Electronic Materials Letters, Vol. 3, No. 2 (2007), pp. 87-91

Observation of Perpendicular Magnetization Using CoFe/Pd Multilayers

Jin Seock Ma[1,2], Hyun Cheol Koo[1,*], Jongwha Eom[1,3], Joonyeon Chang[1]
Suk-Hee Han[1], and Chulwoo Kim[2]

[1]Center for Spintronics Research, Korea Institute of Science and Technology, Seoul 130-650, Korea
[2]School of Electrical Engineering, Korea University, Seoul 136-713, Korea
[3]Department of Physics, Sejong University, Seoul 143-747, Korea

Perpendicular magnetization using CoFe/Pd multilayers is presented. The magnetic behaviors of perpendicular and horizontal direction do not follow the conventional demagnetizing factor theory. The interfacial anisotropy is attributed to the perpendicular magnetization. A ferromagnetic layer is coupled with other ferromagnetic layers, so a thicker Pd layer weakens the perpendicular magnetization. The small thickness changes of both the CoFe and Pd generate tremendous variation of perpendicular anisotropy. In addition, sputtering power also affects the magnetic property of multilayers.

Key words: CoFe/Pd, multi-layers, perpendicular magnetization, saturation magnetization, remanent

1. INTRODUCTION

Spin electronic devices have garnered strong interests in the field of advanced electronics due to their non-volatile characteristics and their high potential in the area of high speed switching. Generally, in spin electronic devices, the spin polarization is produced using ferromagnetic metals such as Ni, Fe, Co, and their alloys. This transition metal has strong magnetic properties up to room-temperature, which allows its use as both a spin injector and a detector. It also has high remanent magnetization, implying that non-volatile memory applications are also feasible. Recently a magnetic semiconductor has been considered as a spin source, due to the good conductance matching with semiconductor-based devices. However, because the Curie temperature is very low, such device applications are still far away.

Perpendicular magnetization is very attractive in the area of high density recording media and spin devices. The magnetization vector exists out of the plane, so implying that the lateral magnetic interaction is very small. Therefore, the neighboring cell distance can be reduced substantially. The magnetic easy axis and domain configuration of the ferromagnetic metal is determined by the shape anisotropy of the magnetic patterns [1-4]; thus, obtaining perpendicular magnetization is not simple in a thin-film system.

2. DEMAGNETIZING FACTOR CALCULATION

If it is assumed that the demagnetizing factors of a Cartesian coordinate system are D_x, D_y, and D_z, they always have the relationship of $D_x + D_y + D_z = 1$. The meaning of the small value of the demagnetizing factor in a certain axis is that the magnetic vector tends to align its axis. Figure 1 shows the demagnetizing factor as a function of the aspect ratio (c/a) using an analytic expression[4]. The lateral size of film plane is $a \times b$ and the c value represents the film thickness, as shown in inset of the figure. In this calculation set $a = b$, thus it is possible to obtain same value of D_x and D_y. Generally, in a thin-film system, the aspect ratio (c/a) is extremely low. Assuming a millimeter lateral size and tens of nanometers, the aspect ratio is 10^{-5}. In this case, the

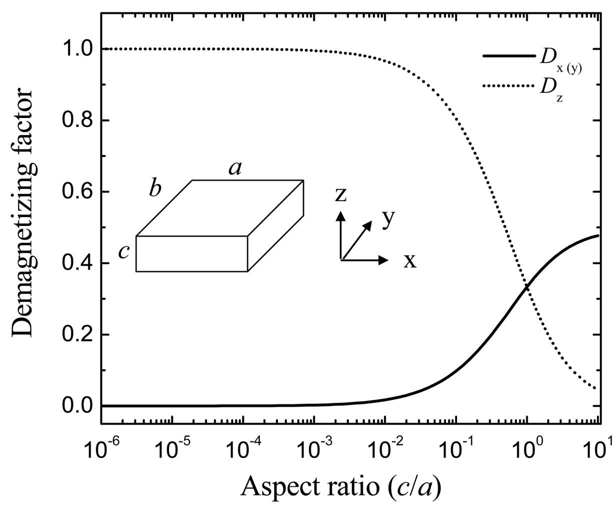

Fig. 1. Demagnetizing factor as a function of the aspect ratio (c/a). The inset shows the schematic geometry.

