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Magnetization reversal in triangular $L1_0$-FePt nanoislands

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ABSTRACT

Triangular FePt nano-islands with size ~70 and ~330 nm have been prepared by using regular single-layer arrays of nanospheres (173 nm) and microspheres (978 nm), as deposition masks. The coercivity of the 330 nm islands is close to that of the continuous film (11 kOe) whereas the 70 nm ones have coercivity close to 9 kOe and their hysteresis is characterized by the coexistence of an uncoupled soft phase. The switching behavior is characterized by non-zero dM-plots. The lower dM is obtained for the 70 nm sample heat-treated at 500 °C for 15 min and increases for longer times and higher heat-treatment temperatures. 10% of the islands are in multi-domain state. These findings are compared with micromagnetic modeling which shows that for anisotropy values high enough to match the observed coercivity, multidomain islands can result in due to the existence of either a softer part or different anisotropy direction part within each magnetic entity.

1. Introduction

The spectacular growth of magnetic recording media applications during the last decades has intensified the efforts for the preparation and characterization of nanostructures consisting of high anisotropy uniform, non-interacting magnetic entities [1]. These characteristics are imposed by the requirements of thermal stability and high signal to noise ratio at high recording densities. The most typical example of such structures are lithographically "patterned media" [2–4]. Alternatively, one might use as templates other materials, for which model nanostructures can be easily obtained by a "bottom-up" approach and thus are suitable for producing nanostructures over large surface areas in a facile low cost way. Examples are anodic alumina [5,6] and monodisperse nanosphere single-layers which tend to form hexagonal close packed patterns [7–11]. The latter can be used either as a template for the deposition of "nanocaps" [12–14] or as a mask for the formation of triangular-like islands [15,16].

In the following we present the preparation and characterization of FePt nanoislands prepared by using regular close packed arrays of polysterene nanospheres as deposition masks for sputter deposition.

2. Experiment

Monodisperse polystyrene nanospheres with average sizes (978 ± 32) nm and (173 ± 6) nm were purchased from microparticles Gmbh Berlin (PS-Reasearch Particles aqueous suspensions 10% w/v LOT PS-R-L2119 and 5% w/v LOT: PS-R-B1164 respectively). In order to form nanosphere single-layers on Si/SiO_2 substrates dilute colloidal suspensions of these nanospheres were spread on appropriately prepared substrate surface according to the following process: First the substrates were sonicated for 2 h in piranha solution (mixture 3:1 v/v concentrated 98% sulfuric acid to 30% hydrogen peroxide solution), rinsed with distilled water in order to remove the acids, sonicated in Isopropyl Alcohol for 15 min and finally dried in N_2 gas. Then 50 μL of the nanosphere colloidal suspension was deposited on substrate surface which were kept tilted vertically and left to dry for 3 h at room temperature.

Fe/Pt bilayer films with total thickness $t=36$ nm were deposited on the above nanosphere covered SiO_2 substrates by magnetron sputtering at room temperature using a MANTIS deposition system. The two layers were sequentially deposited by Fe(3 in.) and Pt(2 in.) sources. Prior to the deposition the chamber is evacuated to a base pressure of 7×10^{-7} Torr and the process gas (Ar 5N) pressure was 2.5 mTorr. The Fe layers have been deposited at a rate of 0.17 Å/s by applying 100 W RF and the Pt layers at a rate of 0.47 Å/s by applying 120 W RF. After the deposition, the nanosphere layers have been taped-off leaving arrays of triangular-like

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Fe/Pt islands. The samples have been sealed in evacuated quartz tubes and heat-treated at 500–650 °C for 15–30 min. The typical θ–2θ X-ray diffraction (XRD) and grazing incidence diagrams were collected with a Bruker D8 Advance Diffractometers using CuKa ($\lambda = 1.5418$ Å). The film thicknesses were determined by X-ray reflectivity measurements. The magnetic measurements at room temperature were performed with a Lake Shore vibrating sample magnetometer (VSM). Low temperature hysteresis loops as well as the First Order Reversal Curves (FORC) have been produced by analyzing data obtained by a MPMS-XL-7AC SQUID magnetometer (Quantum Design) for selected samples. The Atomic Force (AFM) and Magnetic Force (MFM) images have been obtained with a AutoProbe CP using Co hard magnetic alloy coated MFM probes (Bruker, High Peformance, MESP-RC).

The measurements were done in non-contact mode after adjusting the height to the point where topography signal disappears. Prior to the MFM studies the sample were brought to DC demagnetized state in the VSM electromagnet. The images have been processed and analyzed with the Gwyddion 2.26 [17] and ImageJ 1.44p [18] programs.

