The effect of shape toward characteristics of cerium-iron-boron thin layer

A Indriawati¹*, R Sari¹ and Sulanjari²

¹Departement of Physics, Universitas Bangka Belitung, Indonesia
²Department of Mechanical Engineering, Universitas Pamulang, Indonesia

*E-mail: anisaind.ind@gmail.com

Abstract. The development of spintronic devices in the magnetic memories industry has attracted researchers over decades. Therefore, researchers are trying to obtain materials which compatible to improve device performance. These materials are made in the form of thin layer. Cerium-iron-boron (Ce-Fe-B) alloy is one of potential materials to be applied for magnetic devices. In this study, the nucleation changes in the Ce-Fe-B thin layer were analyzed using circular and rectangular shapes. This phenomenon was observed through micromagnetic simulations. The magnetic moment stability of Ce-Fe-B was analyzed based on the response of the magnetic moment towards the presence of an external magnetic field. The magnitude of applied external magnetic applied is 0.4 Tesla in x-axis direction. Changes in the arrangement of magnetic moments due to external magnetic fields produce magnetization and anisotropy energy value which describing the characteristics of the Ce-Fe-B thin layer. Magnetization value of Ce-Fe-B thin film in circular shape was greater than rectangular shape. These value was 0.98 for circular shape and 0.93 for rectangular shape. On the other hand, anisotropy energy value on magnetic external applied 400 mT, circular shape anisotropy energy’s value of Ce-Fe-B was $4.85 \times 10^{-18}$ J, and $6.71 \times 10^{-18}$ J for rectangular shape.

1. Introduction

Bangka Belitung Island is one of the areas with a fairly abundant distribution of monazite minerals. Monazine is a mineral that contains rare earth elements. In monazite, cerium is one of the rare earth elements with fairly high content compared to other elements, with a percentage of 33.14% [1]. Cerium can be purified from other Rare Earth Metals with concentration above of 98% [2]. As candidate of magnetic materials, cerium can be combined with iron and boron (Ce-Fe-B). Ferromagnetic materials play an important role in various fields as spintronic-based data storage devices [3] in the magnetic recording industry. In data storage devices, magnetic materials are usually made with the form of thin layer.

Ce-Fe-B is one of the magnetic material’s candidate which has recently begun to be widely studied. The simulation of ground satate conditions in the absence of an external magnetic field on CeFeB has been investigated in the form of nanodisk with configurations of thermal demagnetization, vortex, x-direction, and z-directions [4]. The next research related to the analysis of the magnetic properties of CeFeB is micromagnetic simulation on a thin layer of CeFeB where CeFeB has been saturated in 400 mT magnetic field [5].
In this research, a micromagnetic simulation will be carried out using Object Oriented Micromagnetic Framework (OOMMF) software on CeFeB thin layer. The size of the cross-sectional area of the thin layer is 61.600 nm$^2$ and a thickness is 10 nm. The simulated of cross-sectional shapes are rectangle and circular, so that each will form a thin beam and a thin cylinder of nano order. This is done because differences in shapes can affect the ease and difficulty of magnetic moment’s saturation. Furthermore, the illustration of magnetic moment’s phenomenon movement due to the presence of an external magnetic field is shown through the saturation pattern on the curve. Anisotropy energy also changes with the passage of the external magnetic field.

2. Method
The research was conducted using Object Oriented Micromagnetic Framework (OOMMF) software which is a numerical solution of the Landau Lifshitz Golbert equation [6,7].

\[
\frac{dM}{dt} = -\gamma \times H_{\text{eff}} + \frac{\alpha}{M} \times \frac{dM}{dt}
\]

\[
H_{\text{eff}} = -\frac{2A}{\mu_0 M_s^2} \nabla^2 M - H_d + \frac{2K_1}{\mu_0 M_s^2} (M \cdot u) u
\]

Parameter values inputted in the OOMMF software [8] are shown in Table 1.

| Parameters          | Parameter’s value |
|---------------------|-------------------|
| Saturation Magnetization (Ms) | $9.3 \times 10^5$ A/m |
| Exchange Constant (A)       | 5 pJ/m            |
| Anisotropy Constant (K)     | $5 \times 10^5$ J/m |
| Damping Constant ($\alpha$)  | 0.05              |

Illustration of the initial conditions of the CeFeB thin layer is shown in Figure 1. Both forms have a volume of 616.000 nm$^3$. Magnitude of external magnetic field gives is 400 mT in the x-axis.

3. Result and Discussion
Figure 2 showed the results of plotting the relationship curve between the external magnetic field and the magnetization value. The magnetic moment in a thin layer with circular shape has a greater magnetization value than rectangle when external magnetic field was 400 mT. Magnetization process of two shapes has the same pattern. At an external magnetic field of 400 mT, the magnetization value in the circular shape was 0.98, while in the rectangular shape was 0.97.

At an external magnetic field of 0 mT to 300 mT, magnetization process of CeFeB with circular shape was more difficult than rectangular. At the initial conditions, the resultant of magnetic moment in the x-direction in a square shape was suspected greater than circular shape. Above a magnetic field of 300 mT, the resultant magnetic moment in the x-direction in circular shape was greater than in square shape. This was because the polarization process only occurs at the edges.
Figure 1. Initial state of the CeFeB thin layer in the shape of a (a) circular and (b) rectangle.