*Corresponding author: hckoo@kist.re.kr

demagnetizing factor of D_z is nearly unity. This value implies that the z axis is the magnetic hard axis and that this-film cannot have perpendicular magnetization without an extraordinarily strong field. In order to have an easy axis in the perpendicular direction, the film thickness should be greater than the lateral dimension; hence, a normal case of thin-film system cannot have perpendicular magnetization without an external field.

In order to overcome the anisotropy of the shape, deposition of ferromagnet/non-ferromagnet metal (FM/NM) multilayers is a typical technique used in thin-film technology. Many groups[5-13] have investigated the perpendicular magnetization property of Co/Pd, Co/Pt, and Co/Au multilayers and the metal super-lattices consist of alternating FM and NM layers. This phenomenon is observed only in a very thin FM film. The reason for this interesting characteristic lies in the interfacial property of FM and NM films.

3. EXPERIMENTAL PROCEDURE

Figure 2 shows the vertical structure of CoFe/Pd multilayers. In this experiment, a thin film was fabricated through the system of three-inch, six-gun type DC magnetron sputtering. A SiO_2 wafer was prepared, placed into an ultrasonic washer with Aceton for 20 minutes and Methanol for 10 minutes in order to remove impurities, and cleaned with DI-water. The sputtering targets used for the fabrication of the thin film were prepared by mixing high-purity metal powders (99.99%). Each material was deposited at room temperature without the application of a magnetic field. The initial vacuum pressure was maintained at 5.0×10^{-7} Torr using a turbo molecular pump and the working pressure was maintained at 2.0×10^{-3} Torr after flowing 15 sccm of Ar gas by using an MFC (Mass Flow Controller). A shutter was utilized in order to prevent the mixing of targets.

The thin film was fabricated with the structure of SiO_2/Ta50 Å/[Pd/CoFe]× 7 Layers/Ta50 as shown in Fig. 1. In this experiment, 90%-cobalt CoFe was used. After fabrica-

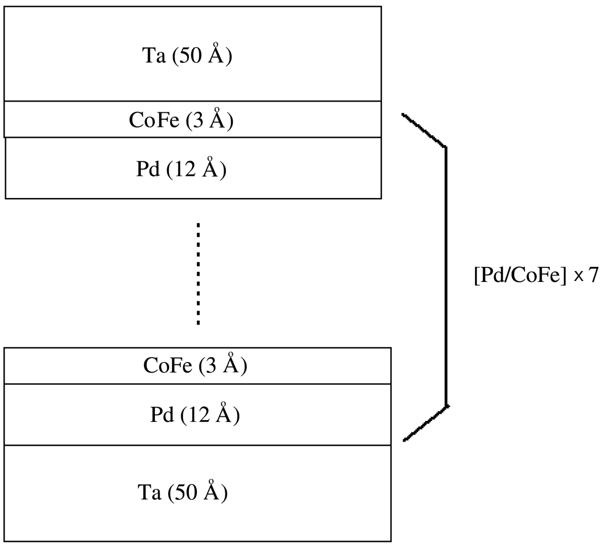

Fig. 2. Vertical structure of the Pd/CoFe multilayers.

