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Cite as: AIP Conference Proceedings **2221**, 110025 (2020); https://doi.org/10.1063/5.0005256
Published Online: 31 March 2020

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Study of Physical and Magnetic Properties of Barium Hexaferrite Substituted by Nd_2O_3

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Abstract. The study of physical and magnetic properties of manufactured barium hexaferrite substituted by Nd_2O_3 had been done. Magnetic samples of barium hexaferrite were synthesized from row materials of Fe_2O_3, $BaCO_3$ and Nd_2O_3 as an additive material. The compositions of Nd_2O_3 were varied by 0; 0.4; 0.8 and 1.2 wt.%. Each component materials was grinding using high energy ball milling with a variation of time milling, then compacted and pressed at 8 tons of pressure. All samples were sintered at various temperatures of 1000°C, 1100°C and 1200°C. Bulk density was measured in which the values increased as increasing the sintering temperature. On the other hand, the measurement of magnetic properties was performed using Vibrating Sample Magnetometer (VSM). The magnetic characterizations were observed on sample having a concentration of 0.8 wt Nd_2O_3, such as remanent magnet, B_r, H_{cj} and B_{hmax} were 464.75 Gauss, 2.135 G, 2.907 kOe and 0.927 MGOe, respectively. Other properties such as XRD and determination of particle analyzer are still performing.

INTRODUCTION

Now days, barium hexaferrite is known as one of the most functional magnetic materials. Hexagonal barium hexaferrite ($BaFe_{12}O_{19}$) is commonly used as permanent magnets, particulate media for magnetic recording as well as in microwave devices [1–3]. The ferromagnetic oxides such as ferrites and garnets exhibit dielectric and magnetic characteristics. These materials are useful for a variety of radio frequency (RF) and microwave applications. The essential requirement of microwave devices require high electrical resistivity ferrites, coupled with reasonably low magnetic losses in order to maintain low insertion loss.

One type of permanent magnet is a barium ferrite that has the chemical formula of BaO. $6Fe_2O_3$. This ferrite magnet is generally lower energy compared to other permanent magnets such as NdFeB, SmCo and Alnico [4]. The structure is magnetoplumbite (M-type) in which the general formula of magnetoplumbite is ($MFe_{12}O_{19}$) or $M_{0.6}Fe_2O_3$, where M can be barium (Ba), strontium (Sr) or lead (Pb) [5]. The effect of ion Mg and Al addition was not changed the M-hexagonal structure of barium hexaferrite. The Mg and Al ions have been substituted Fe ion in barium hexaferrite system which is indicated by change of lattice parameters.

One of the examples of this material based on $BaFe_{12-2x}Mg_xAl_xO_{19}$ (x = 0, 0.5, 1, and 2) had been reported [6] and is one of the examples for microwave absorber. On this sample, same magnetic properties were already found such as saturation (M_s), remanence (M_r) and energy product (BH_{max}). Optimum condition was obtained on $BaFe_{11}Mg_{0.5}Al_{0.5}O_{19}$ with M_s = 129.0 emu/g, M_r = 69.0 emu/g, H_c = 3.90 kOe, and B_{Hmax} = 3.40 MGOe. Moreover,

The 1st International Conference on Physics and Applied Physics (The 1st ICP&AP) 2019
AIP Conf. Proc. 2221, 110025-1–110025-6; https://doi.org/10.1063/5.0005256
Published by AIP Publishing. 978-0-7354-1980-3/$30.00

the value of the maximum reflection loss is -36.4 dB at 10.6 GHz. In this experiment, the effect of additive material on barium hexaferrite is studied especially on its physical and magnetic properties as a variation of Nd_2O_3 concentration.

EXPERIMENTAL PROCEDURE

Powders of $BaCO_3$, Fe_2O_3 and Nd_2O_3 weighted in which the additive material of Nd_2O_3 has a various concentration of 0; 0.4; 0.8 and 1.2 wt % and the composition of barium hexaferrite used is set into a stoichiometric composition (BaO: Fe_2O_3 = 1: 6). Then, all are mixing using a mortar to form $BaFe_{12}O_{19}$. Each type of sample was compacted and pressed using hydraulic press of 8 tons. After that, all samples were calcined at temperature of 1000 ℃, laying, sintering at various temperatures of 1000°C, 1100°C and 1200°C.

