

How to Cite

Adnyana, I. G. A. P., & Suarbawa, K. N. (2022). Study of the effect of lanthanum and cerium doping combination on magnetic properties of M-type hexaferrite oxide permanent magnets. *International Journal of Chemical & Material Sciences*, 5(1), 34-37. <https://doi.org/10.21744/ijcms.v5n1.2052>

Study of the Effect of Lanthanum and Cerium Doping Combination on Magnetic Properties of M-Type Hexaferrite Oxide Permanent Magnets

I Gusti Agung Putra Adnyana

Program of Physics study, Department of Physics, Faculty of Mathematics and Natural Sciences, Udayana University, Denpasar, Indonesia
Corresponding author email: igaadnyana@unud.ac.id

Komang Ngurah Suarbawa

Program of Physics study, Department of Physics, Faculty of Mathematics and Natural Sciences, Udayana University, Denpasar, Indonesia

Abstract---A study has been carried out on the effect of combination of Lanthanum and Cerium doping on the magnetic properties of M-Type hexaferrite permanent magnet oxide. The research was conducted using the wet mechanical milling method. The research materials used were Fe₂O₃, BaCO₃, La₂O₃, and CeO₂, all of which were of high purity 99.9%. This research also uses technical materials such as Ethanol and Nitrogen. Stoichiometric calculations were carried out to calculate the composition of the mixture of each ingredient. The combination of Lanthanum and Cerium substitution was varied with the composition of the doping ion concentration ($x = 0 - 0.5$ and $y = 0 - 0.1$). Permagraph characterization was carried out to determine the magnetic properties of each test sample. Results based on the permagraph characterization, the properties of M-type hexaferrite permanent magnets increased with the increase in the doping ion concentration in the sample. The presence of doping ions that have a magnetic moment is strongly suspected to contribute to the interaction of the type and the total moment in the M-type hexaferrite structure.

Keywords---Lanthanum, magnet oxide, magnetic properties, M-type hexaferrite, permagraph

Introduction

The development of permanent magnet materials has been progressive since the first-time steel was used as a permanent magnet in the 1900s. The focus of research in the field of permanent magnets is more on the search for new materials that have a higher magnetic energy density. Research activities have continued for more than a hundred years with the discovery of rare earth metal magnets which have a magnetic energy density 68 times higher than steel magnets. Research activities continue along with technological developments to produce nanometer-sized structural materials. The focus of this permanent magnet research is the search for new materials by utilizing rare earth metal elements as an alternative material to produce permanent magnets and at the same time engineering the structure of the material towards permanent magnets with high energy density capabilities. Permanent magnets that are widely developed today are permanent magnetic oxides based on Barium Hexaferrite. In this study, the effect of the combination of lanthanum and cerium doping concentrations on the magnetic parameters of the sample will be studied. The expected result is an increase in the magnetic parameters of the resulting permanent magnetic oxide powder (Neumann & Walter, 2006; Simner et al., 2003).

Materials and Experiments

The materials used in this study were Barium Carbonate powder (BaCO_3), Ferrioxide powder (Fe_2O_3), Cerium Oxide powder (CeO_2), and Lanthanum Oxide powder (La_2O_3). All research materials are 99.99% pure. Each mixed composition was ground using high energy milling (PW1000) with several steel balls with an average diameter of 12 mm and a milling speed of 1000 rpm (Nonaka et al., 2000; Rezlescu et al., 1999; Vinnik et al., 2018; Xu et al., 2006). The ratio of ball mass to powder mass was 2:1, milling time was 5 hours, then compacted at 7000 psi and sintered at 1200°C for 2 hours. Magnetic parameter characterization for each sample was measured using permagraph magnetometer (Physik 255) at room temperature (Coe, 2006; Oliveira et al., 2002).

Results and Discussions

The results of measuring the magnetic properties of the $\text{Ba}_{1-x-y}\text{La}_x\text{Ce}_y\text{Fe}_{12}\text{O}_{19}$ sample ($x = 0, 0.02, 0.04$ and $y = 0, 0.05, 0.1$) using a permagraph and measured in the range -1.6 T to 1.6 T are presented in Figure 1. The magnetic hysteresis loop of the $\text{Ba}_{1-x-y}\text{La}_x\text{Ce}_y\text{Fe}_{12}\text{O}_{19}$ sample ($x = 0, 0.02, 0.04$ and $y = 0, 0.05, 0.1$) showed an increase in magnetic properties (Mathews & Babu, 2021; Lechevallier & Le Breton, 2005). The three magnetic parameters including the coercivity field, remanent magnetization and saturation magnetization change depending on the concentration of doping ions La^{3+} and Ce^{4+} .

