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Magnetic Behavior of Co/Pt and TbCo Nanocaps Assembly for Bit Pattern Media

A. Sediri[1], L. Piraux[2], V. A. Antohe[2], F. Abreu Araujo[2], M. Hehn[1], D. Lacour[1], S. Mangin[1], T. Hauet[1]

[1] *Institut Jean Lamour, UMR CNRS 7198, Nancy-Université, 54506 Vandoeuvre lès Nancy, France*
[2] *Institute of Condensed Matter and Nanosciences, Université catholique de Louvain, Place Croix du Sud, B-1348, Louvain-la-Neuve, Belgium*

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Large area patterning of self-assembled alumina nanobumps, with hexagonally close-packed order, has been used to create ordered array of bit pattern magnetic media. We have studied the magnetic properties of perpendicular magnetic TbCo alloy and Co/Pt multilayers deposited on self assembled alumina nanobumps. Measurement of reversal field as a function of field intensity, as well as magnetic force microscopy images confirm the weakness of exchange coupling between bits in the case of Co/Pt multilayer while stronger coupling is observed in the case of TbCo alloys.

Keywords: Bit pattern media, Nanomagnetism, Self-assembly, Anodic alumina template, Multilayer, Alloy.

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1. INTRODUCTION

Magnetic storage and magnetic recording refer to systems that store data on a magnetic medium, providing non-volatility and unlimited rewriting capability [1]. As of today, Hard Disk Drive (HDD) are widely used to store computer data as well as audio and video signals. One of the most promising methods to circumvent the density limitations of current media in HDD and to keep increasing the areal density is the use of bit patterned media (BPM) [1]. In this unconventional media, the magnetic layer is created as an ordered array of highly uniform islands, each island capable of storing an individual magnetic bit. Since each island is a single magnetic domain, patterned media is thermally stable, even at densities far higher than can be achieved with current conventional media. However, pattern media implementation faces several technological challenges, including thermal stability or dot-to-dot switching field distribution. One of the main issue in the view of building BPM consists in finding a reliable patterning process to create an array of perfectly aligned and controlled in size magnetic dots over a millimeter scale. There are many ways to obtain isolated magnetic nano-objects [1]. For bit patterned media two classes of pattern transfer processes can be distinguished according to where in the process flow the lithography step occurs. In the first class, namely the pre-patterning process, a seed layer is first deposited on the substrate and then patterned to create a surface of magnetic pillars and trenches, or with holes, over which the magnetic medium is sputter deposited [2]. In that case, the final magnetic bits stand either on top of the seed dots or in the holes. On the other hand, in the processes referred to as post-patterning, seed layer and magnetic film are first deposited; then subtractive lithography steps are applied to create an array of magnetic dot. The relative advantages and disadvantages of these two approaches are still under debate in view of their integration into real HDD recording [1,2].

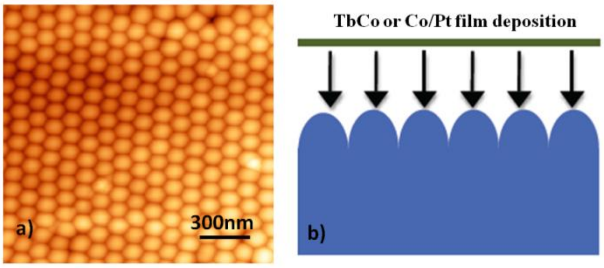

Fig. 1 – a) Atomic force microscopy image of the bumpy surface used at pre-patterned seed layer. b) Sketch of the deposition of Co/Pt multilayer or TbCo alloy on the bumpy AAO surface.

We have recently developed a simple and inexpensive pre-pattern method using self-assembly anodic alumina templates (AAO) [3]. The method involves the growth of magnetic nanocaps on the bumpy back of nanoporous anodic alumina templates (AAO), which is a typical self-ordered nanopore-array material formed by the electrochemical oxidation of Al in acidic solutions [4]. It is described in more details in Ref. [3]. Our method is very similar to the BPM arrays obtained with self-assembly of colloidal nanospheres [5]. However, several problems associated with attractive forces between the polystyrene spheres should prevent the formation of array of spheres with good long range order when considering diameters below 50 nm whereas regular nanopore arrays in AAO with ultra small pore diameter (even less than 10 nm) and pore interdistance as small as 15 nm have already been demonstrated [6,7].

