Structural Modification of Magnetic Properties in Perpendicularly Magnetized Co/Pd Multilayer for M RAM

Budi Purnama[1]

***Abstract* — The structural modification of magnetic properties in as grown films of Co/Pd multilayer with perpendicular magnetic anisotropy (PMA) has been systematically studied. The thickness dependence of element multilayer for both the Co thickness t_{Co} and the Pd thickness t_{Pd} as parameters was investigated. Occurred PMA should be correlated to between bi-layers and following the enhancement of interface interaction due to the increase of repetition number bi-layers. The optimal experimental result was obtained for Co = 1.7 Å and Pd = 8.0 Å realizing very good square shape hysteresis curve and high coercive field H_c of 1.5 kOe.**

Keywords — **Multilayer, PMA, MRAM.**

I. Introduction

Since it was firstly introduced by Suna, *et al*., in 1985 [1] Co/Pd multilayer with perpendicular magnetic anisotropy (PMA) has been intensively investigated due to their potential for high recording medium as well as spin electronic device materials. For ultra high-density magnetic recording media application [2], recently the heat assisted magnetization reversal is believed as one prospective scheme. The concept can be adapted to a magnetic random access memory (MRAM) [3, 4]. In thermally assisted MRAM, the switching field is temporally reduced by heating the selected memory cell in the writing process. Consequently the magnetic anisotropy of the storage layer should be large enough to insure thermal stability when is patterned into very small lateral dimension without lose their energy barrier i.e. one of essential key for practical read-write process in spin electronic device. Thus, PMA which suitable for thermally assisted MRAM becomes an essential issue of material magnetic for spin electronic application.

Various efforts for the PMA mechanism have been reported, that the atomic scale is broken symmetry at the interface [1], the stress induced anisotropy in Co and/or Co-Pd alloy [5, 6], hybridization of Co 3*d* and Pd 4*d* [7]. However, the origin mechanism for perpendicularly anisotropy appearance is still unclear. After that, major researcher reported on enhancement of perpendicular anisotropy by using some treatments such as inserted various under layer (single or multi), buffer layer, using selected substrate e.g. Si (111), MgO (111) and annealing at air condition.

In case for TAMR application, high PMA is one criterion and material magnetic owing medium Curie T_C temperature ranging from 120°C to 200°C is required. The medium of the T_C ensure low power consuming in practical application. It is believed that the reduction of field required for magnetization reversal correspond to the reduced of coercive field H_c at elevating temperature. However, recent report indicate that the reduced of field required for switching in TAMR is not simple which material dependence of switching field is one of the variables. Moreover, the strength of medium PMA is closer related to MRAM application [8, 9]. In this paper, the structural control of magnetic properties in Co/Pd multilayer is investigated. By tailoring Co layer, not only fundamental magnetic property of Co/Pd multilayer system can be easily modified, but also thermo-magnetic property material [10]. Here, preliminary material investigation is reported and is discusses on magnetic property at room temperature.

II. Theory

The perpendicular anisotropy constant ($K_\perp$) is generally described (Carcia *et al*, 1984) as:

$$K_\perp = -\left(2K_s + K_v t_{Co} + 2\pi M_0^2 t_{Co}\right)/\lambda \qquad (1)$$

Where K_s is the interface anisotropy energy at each of the two interacting bi-layer period, volume anisotropy (K_v) and the shape anisotropy of the Co layers ($2\pi M_0^2 d$). Clearly here, the balanced of three element anisotropy define the strength PMA.

The interface anisotropy are mainly attributed from interaction between bi-layer in multi-layer system. In case of ultra thin film with perpendicular anisotropy has one possibility to improve interfacing used under layer film. Later, many experiment reports successfully improve the strength of PMA by using under layer film.

The second element for PMA rises from the K_v. The magnitude of the K_v is larger than the crystallographic value for hexagonal Co and may be due to magnetostrictive effects [11]. A tensile stress in Co due to lattice mismatch of Co and Pd brings into being a large magnitude of K_v. Here, tailoring Co thickness in Co/Pd structure will modify PMA.

The third element for PMA comes from the shape anisotropy of Co layer. The factor is origin from Co element and magnetization tends to in-plane film.

III. Experimental

The structured multilayer films were fabricated on glass substrates by a tandem type DC magnetron sputtering with a multi-cathode system (Anelva SPC-350). The background pressure before deposition was below 5.0×10^{-7} Torr and the Ar pressure during the deposition was 20 m Torr at 1.0×1.0 cm glass substrate.

[1]Budi Purnama is with the Department of Physics, Faculty of Mathematics and Natural Science, Universitas Sebelas Maret, Surakarta, Indonesia. E-mail: bpurnama@uns.ac.id.

