Computational and Experimental Research in Materials and Renewable Energy (CERiMRE)
Volume 4, Issue 2, page 102-109
eISSN : 2747-173X

Submitted : August 25, 2021
Accepted : October 29, 2021
Online : November 24, 2021
DOI : 10.19184/cerimre.v4i2.28377

The Effect of Arrive Angle of External Magnetic Field on The Shape of Hysterisis Curve Permalloy $Ni_{80}Fe_{20}$ By Simulations

Merinda Lestari[1], Widia Nursiyanto[2,a], and Agung Tjahjo Nugroho[1]

[1]Department of Physics, FMIPA, University of Jember, Jember, Indonesia

[2]Program Studi Teknik Mesin, Universitas Pancasila, Srengseng Sawah, Jagakarsa, Jakarta 12640, Indonesia

[a]widianursiyanto@gmail.com

Abstract. One of the developments of magnetic materials is found in hard disk applications, MRAM and storage media sensors. Storage media sensors that are currently being developed are magnetic sensors. Magnetic sensor is a type of sensor that utilizes changes in resistance caused by changes in the magnetic field H or B. One of the suitable magnetic materials to be used as a study material for making magnetic sensors is permalloy $Ni_{80}Fe_{20}$. The reading error of the magnetic sensor of the $Ni_{80}Fe_{20}$ permalloy material affects the results of the hysteresis curve of the material and requires correction of the angle of incidence of the external magnetic field in order to provide accurate results on the storage media. Research on the effect of the angle of incidence of the external magnetic field (H) on the hysteresis curve was carried out on an application based on Finite Difference OOMMF. The research was conducted by reviewing the parameter literature of the $Ni_{80}Fe_{20}$ permalloy material and then compiling it in a script and simulating it on an application based on Finite Difference OOMMF. The data obtained from the simulation are normalized magnetization (m), external magnetic field (H) and coercivity field (Hc) which have been influenced by the angle of incidence. The results of the hysteresis curve at a size of 5 nm with a variation of the angle of incidence 0^o are indicated by the value of the external magnetic field (H) of 10000 mT to -10000 mT with a coercive field (Hc) of 5000 mT to -5000 mT. The normalized magnetization value (m) is 1 to -1. The variation of the angle of incidence of 30^o produces a coercive field (Hc) of -108.3 mT to 108.3 mT and a normalized magnetization of 0.86 to -0.86. The 45^o incident angle variation produces a coercive field (Hc) -88.4 mT to 88.4 mT and a normalized magnetization of -0.7 to 0.7.

Keywords: Hysteresis Curve, Angle of Arrival Variation, OOMMF, $Ni_{80}Fe_{20}$

Introduction

Magnetic sensors are magnetic memory cells that are used to read data head recording systems on various storage media, one example of which is MRAM (Magnetoresistive Random Access Memory). Magnetic sensor design errors in MRAM which refer to the slope of the material layer affect the reading process and increase the size of the bit cell. This requires angle correction in the provision of an external magnetic field so that the capacity of the data stored in the MRAM is greater. The appropriate magnetic material used in this case is $Ni_{80}Fe_{20}$ permalloy. Permalloy materials have many beneficial properties, one of which is that the material can only accept one state of magnetization or a single magnetization.

Lefter and Dimian conducted a study on the correction of the angle of incidence of the external magnetic field in 2012 [1]. The research used permalloy magnetic material and a simulation program based on the Finite Element NMAG method. The angle variations used are 0^o, 30^o, 45^o, 60^o, and 90^o. The results obtained in the form of a hysteresis curve that is decreasing and vortex formation is given an external magnetic field that has been influenced by angle [1].