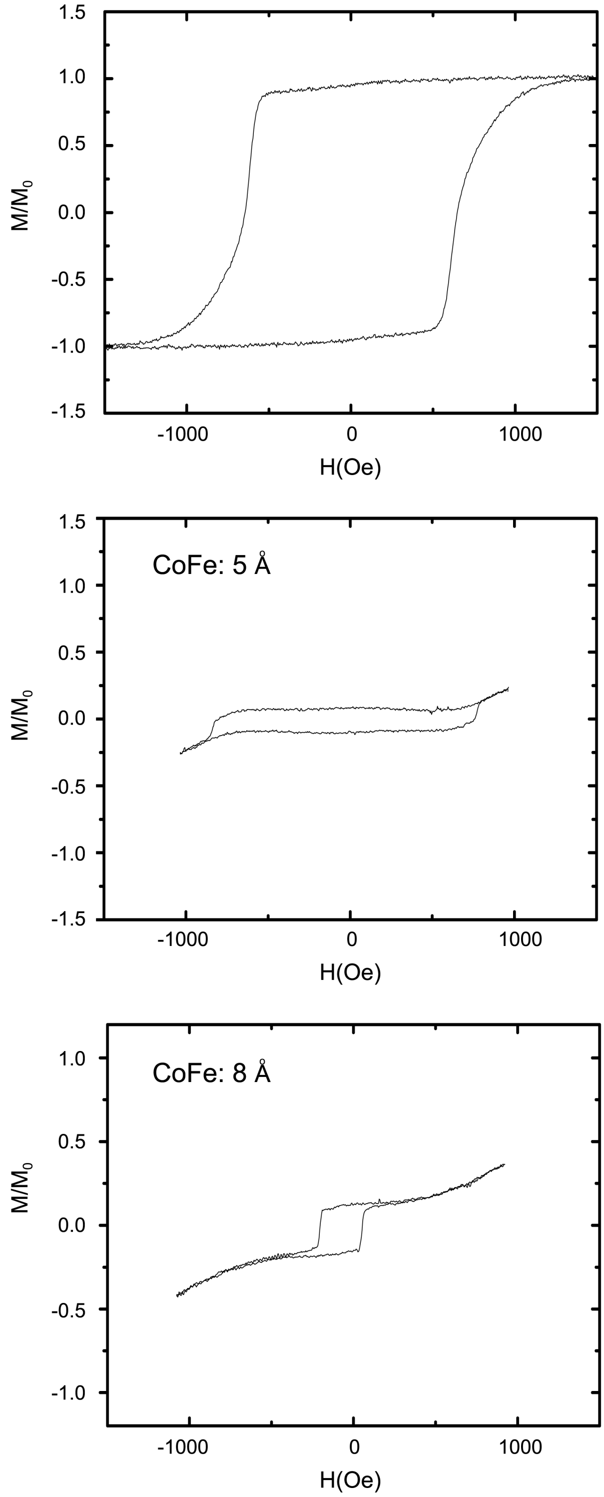

Fig. 3. M-H curves for various CoFe thicknesses. The thickness of Pd is 13Å.

tion, the samples were cut and measured with an AGM (Alternating Gradient Magnetometer) by applying a magnetic field horizontal and perpendicular to the film plane.

4. RESULTS AND DISCUSSION

Figure 3 shows the magnetization curve of a multilayer film in the perpendicular direction as a function of the CoFe thickness. The thickness of Pd is 13 Å and the CoFe thicknesses are 3, 5, and 8 Å. The perpendicular and horizontal magnetizations were measured with a magnetic field. Considering the demagnetizing factor as shown in Fig. 1, the thicker film has stronger perpendicular magnetization. However, when the CoFe film thickness is 3 Å, the saturation magnetization (M_S) is the largest. Below 3 Å, the thickness control is very hard, making a reproducible deposition a challenge. The coercivity of the perpendicular direction is also very small when the CoFe thickness is above 5 Å. Therefore, in order to obtain perpendicular anisotropy particularly for high density recording media, an ultra-thin CoFe film is necessary. When the CoFe thickness is 8 Å, the horizontal axis becomes an easy axis. Therefore, perpendicular

