematic Review). *Jurnal Penelitian Pendidikan IPA*, *11*(5), 16–22. https://doi.org/10.29303/jppipa.v11i5.11276

was applied as an absorbent material data recorder and microwave. The BaM has a high saturation magnetization (78 emu/g), large field coercivity is (6700 Oe), a high- temperature Curie (450^{o}C), good chemical stability and corrosion resistance, with electrical and magnetic properties that can be set to suit the application required (Saidah & Zainuri, 2012). However, the high of the magnetic field (coercivity field) causes BaM to have weak absorption properties making it less effective as the microwave absorbing the material. To solve these problems it is necessary to substitute or doping Fe3+ ions with other metal cations whose sized is almost the same (Al^{3+}, Ga^{3+}, and Cr^{3+}) (Vinnik et al., 2014), in order to lower the magnetic properties of BaM from hard magnetic to be soft magnetic. There are two approaches to substitution ionic, commonly used is the approach of using a single ion substitution and using multiple ion substitutions. The substitution double ion is a popular method in the study of BaM, and a number of studies have been undertaken to modify the properties of the magnetic as the use of double ion substitution (Mn-Ti, Co-Ti, Ni-Ti, and Zn-Ti) (Sözeri et al., 2014), Co–Zn, and Ni-Zn (Agustianto & Widyastuti, 2014), as well as the Co-Mn (Susilawati et al., 2017). The substitution that was performed in this study used a combination of elements of the transition metal is Zn-Mn, because both of these elements has a radius and configuration of the ionic similar to Fe^{3+} (ionic radius Fe = 0.065 nm; Zn = 0.074 nm; and Mn = 0.08 nm).

In today's scenario, the increase in high-frequency electronic devices has made our life easy. This causes a serious issue of electromagnetic interference (EMI). To hinder the EMI problem, various materials are synthesized by many researchers. In this perspective, research has been focused recently on the advancement in EM wave absorbing and interference shielding materials among which hexaferrites have attracted immense concern. Doped hexagonal ferrites are one of the solutions of EMI because they are the most promising materials with excellent electromagnetic properties (Narang & Hudiara, 2006; Arora & Narang, 2018; Naidu & Madhuri, 2017). The doped Barium hexaferrites (BAHF) can meet the requirements in the GHz frequency band with large microwave absorption bandwidth. The substitution of Ba^{2+} ion and Fe^{3+} ion in barium hexaferrite is done to tailor its electromagnetic properties, which play an important role in microwave absorption characteristics. An extensive research is going on relating to the suppression of electromagnetic signals and radar signatures (Naidu & Madhuri, 2017; Farhadizadeh et al., 2015). Most of the researchers use simulation to calculate the microwave absorption using metal-backed plate approach. But a few researchers used open-circuit approach for analysis of microwave absorption characteristics of a material (Narang et al., 2018; Arora et al., 2019).

Therefore, this research wants to know the research trend in effect of doping for barium m-hexaferrite material composition on microwave absorption effect.

Method

This research method is descriptive and analytical, which aims to understand and describe research trends in the effect of doping for barium m-hexaferrite material composition on microwave absorption effect. The data used in this study was obtained from information sources indexed by Google Scholar using analytical tools such as Publish or Perish and Dimension.ai.

In this research, an analysis was carried out on 1,000 documents that had been indexed by Google Scholar between 2016 and 2025. The Google Scholar database was chosen as a place to search for documents because Google Scholar applies consistent standards in selecting documents to be included in its index, and Google Scholar displays more documents than the top databases. Others, especially research in the field of education (Hallinger et al., 2019, 2020; Zawacki-Richter et al., 2019). To filter data that has been collected via Publish or Perish, researchers used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Result and Discussion

This research aims to describe research trends on the effect of doping for barium m-hexaferrite material composition on microwave absorption effect conducted from 2016 to 2025. Figure 1 shows that the trend in research on the effect of doping for barium m-hexaferrite material composition on microwave absorption effect from 2016 to 2025 experiencing ups and downs.

The most publications occurred in 2024, namely 857 publications. This proves that research to find renewable energy is being carried out more and more frequently. Many studies have explored natural elements to be used as renewable energy sources, one of which is Strontium Ferrite and Barium M-Hexaferrite Based on Natural Iron Sand. Below are also table 1 presented research of effect of doping for barium m-hexaferrite material composition on microwave absorption based on the type of publication.