Computational and Experimental Research in Materials and Renewable Energy (CERiMRE)
Volume 4, Issue 2, page 102-109
eISSN : 2747-173X

Submitted : August 25, 2021
Accepted : October 29, 2021
Online : November 24, 2021
DOI : 10.19184/cerimre.v4i2.28377

The hysteresis curve is obtained by provides a sufficiently large magnetic field in one direction and then decreases so that it goes to zero and then it is reversed in the opposite direction [2]. Hysteresis curve is a curve that shows the relationship between the magnetization (M) that occurs in a material with the magnetic field that causes it or the external magnetic field (H). The hysteresis curve is obtained by providing a sufficiently large magnetic field in one direction and then reducing it to zero and then inverting it in the opposite direction. Another way is to map the induced magnetic field B in the ferromagnetic material to the different magnetic field strengths H and fulfill the equation:

$$B = \mu_0(H + M) \tag{1}$$

Where B is the magnetic induction (Tesla), H is the applied magnetic field (A/m), M is the magnetization (A/m), and μ_0 is the permeability of the vacuum. The following is a picture of the hysteresis curve.

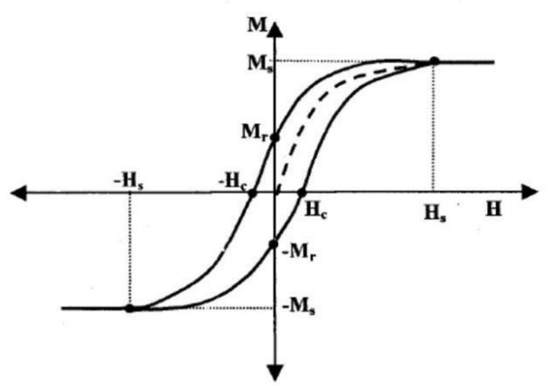


Figure 1. Hysteresis Curve

Magnetization (M) and magnetic field (B) will provide information about magnetic parameters that may be needed in the study of a material. These parameters include:

- M_s is the saturation magnetization (maximum).
- M_r is the permanent magnetization or residual magnetization.
- H_s is the magnitude of the magnetic field at saturation.
- H_c is the magnitude of the magnetic field when it reaches the coercivity.

The magnitude of the magnetic field H which is applied continuously makes the magnetization reach a saturation (saturated) state which is known as the M_s saturation magnetization state. The magnitude of the magnetic field required to reach the saturation state is known as the saturation field H_s. This situation makes all the magnetic moments form a single domain that is in the direction of the application of the H magnetic field. The saturation state when the external magnetic field H is reduced to a state called the nucleation field [3]. The H_n nucleation field is defined as the initial field that makes the state of the domain structures no longer parallel to each other [4]. The external magnetic field H is reduced to zero, but the residual magnetization makes the curve not return to its original shape, the residual magnetization is known as M_r, remanent magnetization. The magnetic domains do not return to their orientation before being given an external magnetic field H, so the material is partially magnetized. The next process of

Computational and Experimental Research in Materials and Renewable Energy (CERiMRE)
Volume 4, Issue 2, page 102-109
eISSN : 2747-173X

Submitted : August 25, 2021
Accepted : October 29, 2021
Online : November 24, 2021
DOI : 10.19184/cerimre.v4i2.28377

reversing the direction of the H field at M = 0 is called coercivity.

The magnetization reversal mechanism in single-domain structured particles is known as Stoner-Wohlfarth particles. When the sample is magnetized toward saturation, or when the sample is small enough that the magnetization is uniform throughout, the sample may consist of a single magnetic domain. The magnetization process of a single domain under the influence of an external field here is different from usual, where the magnetization reversal occurs by rotation - rotation in the critical field without any movement of the domain wall [5].

The Stoner-Wolfarth model describes the curve magnetization of a single domain particle set with uniaxial anisotropy as a result of the shape of particles or from magnetocrystalline anisotropy.

