SPEKTRA: Jurnal Fisika dan Aplikasinya
Volume 5, Issue 2, August 2020
Homepage: doi.org/10.21009/SPEKTRA

DOI: doi.org/10.21009/SPEKTRA.052.01

THE EFFECT OF COBALT CONTENT ON MAGNETIC PROPERTIES OF CoFe ALLOYS

Widia Nursiyanto[1,*], L. Rohman[2], M. Alfatun N.[2], E. Purwandari[2]

[1]*Program Studi Teknik Mesin , Universitas Pancasila, Srengseng Sawah, Jagakarsa, Jakarta 12640, Indonesia*
[2]*Jurusan Fisika, FMIPA, Universitas Jember Jln. Kalimantan 37, Jember, Indonesia*

*Corresponding Author Email: widianursiyanto@gmail.com

Received: 8 May 2020
Revised: 31 July 2020
Accepted: 5 August 2020
Online: 30 August 2020
Published: 31 August 2020

SPEKTRA: Jurnal Fisika dan Aplikasinya
p-ISSN: 2541-3384
e-ISSN: 2541-3392

ABSTRACT

Hard Disk Drive (HDD) as a data storage device when operated with high temperatures (around 66^{o}C), its function will be constrained. The CoFe alloys have a large coercivity field and can be patterned in very small sizes that are suitable for HDD devices. In this study, Co_{1-x} Fe_x cube alloy was used (x = 0.25; 0.30; 0.50; 0.75). Samples were treated with temperature changes to get the Curie temperature. The coercivity field value is obtained by giving the external field and temperature below Curie temperature and also above Curie temperature to the samples. The VAMPIRE software is a micromagnetic simulation program based on atomistic models. The results showed that Curie's temperature decreased when Co content increased. The composition of $Co_{0.25}$ $Fe_{0.75}$ has the highest Curie temperature that is equal to 1075 K. The temperature Curie is not affected by the size of the cube. When the sample is given a temperature rise below the Curie temperature, the value of the coercivity field decreases. The value of the coercivity field is very difficult to determine when the temperature used is above the Curie temperature. The percentage of composition does not affect the coercivity field value. Therefore, cube-shaped CoFe material is very suitable for use as a material data storage device operated at temperatures below the Curie.

Keywords: CoFe alloy, Currie temperature, hysteresis curve, coercivity field

INTRODUCTION

Hard disk drive (HDD) magnetic recording media has problems in their use related to the physical characteristics of materials, such as high-temperature resistance and the occurrence of unstable data stored conditions due to super-paramagnetic effects. Super-paramagnetic effects are properties that appear on nano-sized materials and one-order magnetic domains, so the particles will be very reactive to external magnetic fields [1]. However, if the external magnetic field is slowly removed, the properties will be similar to paramagnetic material. If the temperature rises in a state of decreased magnetization energy, there will be a process of demagnetization and a change in the orientation of the magnetization [2]. This results in unstable data stored information, and the worst possible damage will occur.

HDD temperature conditions when the computer starts up between 30 - 50^{o}C, whereas when it starts processing data, the HDD temperature reaches 50 - 58^{o}C. When the HDD works continuously, the temperature will reach a maximum called the overheat temperature, which is around 66^{o}C [3,4]. If the HDD always works at overheat temperatures or even exceeds it, it can make the HDD work slower, and the worst possibility will shorten the HDD's life due to permanent damage.

To make magnetic recording media that is resistant to heat, ferromagnetic material that has a high Curie temperature and high anisotropic magnetic material needs to be chosen. Materials that are suitable and have the potential to be applied as magnetic recording media are ferromagnetic magnetic materials. Curie temperature values are obtained from the relationship between magnetization and susceptibility to temperature. The hysteresis curve is obtained from the relationship between magnetization and external fields. CoFe alloys material that has a high Curie temperature value, a coercivity field, and a good saturation field is a material that can be used as a basic material for making a good HDD. Due to variations in temperature input and the influence of the critical size. So based on the Curie temperature value and hysteresis curve characteristics, it can be used to choose component HDD that can be decreased from the problem of high-temperature resistance [5,6].

