



## Conference Paper

# Effect of Co-Ti Substitution on Magnetic Properties of Nanocrystalline $\text{BaFe}_{12}\text{O}_{19}$

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**Abstract** The synthesis of nanocrystalline  $\text{BaFe}_{12-2x}\text{Co}_x\text{Ti}_x\text{O}_{19}$  with variations of  $x$  ( $x = 0, 1, 2,$  and  $3$ ) have been investigated. The formation of polycrystalline samples that the cationic of  $\text{Co}^{2+}$  and  $\text{Ti}^{4+}$  in Co-Ti substituted Fe in  $\text{BaFe}_{12}\text{O}_{19}$  ferrites structure were prepared by solid state reaction method. The crystal structure, microstructure, and magnetic properties were characterized using powder X-ray diffraction, scanning electron microscope (SEM) and permagraph meter, respectively. The results show that the nanocrystalline  $\text{BaFe}_{12-2x}\text{Co}_x\text{Ti}_x\text{O}_{19}$  has single phase with polycrystalline structure, the grain size decrease by doping, the coercivity ( $H_c$ ) and saturation magnetization ( $M_s$ ) decrease with increasing Co-Ti substitutions.

**Keywords:** Nanocrystalline, polycrystalline,  $\text{BaFe}_{12}\text{O}_{19}$ , coercivity, Co-Ti substitution

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## 1. Introduction

Recently, investigations of barium ferrite  $\text{BaFe}_{12}\text{O}_{19}$  as hard magnetic material has been developed. The enhancement of magnetic properties such as saturated magnetization ( $M_s$ ), remanence ( $M_r$ ), and coercive force ( $H_c$ ) become major interest to be investigated. An effect of the various processes [1] and designing crystal structure of the barium ferrite to magnetic properties were investigated systematically [2-5]. In order to improve the magnetic properties, the nanocrystalline  $\text{BaFe}_{12}\text{O}_{19}$  ferrites has potential opportunity to be developed. As reported, the development of the barium ferrite compositions were substituted by Ba and (Sr) [6-8]. In order to understand the magnetic properties of  $\text{BaFe}_{12}\text{O}_{19}$ , the Fe was substituted by Al, Sn, NiSn, Ti, or Co [9-13]. Furthermore, the improvement of coercivity of  $\text{BaFe}_{12}\text{O}_{19}$  is needed to realize magnetic absorption materials such as microwave [14-16].

In this report, we have synthesized nanocrystalline  $\text{BaFe}_{12-2x}\text{Co}_x\text{Ti}_x\text{O}_{19}$  with  $x = 0, 1, 2, 3$ . The formations of polycrystalline samples that the cationic of  $\text{Co}^{2+}$  and  $\text{Ti}^{4+}$  in Co-Ti substituted Fe in  $\text{BaFe}_{12}\text{O}_{19}$  ferrite were prepared by solid state reaction method. The crystal structure, microstructure and magnetic properties of  $\text{BaFe}_{12-2x}\text{Co}_x\text{Ti}_x\text{O}_{19}$  will be discussed systematically.



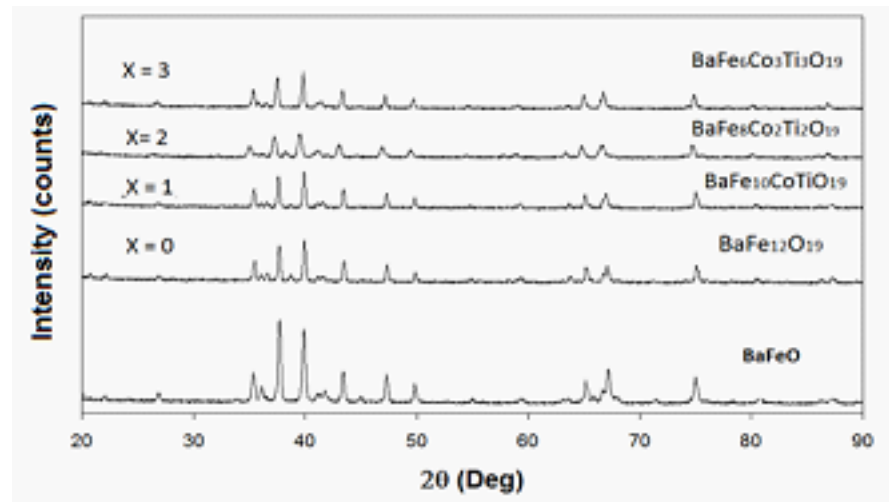


Figure 1: XRD patterns of  $\text{BaFe}_{12-2x}\text{Co}_x\text{Ti}_x\text{O}_{19}$  samples with  $x = 0, 1, 2, 3$ .