Sample characterization was performed by using physical test that was bulk density test and shrinkage burn. The density of the samples from their green to sintered state was measured using the well-known Archimedes method. The measurements were carried out to record the change in density subsequent to various sintering treatment protocols. X-Ray diffraction (XRD) experiment was performed using K-Series Magnetizer with voltage (V) = 1400 V and 4.76 kA current was used to magnetize printed samples and to measure magnetic properties using gaussmeter and VSM.

RESULTS AND DISCUSSION

The bulk density as a function of sample composition of Nd_2O_3 was shown in the below Table 1 and graphically depicted in Fig. 1 for samples of 0; 0.4; 0.8 and 1.2 wt % with various sintering temperature.

TABLE 1. The bulk density of Nd_2O_3 addition at various sintering temperature

Additive Nd_2O_3 (wt. %)	**Bulk density (g/cm^3) at sintering temperature**		
	1000°C	**1100°C**	**1200°C**
0	2.794	3.384	4.668
0.4	2.804	3.402	4.714
0.8	3.045	3.446	4.868
1.2	2.783	3.362	4.554

It is clearly seen from the Fig. 1 that the value of bulk density is increasing by the increase of temperature for all composition of additive materials. It is understood since the volume usually increases because the faster moving molecules are further apart. The minimum bulk density value is found to be 2.794 g/cm^3 in the sample with the addition of 0 % Nd_2O_3 with a sintering temperature of 1100℃, and the optimum density is 4.868 g/cm^3 with the addition of Nd_2O_3 0.8% at 1200℃.

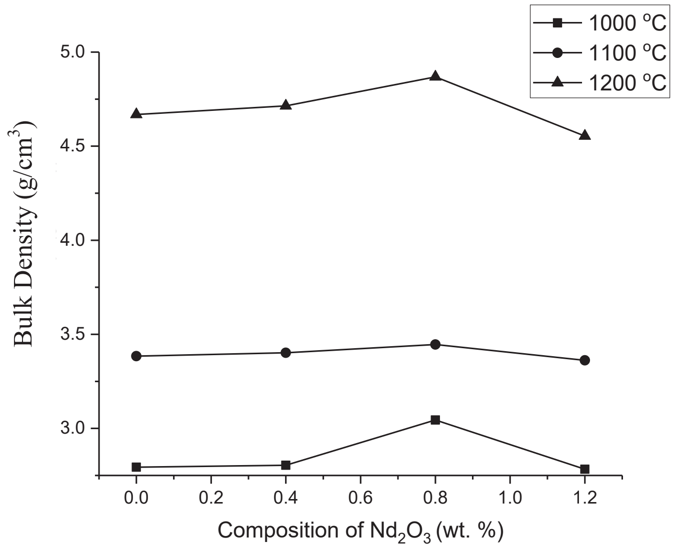

FIGURE 1. Bulk density as a function of composition of additive Nd_2O_3 on preparing $BaFe_{12}O_{19}$ samples

The addition of Nd_2O_3 0.8% caused the increased value of bulk density seen on graph at 1200°C. It can be concluded from Fig. 2 that the optimum value of bulk density is found at composition of 0.8 % of Nd_2O_3 0.8%.