Based on Table 1, it is known that research effect of doping for barium m-hexaferrite material composition on microwave absorption from 2016 to 2025 contained in 6 types of publications. In the form of articles there were 5,278 documents, chapter 560 documents, edited books as many as 309 documents, proceeding 167 documents,

preprints as many as 91 documents and also 74 documents from monograph. Research trends effect of doping for barium m-hexaferrite material composition on microwave absorption in article form is the type of publication that contains the most research compared to other types of publications. Meanwhile, the type of publication contains the least amount of research results is a monograph. Research conducted by Oltarzhevskyi (2019) states that an article is a complete factual essay of a certain length created for publication in online or print media (via newspapers, magazines or bulletins) and aims to convey ideas and facts that can convince and educate. These articles are usually published in scientific journals both in print and online (Suseno et al., 2020).

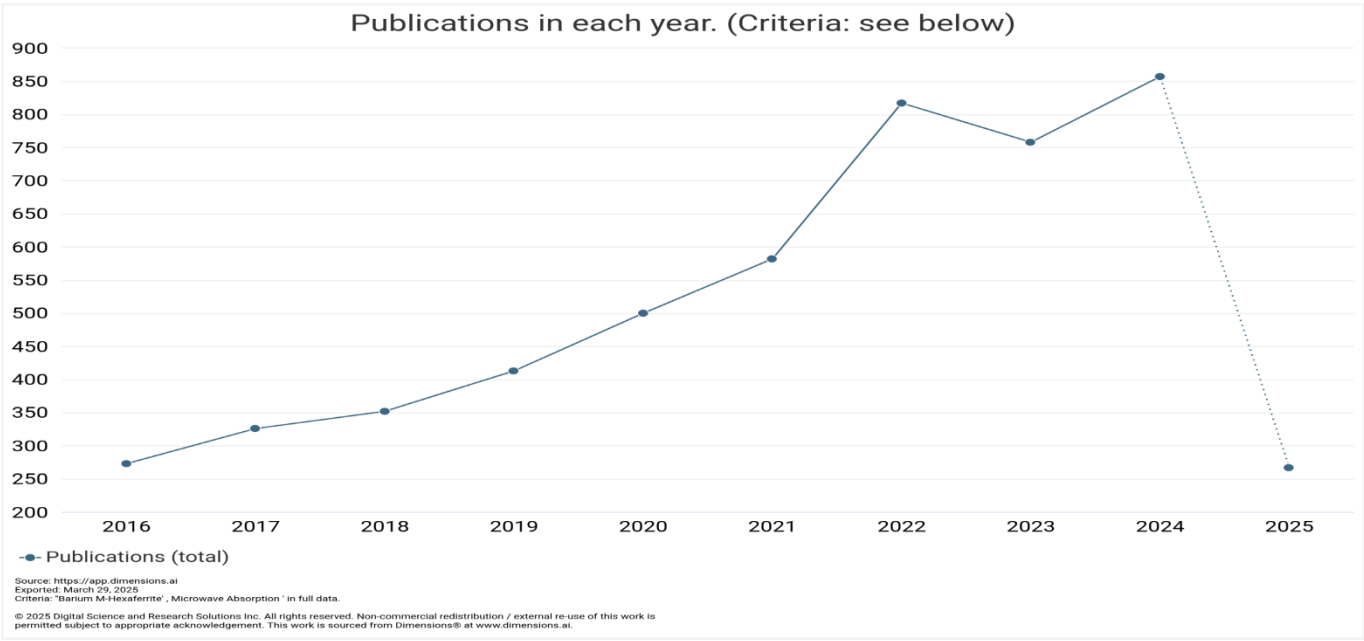

Figure 1. Research trends in effect of doping for barium m-hexaferrite material composition on microwave absorption

Table 1. Trends in Effect of Doping for Barium M-hexaferrite Material Composition on Microwave Absorption Research Based on Publication Types

Publication Type	Publications
Article	5,278
Chapter	560
Edited Book	309
Proceeding	167
Preprint	91
Monograph	74

Below are also table 2 presented top sources title trends in research on effect of doping for barium m-hexaferrite material composition which are often cited by other researchers related to this matter.

Table 2 shows that the most widely published source of research trends on the doping for barium m-hexaferrite material composition is the Ceramics International, namely 512 publications with 14,821 citations and an average citation of 28.95. Ceramics International covers the science of advanced ceramic materials. The journal encourages contributions that demonstrate how an understanding of the basic chemical and physical phenomena may direct materials design and stimulate ideas for new or improved processing techniques, in order to obtain materials with desired structural features and properties.