The CoFe alloys are one example of ferromagnetic alloys suitable for HDD materials that can improve the magnetic properties of materials with varying degrees of quality. Each of these quality levels differs in their composition and heating treatment to obtain the properties of ferromagnetic materials that are appropriate to their needs or use. The magnetic material of the CoFe alloy is an important hard magnet because it has unique magnetic properties, including high magnetization saturation, high permeability, high coercivity, and good thermal stability [7,8]. The Curie temperature value is influenced by the percentage composition of the CoFe alloy. To gain an understanding of the macroscopic properties of CoFe magnetic materials such as anisotropic surfaces, spin dynamics, and microstructural effects, it can be done with a Vampire micromagnetic simulation program, an open-source software that uses atomic modeling based on the classic Hamiltonian spin and the Landau-Lifshitz-Gilbert (LLG) equation. [9,10].

METHOD

This research was conducted with a simulation method, using VAMPIRE public domain software that can determine magnetic properties such as curie temperature and hysteresis curves. Atomic modeling is based on the spin of neighboring atoms following the Heisenberg exchange, so that the energy from the system is obtained Hamiltonian as follows:

$$H = -\frac{1}{2}\sum_{(i,j)} J_{ij} S_i . S_j - \sum_{i=1}^{N} D_i (S_i . n_i)^2 - \sum_{i=1}^{N} \mu_i B . S_i \qquad (1)$$

Where :

J_{ij} : energy exchange between spin i and j

S_i : normal vector $|S_i| = 1$

D_i : uniaxial constant (assumed along z)

n_i : anisotropy vector direction

μ_i : magnetic moment on i

B : vector of the magnetic field

N : total number of spins

To get the dynamics of magnetization used the Landau-Lifshitz-Gilbert (LLG) equation with the Langevin dynamics as follows:

$$\frac{dS_i}{dt} = -\frac{\gamma_i}{(1+\lambda_i^2)\mu_i}\left(S_i \; x \; H_i^{eff} + \lambda_i S_i \; x \left[S_i \; x \; H_i^{eff}\right]\right) \qquad (2)$$

Where :

λ_i : Gilbert damping parameters

γ_i : gyromagnetic ratio

H_i^{eff} : effective magnetic field

The magnitude of the effective field is obtained by the equation:

$$H_i^{eff} = -\frac{1}{\mu_i}\frac{\partial H}{\partial S_i} \qquad (3)$$

Where : μ_s is local spin moment

The ferromagnetic material $Co_{1-x}Fe_x$ (x = 0.25; 0.30; 0.50; 0.75) used in the form of cubes has cubic side size variations of 5 nm, 10 nm, 15 nm, and 20 nm as shown in FIGURE 1.

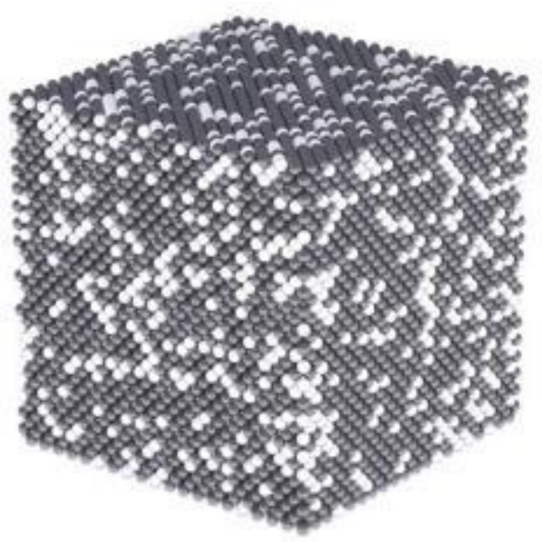

FIGURE 1. The geometry of $Co_{1-x}Fe_x$ ferromagnetic material.

The stages of this research are as follows:

Simulation to determine the Curie temperature by making a curve between magnetization and temperature. The amount of temperature input is from 0 K to 1500 K with a range of 25 K. Curie temperature display, as shown in FIGURE 2.