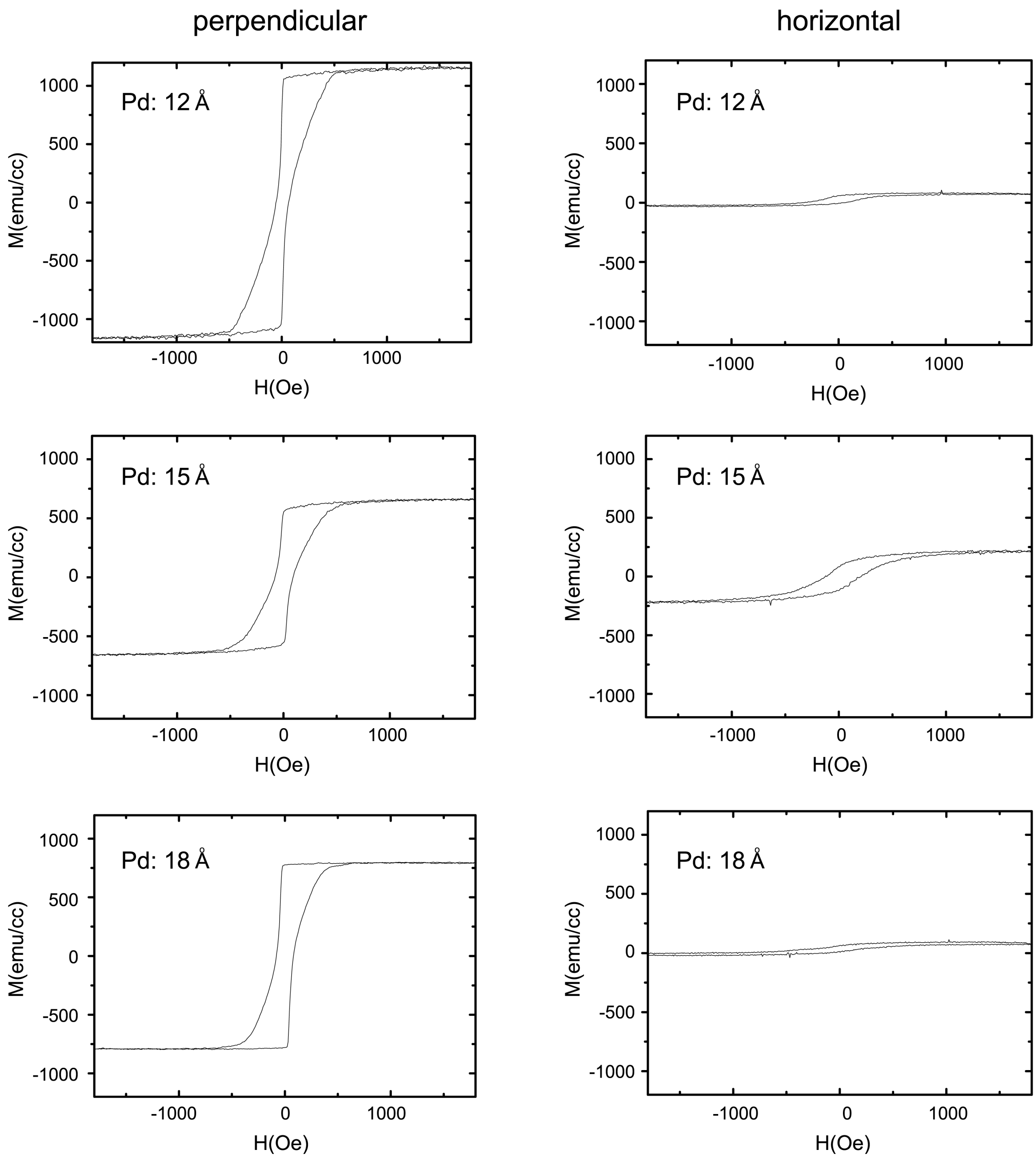

Fig. 4. Perpendicular and horizontal M-H curves for various Pd thicknesses. The thickness of CoFe is 3Å.

anisotropy of the Pd/CoFe junction disappears and the magnetic multi-layers follow the conventional manner in which the easy axis exists in the film plane. The origin of perpendicular magnetization is the interfacial anisotropy [6], thus the large volume of ferromagnetic layer cannot contribute to the vertical magnetic moment. Interestingly the higher the film thickness, the lower the saturation field, as the interface perpendicular anisotropy is weak for a thicker film [11].

