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Magnetization Reversal and Switching Field Distribution in Co-Tb based Bit Patterned Media

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Abstract. We have fabricated ordered array of ferromagnetic nanodots, so-called nanobumps by depositing Ta(5nm)/Pt(5nm)/Co88Tb12(5nm)/Cu(2nm)/Pt(5nm) mutilayers onto the barrier layer of auto-assembled anodic alumina template with 100 nm period. The same multilayers was deposited on a flat Si/SiOx substrate (the so-called reference sample) for comparison. We used extraordinary Hall Effect (EHE) measurements to probe magnetization reversal mechanism and switching field distribution (SFD) of these two kinds of materials. The extraordinary Hall resistivity measurements were performed by a standard four-probe method. The measurement of the coercivity as a function of magnetic field angle with respect to the sample surface reveal that ferromagnetic nanodots follow Stoner-Wohlfarth model with a shallower variation, which is typical of a dot-by-dot reversal but with a nucleation/propagation process for each dot. On the other hand, multilayers deposited on flat substrate follow Kondorskey model, which indicate nucleation/ propagation type reversal. Finally, we have calculated switching field distribution for nanobump material.

INTRODUCTION

Recently, bit patterned media (BPM) technologyhas been emerged as one of the promising way to enhance the areal density of media used in hard disk drive [1-3]. In such BPM, isolated magnetic nanostructures are artificially created through lithography technique or combination of e-beam lithography methods with other techniques such as electro-depositionand self-assembling block copolymers.Since the lithographic techniques are very expensive and time-consuming technique, the other way to fabricate BPM in economical way is using non-lithography techniques, such as using ordered array of nanostructured bumps which serve as pre-patterned substrate [4]. In addition to BPM fabrication, there are several other challenges such as cost, uniform pattern size, controlling switching field distribution (SFD) etc., which have to be overcome prior to the commercialization of media. One the most important characteristics which need to be controlled is the SFD of the magnetic dots [5-9] and it should be sufficiently narrow to address each bit of the media. Ideally, the magnetic nanodots should have a single write field at which their magnetization is reversed. However, the variations in the magnetic properties such as anisotropy field, saturation magnetization and exchange coupling, influence the distribution of switching field [1 -3]. Since a larger SFD will lead to increased amount of write-in errors, SFD is an important topic studied by several researchers.Among various available tools, Extra ordinary Hall effect (EHE) measurement have been taken as a simple and effective tool to understand the magnetization reversal and switching field distribution of bit patterned media [10].In such EHE measurement, the Hall voltage can serve as a direct measurement of magnetization and it can be understand by the fundamental equation of Hall Effect in magnetic materials, i.e.$\rho_H = R_0 H + R_S M_Z$. Here $\rho_H$is the Hall resistivity, Ro is the ordinary Hall coefficient, $R_s$is the extraordinary Hall coefficient, and $M_z$the component of magnetization perpendicular to the plane.In present work, we have used EHE measurement to probe the magnetization reversal and switching field distribution of Co-Tb based bit patterned media.

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EXPERIMENTAL DETAILS

We have depositedTa(5nm)/Pt(5nm)/Co88Tb12(5nm)/Cu(2nm)/Pt(5nm)onto the barrier layer of auto-assembled anodic alumina template with 100 nm period using sputtering machine to form an ordered array of ferromagnetic nanodots, so-called nanobumps. The barrier layer of AAO, which serve as prepatteredsubstrate was used to modulate the thickness of thin film of Co-Tb alloy deposited on it. Due to the bumpy surface of AAO, the deposited film experiences a variable thickness along the surface, up to the total thickness of the magnetic stack at the top and much thinner close to the bottom of the bumps [4, 10].Arepresentative diagram for deposition of materials is shown in Figure 1 (a).The same multilayer was deposited on a flat Si/SiO_x substrate (the so-called reference sample) for comparison. The extraordinary Hall resistivity measurements were performed by a standard four-probe method in order to probe magnetization reversal and SFD.