TABLE 2. The keel fuel value of the sample with Nd_2O_3 addition to temperature change sintering

Additive composition of Nd_2O_3 (wt%)	**Keel fuel (%) at sintering temperature**		
	1100°C	**1150°C**	**1200°C**
0	11	11.2	13.7
0.8	0.9	1.5	10.2
1.2	0.9	10.5	20.9

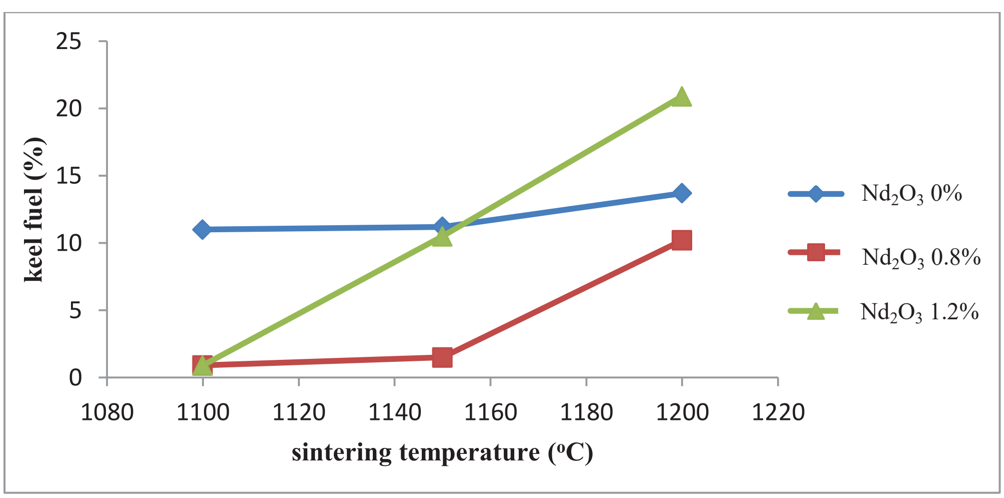

FIGURE 2. Relationship between the keel fuel with the addition of Nd_2O_3 as a function of sintering temperature

Based on Fig. 2, it is clearly depicted that the percentage of keel fuel increases as increasing of sintering temperature. Sample with 1.2 % additive Nd_2O_3 shows a drastic increase of keel fuel value compared to other two additive samples. It happened because of the growth of grains so that the sample shrank as the temperature increased. The maximum keel fuel value of 13.7% was found in the addition of Nd_2O_3 additive (0%) at a sintering temperature of 1200℃ while with the addition of a maximum additive keel fuel value of 20.9% at 1.2% Nd_2O_3 at a sintering temperature of 1200℃.

In order to understand the magnetic properties of material $BaFe_{12}O_{19}$, the measurement of flux density had been performed using Gaussmeter, as the following table:

TABLE 3. Magnetic flux density measurement of addition Nd_2O_3 as a various sintering temperature

Composition of Additive Nd_2O_3 (wt. %)	**Magnetic flux density at sintering temperature (G)**		
	1000°C	**1100°C**	**1200°C**
0	298.88	291.04	239.12
0.4	278.37	286.32	292.22
0.8	266.23	271.28	372.22
1.2	232.56	218.86	189.64

Based on the above results, it is found that the value of magnetic flux density is decreased as increasing percentage of additive material Nd_2O_3. The optimum value of magnetic flux density is found to be 372.22 G on additive sample of 0.8 wt.% with sintering temperature of 1200°C. Moreover, the increase of sintering temperature, the value of magnetic flux density is getting decreased, except for sample with additive Nd_2O_3 0.8 wt.%.

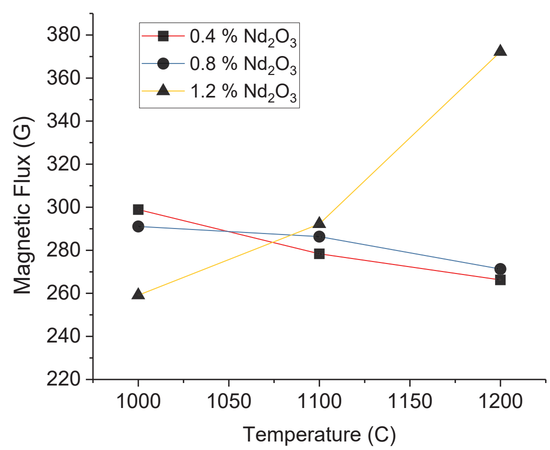

FIGURE 3. Magnetic flux density as a function of sintering temperature for various composition of additive Nd_2O_3 samples

Detail investigation on magnetic properties on selected samples had been performed using the vibrating sample magnetometer (VSM) with applied magnetic field of 4000 G. The following is a hysteresis curve for additive 0% Nd_2O_3 and 0.8% Nd_2O_3 samples.