3. Results and discussion

Following the above described method of application polystyrene sphere colloidal suspensions on appropriately prepared silicon wafer surface we have obtained hexagonal 2D lattices of nanospheres characterized by structural coherence of the order 10–20 sphere diameters. At the edges of these structurally coherent areas imperfect close packing creates lines analogous to the grain boundaries of a crystal [19,20]. After the sputter deposition of FePt and removal of the polystyrene spheres we are left with regular arrays of islands (Figs. 1 and 2). These islands are triangular-like and, ideally would correspond to the curvilinear equilateral triangles that are defined by the empty areas left by a hexagonal 2D-array of close packed circles. Assuming a line-of-sight coverage with the atom flux perpendicular to the substrate, the area left between the spheres of diameter D is $(\sqrt{3}/4)-(\pi/8)D^2$ which corresponds to the area of equilateral triangle of side

$$\sqrt{1-\frac{\pi}{2\sqrt{3}}}D \approx 0.305D.$$

In comparison, the largest inscribed equilateral triangle has a side of $(2-\sqrt{3})D \approx 0.268D$ [8]. Accordingly, the size of the islands has been calculated as the side of the equilateral triangle that gives the same area, as determined from the images using the ImageJ software [18]. The values are very close to those obtained by the Feret size [21]. For the microspheres (978 nm) the size of islands is (326 ± 47) nm. This amounts to the $0.34D$ of the microsphere diameter (Fig. 1). In the case of the nanospheres (173 nm) the islands are (73 ± 19) nm which is $0.42D$ of the nanosphere (Fig. 2). The imperfect matching at the sphere array "grain boundaries" results in additional lines of deposited material. For brevity hereinafter we refer to them as the 330 nm and 70 nm islands.

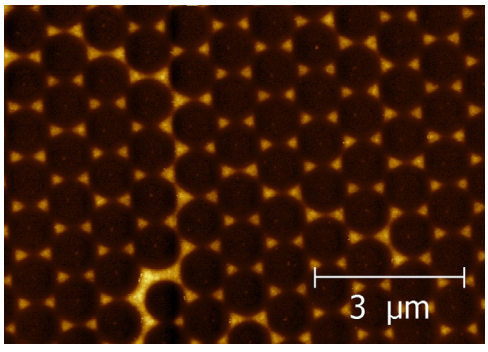

Fig. 1. Atomic force microscopy image showing the 330 nm islands obtained by a 978 nm microsphere array as deposition mask.

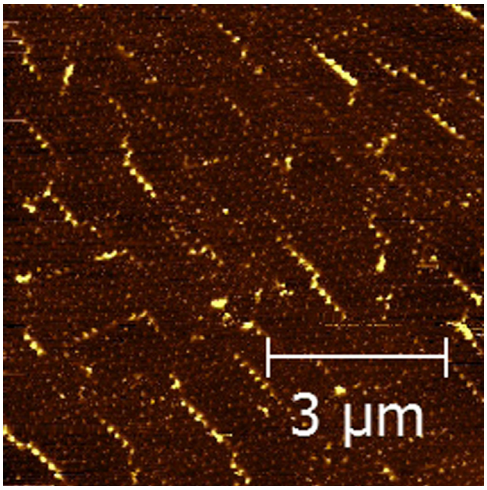

Fig. 2. Atomic force microscopy image showing the 70 nm islands obtained by a 173 nm nanosphere array as deposition mask.

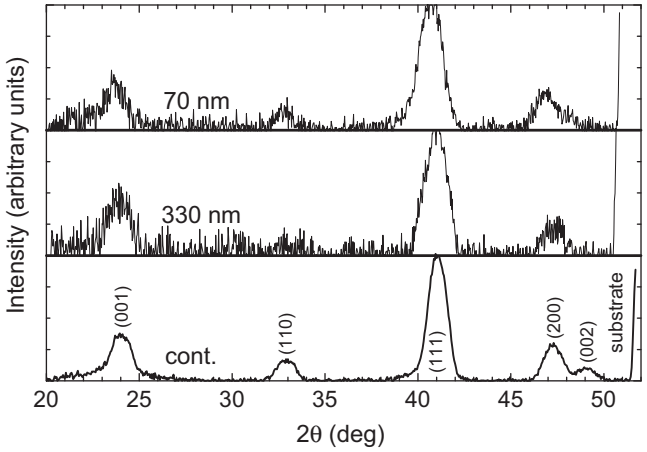

Fig. 3. Grazing incidence X-ray diffraction patterns of FePt films and nano-island arrays after heat-treatment at 650 °C for 15 min. The background has been subtracted using the EVA software of Bruker-AXS in order to facilitate the comparison. Top: 70 nm islands. Middle: 330 nm islands. Bottom: continuous film.

The as-deposited films are fcc (A1 structure) and magnetically soft and the high anisotropy tetragonal $L1_0$ phase is produced by annealing. Fig. 3 shows the grazing incidence XRD pattern of a continuous film as well as the 70 nm and 330 nm samples after heat-treatment at 650 °C for 15 min. The diffraction pattern of the continuous film shows clearly the formation of the $L1_0$ since the superstructure reflections (001) and (110) appear and the (002) and (200) peaks are split. The tetragonicity c/a ratio is 0.96. For the bulk material the room temperature value is $c/a = 0.9636$ while at higher temperatures values as low as 0.954 are reported, mainly due to shrinking of the atomic volume of Fe [22]. The c/a values are comparable to those reported for chemically synthesized FePt nanoparticles [23].

In continuous films lower values of c/a than that of the bulk have been reported at room temperature [24]. This value probably appears as a result of the different degree of strain between differently textured components [25]. In the patterns of the nanostructured films the splitting between (002) and (200) is not clearly observed but the formation of $L1_0$ is evidenced by the (001) and (110) reflections. The conventional θ–2θ scans indicate