Investigation of Dynamic Magnetization in FePt and FePd Disk Ferromagnets Using Micromagnetic Simulation

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Abstract. In this study, we have observed the magnetic hysteresis loop of the highly anisotropic ferromagnetic materials FePt and FePd with disk model by micromagnetic simulation method based on the Landau-Lifshitz-Gilbert (LLG) equation. We used disk shaped model with varied size from 50 to 500 nm, thicknesses of 5 and 10 nm, and damping constant \( \alpha = 0.05 \). The cell size of \( 2.5 \times 2.5 \times 2.5 \text{ nm}^3 \) was used and the in-plane and out-plane fields were applied to the materials. The results showed that the hysteresis loop has a large coercivity when the external in-plane field and close to zero when the external out-of-plane field was applied. This characteristic was similar as typical of the material’s hysteresis loops given the field toward the hard-axis. However, coercivity still observed in materials with size below \( \leq 100 \text{ nm} \) with ranging values between 20 and 80 mT. From the results, a certain value of the coercivity field appeared in out-plane applied field indicated a perpendicular magnetic anisotropy (PMA) behaviour in FePt and FePd ferromagnets. Moreover, the nucleation field was shifted as the material’s size varied. The results showed that the size affected the magnetic properties of the FePt and FePd thin layers.

Keywords: FePt, FePd, hysteresis loop, micromagnetic simulation, PMA

1. Introduction
Magnetic devices have been widely explored for data storage media (magnetic memory devices) and magnetic sensor applications. Magnetic recording with high storage density and smaller size is the reason why the magnetic devices has always been developed to realize a storage media with fast data processing capabilities and low energy consumption (smaller, faster, and efficient) [1]. Data storage devices capacity is increased to store more information (bits) by increasing its area density inside a memory disc. Initially, the process of storing data on magnetic media is carried out by longitudinal recording method. The bits on a disc change in parallel or anti-parallel to the direction of the head that moves relative to the disc. To increase its density, the size of the data bit must be made in small size. However, the thermal effect of the ferromagnetic substance known as the superparamagnetic effect appeared because of influence of thermal fluctuations. To overcome the superparamagnetic effect, perpendicular magnetic recording on the materials with perpendicular magnetic anisotropy (PMA) was used to increasing the bit density in recording media [2]. Compared with in-plane magnetic anisotropy (IMA) material, materials with PMA properties are widely used for recorders and data storage. By
using perpendicular magnetic recording technology with aligned the magnetic recording bits perpendicular to the disk plate, it is expected that the superparamagnetic effect will be decrease and higher storage densities would be achieved.

Another way to avoid thermal instability is using materials which has higher magnetic anisotropy constant [3,4]. One of the most promising candidates for perpendicular magnetic recording media due to the large uniaxial magnetocrystalline anisotropy are FePt and FePd alloys that can reach as high as $10^7$ J/m$^3$ [5]. Pt- and Pd-based alloys are selected materials that are used for magnetic recording media because of their perpendicular magnetic anisotropy (PMA) properties [6]. FePt nanoparticles have almost the same percentage of Fe and Pt atoms and an important class of magnetic nano materials. The anisotropy constant of FePt is $7 \times 10^6$ J/m$^3$, which is one of the greatest values among all known hard magnetic materials [7]. This high uniaxial anisotropy makes FePt overcome thermal fluctuations even in very small practices [8]. The anisotropy constants of FePd is $2.6 \times 10^6$ J/m$^3$ which is smaller than FePt but larger than Co-Cr-based alloys that commonly used in recording media [9].

In order to have better understanding of the magnetic properties, we have investigated the characteristics of hysteresis loops from FePt and FePd disk-shaped model with different sizes and thicknesses using micromagnetic simulation. Perpendicular magnetic anisotropy properties was observed by applied magnetic field on the in-plane direction and out-of-plane direction.

2. Simulation Procedure
This study was carried out using a public micromagnetic simulation software OOMMF (Object Oriented Micromagnetic Framework) [10]. The OOMMF simulation software was built based on the Landau-Lifshitz-Gilbert (LLG) equation which is a fundamental part of time-dependent computational micromagnetics. In this simulation, the FePt and FePd with the disk shaped were used with variations in diameter $d$ from 50 nm to 100 nm for nanometer order and 200 nm to 500 nm for mesoscopic order with two variations of thickness $t$ of 5 and 10 nm. The cell size of discretization was fixed to be $2.5 \times 2.5 \times 2.5$ nm$^3$, and the damping constant $\alpha$ of 0.05. The material parameters for the micromagnetic simulation are set for FePt [11] $M = 1.14 \times 10^6$ Am$^{-1}$, the anisotropy constant $K = 6.6 \times 10^6$ J/m$^3$, the exchange constant $A = 10 \times 10^{-12}$ J/m$^{-1}$ and FePd [12] $M = 1.06 \times 10^6$ Am$^{-1}$, the anisotropy constant $K = 2.6 \times 10^5$ J/m$^3$, and the exchange constant $A = 6.9 \times 10^{-12}$ J/m$^{-1}$. Then, the FePt and FePd materials with illustrated as Figure 1 are simulated in two different states (i) the system is simulated with magnetic field in in-plane direction and (ii) out-of-plane direction with an external magnetic field -1000 mT to 1000 mT.