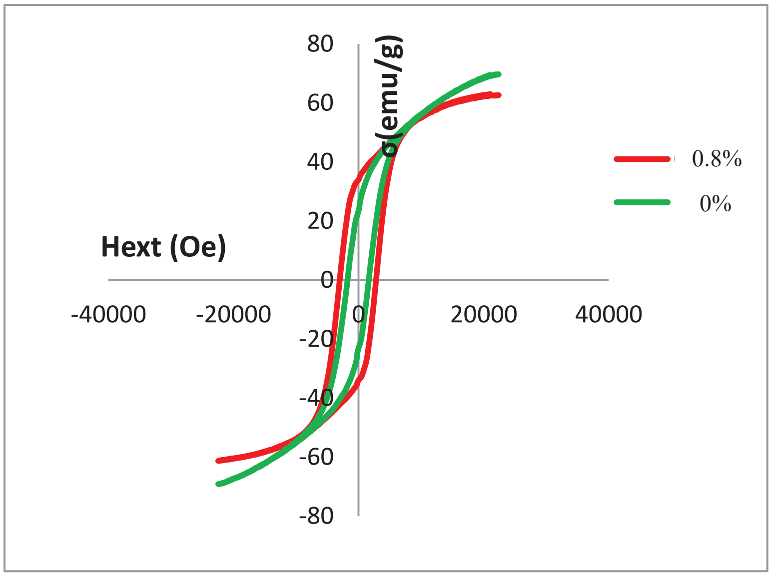

FIGURE 4. Hysterical Curve of samples with composition of 0 % Nd_2O_3 and 0.8% Nd_2O_3

According to the Fig. 4 the area of curve for sample with additive 0.8 wt. % Nd_2O_3 is slightly wider compared to area of sample of 0% Nd_2O_3. The fluctuation of magnetic flux density is due to possibility to the change of crystal size and lattice parameters on each sample. Other magnetic properties of both samples are depicted on the following table.

TABLE 4. Data of magnetic properties test results (VSM)

Additives Nd_2O_3	M_r (emu/g)	M_s (emu/g)	B_r (kG)	H_{cj} (kOe)	BH_{max} (MGOe)
0%	22.96	69.74	1.383	1.694	0.35715
0.8%	33.72	63.08	2.135	2.907	0.92695

From Table 4, it can be seen that Br value increased with addition of additive material of 0.8% Nd_2O_3 which has value from 1.383 kG to 2.135 kG, H_{cj} with value 1.694 kOe became 2.907 kOe, and the energy of the product was valued from 0.35715 MGOe to 0.92695 MGOe. The heights values of BH_{max} were obtained in the sample with the addition of 0.8% Nd_2O_3 additive.

CONCLUSION

Based on the above result, it can be summarized that the optimum sintering temperature to make a magnetic material $BaFe_{12}O_{19}$ was 1200°C found on the sample with additive material Nd_2O_3 of 0.8 %. In this condition, it was obtained some physical and magnetic properties as bulk density = 5.043 g/cm^3 and magnetic flux = 464.75 G. VSM test with addition of 0.1% Nd_2O_3 additive, which has properties: Br = 2.135 kG, H_{cj} = 2.907 kOe, BH_{max} = 0.92695 MGOe. Addition of Nd_2O_3 additive did not affect the crystal size of barium hexaferite, its crystal structure remained hexagonal. The temperature sintering effected on the increase of physical properties and magnetic properties of barium heksaferit ($BaFe_{12}O_{19}$).

ACKNOWLEDGEMENT

The authors gratefully acknowledge the Center of Physics Research of Indonesian Institute of Science (Pusat Penelitian Fisika-Lembaga Ilmu Pengetahuan-P2F LIPI) Kawasan Puspitek Serpong for using Vibrating Sample Magnetometer (VSM) and X-Ray Diffractometer.

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