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Magnetic Susceptibility of Ferromagnetic Alloy Material $Co_{(1-x)}Ni_{(x)}$ Nanocube and Nanosphere Models

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Abstract. A hard disk is a data storage medium composed of a thin layer of magnetic material. Hard drives take advantage of the characteristics of magnetic materials that are stable to heat and have sensitivity to magnetic fields. One of the best materials to use a thin layer ferromagnetic on a hard disk is CoNi alloy. Hard drives with larger storage capacities require magnetic materials with high magnetic susceptibility values and Curie temperatures to obtain the best magnetic properties. The magnetic susceptibility of alloy ferromagnetic material $Co_{(1-x)}Ni_{(x)}$ nanocube and nanosphere is calculated using vampire-based micro magnetic simulation. The research was conducted using a literature review on the parameters of the CoNi alloy material, and then it was simulated in the vampire program. The data generated from the simulation are magnetic susceptibility (1/tesla) and temperature (K). The spectrum of the magnetic susceptibility graph that shifts to the right as the Ni (x) composition decreases, it is assumed that the higher Curie temperature is produced. Otherwise, The increase in Ni (x) composition causes the magnetic susceptibility spectrum to shift to the left, with the Curie temperature's predicted value getting minor than the other. The nanocube-shaped material has a higher susceptibility value than the nanosphere-shaped material in terms of each Ni (x) composition variation at its maximum magnetic susceptibility.

Keywords: Magnetic susceptibility, temperature Curie, *Vampire*.

Introduction

The need for diverse magnetic technology is the main reason for improving the quality and quantity of products, especially in data storage media. One of the data storage media used is HDD (hard disk drive). Hard disk functions to store data by placing a magnetic field through a thin layer of magnetic material [1]. The characteristics of magnetic materials that are stable to heat have expanded their use as a data storage medium. That is, magnetic materials with good magnetic properties will not lose energy when given a heating effect [2].

Ferromagnetic materials have the required criteria to obtain the desired storage quantity. Where these materials have a high Curie temperature value, strong magnetic properties have a magnetic moment orientation that is almost in the same direction and good magnetic susceptibility values [3]. To reduce the excessive exploration of pure ferromagnetic materials, alloying materials have become an alternative in the development of materials. In addition, alloying technology makes it possible to obtain materials with good magnetic properties, one of which is based on their magnetic susceptibility and Curie temperature.

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Another study on the magnetic properties of $Co_{(1-x)}Ni_{(x)}$ nanocube model has observed the Curie temperature value by varying the composition of the material in the form of random alloy and double layers. In random alloy with composition $Co_{0.2}Ni_{0.8}$, $Co_{0.5}Ni_{0.5}$ and $Co_{0.8}Ni_{0.2}$ with Tc values 800K, 1000K, and 1250K, respectively. In double layer with composition $Co_{0.2}Ni_{0.8}$, $Co_{0.5}Ni_{0.5}$ and $Co_{0.8}Ni_{0.2}$ with Tc values of 1200K, 1325K, and 1385K, respectively. Variations in the composition of Co and Ni affect the size of the Curie temperature value of $Co_{(1-x)}Ni_{(x)}$ [4]. In addition, research on magnetic susceptibility was also carried out [5], where the magnetic susceptibility graph showed low magnetic susceptibility values when below the Curie temperature. In this research, we have investigated susceptibility magnetic of ferromagnetic alloy material $Co_{(1-x)}Ni_{(x)}$ in the shape geometry: nanocube and nanosphere models.

Theoretical Background

Magnetic susceptibility is a basic measure of how magnetic material is. By knowing the value of magnetic susceptibility, the magnetic properties of a material can be known. Ferromagnetic materials have a magnetic susceptibility value that is influenced by temperature and is assumed by the Curie temperature, when the ferromagnetic material is above the Curie temperature it will turn into a paramagnetic material.

At room temperature, thermal energy tends to randomize the direction of the domains rather than rectify the magnetic moments. In ferromagnetic materials, it is usually easy to reach a state of saturation, where all the atomic moments are in the same direction. In some cases, the saturation state can occur in low-scale fields (Sunaryo and Widyawidara, 2010). Magnetic susceptibility can be used to determine the Curie temperature of a material by reviewing the highest magnetic susceptibility produced as shown in Figure 1 (Evans and Biternas, 2014).