The substrate mounted on a sample holder was rotated at 50 rpm around the Co and Pd targets with a PC controlled shutter system. The sputtering rates for Co and Pd are 1.0 Å/sec and 0.36 Å/sec, respectively. The structural control of magnetic properties were studied for the following materials $[Co(t_{Co})/Pd(5.5\ Å)]_{30}$ where t_{Co} = 2.4 Å; 2.8 Å; 3.2 Å and 3.6 Å and $[Co(t_{Co})/Pd(8.0\ Å)]_{30}$ where t_{Co} = 1.0 Å; 1.7 Å; 2.0 Å; 3.0 Å and 3.6 Å

In order to evaluate the magnetic property, vibrating sample magnetometer (VSM) is performed and measurement carried out in room temperature for as grown sample. It is noted that the applied field is perpendicular to the films, which is the case for all measurements presented in this paper.

IV. RESULT AND DISCUSSION

Fig. 1. Shows the magnetization curve profiles associated with the above structure. The multilayer explored are optimized to minimize the domain wall pinning realizing strongly PMA with the square shape of the *M-H* curve. For all of the *M-H* curves, the saturation magnetization increases with the increase of Co thickness layer (t_{Co}). The raise of t_{Co} also decreases of nucleation field H_n for all typical structural samples. Moreover in case of structured multilayer of $[Co(t_{Co})/Pd(5.5\ Å)]_{30}$ with t_{Co} = 3.2 Å, the H_n of -18 Oe and H_c of 500 Oe is obtained. However, it is compensated by poor square shape and a large field required for switching due to complicated multi domain configuration as shown at Fig. 1(a).

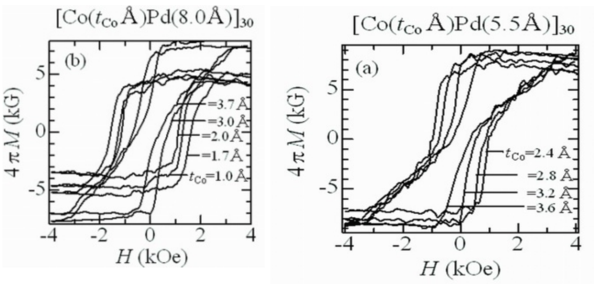

Fig. 1. The hysteresis magnetization (*M-H*) curve of perpendicular anisotropy magnetic for (a) $[Co(t_{Co})/Pd(5.5\ Å)]_{30}$ where t_{Co} = 2.4 Å; 2.8 Å; 3.2 Å and 3.6 Å (b) $[Co(t_{Co})/Pd(8.0\ Å)]_{30}$ where t_{Co} = 1.0 Å; 1.7 Å; 2.0 Å; 3.0 Å and 3.6 Å

A little different results demonstrates for $[Co(t_{Co})/Pd(8.0\ Å)]_{30}$ multilayer series. The H_c gradually decreases with the increase of the t_{Co} exception for very thin Co thickness layer of 1.0 Å. It is can be attributable to an imperfect interface between Co and Pd layer. However, samples loss their square shape of the *M-H* curve when t_{Co} > 2.0 Å. As alloying multilayered Co/Pd dependence of elements layer is discussed, so there is a condition for both Co and Pd layers element completely compounded to be alloy realization. Here, stress induced anisotropy promote a perpendicular anisotropy magnetic realization. In increasing number of bi-layer, the huge interface anisotropy energy occur breakthrough symmetry, thus realizing a large perpendicular anisotropy magnetic. Furthermore, the raise of individually element cannot change the alloying composition; however only enrich Co (transition metal element = TM) or Pd (rare earth element = RE) contain in Co/Pd multilayer structure.

Regarding Equation 1 for case of TM rich multilayer, the enhancement of both volume and shape anisotropy is suggested dominantly compete with interface anisotropy energy. Since the K_{shape} of Co tends to in-plane anisotropy so the poor square shape of *M-H* curve is obtained as shown in Fig. 1b. ($t_{Co} \geq 2.0$ Å). Contrast for RE rich multilayer, remaining RE element layer reduces interface interaction between bi-layer. Here, the reduced of strength PMA hardly change square shape of *M-H* curve. The highest H_c of 1.5 kOe for t_{Co} = 1.7 Å can be suggested with the minimum miscible elements of alloying Co/Pd in surface.

The structural composition dependence of saturated magnetization ($4\pi M_S$) for two series is depicted in Fig. 2. For all case, saturated magnetization of t_{Pd} = 5.5 Å series is much larger than t_{Pd} = 8.0 Å. This is can be related to the volume anisotropy (K_v) and the shape anisotropy (K_{shape}) of the remaining Co layers after alloying bi-layer which is represented to ratio of TM and RE element in bi-layer structure. Minimum value of ratio TM-RE for t_{Pd} = 5.5 Å series is 0.44 (t_{Co}/t_{Pd} = 2.4/5.5) and 0.125 (t_{Co}/t_{Pd} = 1.0/8.0) for t_{Pd} = 8.0 Å series. From this data, the remaining Co layer for t_{Pd} = 5.5 Å series were much larger than t_{Pd} = 8.0 Å series within result, a large magnetization saturated of t_{Pd} = 5.5 Å series.