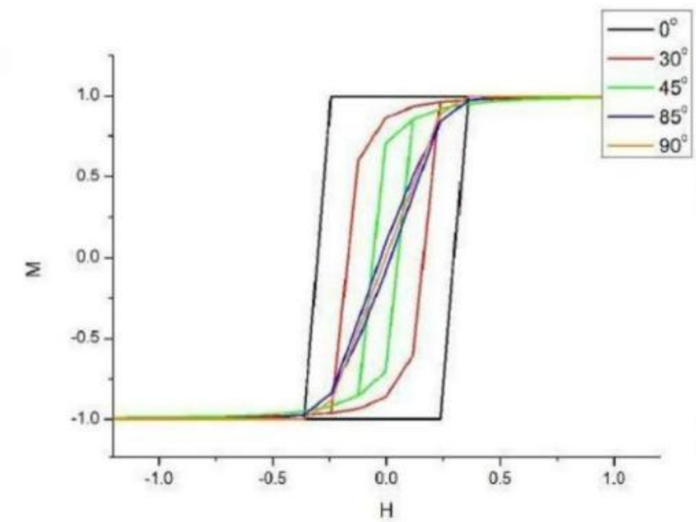


Figure 2. Stoner Wohlfarth of Hysteresis Curve

Research Methods

The hysteresis curve using an external magnetic field that is influenced by the angle of incidence is simulated using the OOMMF micromagnetic program based on Finite Difference which is the solution to the Landau-Lifshitz-Gilbert equation.

$$\frac{dM}{dt} = -\frac{\gamma}{(1+\alpha^2)}\left(M \times H_{eff}\right) - \frac{\gamma\alpha}{(1+\alpha^2)M} \times \left(M \times H_{eff}\right) \qquad (2)$$

The type of data in the form of permalloy parameters used in the simulation is in table 1 and the geometry size and angle variation used in table 2.

Table1. Permalloy Material Parameters [6]

Keterangan	Unit	Magnitude
M_S (Saturated Magnetization)	(A/m)	860×10^3
K (Anisotropy Constant)	(J/m)	5×10^3
A (Exchange Stiffness)	$(J/m^{3)}$	1.3×10^{-11}

Computational and Experimental Research in Materials and Renewable Energy (CERiMRE)
Volume 4, Issue 2, page 102-109
eISSN : 2747-173X

Submitted : August 25, 2021
Accepted : October 29, 2021
Online : November 24, 2021
DOI : 10.19184/cerimre.v4i2.28377

Table 2. Side Sizes of Cube Geometry and Angle of Arrival External Field Variations

Side Sizes of Cube	Angle of Arrival External Field Variations
5 nm	0^o
	30^o
	45^o
	60^o
	90^o

Permalloy material parameters and external magnetic field (H) which have been influenced by angle are arranged in a script with .MIF format then entered in the OOMMF program. After the simulation process is complete, a file in the form of ODT is generated.

In the file ODT, there are the results of the normalized magnetization of the material (m) and the external field that forms it. The results of magnetization and external fields were then analyzed in the origin program and produced a hysteresis curve.

Results and Discussion

In this section, we observe the effect of variations in the angle of incidence of 0^o, 30^o, 45^o, 60^o, 90^o and the geometry of the 5 nm permalloy material in the form of a nanocube with the provision of an external field in the direction of the x-axis and y-axis. The first is the result of the direction of the external field x at an angle variation of 0^o. The range of external fields required for the material to be magnetized 1 is -10000 to 10000 mT. According to Widodo [7], related to the hysteresis curve, for the small size of the material ferromagnets do require a large external magnetic field (H) so that the material is capable of being magnetized and demagnetized. This means the size of the material also affects the formation of the coercivity field. For a relatively small size of ferromagnetic material, it does require a large enough external field so that the material is able to be magnetized and demagnetized. The coercive field formed is -5000 to 5000 mT. The simulation with a size of 5 nm uses an external magnetic field value in the range of 10000 mT to -10000 mT or 10 T. The coercive field value is in the -5000 mT to 5000 mT range. This value becomes a reference to determine the effect of angles 30^o, 45^o, and 60^o.

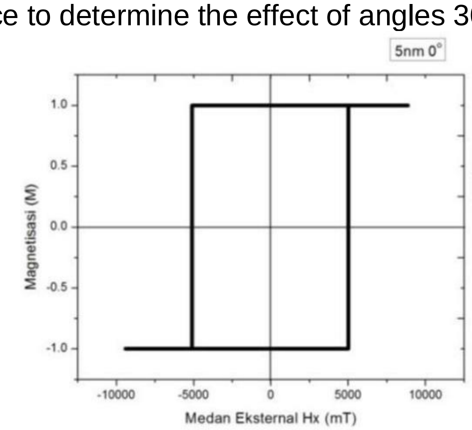


Figure 3. Hysteresis curve 5 nm at X-Axis and Angle 0^o

Computational and Experimental Research in Materials and Renewable Energy (CERiMRE)
Volume 4, Issue 2, page 102-109
eISSN : 2747-173X