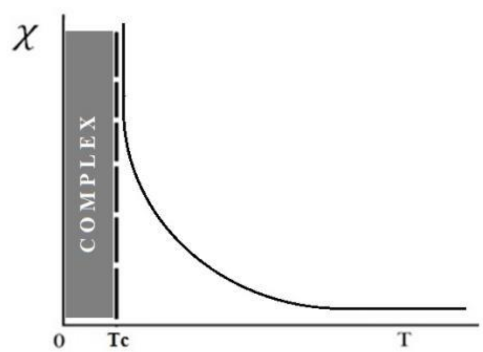

Figure 1. Susceptibility graph, magnetic (χ) against temperature (T in unit K) (Source: Anwar, 2011)

The Vampire simulation program is an atomistic simulation for magnetic nanomaterials. The program creates atomistic simulations of magnetic materials that are available openly and designed with ease of use in mind, including an extensive set of input parameters to control the simulation via input files. The Vampire simulation program can be used to determine the Curie temperature of a material. Some of the essential advantages of Vampire are that it is based on the finite element method, which is suitable for computing non-cube structures. Visualization of

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the output file, which includes magnetization data, can be processed using the Pov-Ray program (Evans et al., 2013).

Materials and Methods

To produce magnetic susceptibility values and Curie temperatures on ferromagnetic $Co_{(1-X)}Ni_{(X)}$ alloy materials with nanocube and nanosphere geometric shapes, we need data input of material parameters. The data input refers to existing research results. Details of the data CoNi material parameters used for simulation inputs can be seen in Table 1.

Table 1. Parameters of $Co_{(1-X)}Ni_{(X)}$ materials in micromagnetic simulation

Material	μ_s (μ_B)	J (J/link)	K (J/atom)
Co	1.72	6.064 x 10^{-21}	6.69 x 10^{-24}
Ni	0.606	2.757 x 10^{-21}	5.47 x 10^{-26}
$Co_{(1-X)}Ni_{(X)}$		4.164 x 10^{-21}	8.12 x 10^{-25}

(Sumber: Evans *et al.,* 2013, Broeder, 1992, Vivas *et al.,* 2012)

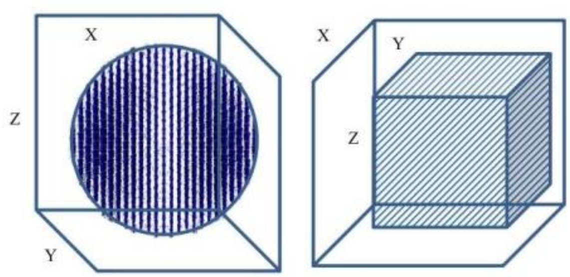

Figure 2. Geometry: a) Nanosphere with diameter 10 nm and b) Nanocube with side length 10 nm

The stages in the research are carried out as shown in Figure 3.

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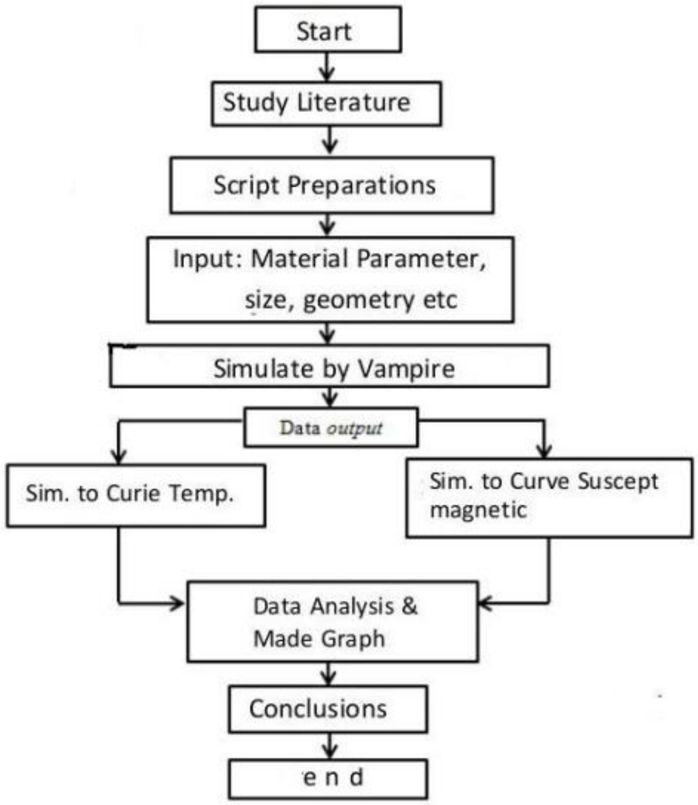

Figure 3. Research flow chart

Results and Discussion

Magnetic susceptibility observations were carried out by varying the composition of Ni (x) with nanocube and nanosphere geometric shapes. The composition of Ni (x) used is 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9, in addition, the size of the material is 5 nm. Based on the simulation results obtained, a graph is made between temperature and magnetic susceptibility. The analysis was carried out by observing the magnetic susceptibility spectrum with a temperature change, in this case at a temperature of 0K to 2000K. The graph results of magnetic susceptibility to temperature can be seen in Figures 4 and 5.