In the present paper, we report on the use of TbCo alloy and Co/Pt multilayer as magnetic nanocap media deposited on top of our AAO-based nanobump array. We demonstrated that although the direct exchange coupling between Co/Pt nanocaps is weak, the exchange coupling between caps strongly affects the magnetic behavior of the TbCo media. Such a difference may be explained by considering the different nature (amorphous alloy or multilayer) of the media and its growth in between the bumps.

2. SAMPLE FABRICATION

The pre-patterned substrates are form of a hexagonally close-packed array of nanobumps having about 100 nm lateral modulation period and 50 nm height variation. Fig.1(a) represents a typical atomic force microscopy image of the surface of the bump array. TbCo amorphous alloy and Co/Pt multilayer film was respectively coated onto two identical bumpy substrates by magnetron-sputtering deposition (Fig. 1(b)). The same samples were simultaneously grown on flat Si substrate as reference samples for comparison. The multilayer consisted in a Ta(5 nm)/Pt(5 nm)/[Co(0.36 nm)/Pt(0.73 nm)]$_4$ /Pt(3.5 nm). The amorphous alloy stack consisted in Ta(5nm)/Pt(5nm)/Co88Tb12(5nm)/Cu(2nm)/Pt(5nm). The top Pt layer is used to prevent oxidation. Both systems corresponds to model system for BPM since they have strong perpendicular magnetocrystalline anisotropy such that the magnetization aligns normal to the films surface and has a large stability against thermal activation.

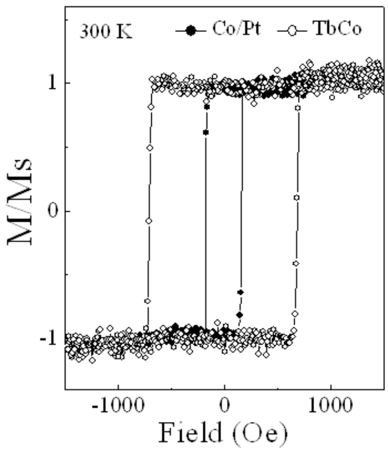

Fig. 2 – Hysteresis loops at 300 K, for Co/Pt and TbCo deposited on flat Si substrate. The field is applied perpendicular to the film

3. MACROSCOPIC MAGNETIC FEATURES

On Fig. 2, the magnetic properties of TbCo and Co/Pt films deposited on Si flat wafer are shown. These curves have been measured using a commercial vibrating sample magnetometer at room temperature. The magnetization at saturation of TbCo, resp. Co/Pt, is 600 emu/cm^3, resp. 550 emu/cm^3. The coercive field for TbCo, about 700 Oe, is higher than those of Co/Pt, about 200 Oe. As a conclusion from this part, both TbCo and Co/Pt have very similar magnetic behaviour when deposited on flat Si substrate. The higher Hc for TbCo must originate either from the larger anisotropy in TbCo (K>3.10^7 erg/cm^3) than in Co/Pt (K≈10^{-7} erg/cm^3) from a larger number of strong domain wall pinning sites in this film due to its amorphous nature.

Magnetization versus external magnetic field amplitude for the Co/Pt multilayer and TbCo grown on the bumpy sample are shown on Fig.3. The bumpy TbCo sample coercivity is 5 times larger as compared with

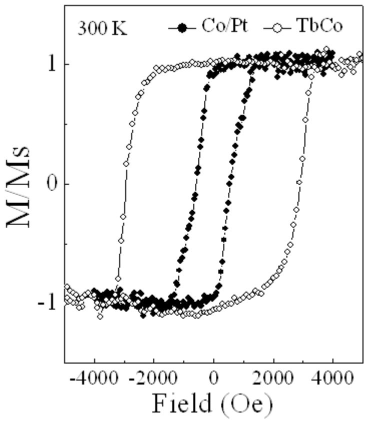

Fig. 3 – Hysteresis loops at 300 K, for Co/Pt and TbCo deposited on AAO bumpy substrate. The field is applied perpendicular to the film

the same films grown on flat substrate. The Co/Pt coercivity is only increased by 3 but the loop gets tilted as compared with the flat one. Complete or incomplete exchange decoupling of spins inside the magnetic layer would explain such differences in the hysteresis curves between bumpy and flat substrate.