Condition of the magnetic moment in the CeFeB thin layer for circular and rectangular shapes is shown in Figure 3. CeFeB in Figure 3 was the condition of the magnetic moment in a magnetic field of 300 mT. According figure 3, the blue areas still appear which indicates the magnetic moment in the thin layer has not been completely saturated. In circular shape, there are more blue areas than rectangular shape. This is in accordance with the plotting curve in Figure 2 which showed that the magnetization value of the CeFeB thin film with circular shape is higher than that of the rectangular shape at magnetic fields above 300 mT.
At a 400 mT magnetic field, the blue region of the CeFeB thin film with rectangular shape is wider than that of circular shape. However, a slight blue area still remains in the circular shape indicating that a magnetic field greater than 400 mT is required to magnetize the entire magnetic moment. Based on research a thin layer of CeFeB in a rectangular shape with an area of 100.000 nm$^2$, a thickness of 10 nm and K=0, is perfectly magnetized, when the applied magnetic field is 400 mT [5]. In this study, the high anisotropy constant results in the need for a high external magnetic field to magnetize all magnetic moments.

Figure 3. Magnetic moment on a CeFeB thin layer with (a) circular shape and (b) rectangular shape, at a thickness of 10 nm.

Figure 4. The condition of the magnetic moment of the Ce-Fe-B thin film in a 400 mT magnetic field with (a) circular shape and (b) rectangular shape.

The curve of the relationship between the external magnetic field and the anisotropy energy is shown in Figure 5. Magnetic anisotropy plays a role in changes in the formation of the magnetic moment in the material [9]. The magnitude of the anisotropy constant results in an insignificant decrease in the anisotropic energy. The decrease in anisotropic energy occurs slowly, where the maximum value of anisotropic energy occurs at the initial conditions. In this condition, the magnetic moment is not isotropic and random. Level of anisotropy was very high and decreases with the magnetization process. The anisotropic energy’s value in an external magnetic field of 400 mT are 6.71×10$^{-18}$ J in a square shape and 4.85×10$^{-18}$ J in a circular shape. These values indicate that in a 400 mT magnetic field, the magnetic moment in the CeFeB thin layer
in circular shape is more isotropic than square shape. However, experimental data showed that parameters was effected by some factors include temperatures, thickness, and concentration’s alloy [10]. The nucleation and shift of the domain wall in the form of a CeFeB thin layer will be a reference in studying the magnetic properties of rare earth-based materials [11].

**4. Conclusion**

Changes in the arrangement of magnetic moments due to external magnetic fields produce magnetization and anisotropy energy value which describing the characteristics of the Ce-FeB thin layer. Magnetization value of CeFeB thin film in circular shape was greater than rectangular shape. These value was 0.98 for circular shape and 0.93 for rectangular shape. Both of rectangular and circular shape have the same trend of anisotropy energy’s curve and magnetization value’s curve. Anisotropy energy value on circular shape of CeFeB and for rectangular shape was $4.85 \times 10^{-18}$ J and $6.71 \times 10^{-18}$ J when the external magnetic field was applied 400 mT. When external magnetic field was 400 mT magnetic moments in the CeFeB on both circular and rectangular shapes wasn’t totally saturated. It was caused by anisotropy constant value which is great enough.

**References**

[1] Fabiani V A and Nurhadini 2017 Universitas Bangka Belitung, Conference Paper at SNPPM 1.

[2] Renata D, Abreu, Charles A, Morlais 2010 Minerals Engineering. 23

[3] Indriawati A 2018 *J.Flux.* 14 2

[4] Liu D, Li G, Zhao X, Xiong JF, Hu X, Sun R, and Shen B G 2017 *AIP Advances.* 8 5

[5] Indriawati A, Aldila H, Kurniawan W B, Tiandho Y, Afriani F, Fabiani V A, 2019 *International Conference on Maritim and Archipelago.* 167

[6] Landau L D and Lifshitz E M 1935 *Phys. Z. Sowjetunion.* 8 153

[7] Gilbert T L 1955 *Phys. Rev.* 100 1243

[8] Herbst J F 1991 *Rev. Mod. Phys.* 63, 819

[9] Fattouhi M, El Hafidi MY, El Hafidi M, 2020, *Journal of Magnetism and Magnetic Materials.* 45

[10] Nagosa N and Tokura Y 2008 *Nat. Nanotech.* 8 899

[11] Shulan Z, Ming Z, Rui L, Ying Z, Licong P, Jiefu X, Dan L, Tongyun Z, Baogen S, Fengxia H, Jirong S 2017 *Acta Materialia.* 17

![Figure 5](image_url)  
*Figure 5. Graph of the relationship between anisotropy energy and the magnitude of the external magnetic field applied to a thin layer of Ce-Fe-B with $K=5 \times 10^5$ J/m$^3$.**
Acknowledgments
I would like to thank the Faculty of Engineering which has played a role in financing this international seminar through the distribution of RKAKL funds.