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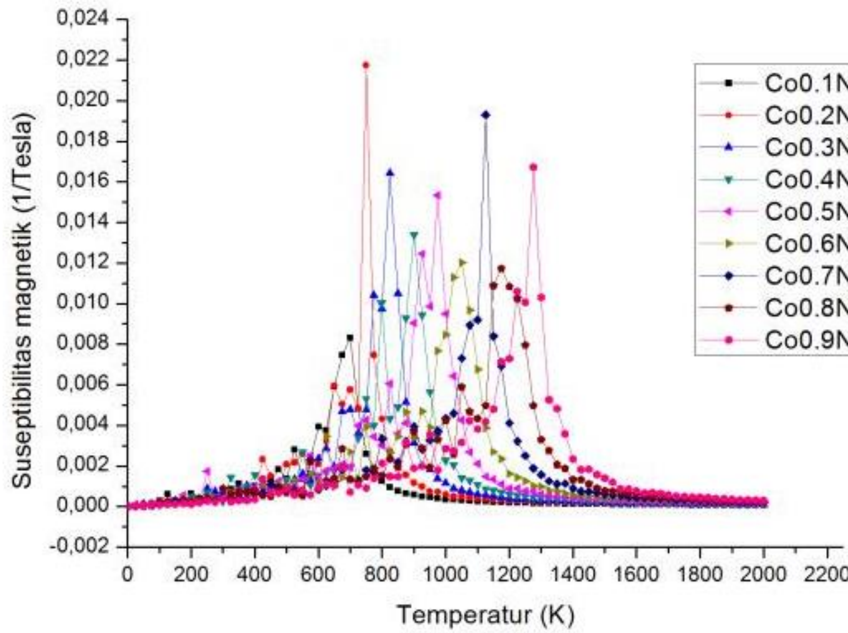

Figure 4. Graph of magnetic susceptibility to temperature nanocube model

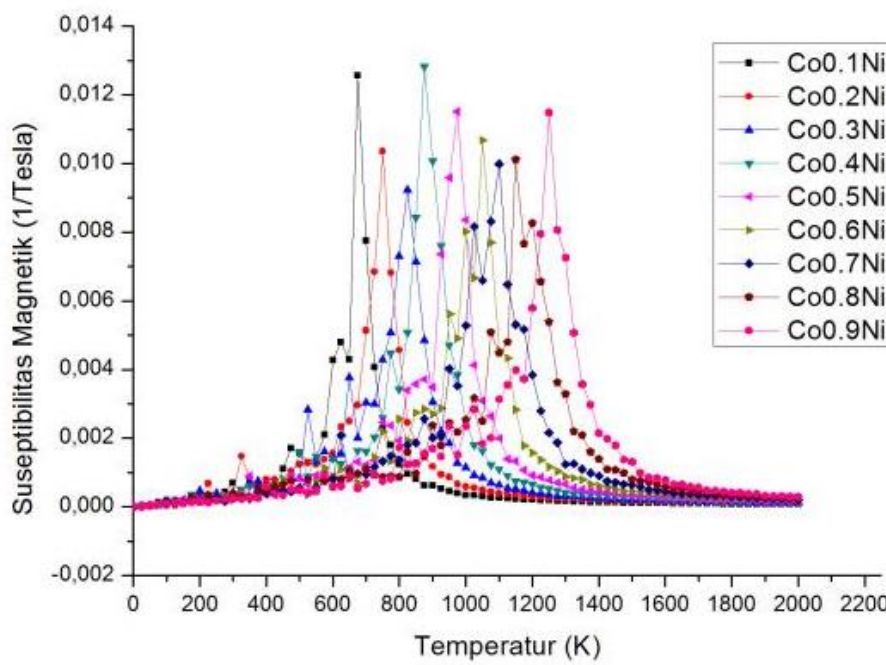

Figure 5. Graph of magnetic susceptibility to temperature model nanosphere

Based on Figures 4 and 5, the resulting magnetic susceptibility spectrum is influenced by changes in Ni (x) composition in each geometric shape of the material. The resulting magnetic susceptibility spectrum will shift to the right in nanocube-shaped materials if the Ni (x) composition decreases, with the predicted Curie temperature value also increasing. On the other hand, the Curie temperature produced is thought to decrease if the composition of the

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Ni(x) material increases, so that the resulting Curie temperature is also expected to decrease. This phenomenon is cause nickel (Ni) has lower magnetic properties than cobalt (Co). The magnetic susceptibility spectrum in the form of the nanosphere also shows the same graphic profile as the nanocube-shaped material.