Table 2. Top Sources Title Trend of Effect of Doping for Barium M-hexaferrite Material Composition Research in 2016-2025

Name	Publications	Citations	Citations Mean
Ceramics International	512	14,821	28.95
Journal of Alloys and Compounds	426	13,851	32.51
Journal of Magnetism and Magnetic Materials	373	15,952	42.77
Journal of Materials Science: Materials in Electronics	240	3,980	16.58
Materials Chemistry and Physics	163	3,158	19.37
IEEE Transactions on Magnetics	123	2,415	19.63
Journal of Superconductivity and Novel Magnetism	121	1,716	14.18
Applied Physics A	113	1,585	14.03

In the articles researched and written by these researchers, there are many terms/keywords related to effect of doping for barium m-hexaferrite material composition. Below are presented the most popular keywords related effect of doping for barium m-hexaferrite material composition.

Table 3. Keywords on Trend of Effect of Doping for Barium M-Hexaferrite Material Composition Research in 2016-2025

Terms	Occurrences	Relevance
Radar absorbing material	4	1.33
Magnetic properties	3	1.27
Coprecipitation method	7	1.19
Iron sand	5	1.14
Characterization	7	0.66
Zn ion	3	0.63

Below are the visualization is accomplished by generating a landscape map, which offers a visual representation of subjects related to scientific studies. The outcomes of bibliometric mapping for the co-word network in articles related to the effect of doping for barium m-hexaferrite material composition are illustrated in Figure 2.

Figure 2 shows the results of bibliometric keyword mapping on research trends on the effect of doping for barium m-hexaferrite material composition. In Figure 2 there are 32 keyword items that are often used in research on the effect of doping for barium m-hexaferrite material composition from 2016 to 2025. Figure 2 also contains 5 clusters, where the first cluster is colored red and consists of 12 keyword items, namely magnetic material, bam, ram, etc. The second cluster in green consists of 6 keyword items, namely permanent magnet, microwave absorbtion, etc. The third cluster in blue consists of 5 keyword items, namely natural iron sand, synthesis, etc. The fourth yellow cluster consists of 5 keyword items, namely characterization, Zn ion, etc. The fifth purple cluster consists of 5 keyword items, microwave, x band frequency range, etc.

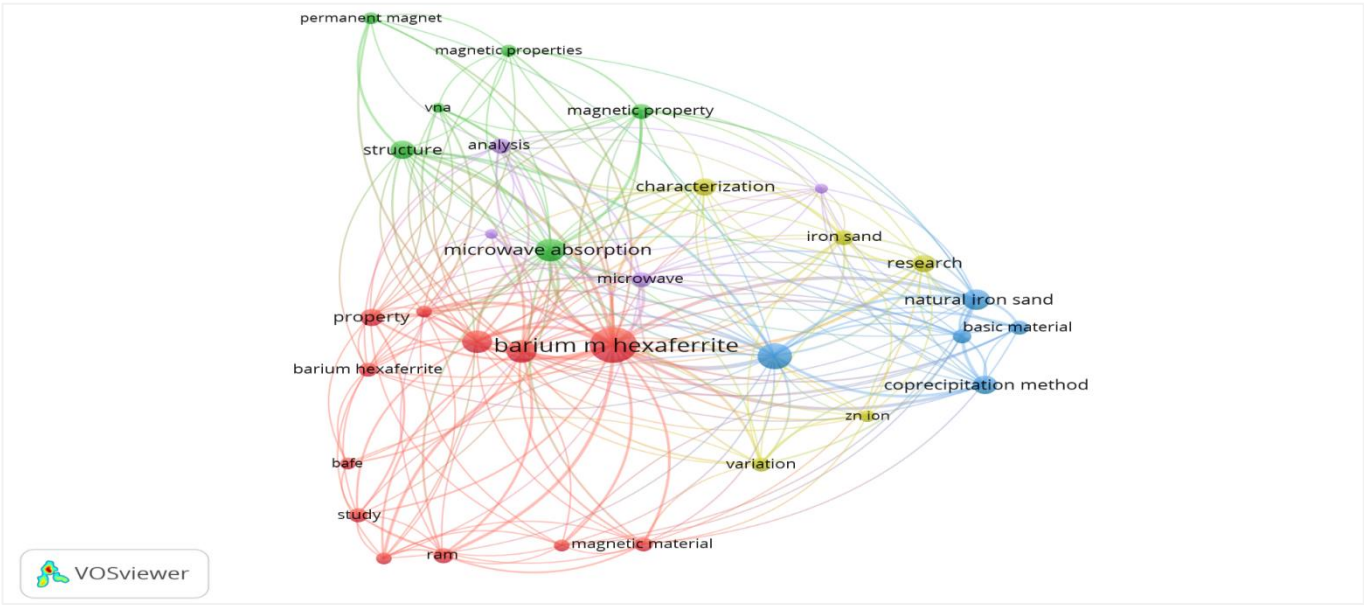

Figure 2. Network visualization on trend effect of doping for barium m-hexaferrite material composition research

Figure 2 above also shows that network visualization shows the network between the terms being visualized. Keywords classified into four clusters are arranged in a color chart showing the divisions/clusters that are connected to each other. The results of this analysis can be used to determine keyword research trends in the last year. This analysis shows several keywords that are often used in research on effect of doping for barium m-hexaferrite material composition. The more keywords that appear, the wider the visualization displayed. Below are also presented keywords regarding the effect of doping for barium m-hexaferrite material composition based on overlay visualization.