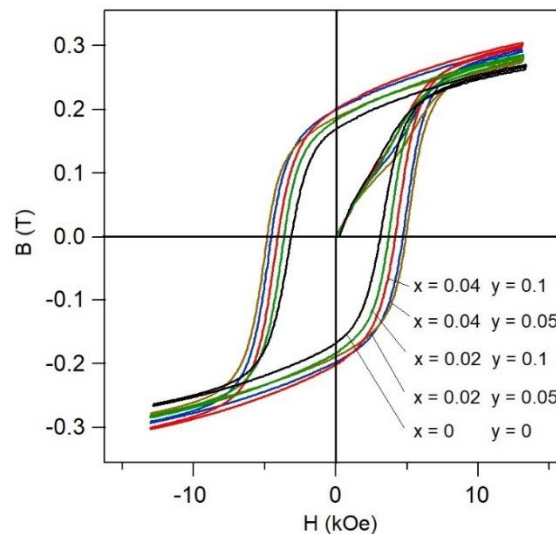


Figure 1. Hysteresis curve of the $\text{Ba}_{1-x-y}\text{La}_x\text{Ce}_y\text{Fe}_{12}\text{O}_{19}$ sample ($x = 0, 0.02, 0.04$ and $y = 0, 0.05, 0.1$)

In Figure 1 it can be seen that the pure barium hexaferrite sample ($x = 0$ and $y = 0$) has a coercivity field, remanent magnetization and saturation magnetization are 3.38kOe, 0.181 T and 0.28 T respectively (Kortz et al., 2009; Coey & Sun, 1990). Coercivity, remanent magnetization and saturation magnetization increase significantly when the doping ion concentration is $x = 0.02$ and $y = 0.05$ and $x = 0.04$ and $y = 0.05$, while they decrease when the doping ion concentration is $x = 0.02$ and $y = 0.1$ and $x = 0.04$ and $y = 0.1$ although the value is still greater than barium pure hexaferrite. In detail the values of the coercivity, remanent magnetization and saturation magnetization of several compositions from the $\text{Ba}_{1-x-y}\text{La}_x\text{Ce}_y\text{Fe}_{12}\text{O}_{19}$ sample ($x = 0, 0.02, 0.04$ and $y = 0, 0.05, 0.1$) are presented in Table 1 (Fisher et al., 2016; Haritsah et al., 2019; Li et al., 2007; Mosleh et al., 2014).

Table 1

Parameters of the magnetic properties of the sample $\text{Ba}_{1-x-y}\text{La}_x\text{Ce}_y\text{Fe}_{12}\text{O}_{19}$ ($x = 0, 0.02, 0.04$ and $y = 0, 0.05, 0.1$)

x	y	Hc (kA/m)	Hc (kOe)	Br (T)	Bs (T)	Ha (kA/m)	BHmax (kJ/m ³)
0	0	270.7	3.38	0.181	0.28	55.48	5.2
0.02	0.05	364.5	4.56	0.183	0.29	61.57	5.8
0.02	0.1	295	3.68	0.187	0.27	56.36	5.4
0.04	0.05	391.4	4.89	0.191	0.3	62.83	6.1

0.04	0.1	342.9	4.29	0.194	0.28	58.16	5.5
------	-----	-------	------	-------	------	-------	-----

Based on the results of the permagraph test for each sample, it was generally obtained that the magnetic properties increased as the concentration of doping ions in the sample increased. In the hexagonal ferrite system, it is the Fe^{3+} ion that is fully responsible for the magnetic properties of this system through the Fe^{3+} - O_2 - Fe^{3+} super exchange interaction mechanism. The mechanism of this super exchange interaction occurs in the magnetic moment of the ion with spin up and down at the tetrahedral and octahedral sites in the hexagonal ferrite crystallographic structure (Sardjono, 2015; Salimkhani et al., 2015).