## 2. Experimental

Magnetic materials of the  $\text{BaFe}_{12-2x}\text{Co}_x\text{Ti}_x\text{O}_{19}$  samples with  $x = 0, 1, 2, 3$  were synthesized by ultrasonic mixing process from  $\text{BaCO}_3$ ,  $\text{Fe}_3\text{O}_4$  (from iron sand),  $\text{Co}_3\text{O}_4$ , and  $\text{TiO}_2$ . The compositions and the stoichiometry of samples were diluted in demineralized water. Then, the solution was calcinated at  $750^\circ\text{C}$  for 30 minutes and sintered at  $1100^\circ\text{C}$  for 3 hours. The formations of polycrystalline samples that the cationic of  $\text{Co}^{2+}$  and  $\text{Ti}^{4+}$  in Co-Ti substituted Fe in  $\text{BaFe}_{12}\text{O}_{19}$  ferrite by solid state reaction method have been obtained. The crystal structure of samples powders were investigated by X-ray diffraction (XRD) Phillips diffractometer. The morphology was examined by JEOL JSM 5310LV scanning electron microscope (SEM). The magnetic measurement was carried out by permagraph at room temperature.

## 3. Results and Discussion

The XRD pattern of the  $\text{BaFe}_{12-2x}\text{Co}_x\text{Ti}_x\text{O}_{19}$  ( $x=0, 1, 2, 3$ ) ferrites. The peaks of hematite ( $\text{BaFeO}$ ) coincide with magnetite/iron sand ( $x=0$ ). It's believed that magnetite from iron sand can be used for the barium ferrite. The peaks for the substituted barium ferrite ( $x=1, x=2$ , and  $x=3$ ) also coincide with non-substituted ferrite ( $x=0$ ). The results prove that formation of  $\text{BaFe}_{12-2x}\text{Co}_x\text{Ti}_x\text{O}_{19}$  ( $x=0, 1, 2, 3$ ) ferrites at  $1100^\circ\text{C}$  can be synthesized. It is  $100^\circ\text{C}$  lower than classical barium ferrite. In the substituted barium ferrite, the dopants of  $\text{Co}^{2+}$  and  $\text{Ti}^{4+}$  occupy the structure.

The XRD pattern of doped barium ferrite ( $x=1$ ) is shown in Figure 2. The refinement by *HighScore Plus Version 3.0e PANalytical software* indicates that the crystallite size is 50 nm. It's confirmed that the  $\text{BaFe}_{12-2x}\text{Co}_x\text{Ti}_x\text{O}_{19}$  has polycrystalline structure.

The Figure 3 indicates that the microstructure of doped barium ferrite has different grain size with undoped. The grain size decreases by increasing the doping, as result the nanocrystalline structure has formed.

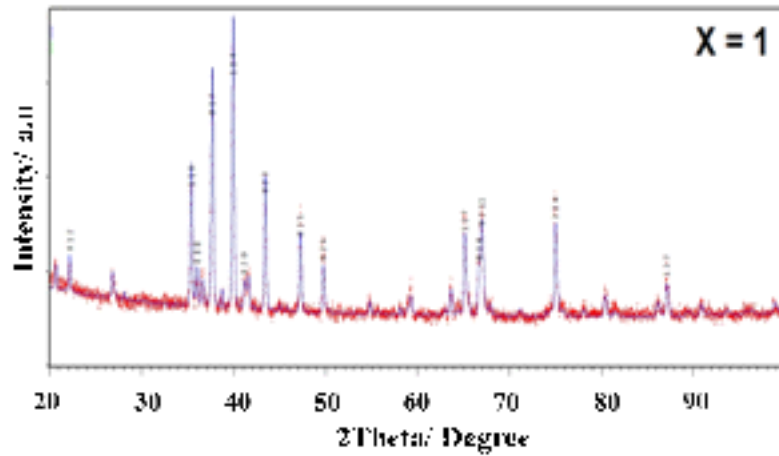


Figure 2: The refinement of XRD data of  $BaFe_{12-2x}Co_xTi_xO_{19}$  ( $x = 1$ ).