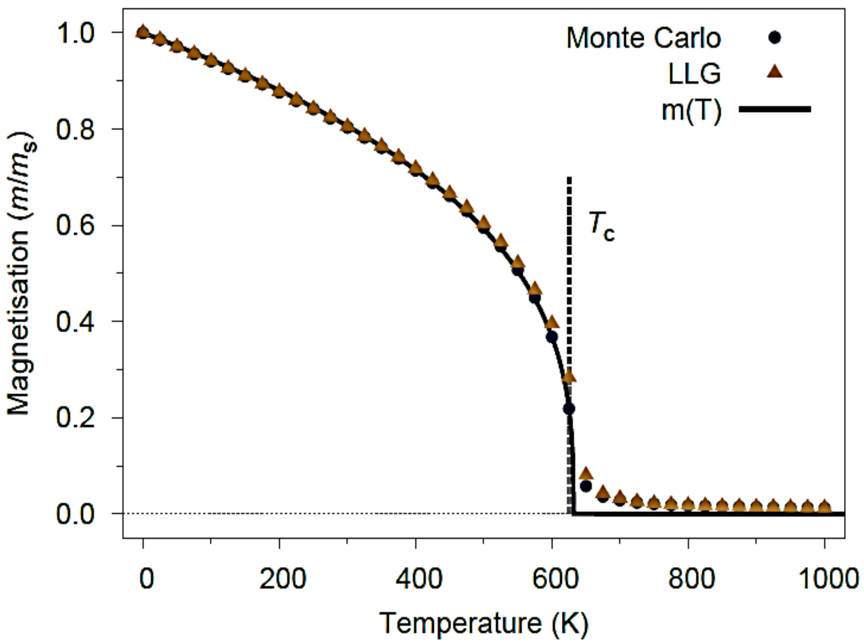

FIGURE 2. Curie's temperature curve for ferromagnetic material [11].

Simulations for making hysteresis curves were carried out for each composition, side size of the cube, and temperature variations below the Curie temperature, namely 0 K, 300 K, 328 K, 373 K, and temperatures above the Curie temperature. The magnitude of the external field given starts from - 6 to 6 T with a stage of field change of 0.1 T. The hysterical curve display, as shown in FIGURE 3.

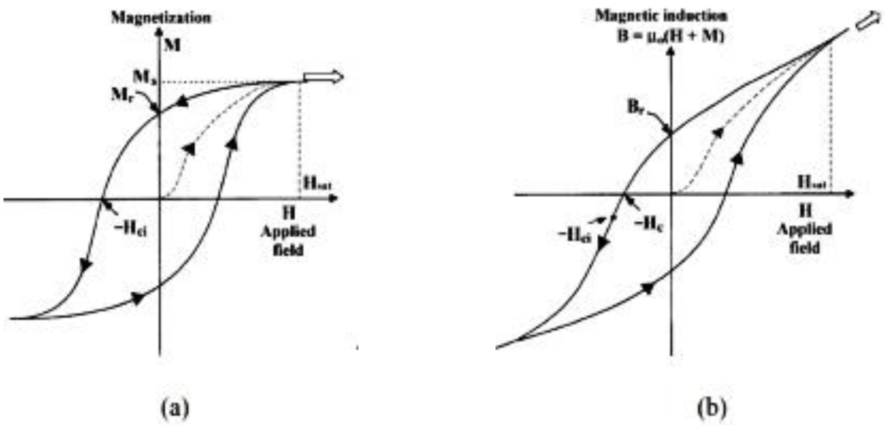

FIGURE 3. Hysteresis curves for the ferromagnetic material. (a) M with respect to H: Mr is remanent magnetization; Hci is intrinsic coercivity; Ms is saturation magnetization; (b) B with respect to H: Br is remanent; Hc is coercivity [12].

RESULT AND DISCUSSION

Based on the simulation results obtained by the magnetization relationship curve to the temperature, which shows the Curie temperature. FIGURE 4 shows the Curie temperature values of the CoFe material with variations in composition at 5 nm in size.