Figure 4 shows the magnetization curve of multilayer film in the perpendicular and horizontal direction as a function of the CoFe thickness. The thickness of CoFe is 3 Å and the Pd thicknesses are 12, 15, and 18 Å. As shown in the perpendicular magnetization graph, the magnetization value is largest when the Pd thickness is 12 Å. Essentially, in this experiment, the volumes of the ferromagnetic materials are all identical, and only the thickness of Pd, which is a non-magnetic metal, is different. These results indicate that the perpendicular magnetization vector in the FM/NM multilayers cannot be understood by conventional magnetic theory. As the Pd thickness increases, the perpendicular (horizontal) magnetization decreases (increases). As the spacer between the ferromagnetic layers becomes thicker, the ferromagnetic coupling between inter-layers becomes weaker. Interfacial anisotropy is a crucial factor to induce perpendicular magnetization, but for a thicker Pd system, the distance between the interfaces is relatively large. In order to obtain an effective anisotropy constant for the FM/NM multi-layers, the dependence of the dipolar spin waves on the magnetic field is necessary [12]. This method is in good agreement with the AGM results [12], showing that the interfacial anisotropy is attributed to the results of this experiment. Considering the perpendicular magnetization curves, the switching processes do not occur sharply, as in the middle of the magnetic reversal process, a serpentine domain appears and disappears again with the saturation field. In the middle of the switching process of an FM/NM system, serpentine patterns are typically observed [11-13].

Figure 5 shows the magnetic properties as a function of the CoFe sputtering power (*P*). The saturation magnetization in the perpendicular direction is nearly constant with different powers, but the saturation magnetization in the horizontal direction becomes smaller, when $P = 50$ W. Above $P = 50$ W, control of the thickness becomes very difficult. From these results, it was found that at least 50 W of sputtering power is necessary in order to suppress the horizontal magnetization. The remanent magnetization, which is an important factor in non-volatile application, is also highest , when $P = 50$ W.

The next issue is the level of the iteration effect on perpendicular magnetization. The perpendicular magnetic properties do not linearly improve as the number of iterations increases. In this case, seven iterations of CoFe/Pd appear most viable for high saturation magnetization and remanent magnetization. However, for other systems, the optimal number of iterations to produce strong anisotropy is different. Gubbiotti *et al.,* [12] reported that a Co/Au multi-layer has high perpendicular anisotropy when 30-50 iterations are done.

