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The Effect of Size Distribution on the Switching Field Distribution of Co/Pd Multilayered Nanostructure Arrays

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Abstract — **We use Ion Beam Proximity Lithography (IBPL) to produce 4mm x 4mm arrays of 220 nm dots in perpendicularly - oriented Co/Pd multilayered media. IBPL is used to reduce the size distribution σ_D of the arrays, and subsequently He$^+$ ion irradiation is used to reduce their anisotropy. The Switching Field Distribution σ_{Hcr}/H_{Cr} is measured for each sample before and after irradiation, and a linear relationship is experimentally found between σ_{Hcr}/H_{Cr} and σ_D. We argue that the slope of the line is due to the self-demagnetization effect of individual dots (and therefore, it is not strictly a line) and that the intercept of the line is inversely proportional to the permeability of the nanostructured material.**

INTRODUCTION

THE origin and control of the distribution of the switching fields (SFD) of nanostructured arrays of single-domain, perpendicularly-oriented magnetic materials is mystery in need of a solution before data storage schemes based on bit patterned arrays and digital logic devices based on magnetic cellular automata can be successfully implemented [1-6]. Several causes have been proposed, lithographic [3], microstructural [4], and magnetic [5]. Indeed, these are not mutually exclusive, as the orientation of the grains affects their anisotropy, providing ideal sites for nucleation embryos [6].

In this talk we will discuss the effects of nanodot size and perpendicular anisotropy from carefully controlled experiments on perpendicularly-oriented Co/Pd nanostructures that will allow us to quantify lower bounds for their contributions to the SFD. The standard deviation in the diameter σ_D can be used to characterize the size distribution of the nanodots, and we control this parameter systematically using a multiple exposure ion beam proximity lithography (IBPL) technique. From this we will determine the minimal percentage of the SFD that comes from demagnetization effects and extract a parameter unrelated to them. This parameter will then be investigated by

He$^+$ ion irradiation of the samples, which has been found to change the anisotropy K_U and the coercivity H_c of Co/Pd samples without affecting their saturation magnetization M_S [7].

SAMPLE PREPARATION

High anisotropy perpendicular media comprised of Co/Pd multilayers are prepared by magnetron sputtering at room temperature. The base pressure before deposition is better than 2.0×10^{-8} Torr and the pressure during deposition is maintained at 2.5 mTorr. A seed layer of 5nm Ta is deposited on a thermally oxidized Silicon substrate followed by ten alternating layers each of Co and Pd using thicknesses optimized for perpendicular recording creating a final structure of SiO$_x$/Ta 5nm/[Co 2Å/Pd 8Å]$_{10}$.

Patterning of the sputter deposited materials is carried out by spinning the positive tone photoresist, PMMA, onto the magnetic materials and exposing the sample to 30 keV He$^+$ ions through a stencil mask. The stencil mask fabrication process has been previously described [8]. After development Al is evaporated on the sample followed by lift off to perform a tone reversal of the print. The Al is used as a hard mask for Ar$^+$ ion milling through the magnetic multilayers (t=10nm).

Size variation in the nanodots is unavoidable and a result of variations in the electron beam patterning and reactive ion etching used to create the openings in the stencil mask. However, IBPL is a very flexible technique, and we have devised a means for reducing the size variation of the final magnetic nanodot arrays.

A set of deflection plates are used to deflect the broad ion beam in the x- and y- directions, and previously used to define unit cell patterns and dose correction through array aperture lithography [9]. This same deflection scheme will now be used to deflect the beam such that the dose for each printed feature is a summation of fractional doses printed by N near neighbors. In the case of overlapping 4 nearing neighbors, each nanodot would be printed with $1/(N+1) = 1/5$ of the desired dose from neighboring openings through deflection. This process could be carried out repeatedly for N number of near neighbors.

Four samples are produced using this near neighbor technique where the N used is 0 (single exposure), 2, 4, and 8. Size mean and standard deviation are computed using least-squares fit to a Gaussian distribution. The size variation is measured as 24, 38, 20, and 15nm, respectively. The samples all posses a mean diameter of 220nm and a pitch of 333nm.

After measurement, the same four samples are irradiated with He+ ions to reduce the anisotropy [7].

DICSUSSION

Magnetic measurements are performed with a polar MOKE. The remnant hysteresis loop is measured and a Gaussian curve fit to its numerical derivative, dM_r/dH, where the width of the Gaussian fit is denoted as σ_{Hcr}. The fitting procedure is shown in Figure 2. We then characterize the SFD by the normalized ratio $s=\sigma_{Hc}/H_{Cr}$. The variation of s with σ_D was experimentally determined to be linear, $s(\sigma_D)=s_0+s_\sigma\sigma_D$, where s_σ is the slope and s_0 is the intercept of the line shown in Figure 3. The line's slope was found to be dependent upon the self-demagnetization field H_d of the dots,

$$S_\sigma = \frac{1}{H_{Cr}}\frac{dN_d}{dD}.$$

The slope of line in Figure 3 is exactly this quantity, computed using the $M_s = 1300$ emu/cc to match the surface charge on the oblate spheroid from which H_d is calculated.