Submitted : August 25, 2021
Accepted : October 29, 2021
Online : November 24, 2021
DOI : 10.19184/cerimre.v4i2.28377

At 30^o angle variation requires an external field of -8660 to 8660 mT. This figure is the result of the effect of the 30^o angle on the x-axis of the field of 10000 mT. The value of the reduced coercivity field is in the range of -108.3 mT to 108.3 mT. The maximum normalized magnetization that the material can achieve is 0.866.

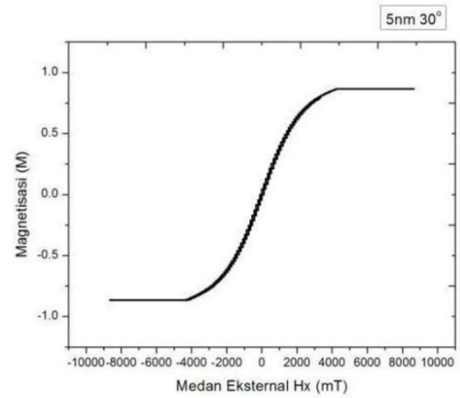


Figure 4. Hysteresis curve 5 nm at X-Axis and Angle 30^o

At 45^o angle variation requires an external field of -7071 to 7071 mT. This figure is the result of the influence of the 45^o angle on the x-axis of the field of 10000 mT. The value of the reduced coercivity field is in the range of -88.4 mT to 88.4 mT. The maximum normalized magnetization that the material can achieve is 0.70.

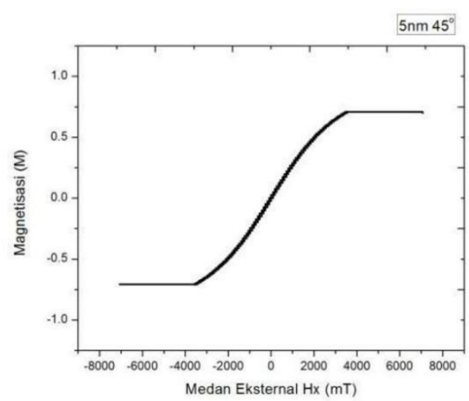


Figure 5. Hysteresis curve 5 nm at at X-Axis and Angle 60^o

Variation of 90^o angle does not form hysteresis curve and coercivity field. This happens because the magnetization process is carried out by providing an external magnetic field (H) in the direction of the easy axis of the material, which is located along the x-axis on the dimensions of the material, while when the angle variation is 90^o, The external magnetic field (H) is applied in the direction of the y-axis so that the external magnetic field (H) only hits the y-axis and there is no magnetization on the x-axis, the magnetization value is zero.

The simulation results of the influence of the angle of incidence of the external magnetic field or the external field as a whole obtained based on the formation of the hysteresis curve and the

Computational and Experimental Research
in Materials and Renewable Energy (CERiMRE)
Volume 4, Issue 2, page 102-109
eISSN : 2747-173X

Submitted : August 25, 2021
Accepted : October 29, 2021
Online : November 24, 2021
DOI : 10.19184/cerimre.v4i2.28377

coercivity field to the variation of the angle that according to the Stoner-Wohlfarth model the shape of the hysteresis curve depends on the angle between an external magnetic field (H) with the easy axis of the material (anisotropy) affecting it. At = 0^{o} the shape of the hysteresis curve will be square and the maximum normalized magnetization will be 1.

Many factors affect the size of the coercive field value, in [8] it has been proven that the size of the material geometry affects the magnitude of the coercive field, i.e. the smaller size of the geometry of the material, the greater the coercivity field and vice versa if the size of the geometry is larger, the smaller the coercive field produced. Likewise in this study, produces a smaller coercivity field than 5 nm size variation. Based on the simulation results, the effect of the angle of incidence of the external magnetic field or the external field as a whole obtained based on the formation of a hysteresis curve of the coercive field value to the geometry size is an inversely proportional relationship formed. This relationship is characterized by the greater the angle variation that affects the external magnetic field used, the smaller the coercivity field and hysteresis curve are produced. At 5 nm the angle variation that does not produce a hysteresis curve is 90^{o}. This happens because the direction of the external magnetic field is towards the y-axis, while at an angle of 90^{o} the external magnetic field is affected by the y-axis, resulting in a zero-value curve.