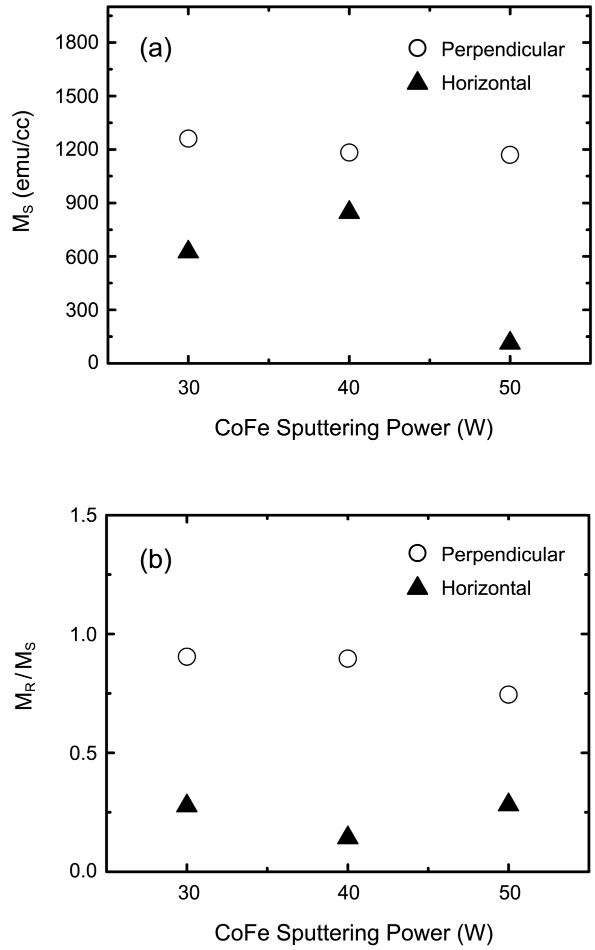

Fig. 5. CoFe sputtering power dependence of magnetic properties. (a) Saturation magnetization(M_S) (b) Ratio of remanent magnetization to saturation magnetization (M_R/ M_S).

4. CONCLUSIONS

CoFe/Pd multi-layers were fabricated in order to obtain a thin-film-based perpendicular magnetization system. The magnetic behaviors in the perpendicular and horizontal directions do not follow the conventional demagnetizing factor theory. Considering the demagnetization factor, a great amount of film thickness is required for a perpendicular anisotropy. Ferromagnetic layers are coupled with other ferromagnetic layers, allowing the thicker Pd layer to create multilayers that have in-plane anisotropy. Small changes in the film thickness and sputtering power induce tremendous variation of perpendicular anisotropy, leading to a relatively small geometry and process margin. However, perpendicular magnetization based on the thin-film technology contributes to the development of high-density recording media. Recently, perpendicular anisotropy has garnered much interest in the field of current-induced domain-wall motion.

ACKNOWLEDGMENT

This work was supported by the KIST Institutional Program.

REFERENCES

1. A. Aharoni, *J. Appl. Phys.* **83**, 3432 (2003).
2. J. H. Kwon, H. C. Koo, H. Yi, and S.-H. Han, *Solid State Phenomena* **124-126**, 911 (2007).
3. R. D. Gomez, T. V. Luu, A. O. Pak, K. J. Kirk, and J. N. Chapman, *J. Appl. Phys.* **85**, 6163 (1999).
4. H. Koo, T. V. Luu, R. D. Gomez, and V. V. Metlushko, *J. Appl. Phys.* **87**, 5114 (2000).
5. H. J. G. Draaisma, F. J. A. den Broeder, and W. J. M de Jonge, *J. Appl. Phys.* **63**, 3479 (1988).
6. P. F. Garcia, *J. Appl. Phys.* **63**, 5066 (1988).
7. H. J. G. Draaisma and W. J. M de Jonge, *J. Appl. Phys.* **62**, 3318 (1987).
8. Garcia, F. Fettar, S. Auffret, B. Rodmacq, and B. Dieny, *J. Appl. Phys.* **93**, 8397 (2003).
9. S. M. Zhou, L. Sun, P. C. Searson, and C. L. Chien, *Phys. Rev. B* **69**, 024408 (2004).
10. Z. Y. Liu and S. Adenwalla, *Phys. Rev. Lett.* **91**, 037207 (2003).
11. F. Albertini, G. Carlotti, F. Casoli, G. Gubbiotti, H. Koo, and R. D. Gomez, J. *Magn. Magn. Mater.* **240**, 526 (2002).
12. G. Gubbiotti, G. Carlotti, F. Albertini, F. Casoli, E. Bontempi, L. E. Depero, P. Mengucci, A. Di Cristoforo, H. Koo, and R. D. Gomez, *J. Appl. Phys.* **93**, 7241 (2003).
13. G. Gubbiotti, G. Carlotti, F. Albertini, F. Casoli, E. Bontempi, L. E. Depero, H. Koo, and R. D. Gomez, *Thin Solid Films* **428**, 102 (2003).