We are therefore lead to the interpretation of s_0 as the total contribution of the switching field distribution not related to volumetric self-demagnetization effects, and this allows us to extract a minimum percentage of s that comes from fabrication effects.
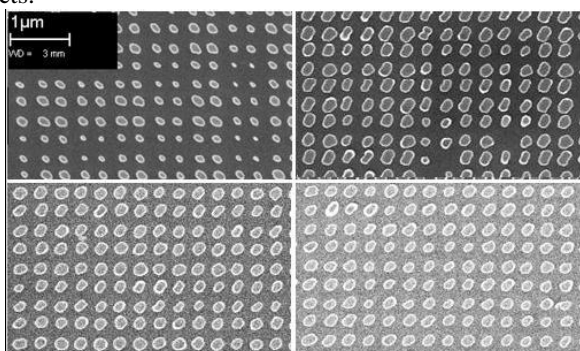

Figure 1: SEM images of the patterned arrays after (a) 1, (b) 2, (c) 4, and (d) 8 exposures evidencing the improvement in the size distribution of elements of the arrays.
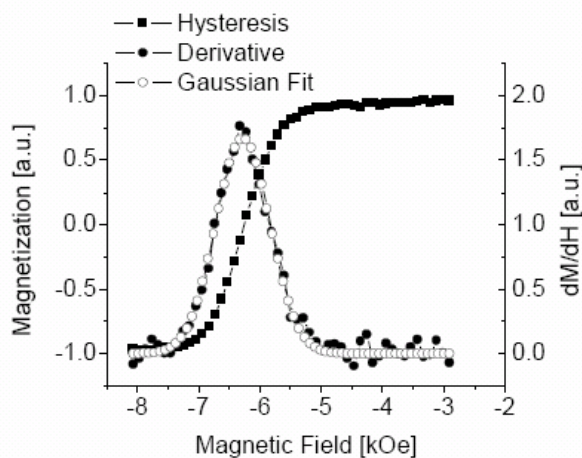.

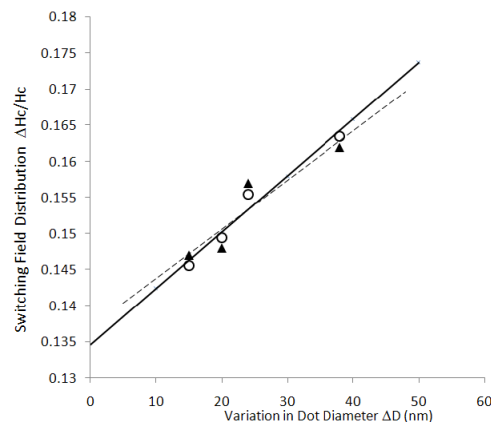**Figure 2:** Fit of the switching field distribution to the remnant hysteresis loop of the N = 4 sample.

Figure 3: The normalized switching field distributions showing the linear relationship between the size distribution and the measured switching field distribution (closed triangles) along with comparison to the predicted values (open circles). The solid line is the fit to the theory and the dashed line is the best fit curve.

REFERENCES

[1] D. Litvinov, C. E, V. Parekh, D. Smith, J. Rantschler, S. Zhang, W. Donner, T.R. Lee, P. Ruchhoeft, D. Weller, and S. Khizroev, "Design and Fabrication of High Anisotropy Nanscale Bit-Patterned Magnetic Recording Medium for Data Storage Applications," ECS Transactions, vol. 25, pp. 249-258, 2007.

[2] J. Shaw, W. Rippard, S Russek, T. Reith, and C. Falco, "Origins of Switching Field Distributions in Perpendicular Nanodot Arrays," *J. Appl. Phys.*, vol. 101, 023909-1-4, 2007.

[3] Y. Kitade, H. Komoriya, and T. Maruyama, "Patterned Media Fabricated by Lithography and Argon-Ion Milling," *IEEE Trans. Magn.*, Vol. 40, pp.2516-8, 2004.

[4] C. Haginoya, S. Heike, M. Itabashi, N. Nakamura, K. Koike, "Magnetic Nanoparticle Array with Perpendicular Crystal Magnetic Anisotropy," *J. Appl. Phys.*, vol. 85, pp. 8327-30, 1999.

[5] T. Thomson, G. Hu, and B.D. Terris, "Intrinsic Distribution of Magnetic Anisotropy in Thin Films Probed by Patterned Nanostructures," *Phys. Rev. Lett.*, vol. 96, pp. 257204-1-4, 2006.

[6] J. W. Lau, S.-H. Chung, R.D. McMichael, J. O. Rantschler, V. Parekh, D. Litvinov, "Microstructural Origin of Switching Field Distribution in Patterned Co/Pd Multilayer Nanodots," *Appl. Phys. Lett.*, accepted for publication.

[7] V. Parekh, "He+ ion irradiation study of continuous and patterned Co/Pd multilayers," *J. Appl. Phys.*, vol. 101, pp. 083904-1-4, 2007.

[8] V. Parekh, E. Chunsheng, D. Smith, A. Ruiz, J. C. Wolfe, P. Ruchhoeft, E. Svedberg, S. Khizroev, and D. Litvinov, *Nanotech.*, 17, pp. 2079-2082, 2006.

[9] P. Ruchhoeft and J. C. Wolfe, *J. Vac. Sci. & Tech. B*, vol. 19, pp. 2529-2532, 2001.