![Figure 1. The dimension and geometry of FePt and FePd disk ferromagnets. The length size $d$ was varied from 50 nm to 500 nm with external field is applied in-plane and out-of-plane direction.](image-url)
3. Results and discussion

Figure 2. (a,b,c,d) Hysteresis loops for FePd and FePt disk-shaped with different lengths and thicknesses. The magnetic field was applied in the in-plane direction and out-of-plane (perpendicular) direction. (e and f) Coercivity $H_c$ for FePd and FePt disk-shaped as a function of diameter $d$ and thicknesses.
The magnetic behavior of a ferromagnetic material is characterized by the hysteresis loop. The observation of hysteresis curve is explained by using the magnetization process on FePt and FePd ferromagnetic material. The magnetization curves were simulated with the applied field in parallel and perpendicular direction. By using diameter and thickness variation, hysteresis curves are observed as shown in Figures 2. A straight loop is obtained when magnetic field was applied in parallel direction (a,c) while a slanted loop (b,d) is obtained when magnetic field was applied in perpendicular direction.

Figure 2 (a) and (c) shows a significant change in the coercivity when external field is given in in-plane direction. The coercivity increases with increasing diameter of the materials in range \( d \) 50 nm to 100 nm but start from \( d \) 200 nm to 500 nm coercivity decreases and tends to be constant at 20 mT as shown as Figure 2 (e) and (f). Figure 2 (e) shows that a drastic change of the magnetization loops is observed in the diameter \( d \) between 100 nm and 200 nm for FePt materials. The fluctuation coercivity value with range about 20 mT was observed in FePd material in diameter \( d \) between 70 nm and 80 nm as shown as Figure 2 (f). It shows that the effect of diameter variation only applies in the nano region which is \(< 100 \) nm.

When the thickness is raised to 10 nm, the coercivity value is observed slightly larger than \( t \) 5 nm with a significant large \( H_c \) value of about 160 mT for FePt materials. On the other hand, for FePd materials, the coercivity values is also large but there is no significant differences when the thickness is raised to 10 nm. So, the results show that coercivity increase with increasing thickness of the materials. The hysteresis loops with different diameter showed nearly zero coercivity when the external field was applied in the out-of-plane direction as shown as Figure 2 (b) and (d). However, the coercivity still observed in nano region \( d < 100 \) nm. The coercivity values have ranging between 40 to 80 mT for FePt and 40 to 60 mT for FePd materials. This values indicates perpendicular magnetic anisotropy (PMA) behavior in FePt and FePd ferromagnets.

![Figure 3](image)

**Figure 3.** The nucleation field of FePt and FePd disk-shaped material as diameter function with variation \( d \) 50-500 nm and \( t \) 5 nm (red) and 10 nm (blue).

The magnitude of the field when a magnetization value decreases is known as the nucleation field which is the initial magnetic field that makes the domain structure no longer parallel [13]. The results show that nucleation field \( H_n \) are proportional to the diameter and thickness as shown as Figure 3, the nucleation field increase with increasing diameter and thickness. But, from the figure for FePt
materials, the nucleation field does not show a significant values and tends to be constant when it comes to mesoscopic region. It is indicating that the diameter variation only affects the shifting of the nucleation field below $d\,\sim\,200\,\text{nm}$. According to previous research from Shima (2002) [14], the nucleation field also increase with increasing diameter and thickness and tends to be constant at large size.

![Figure 4](image_url)

**Figure 4.** The switching time of FePt disk-shaped material with variation $d\,\sim\,50-500\,\text{nm}$ and $t\,\sim\,5\,\text{nm}$ (red) and $10\,\text{nm}$ (blue) with magnetic field was applied in the in-plane direction and out-of-plane direction.

The next observations show the change in the reversal time that needed for each diameter. The amount of time which is needed to achieve a positive saturation state from a negative saturation is called switching time. Figure 4 (a) and (b) show the switching time for FePt and FePd materials as function of diameter. When the external field was applied in out of plane direction the switching time increase with increasing diameter but decrease with increasing thickness. But something that interesting comes in mesoscopic region, at $d\,\sim\,300\,\text{nm}$ for both FePt and FePd materials, the switching time increase with increasing thickness. Meanwhile, when the external field was applied in in-plane direction the switching time also increase with increasing diameter and thickness, but up to diameter $d\,\sim\,100\,\text{nm}$, in mesoscopic region the switching time tends to fluctuate.

4. **Conclusion**

Hysteresis loops of FePt and FePd with disk-shaped model was observed at different diameter and thicknesses by micromagnetic simulation. It is found that two different shapes of hysteresis loops are influenced by the direction of the applied field. The results showed that the size of materials affected the magnetic properties of FePt and FePd thin layers. The highest coercivity of 160 mT was obtained for FePt, when the external field was applied in the in-plane direction. The coercivity decreased as the size of materials increased but tends to be constant in mesoscopic scale. The nucleation field was shifted to a larger field with increasing diameter and thickness. FePt materials requires a larger nucleation field compared to FePd materials. Meanwhile, along with increasing diameter, the switching time also increase because of materials with large diameter takes longer time to reverse the orientation of the momen magnet in opposite direction.

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