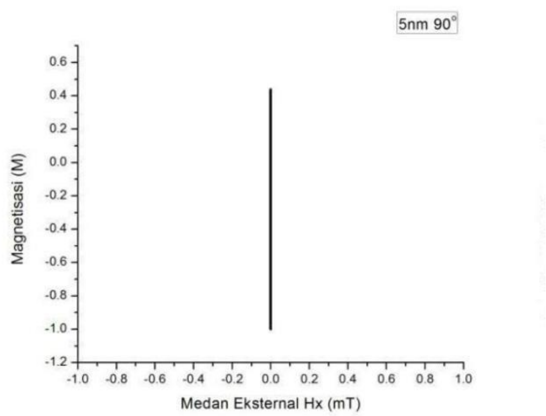


Figure 6. Hysteresis curve 5 nm at X-Axis and Angle 90^{o}

The simulation results on the y-axis external field produce a hysterical curve but it is not as detailed as on the x-axis, because the anisotropy field is directed at the x-axis but the external field also hits the y-axis. So that it can be seen also the influence of the external field on the formation of the y-axis hysteresis curve, see in figure 7, 8 and 9.

Computational and Experimental Research
in Materials and Renewable Energy (CERiMRE)
Volume 4, Issue 2, page 102-109
eISSN : 2747-173X

Submitted : August 25, 2021
Accepted : October 29, 2021
Online : November 24, 2021
DOI : 10.19184/cerimre.v4i2.28377

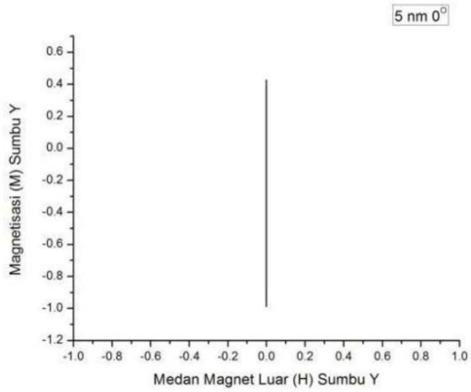
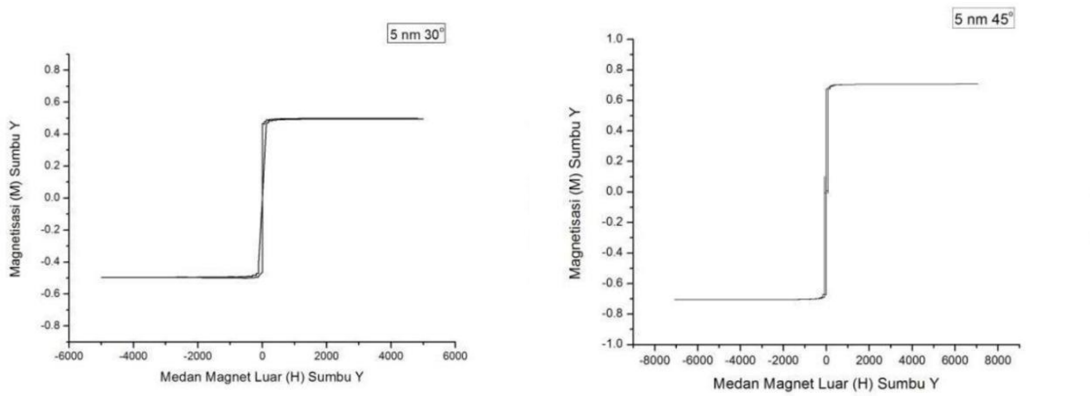
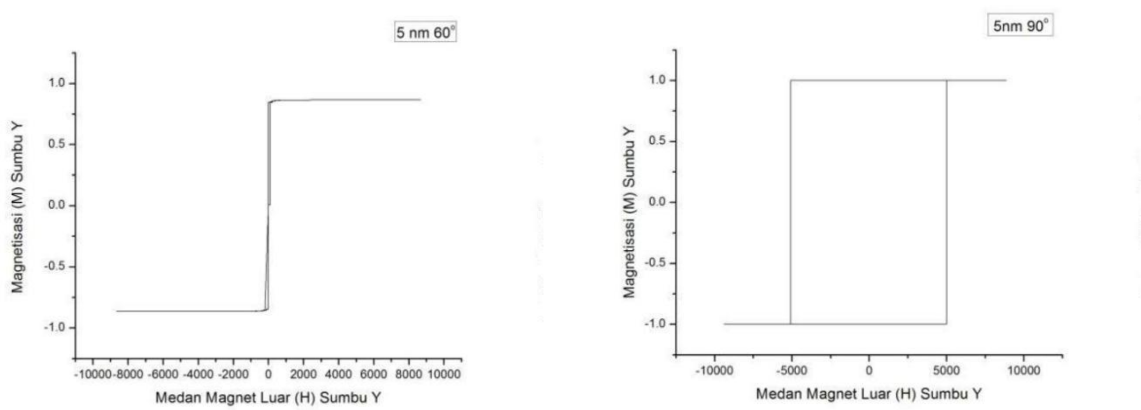