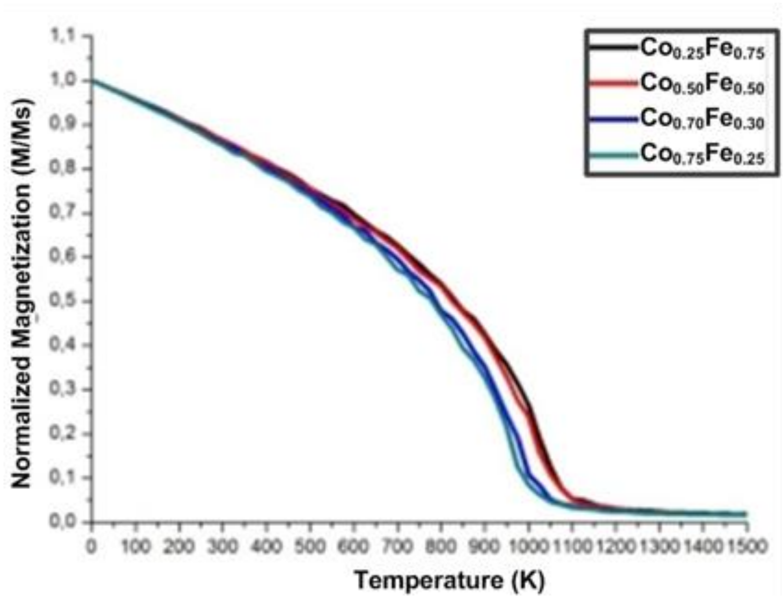

FIGURE 4. The curie temperature curves of CoFe material with variations in composition at 5 nm in size.

The curve of the relationship of composition variation to the Curie temperature for the 5 nm cube side is shown in FIGURE 5.

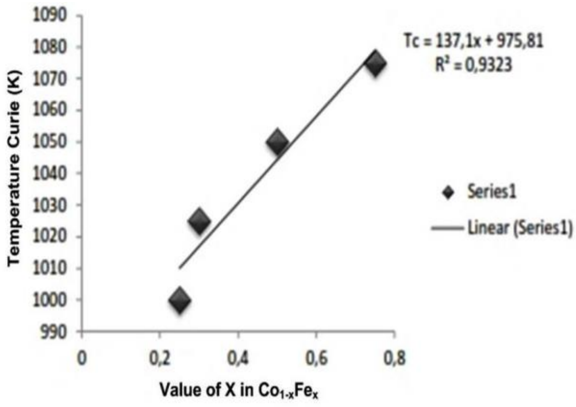

FIGURE 5. Graph of the relationship of variations in the composition of $Co_{1-x}Fe_x$ to Curie temperature.

FIGURE 5 can be determined the linear function of the variation of the composition of the size of 5 nm with the Curie temperature that follows the equation TC = 137.10 x + 975.81(the result from linear regression equation). Curie temperature curves with variations in the size of the side cubes of Co_{1-X} Fe_X material were done with variations in the composition of values x = 0.25, 0.3, 0.5, and 0.7 can be seen in FIGURE 6.