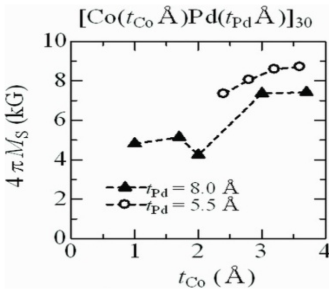

Fig. 2. The magnetization saturated $4\pi M_S$ as a function of structural composition in Co/Pd multilayer system

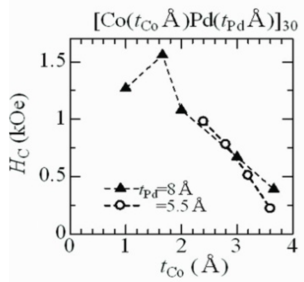

Fig. 3. The coercive field H_c as a function of structural composition in Co/Pd multilayer system

Fig. 3 show the coercive field H_c as a function of structural composition in two various Co/Pd multilayer systems. In general, the H_c decrease with the increase of Co thickness layer except for t_{Co} = 1.0 Å of t_{Pd} = 8.0 Å series. The H_c increases with the decrease of t_{Co} reflecting the property of the surface anisotropy enhanced at the thinner thickness. The highest coercive value is obtained 1.56 kOe for structural composition t_{Co}

= 1.7 Å of t_{Pd} = 8.0 Å. The rapid reduction of H_c at t_{Co} = 1.0 Å of t_{Pd} = 8.0 Å series can be attributable to an imperfect interface between Co and Pd layers

V. Conclusion

The structural control of magnetic properties in as grown films of Co/Pd multilayer has been systematically studied. The thickness dependence of element multilayer for both the Co thickness t_{Co} and the Pd thickness t_{Pd} as parameters was investigated. PMA occurred should be correlated to alloying between bi-layer and following the enhancement of interface interaction due to the increase of repetition number bi-layer. The optimal experimental result was obtained for Co = 1.7 Å and Pd = 8.0 Å realizing very good square shape hysteresis curve and high coercive field H_c of 1.5 kOe.

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References

[1] Carcia, P.F., Meinhaldt, A.D and Suna, A., 1985, *Perpendicular Magnetic Anisotropy in Pd/Co Thin Film Layered Structures*, Appl. Phys.Lett., 47 p.178.

[2] Weller, D and McDaniel, T. , 2006, in *Advanced Magnetic Nanostructures*, edited by D. J. Sellmyer and R. Skomski, Springer, Berlin p.295.

[3] Beech, R. S., Anderson, J. A., Pohm A. V., and Daughton, J. M., 2000, *Curie Point Written Magnetoresistive Memory*, J. Appl. Phys., 87 p.6403.

[4] Prejbeanu, I. L., Kerekes, M., Sousa, R.C., Sibuet, H., Redon, O., Dieny B., and Nozières, J.P., 2007, *Thermally Assisted MRAM*, J. Phys.: Condens. Matter, 19 p.165218.

[5] Hashimoto, S., Ochoai, Y., and Aso, K., 1989, Perpendicular Magnetic Anisotropy and Magnetostriction of Sputtered Co/Pd and Co/Pt Multilayered Films, J. Appl. Phys. 66, 4909-4916.

[6] Kim, S. K., and Shin, S. C., 2001, *Alloy-like Co Environment in Co/Pd Multilayer Films Having Perpendicular Magnetic Anisotropy*, J. Appl. Phys. 89, 3055-3057.

[7] Sawad, M., Hayashi, K., and Kakizaki, A., 2003, *Perpendicular Magnetic Anisotropy of Co/Pd (111) Studied by Spin-Resolved Photoelectron Spectroscopy,* ***J. Phys. Soc. Jpn.*** 72, 1161-1165.

[8] Budi Purnama, Nozaki, Y., and Matsuyama, K., 2007, *Micromagnetic Simulation of Thermally Assisted Magnetization Reversal in Magnetic Nanodot with Perpendicular Anisotropy,* J. Magn. Mag. Mater., 310 p. 2683-2685.

[9] Budi Purnama, Tanaka, T., Nozaki, N., and Matsuyama, K., 2009, *Material Dependence of Thermally Assisted Magnetization Reversal Properties in Microstructured Co/Pd Multilayers*, Appl. Phys. Express 2 p. 033001-033003.

[10] Budi Purnama, Nozaki, Y., and Matsuyama, K., 2008. *Structural Control of Magnetic Properties in Co/Pd Multilayer for Heat Assisted Perpendicular MRAM Application*, Res. Rep. on ISEE of Kyushu University 13(2) p. 75-79.

[11] Cullity, B.D., 1972. Introduction to Magnetic Materials, Addison-Wesley, Reading, MA p. 248.