Figure 3 shows the trend of keywords related to effect of doping for barium m-hexaferrite material composition in Google Scholar indexed journals from 2016 to 2025. Trends in the themes of writing articles related to effect of doping for barium m-hexaferrite material composition from the oldest to the newest year are marked with purple, blue themes, turquoise, dark green, light green and yellow. In the picture below you can see that x band frequency range, Zn ion, magnetic material, etc. This shows that these keywords were widely used by researchers in 2020. In 2023, the

keywords that frequently appeared were iron sand, basic material, etc. While in 2022, there were keywords like synthesis, characterization, etc that frequently appeared.

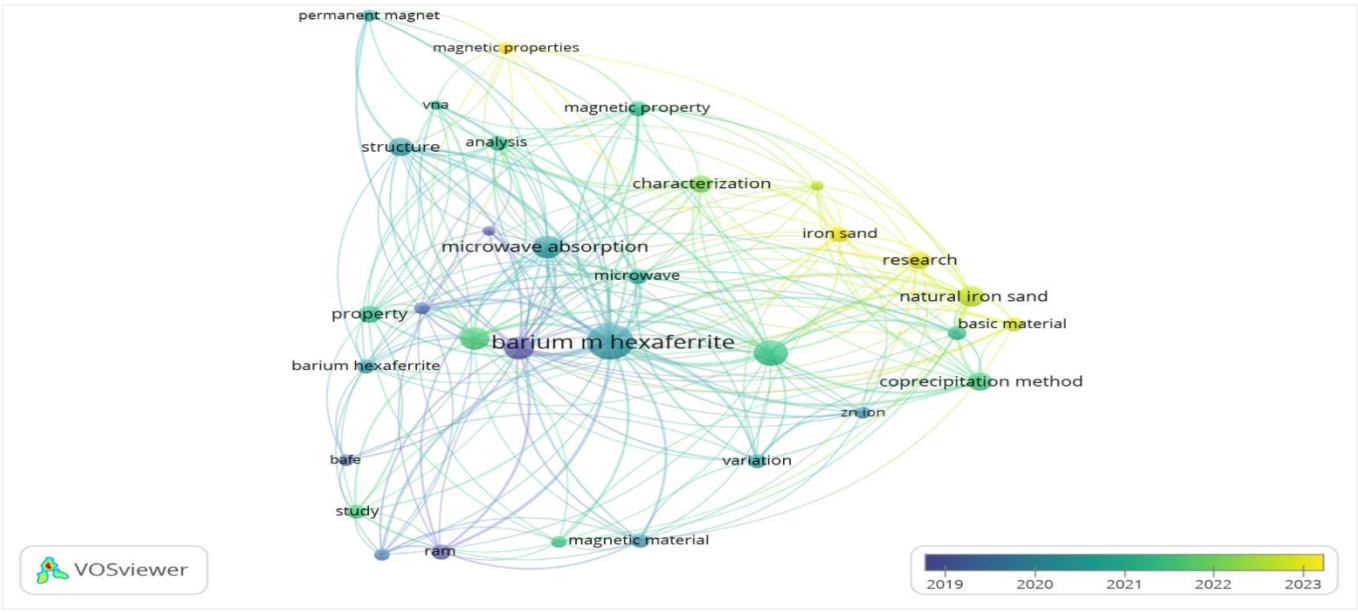

Figure 3. Overlay visualization on trend effect of doping for barium m-hexaferrite material composition research

Research on doping for barium m-hexaferrite material composition is one area of research that has developed rapidly in recent years. The following also presents keywords for doping for barium m-hexaferrite material composition research based on density visualization.

Figure 4 shows density visualization. The density of research themes is shown in bright yellow. The brighter the colors of a theme, the more research is done. The fainter the color means the theme is rarely researched (Kaur et al., 2022; Liao et al., 2018). Faintly colored themes such as permanent magnet, ferrogel are dimly colored keywords. This shows that these keywords can be used as a reference for further research. Doyan et al. (2023) and Bahtiar et al. (2023) stated that yellow indicates keywords that are currently and frequently used in research, like natural iron sand, synthesis, magnetic property, etc.