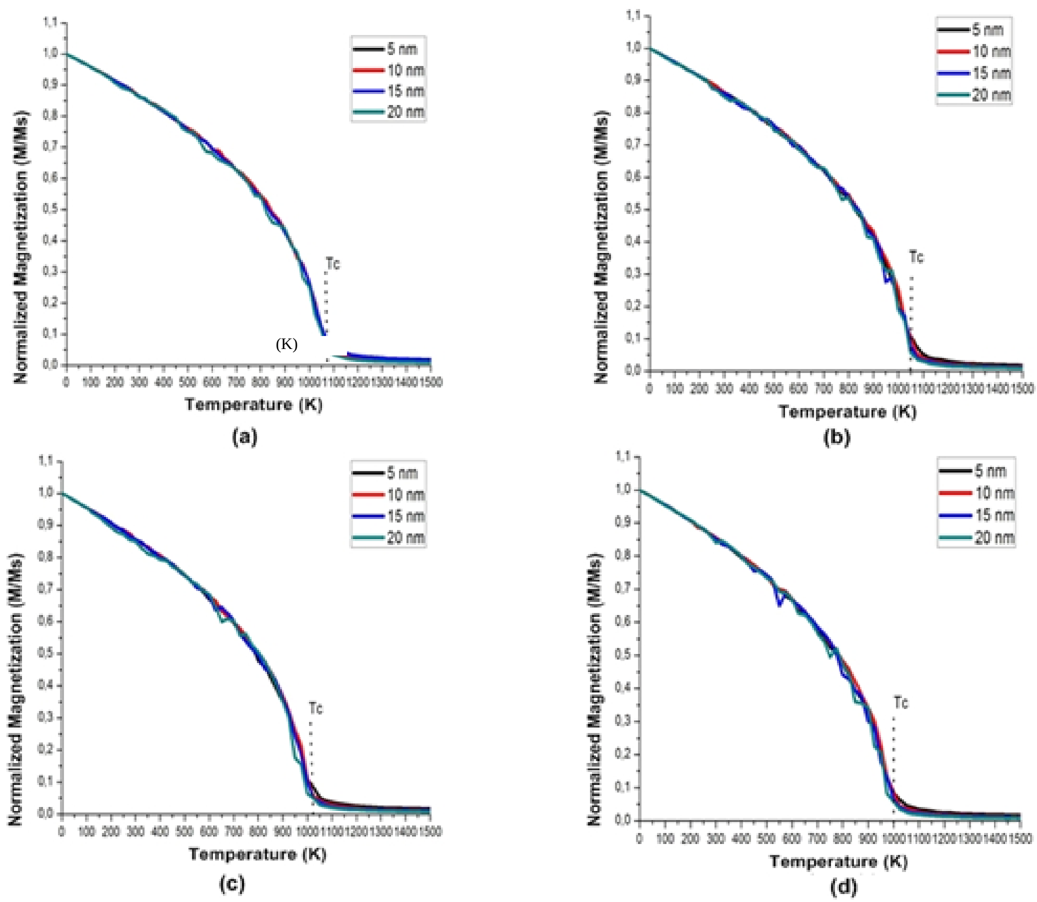

FIGURE 6. Curie temperature curves with varying cube side sizes a) $Co_{0.25}$ $Fe_{0.75}$, b) $Co_{0.5}$ $Fe_{0.5}$, c) $Co_{0.70}$ $Fe_{0.30}$, d) $Co_{0.75}$ $Fe_{0.25}$.

FIGURE 6 can be made a Curie temperature table with various variations in the size of the side of the cube, as shown in TABLE 1.

TABLE 1. Curie Co_{1-x} Fe_x Alloy temperature values

No	Co_{1-x} Fe_x alloy	T_C (K)			
		5 nm	10 nm	15 nm	20 nm
1	$Co_{0.25}$ $Fe_{0.75}$	1075	1075	1075	1075
2	$Co_{0.50}$ $Fe_{0.50}$	1050	1050	1050	1050
3	$Co_{0.70}$ $Fe_{0.30}$	1025	1025	1025	1025
4	$Co_{0.75}$ $Fe_{0.25}$	1000	1000	1000	1000

From TABLE 1 it is seen that Curie's temperature decreases with increasing Co content, but the size of the side of the cubes does not affect Curie's temperature. This shows that the Co_{1-x} Fe_x alloy material has magnetic properties that are relatively stable.

Hysteresis curves of CoFe material with variations in composition when given a temperature of 300 K can be seen in FIGURE 7.