This increase in magnetic properties is related to the magnetic moments of the constituent ions. It is known that Fe^{3+} ions have a magnetic moment of 4.92 μB , Ba^{2+} ions have no magnetic moment, while La^{3+} doping ions have zero magnetic moment values, while Ce^{4+} ions have a magnetic moment of 2.54 μB . The presence of doping ions with magnetic moments is strongly suspected of contributing to the magnetic interactions and the total magnetic moment in this barium hexaferrite structure (Adnyana et al., 2019; Adnyana et al., 2020; Bahadur et al., 2017; El Shater et al., 2018). This happens because this doping ion does not replace some of the Fe atoms but replaces the Ba atom, so that the magnetic moment originating from the Fe^{3+} ion is full. In general, the barium hexaferrite structure has a total magnetic moment (μ) which is completely determined by the Fe^{3+} magnetic moment. 6 Fe^{3+} ions originate from a spin up orientation in the octahedral site (12k and 2a) and 1 bipyramidal Fe^{3+} ion (2b), while 2 Fe^{3+} ions with a spin down orientation are in the tetrahedral (4f1) and octahedral (4f2) sites. So that the total magnetic moment of the Fe^{3+} ion is 23.68 μB . The ion-magnetic cation substitution Ce^{4+} is located at the Ba atomic site, thus causing an increase in the total number of magnetic moments thought to originate from the presence of magnetic doping ions. It is shown based on Table 2, that the magnetic saturation of samples doped with La^{3+} and Ce^{4+} ions is greater than that of pure barium hexaferrite (Gupta & Khan, 2021; Rajini, 2017).

Conclusion

The addition of various doping lanthanum and cerium simultaneously into a barium hexaferrite permanent magnet presents an interesting magnetic property because it can increase the coercivity field and its saturation magnetization. The product energy of this substituted permanent magnet is greater than that of pure barium hexaferrite permanent magnets.

Acknowledgments

This project was funded by Udayana University under PNPB Research grand is high acknowledged.

References

- Adnyana, I. G. A. P., Suarbawa, K. N., Adi, W. A., Wardani, N. N. S. K., & Jalut, L. L. S. (2019). The Effect of Lanthanum Substitution on the Coercivity Field in Oxide Permanent Magnet Based on $\text{Ba}_{1-x}\text{La}_x\text{Fe}_{12}\text{O}_{19}$ ($x=0; 0.02; 0.04; \text{ and } 0.08$). *International journal of physical sciences and engineering*, 3(1), 42-49.
- Adnyana, I. G. A. P., Sukarasa, I. K., & Adi, W. A. (2020). Rare earth ion contribution in barium hexaferrite structure to a change of magnetocrystalline anisotropy to improving its magnetic properties. *International Journal of Physical Sciences and Engineering*, 4(2), 1-13.
- Bahadur, A., Saeed, A., Iqbal, S., Shoaib, M., Ahmad, I., ur Rahman, M. S., ... & Hussain, W. (2017). Morphological and magnetic properties of $\text{BaFe}_{12}\text{O}_{19}$ nanoferrite: A promising microwave absorbing material. *Ceramics International*, 43(9), 7346-7350.
- Coey, J. M. D. (2006). Dilute magnetic oxides. *Current Opinion in Solid State and Materials Science*, 10(2), 83-92. <https://doi.org/10.1016/j.cossms.2006.12.002>
- Coey, J. M. D., & Sun, H. (1990). Improved magnetic properties by treatment of iron-based rare earth intermetallic compounds in ammonia. *Journal of Magnetism and magnetic materials*, 87(3), L251-L254. [https://doi.org/10.1016/0304-8853\(90\)90756-G](https://doi.org/10.1016/0304-8853(90)90756-G)
- El Shater, R. E., El-Ghazzawy, E. H., & El-Nimr, M. K. (2018). Study of the sintering temperature and the sintering time period effects on the structural and magnetic properties of M-type hexaferrite $\text{BaFe}_{12}\text{O}_{19}$. *Journal of Alloys and Compounds*, 739, 327-334.
- Fisher, J. G., Sun, H., Kook, Y. G., Kim, J. S., & Le, P. G. (2016). Growth of single crystals of $\text{BaFe}_{12}\text{O}_{19}$ by solid state crystal growth. *Journal of Magnetism and Magnetic Materials*, 416, 384-390.