RESULTS AND DISCUSSION

Figure 1 (b) shows the room temperature EHE hysteresis loops of materials deposited on nano-bump as well as on flat substrate.The external magnetic field was applied perpendicular to the substrate. It shows that hysteresis curve of the Co-Tb multilayers grown on the flat substrate i.e. reference sample, exhibits sharp reversal. On contrary, the Co-Tb multilayer grown on the bumpy sample, exhibits sheared EHE hysteresis curve. But, it has got very high coercive field as compared with the reference sample. The EHE hysteresis curve measurement for reference sample was carried out at other two low temperatures, i.e. at 100 and 200 K. Figure 2 (a) shows the EHE hysteresis measurements at 100, 200, and 300 K for Co88Tb12 (5nm) alloy deposited on flat Si/SiO_x substrate.The coercivity of reference sample was found to increase with decrease of the temperature and it is shown in the inset of Figure 2 (a). The decrease of coercivity can be understood by the change of magnetization reversal mechanism. In order to understand the magnetization reversal process in reference sample, we have measured the evolution of the coercivity as a function of magnetic field angle at room temperature (Figure 2 b). This curve indicate that the relative reversal field in the reference sample follows the variation calculated for the Kondorsky like behavior (i.e., domain wall propagation driven reversal) [11]. In the case of the reference sample, nucleation occurs in a region with lower-than averaged anisotropy and the full reversal is achieved by domain wall propagation.

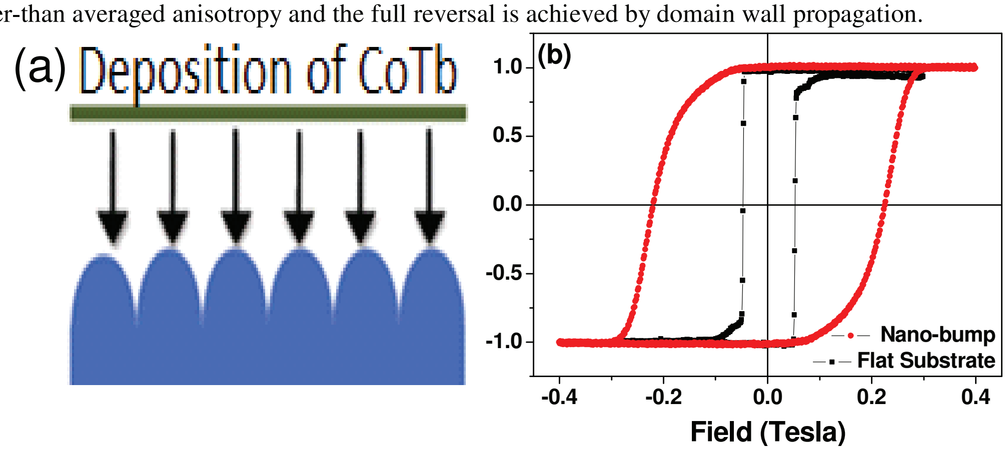

FIGURE 1: (a) Schematic of deposition of Co-Tb on nano-bumps (b) Comparison of EHE hysteresis curve for multilayers deposited on flat substrate and on nano-bumps.

We have measured the EHE hysteresis curve for Co-Tb multilayers deposited on pre-patterned substrate i.e. on nanobumps. The measurements was carried out at various temperatures, i.e. at 300 K, 250K, 200 K and 170 K and they are presented in Figure 3 (a). At 300 K, the loop shows a fully saturated magnetization at remanence but the reversal branches are sheared. As the temperature decreases from 300 K to lower temperatures, down to 170 K, the coercive field increases linearly from 0.22 T at 300 K to 0.776 T at 170 K [inset Fig. 3(a)]. The evolution of the coercivity as a function of magnetic field angle with respect to the surface normal, measured at various temperatures is presented in Figure 3(b). It indicate that the coercivity at 300 K decreases when the field angle increases from 0° to 45° and then increases again from 45° up to 75°. Coercivities at 0° and 75° have almost the same value, and the value at 45° is about ¾ of the value at 0°. It should be noted that *Hc* is usually considered as switching field of the average dots, and thus the field angle dependence is to be compared to the two extreme models that characterize a macrospin type reversal, namely a nucleation/ propagation type reversal, namely the Kondorsky model [11] and the Stoner-Wohlfarthmodel [12]. The experimental results at 300 K are very close to the Stoner-Wohlfarth model but with a shallower variation, which is indication of a dot-by-dot reversal but with a nucleation/propagation process for each dot. It indicate that, the reversal at room temperature takes place dot by dot due to a partial exchange decoupling between the bumps [10]. Although, changing the temperature from 300 K to 170 K does not drastically affect the hysteresis loop shape but there are changes in the field angle dependence of the coercivity [Figure 3(b)]. Below 200 K, the coercivity's angular dependences changes are very similar to nucleation/ propagation type reversal, namely the Kondorsky model [11] i.e. nucleation of one or some reversed domains occurs at low anisotropy spots and magnetization reversal proceeds through propagation of the domain walls over the whole sample. This can be understood by the continuous reduction of thermal effects acting on the nucleation process.