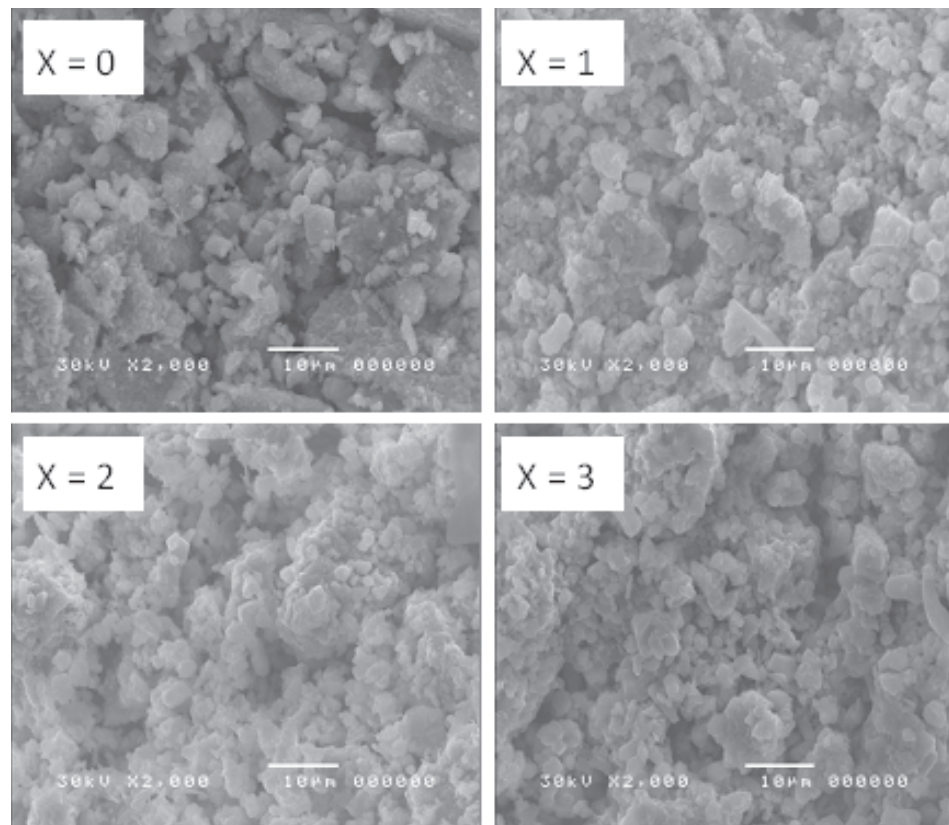
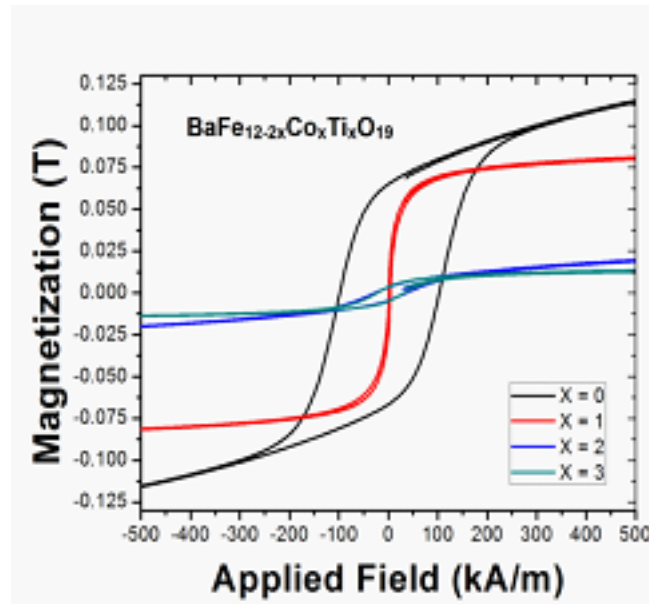


Figure 3: SEM photographs of  $BaFe_{12-2x}Co_xTi_xO_{19}$  samples with  $x = 0, 1, 2, 3$ .

Figure 4 shows the hysteresis loops of the magnetic behavior of the as-synthesized barium ferrite. Meanwhile, the table 1 is the datas for hysteresis loops of the barium ferrite as shown in Figure 4. As can be seen in the Figure 4, the undoped barium ferrite samples have larger coercive force ( $H_c$ ), area, and the higher remanent ( $M_r$ ) than doped barium ferrite. The coercive force of barium ferrite ( $x=0$ ) is about 85.06 kA/m. While, the doped barium ferrites rapidly decrease up to 0.939 kA/m at  $x=1$ . The reduction of the crystal anisotropy in  $x=1$  cause the weak uni-axial anisotropy along the  $c$ -axis of

Composition (x)	Mr (T)	Hc (kA/m)	Ms (T)	Mr/Ms (T)
0	0.045	85.060	0.124	0.365
1	0.020	0.939	0.084	0.234
2	0.004	24,028	0.024	0.159
3	0.005	23,987	0.015	0.372

TABLE 1: Data for hysteresis loops of the barium ferrite.