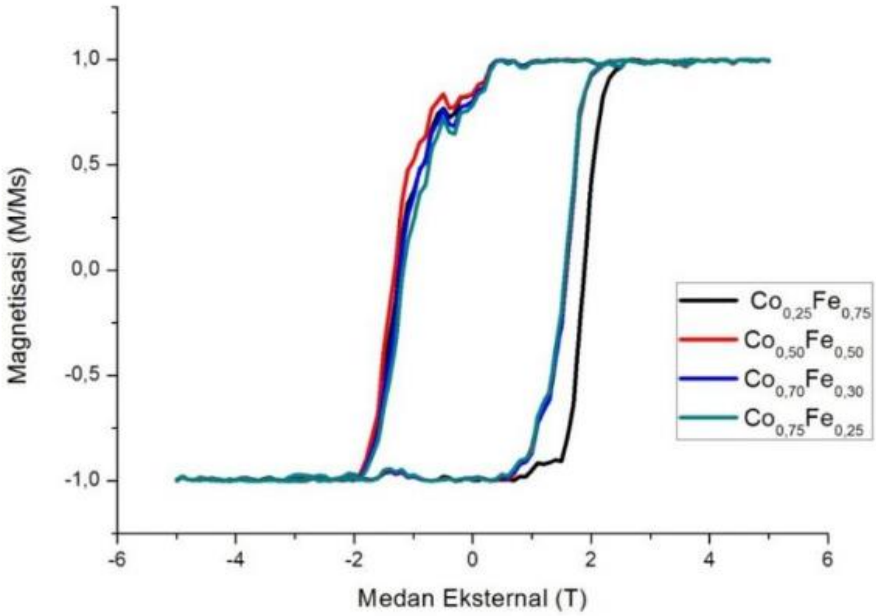

FIGURE 7. Hysteresis curves of CoFe material with variations in composition at 300 K.

Hysteresis curves with temperature variations below the Tc value for variations in the composition of Co_{1-x} Fe_x can be seen in FIGURE 8.

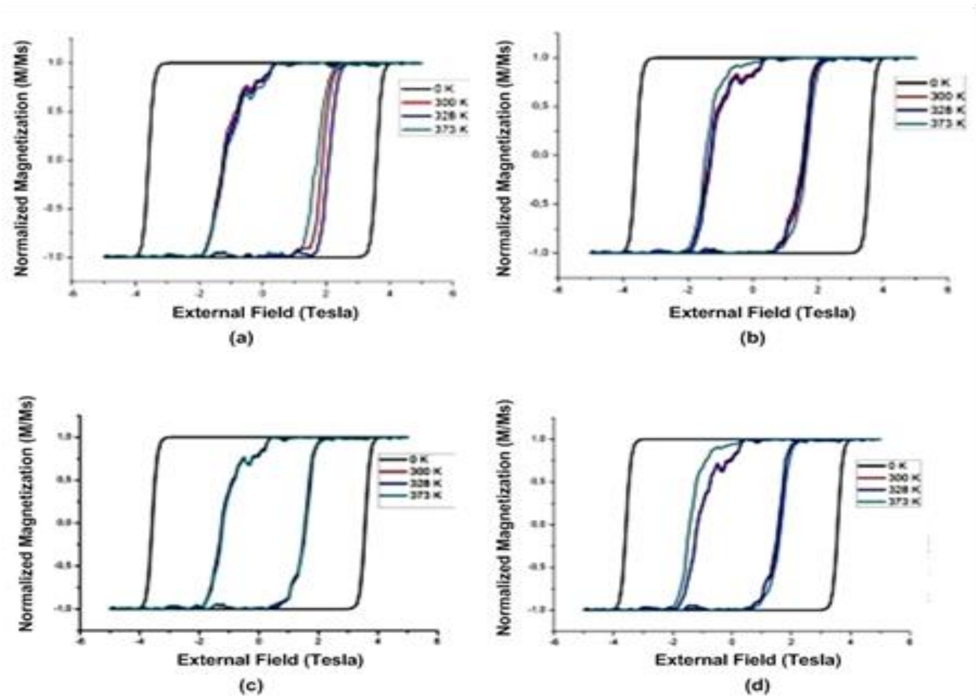

FIGURE 8. Hysteresis curves with temperature variations below the Tc value for a) $Co_{0.25}Fe_{0.75}$, b) $Co_{0.5}Fe_{0.5}$, c) $Co_{0.70}Fe_{0.30}$, d) $Co_{0.75}Fe_{0.25}$.