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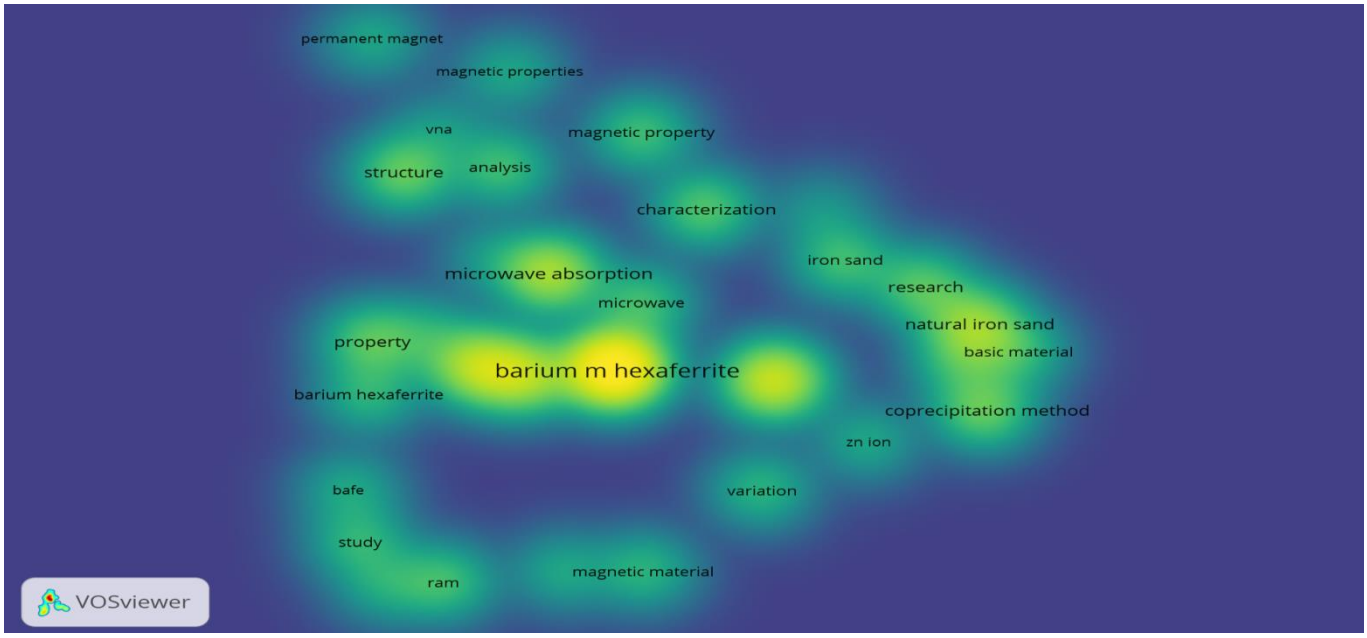

Figure 4. Density visualization on trend effect of doping for barium m-hexaferrite material composition research

Overall, Research in the field of materials, especially the magnetic properties of materials, continues to increase. This is because Indonesia is one of the countries whose technological development is developing very rapidly, where the amount of energy use is on a large scale, so that human needs for renewable energy sources must be met properly. Research can be conducted with the aim of synthesizing and characterizing hard magnetic materials that will be used as one of the renewable energy as a generator material for electricity generation. A generator is an electrical machine that converts mechanical energy into electrical energy by utilizing permanent magnets as the basic material. The materials that can be used are Barium M-Hexaferrite (BaM) and Strontium Ferrite (SrM). So that research is conducted to determine the electrical and magnetic properties of BaM and SrM made from natural iron sand in Indonesia, one of which is on the island of Lombok as a generator material for electricity generation.

Conclusion

Research on doping for barium m-hexaferrite material composition has urgency high because it can be used as one of the renewable energy sources as a material for power generators. The research trend on the doping for barium m-hexaferrite material composition indexed by Google Scholar from 2016 to 2025 has experienced ups and downs. There are many documents in the form of articles, chapters, preprints, monograph, proceeding and edited books that discuss research into the electrical and magnetic properties of strontium ferrite and barium m-hexaferrite based on natural iron sand. Key words that are often used in research about it are synthesis, characterization, permanent magnet, etc.

Acknowledgments
Acknowledgments are expressed by the researchers to the team so that researchers can complete research in the form of journal publications.

Author Contributions
All authors contributed to writing this article.

Funding
No external funding.

Conflicts of Interest
No conflict interest.

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