Figure 7. Hysteresis curve 5 nm at Y-Axis and Angle 0°



(a) (b)

Figure 8. Hysteresis curve 5 nm at Y-Axis and (a) Angle 30° and (b) Angle 45°



(a) (b)

Figure 9. Hysteresis curve 5 nm at Y-Axis and (a) Angle 60° and (b) Angle 90°

Conclusions

The conclusion of research that has been done on the influence of angular variation coming on the external magnetic field on the shape of the hysterical curve is that the greater the variation in angle applied the smaller the coercivity field formed. Relatively, small ferromagnetic materials require a large external field for the material to be magnetized.

ACKNOWLEDGEMENTS

Thank you Dr. Lutfi Rohman for his help and guidance in conducting this research. Thank you to KeRis KMT for the facilities that have been provided.

References

[1] C. Lefter, and M. Dimian, 2012, Micromagnetic Analysis of Magnetization Behavior in Permalloy Nanoparticles for Data Storage Applications, 11th International Conference on DEVELOPMENT AND APPLICATIONS SYSTEMS, Romania.

[2] A. Aharoni, 1998, Introduction to the Theory of Ferromagnetism, Oxford: Clarendon Press.

[3] C. Behrel, V. Neu, L. Schultz, and S. Fahler, 2013, Magnetically and thermally induced switching processes in hard magnets, Journal of Applied Physics, 112(083919), page 1-5.

[4] E. H. Frei, S. Shtrikman, and D. Treves, 1957, Critical Size and Necleation Field of Ideal Ferromagnetic Particles, Phys. Rev. 106(3), page 446.

[5] D. Djuhana, H. G. Piao, S. C. Yu, S. K. Oh, and D. H. Kim, 2009, Magnetic Domain Wall Collision Arround Walker Breakdown in Ferromagnetic Nanowires, Journal of Applied Physics, 106(10), 103926.

[6] A. Indrawati and E. Suharyadi, 2014, Studi Pengaruh Shape terhadap Pergerseran Domain Wall Magnetik pada Lapisan Tipis Permalloy, Jurnal Sains Materi Indonesia, Vol 2(1), page 264-267.

[7] A. T. Widodo, 2013, Studi Mikromagnetik Dinamika Struktur Domain pada Material Feromagnetik Py, Ni, Fe, dan Co Model Nanosprehe, Tesis, Depok: FMIPA Universitas Indonesia.

[8] L. Rohman, D. Djuhana, B. Soegijono, and W. Nursiyanto, 2013, Dynamics Micromagnetic Simulation of La0.7Sr0.3MnO3 (LSMO) Disk Array Patterned Ferromagnetic, International Journal of Basic & Applied Sciences IJBAS – IJENS, vol. 13(03), page 17-20.