Hysteresis curves with temperature variations above the Tc value for variations in the composition of $Co_{1-x}Fe_x$ can be seen in FIGURE 9.

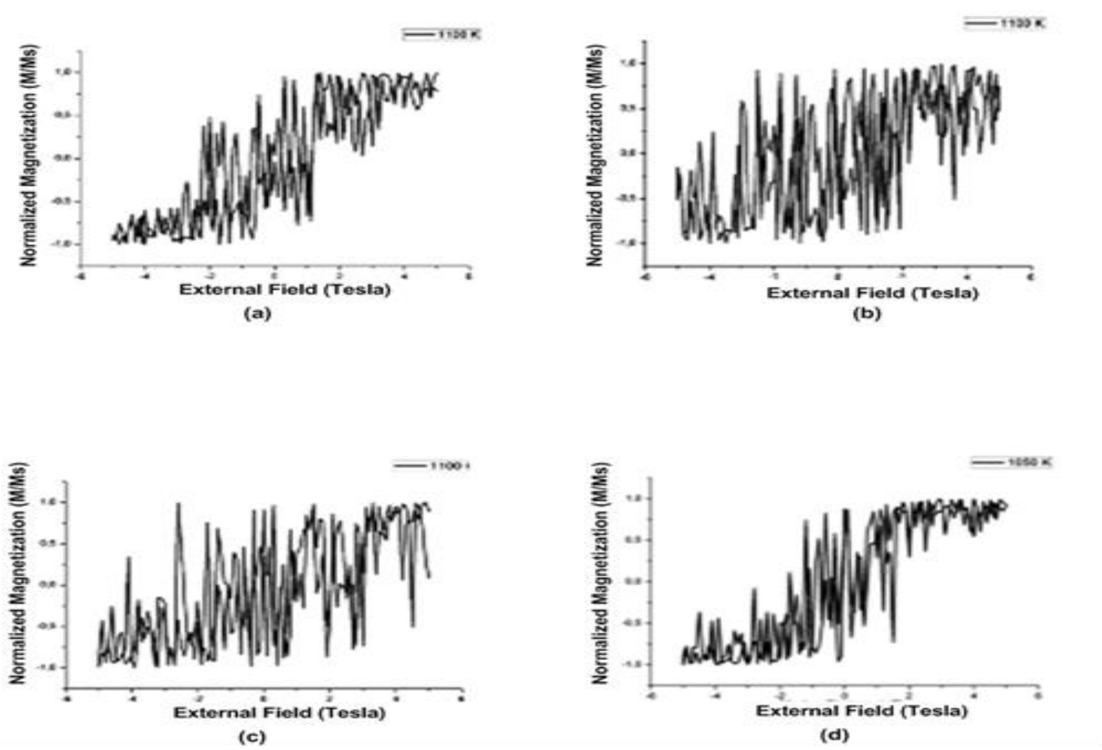

FIGURE 9. Hysteresis curves with temperature variations above the Tc value for a) $Co_{0.25}Fe_{0.75}$, b) $Co_{0.5}Fe_{0.5}$, c) $Co_{0.70}Fe_{0.30}$, d) $Co_{0.75}Fe_{0.25}$.

From FIGURE 8 and 9 can be made of $Co_{1-x}Fe_x$ Alloy coercivity field values table, as shown in TABLE 2.

TABLE 2. The $Co_{1-x}Fe_x$ Alloy coercivity field value.

Temperature (K)	**Coercivity Field Value (T)**			
	$Co_{0.25}Fe_{0.75}$	$Co_{0.25}Fe_{0.75}$	$Co_{0.25}Fe_{0.75}$	$Co_{0.25}Fe_{0.75}$
0	3.6	3.6	3.5	3.6
300	1.9	1.6	1.6	1.6
328	2.0	1.5	1.5	1.4
373	1.7	1.5	1.4	1.4
$T > T_C$	-	-	-	-

The increase in temperature of the magnetic material shows that it can reduce the coercivity field of the material. This is due to the transition from the ferromagnetic phase to the paramagnetic phase in the CoFe material. Because the value of the coercivity field is above 10 kA/m (0.0125 T), the CoFe material can be classified as hard magnets. The greater the coercivity field value, the magnetic properties of material will be stronger. Co composition 25% and Fe 75% has the highest average field coercivity value compared to other compositions.