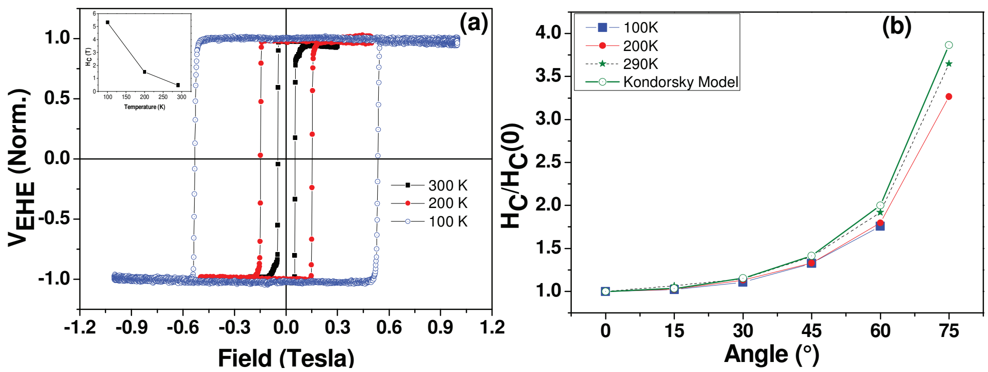

FIGURE 2. (a) EHE measurements at 100, 200, and 300 K for Co88Tb12 (5nm) alloy deposited on flat Si/SiOx substrate. The inset shows the variation of the coercive field with temperature (b) Variation of coercivity as a function of the angle of the applied field measured at 170, 200, 250 and 300 K.

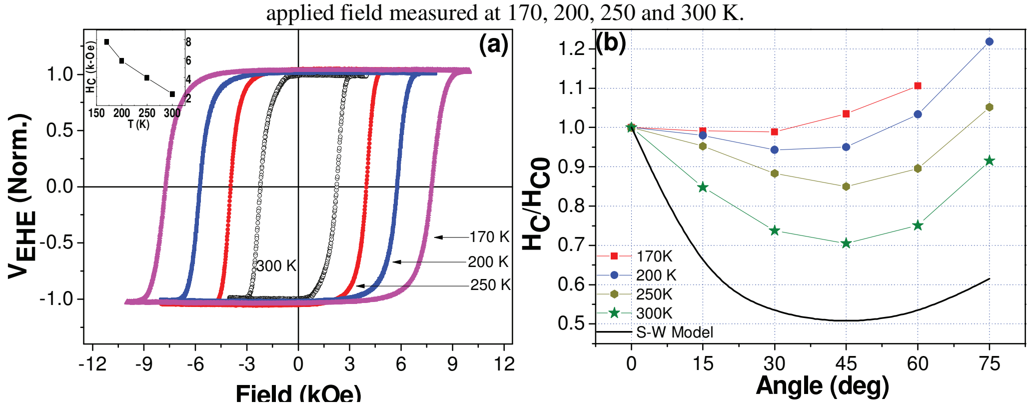

FIGURE 3. (a) EHE measurements at 170, 200, 250 and 300 K for Co88Tb12(5nm) alloydeposited on a bumpy surface of AAO for *p* = 100 nm. The inset shows the variation of the coercive field with temperature (b) Variation of coercivity as a function of the angle of the applied field measured at 100, 200 and 300 K.

In order to characterize BPM switching and especially SFD of BPM systems, we have calculated the derivative of the hysteresis loop reversal branches measured at various temperatures. Figure 4(a) shows the derivatives for the descending branches of loops. For all temperatures, the derivative curve shows a single peak, typical of a single step reversal. We have fitted the hysteresis loop derivative with Gaussian function to extract the peak maximum field and the standard deviation σ of the peak. We chose to define SFD as the standard deviation sigma of a Gaussians function. The inset of Figure 4(b) shows the variation of SFD with temperature and it indicate that the SFD increases linearly with decrease of the temperature. At 300 K, SFD is about 0.24 T and increases up to 0.79 T at 170 K. The increase of SFD with temperature can originate both from the intrinsic SFD (dot-to-dot variation of anisotropy) or from the increase of dipolar field induced SFD. The SFD value is found high as compared with the coercivity value. The relative SFD, i.e. SFD/*Hc,* is about 14% at 300 K, which is little higher than usual values of approximately 10% found in Co/Pt-based BPM [10]. In order to further understand the reversal mechanism, we measured set of recoil curves, as shown in Figure 4 (b). Here, the recoil curves have been generated at reversal fields corresponding to fractions of switched bumps η = 23%, 50%, and 70%. The derivative of the recoils curve as shown in the inset of Figure 4 (b) and it shows that this reversal is much shallower than the minor curve taken at 50% reversal, revealing the influence of the dipolar field on the SFD and possible differences in the reversal mechanism.