- Gupta, M., & Khan, M. A. (2021). Advances in applications of non-destructive testing (NDT): a review. *International Research Journal of Engineering, IT & Scientific Research*, 7(3), 76–86. <https://doi.org/10.21744/irjeis.v7n3.1003>
- Haritsah, I., Adi, W. A., Purwani, M. V., & Manaf, A. (2019, March). Improved separation of Ce, La, and Nd from a concentrate of rare-earth hydroxide via fractional precipitation. In *IOP Conference Series: Materials Science and Engineering* (Vol. 496, No. 1, p. 012013). IOP Publishing.
- Kortz, U., Mueller, A., van Slageren, J., Schnack, J., Dalal, N. S., & Dressel, M. (2009). Polyoxometalates: Fascinating structures, unique magnetic properties. *Coordination Chemistry Reviews*, 253(19-20), 2315-2327. <https://doi.org/10.1016/j.ccr.2009.01.014>
- Lechevallier, L., & Le Breton, J. M. (2005). Substitution effects in M-type hexaferrite powders investigated by Mössbauer spectrometry. *Journal of magnetism and magnetic materials*, 290, 1237-1239. <https://doi.org/10.1016/j.jmmm.2004.11.411>
- Li, R., Pang, S., Ma, C., & Zhang, T. (2007). Influence of similar atom substitution on glass formation in (La–Ce)–Al–Co bulk metallic glasses. *Acta Materialia*, 55(11), 3719-3726.
- Mathews, S. A., & Babu, D. R. (2021). Analysis of the role of M-type hexaferrite-based materials in electromagnetic interference shielding. *Current Applied Physics*, 29, 39-53. <https://doi.org/10.1016/j.cap.2021.06.001>
- Mosleh, Z., Kameli, P., Ranjbar, M., & Salamati, H. J. C. I. (2014). Effect of annealing temperature on structural and magnetic properties of BaFe₁₂O₁₉ hexaferrite nanoparticles. *Ceramics International*, 40(5), 7279-7284.
- Neumann, A., & Walter, D. (2006). The thermal transformation from lanthanum hydroxide to lanthanum hydroxide oxide. *Thermochimica acta*, 445(2), 200-204. <https://doi.org/10.1016/j.tca.2005.06.013>
- Nonaka, T., Ohbayashi, G., Toriumi, Y., Mori, Y., & Hashimoto, H. (2000). Crystal structure of GeTe and Ge₂Sb₂Te₅ meta-stable phase. *Thin Solid Films*, 370(1-2), 258-261.
- Oliveira, L. C., Rios, R. V., Fabris, J. D., Garg, V., Sapag, K., & Lago, R. M. (2002). Activated carbon/iron oxide magnetic composites for the adsorption of contaminants in water. *Carbon*, 40(12), 2177-2183. [https://doi.org/10.1016/S0008-6223\(02\)00076-3](https://doi.org/10.1016/S0008-6223(02)00076-3)
- Rajini N, H. (2017). Automatic classification of MR brain tumor images using KNN, ANN, SVM and CNN. *International Research Journal of Engineering, IT & Scientific Research*, 3(1), 36–44. <https://doi.org/10.21744/irjeis.v3n1.895>
- Rezlescu, L., Rezlescu, E., Popa, P. D., & Rezlescu, N. (1999). Fine barium hexaferrite powder prepared by the crystallisation of glass. *Journal of Magnetism and Magnetic Materials*, 193(1-3), 288-290.
- Salimkhani, H., Movassagh-Alanagh, F., Aghajani, H., & Osouli-Bostanabad, K. (2015). Study on the magnetic and microwave properties of electrophoretically deposited nano-Fe₃O₄ on carbon fiber. *Procedia Materials Science*, 11, 231-237. <https://doi.org/10.1016/j.mspro.2015.11.118>
- Sardjono, P. (2015). Preparation and characterization of 5 wt.% epoxy resin bonded magnet NdFeB for micro generator application. *Energy Procedia*, 68, 282-287. <https://doi.org/10.1016/j.egypro.2015.03.257>
- Simner, S. P., Bonnett, J. F., Canfield, N. L., Meinhardt, K. D., Shelton, J. P., Sprenkle, V. L., & Stevenson, J. W. (2003). Development of lanthanum ferrite SOFC cathodes. *Journal of power sources*, 113(1), 1-10. [https://doi.org/10.1016/S0378-7753\(02\)00455-X](https://doi.org/10.1016/S0378-7753(02)00455-X)
- Vinnik, D. A., Chernukha, A. S., Gudkova, S. A., Zhivulin, V. E., Trofimov, E. A., Tarasova, A. Y., ... & Niewa, R. (2018). Morphology and magnetic properties of pressed barium hexaferrite BaFe₁₂O₁₉ materials. *Journal of Magnetism and Magnetic Materials*, 459, 131-135.
- Xu, X., Wen, Z., Yang, X., Zhang, J., & Gu, Z. (2006). High lithium ion conductivity glass-ceramics in Li₂O–Al₂O₃–TiO₂–P₂O₅ from nanoscaled glassy powders by mechanical milling. *Solid State Ionics*, 177(26-32), 2611-2615.