Figure 4: The room temperature hysteresis loops of  $\text{BaFe}_{12-2x}\text{Co}_x\text{Ti}_x\text{O}_{19}$  samples with  $x = 0, 1, 2, 3$ .

the doped barium ferrite. Substitution of Co-Ti decreases the coercive force of barium ferrite significantly. Further, Co-Ti increases the coercivity  $H_c = 24.028$  kA/m at  $x=2$  and  $H_c = 23,987$  kA/m at  $x=3$ . These results were predicted due to increasing the crystal anisotropy. Furthermore, the low coercivity explains that the doped barium ferrite is the soft magnetic material.

## 4. Conclusions

In conclusions, the  $\text{BaFe}_{12-2x}\text{Co}_x\text{Ti}_x\text{O}_{19}$  with  $x = 0, 1, 2, 3$  have been synthesized by ultrasonic mixing process. According to XRD measurement, the samples have formed polycrystalline structure and the crystallite size about 50 nm. Meanwhile, the magnetic properties i.e. coercivity ( $H_c$ ) and saturation magnetization ( $M_s$ ) decrease with increasing Co-Ti substitutions.

## 5. Acknowledgments

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## References

- [1] H. Sozeri, *J Alloys Compd*, **486**, 809–814, (2009).
- [2] U. Topal and H. I. Bakan, *J Eur Ceram Soc*, **30**, 3167–3171, (2010).
- [3] P. E. Garcia-Casillas, A. M. Beesley, D. Buenoc, J. A. Matutes-Aquino, and C. A. Martinez, Remanence properties of barium hexaferrite, *J Alloys Compd*, **369**, 185–189, (2004).
- [4] J. Dho, E. K. Lee, J. Y. Park, and N. H. Hur, *J Magn Magn Mater*, **285**, 164–168, (2005).
- [5] M. M. Rashad, M. Radwan, and M. M. Hessien, Effect of Fe/Ba mole ratios and surface-active agents on the formation and magnetic properties of co-precipitated barium hexaferrite, *J Alloys Compd*, **453**, 304–308, (2008).
- [6] U. Topala, H. Ozkanb, and H. Sozeri, *J Magn Magn Mater*, **284**, 416–422, (2004).
- [7] P. Kerschla, R. Gr. ossingerb, C. Kussbachb, R. Sato-Turtellib, K. H. M. Ullera, and L. Schultza, *J Magn Magn Mater*, **242–245**, 1468–1470, (2002).
- [8] K. S. Martirosyan, E. Galstyan, S. M. Hossain, Y.-J. Wang, and D. Litvinov, Barium hexaferrite nanoparticles: synthesis and magnetic properties, *Mater Sci Eng B*, **176**, 8–13, (2011).
- [9] P. Hernfindez, C. de Francisco, J. M. Mufioz, J. Ifiiguez, L. Torres, and M. Zazo, *J Magn Magn Mater*, **157/158**, 123–124, (1996).
- [10] V. N. Dhage, M. L. Mane, A. P. Keche, C.T. Birajdar, and K. M. Jadhav, *Physica B*, **406**, 789–793, (2011).
- [11] P. A. Marino-Castellanos, J. C. Somarriba-Jarque, and J. Anglada-Rivera, *Physica B*, **362**, 95–102, (2005).
- [12] A. Gonzalez-Angeles, G. Mendoza-Suarez, A. Gruskova, I. Toth, V. J. Warik, J. I. Escalante-Garca, and M. Papanova, *J Magn Magn Mater*, **270**, 77–83, (2004).
- [13] P. A. Marino-Castellanos, J. Anglada-Rivera, A. Cruz-Fuentes, and R. Lora-Serrano, *J Magn Magn Mater*, **280**, 214–220, (2004).
- [14] A. Gruskova, J. Slama, R. Dosoudil, D. Kevicka, V. Jancarik, and I. Toth, Influence of Co-Ti substitution on coercivity in Ba ferrites, *J Magn Magn Mater*, **242–245**, 423–425, (2002).
- [15] A. Ghasemia, A. Hossienpour, A. Morisako, A. Saatchi, and M. Salehi, *J Magn Magn Mater*, **302**, 429–435, (2006).
- [16] J. Qiu, H. Shen, and M. Gu, *Powder Technol*, **154**, 116–119, (2005).