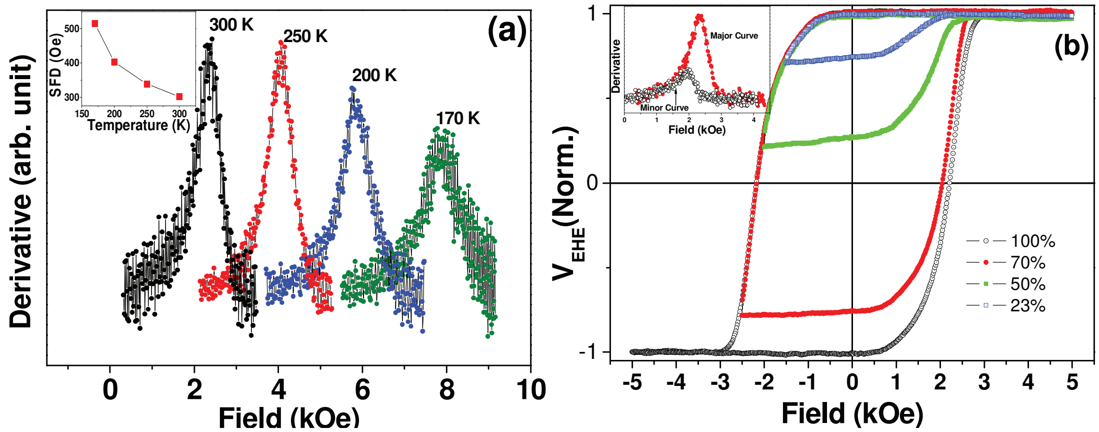

Figure 4. (a) Derivative of EHE loops for Co88Tb12 (5nm) alloy on a 100 nm period bump surface measured at 170, 200, 250 and 300 K. The inset shows the switching field distributionderived from the Gaussian fitting of the derivatives of EHE loops (b) EHE measurement of out-of-plane major and minor loops for Co88Tb12 Nano bump array with p = 100 nm. The percentage values correspond to the ratio of switched nano-bumps during each loop.

CONCLUSION

We have studied the magnetization reversal and switching field distribution in Co88Tb12 (5nm) alloydeposited on top of 100 nm AAO nano-templates. EHE measurement reveal an incoherent magnetization reversal mechanism, most probably based on a nucleation propagation process inside each bump, as usually observed in nano-objects of this size. The relative SFD, was found about 14% at 300 K, which is little higher than usual values of approximately 10% found in other BPM system.

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REFERENCES

1. B. D. Terris, M. Albrecht, G. Hu, T. Thomson, and C. T. Rettner, IEEE Trans. Magn. 41, 2822 (2005).
2. H. J. Richter, A. Y. Dobin, R. T. Lynch, D. Weller, R. M. Brockie, O. Heinonen, K. Z. Gao, J. Xue, R. J. Veerdonk, P. Asselin, and M. F. Erden,Appl. Phys. Lett. 88, 222512 (2006).
3. C. Ross, Ann. Rev. Mater. Res. 31, 203 (2001).
4. L. Piraux, V. Antohe, F. A. Araujo, S. K. Srivastava, M. Hehn, D. Lacour, S. Mangin and T. Hauet' App. Phys. Letter, 101 (2012) 013110
5. J. M. Shaw, W. H. Rippard, S. E. Russek, T. Reith, and C. M. Falco, J. Appl. Phys. 101, 023909 (2007).
6. R. L. White and R. F. W. Pease, IEEE Trans. Magn. 33, 990 (1997).
7. O. Hellwig, J.
8. K. Bosworth, E. Dobisz, D. Kercher, T. Hauet, G. Zeltzer, J. D. Risner-Jamtgaard, D. Yaney, and R. Ruiz, Appl. Phys. Lett. 96, 052511 (2010).
9. P. W. Nutter, I. T. Ntokas, B. K. Middleton, and D. T. Wilton, IEEE Trans.Magn. 41, 3214 (2005).
10. T. Hauet, L. Piraux, S. K. Srivastava, V.A. Antohe, D. Lacour, M. Hehn, F. Montaigne, J. Schwenk, M.A. Marioni, H.J. Hug, O. Hovorka, A. Berger, S. Mangin, F. Abreu Araujo, Phys. Rev. B 89 (2014) 174421
11. E. Kondorsky, J. Phys. Moscow **2**, 161 (1940).
12. E. C. Stoner and E. P. Wohlfarth, Philos. Trans. R. Soc. LondonA **240**, 599 (1948).