Furthermore, the magnetic susceptibility analysis was reviewed through the maximum susceptibility value for each variation of Ni (x) composition in the form of nanocube and nanosphere. The magnetic susceptibility values of $Co_{(1-x)}Ni_{(x)}$ materials are listed in table 2.

Table 2. Maximum magnetic susceptibility of $Co_{(1-x)}Ni_{(x)}$ materials

Composition of Ni(x)	Magnetic Susceptibility (1/Tesla)	
	Nanocubes	*Nanosphere*
0.1	0.01672	0.01149
0.2	0.01173	0.01012
0.3	0.01930	0.00999
0.4	0.01201	0.01068
0.5	0.01533	0.01151
0.6	0.01339	0.01282
0.7	0.01644	0.00923
0.8	0.02174	0.01035
0.9	0.00833	0.01256

After that, a graph of the effect of Ni (x) composition on the maximum susceptibility is made, as shown in Figure 6.

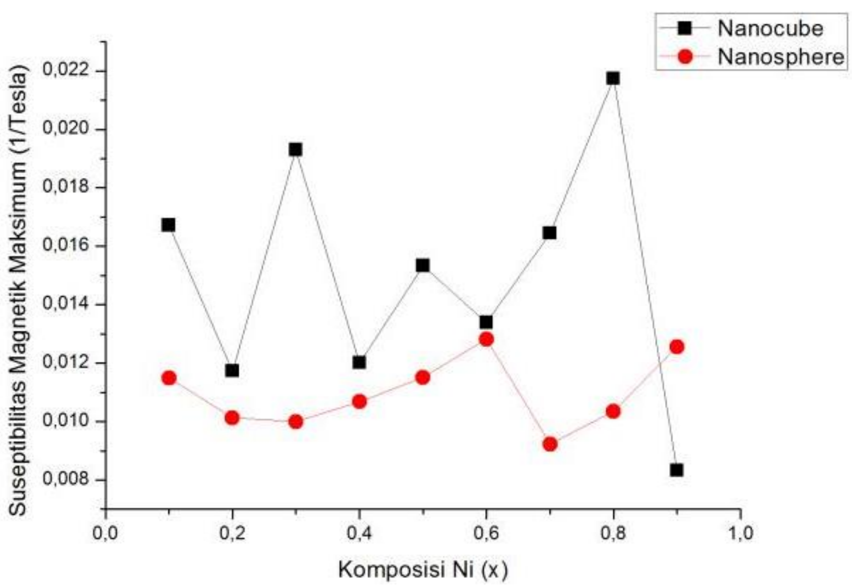

Figure 6. Graph of maximum magnetic susceptibility to variations in the composition of Ni(x)

The graph in Figure 6 shows the magnetic susceptibility value that varies with each Ni (x) composition variation. This phenomenon of the curve on the graph is because it reaches the Curie temperature, the state of the domain at each. The ingredients for each composition are

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different. So the energy possessed by the material is also different. However, in all variations of the Ni (x) composition, the maximum magnetic susceptibility of the nanocube material tends to be greater than that of the nanosphere-shaped material at the composition of Ni (0.1) to Ni (0.8). Except for the composition of Ni (0.9), the maximum magnetic susceptibility in the nanosphere form is more enormous value than in the nanocube form.

Ferromagnetic materials have magnetic susceptibility values that are affected by temperature. The temperature limit at which the material will experience a phase change from ferromagnetic to paramagnetic is indicated by the Curie temperature. The material's magnetic susceptibility shows the highest value. In other words, when a ferromagnetic material has a temperature above the Curie temperature, the material will turn into a phase of paramagnetic material. In the paramagnetic phase, the orientation of the magnetic moment will be random, which causes the magnetic susceptibility of the material to decrease until it reaches the lowest value and then becomes constant. This constant state is caused because the material is challenging to magnetize again, where the energy needed to align the spin directions is getting bigger.

Conclusions

Based on the micromagnetic simulation carried out, the magnetic susceptibility spectrum of the material is affected by variations in the composition of Ni (x). The magnetic susceptibility spectrum will shift to the right when the Ni (x) composition decreases, with the expected Curie temperature increasing. In addition, the maximum susceptibility of the nanocube-shaped $Co_{(1-x)}Ni_{(x)}$ material tends to be higher than that of the nanosphere-shaped material.

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