CONCLUSION

The $Co_{1-x}Fe_x$ material has stable magnetizing properties, although the Curie's temperature decreases with increasing Co content, the size of the side of the cube does not affect the Curie's temperature. Changes in temperature result in a decrease in the coercivity field value of the material, but when there is a change in temperature above the overheat temperature (66^o C or 339 K), $Co_{1-x}Fe_x$ material still has a coercivity field value above 10 kA /m (0.0125 T). It can be concluded that the cube-shaped $Co_{1-x}Fe_x$ material can be used as a data storage device for operations below the Curie temperature.

REFERENCES

[1] W. N. Santi *et al.*, "Kajian Sifat Kemagnetan pada Nanopartikel Cobalt Ferrite (CoFe2O4) yang dicoating dengan Polyethylene Glykol (PEG-4000) dan Silika," Jurnal Fisika Indonesia, 2014, vol. 18.

[2] M. Pauzan *et al.*, "Pengaruh ukuran butir dan struktur kristal terhadap sifat kemagnetan pada nanopartikel magnetit (Fe3O4)," Prosiding Pertemuan Ilmiah XXVII HFI Jateng & DIY, 2013.

[3] B. E. Purnama *et al.*, "Rancang Bangun Alat Kontrol Otomatis Pendingin Komputer Berbasis Mikrokontroler ATMEGA8L," IJNS-Indonesian Journal on Networking and Security, 2013, vol. 2.

[4] T. D. Sugiarto, R. F. Iskandar and I.P. Handayani, "Simulation of Temperature Distribution in Horizontal Fin Heat Sink CPU Processor Using Comsol Multiphysics and Proportional Control," Journal of Measurements, Electronics, Communications, and Systems, 2015, vol. 1.

[5] N. Aiga, "Simulasi Mikromagnetik Sifat-Sifat Material Co0.8Ni0.2 Random Alloy Berbagai Variasi Ukuran Partikel," Repository Universitas Jember, 2018.

[6] W. Nursiyanto and L. Rohman, "Analisis Diameter Kritis dan Suhu Curie Bahan Parmalloy FeCoB Berbentuk Bola-Nano serta Pengaruh Temperatur (Heat Assisted) dengan Menggunakan Program Simulasi Mikromagnetik NMAG dan Vampire," Spektra: Jurnal Fisika dan Aplikasinya, 2017.

[7] M. D. C. Agguire *et al.*, "Co1.00-x Fex magnetic thick films prepared by electrodeposition," Journal of Alloys and Compounds, 2015.

[8] I. Wahyudi, "Suseptibilitas Magnetik dan Temperatur Curie Material Alloy Feromagnetik Co1-xNix Model Nanotube dan Nanosphere," Repository Universitas Jember, 2018.

[9] Evans, F.L dan Biternas, A., "Vampire User Manual : Software Version 4.0.,"Heslington: The University of York, 2014. R. F. L. Evans and A. Biternas, "Vampire User Manual: Software Version 4.0," New York: The University of New York, 2014.

[10] P. Ho *et al.*, "Atomistic Modeling of the Interlayer Coupling Behavior in Perpendicularly Magnetized L10-FePt/Ag/L10-FePt Pseudo Spin Valves," IEEE transactions on magnetics, 2011.

[11] R. F. L. Evans *et al.*, "Atomistic spin model simulations of magnetic nanomaterials," J. Phys.: Condens. Matter, 2014, vol. 26.

[12] A. T. Widodo, "Studi Mikromagnetik Dinamika Struktur Domain Pada Material Feromagnetik Py, Ni, Fe Dan Co Model Nanosphere," Depok: Universitas Indonesia, 2013.