3.1 Magnetic force microscopy measurements

In order to further investigate the difference of magnetization reversal between TbCo and Co/Pt bumpy samples, we performed magnetic force microscopy (MFM) measurement on these two samples. Figure 4(a) and 4(b) shows a typical MFM image of the out-of-plane AC demagnetized Co/Pt and TbCo bumpy samples. In Fig. 4(a) and 4(b), a bicolor pattern corresponding to magnetic domains having opposite magnetization directions is observed in the MFM image. The bright and dark domains correspond to a magnetization pointing towards the negative and positive field directions, respectively. No domains are stable after demagnetization in the references samples deposited on flat Si substrate.

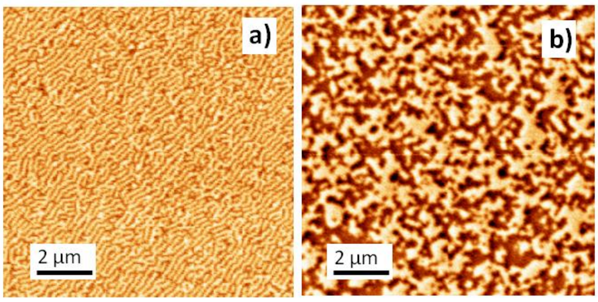

Fig. 4 – (a) and (b) correspond to 10 x 10 µm^2 MFM image obtained after out-of-plane AC demagnetizing the Co/Pt and TbCo bumpy sample respectively

The 2D Fourier transform, calculated from the MFM images on large scale, give an average domain width of about 100 nm (i.e. the width of one bump), resp. 400 nm, in the case of Co/Pt, resp. TbCo bumpy sample. Moreover, the shape of the domain is very asymmetric in Co/Pt whereas the TbCo domains look like isotropic labyrinth patterns. The large difference in domain width and shape can only be understood by a much weaker magnetic exchange-coupling in Co/Pt as compared with TbCo deposited on the AAO bumpy substrates. In the case of Co/Pt, the multilayer on top of the bumps must have a nice layering structure, offering a nice perpendicular anisotropy and locally a strong lateral exchange between spins. However, in between the bumps, due to deposition geometry, alloying of Co and Pt must occur resulting in a local decrease of exchange coupling. This alloying has already been enlightened in Ref. [8] and [9]. The reduction of ferromagnetic exchange coupling between nanocaps enhances the relative influence of the dipolar field interactions that tend to keep anti-parallel the magnetization of two neighboring nanocaps [8,9]. As a result, in the demagnetized state of Co/Pt deposited on hexagonally packed nanobumps corresponds to the state minimizing the dipolar interactions, i.e. parallel lines of nanocaps with the same magnetization with opposite magnetization from line to line. In the case of TbCo alloy, the average atomic structure stays identical in between and on top of the bumps. Therefore the coupling is not reduced as much as in the case of Co/Pt. The competition between dipolar interactions and direct exchange coupling leads to large isotropic domain of few bumps wide. This difference of exchange coupling also appears in the hysteresis loop, Fig. 3(a). Indeed the Co/Pt reversal is much shallower whereas the TbCo one is much steeper.

As a conclusion, we have use an original method to fabricate bit pattern media in depositing magnetic media on ordered magnetic nanobumps arrays obtained from an anodic alumina templates. We have studied magnetic properties of perpendicular magnetic TbCo alloy and Co/Pt multilayers as magnetic media. Macroscopic magnetization measurement and magnetic force microscopy images confirm the weakness of exchange coupling between bits in the case of Co/Pt multilayer while stronger coupling is observed in the case of TbCo alloys. This difference must originate from the nature of the film, i.e. multilayer or alloy.

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