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FABRICATION AND CHARACTERIZATION OF MAGNETICALLY HARD CoPt ORDERED SUB-MICRON STRUCTURES

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The present study describes the properties of magnetically hard $Co_{50}Pt_{50}$ ordered sub-micron structures. The e-beam nanolithography process and the deposition by sputtering resulted in the formation of $Co_{50}Pt_{50}$ ordered arrays 250-1000 nm sized. The thermal annealing of the samples at 650 °C for 30 minutes led to the crystallization of the specimen in the $L1_0$ phase and to their consequent magnetic hardening both in the parallel (H_c = 6.2 kOe) and in the perpendicular (H_c = 4.1 kOe) direction with respect to the film plane.

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1. Introduction

The fabrication and investigation of CoPt ordered structures is frontier research in the field of ultra high density magnetic recording media [1]. The reason of such an interest is due mainly to the high magnetocrystalline anisotropy constant of the $L1_0$ CoPt ordered phase [2], which enables to obtain ferromagnetically hard magnets thermally stable to diameters well below 10 nm [3]. However, despite the strong scientific and technological interest on tetragonal CoPt nanostructures, limited work has been performed until now on arrays fabricated with high resolution patterning methods [4], due to the prevalent implementation of lithographic techniques for integrated circuitry. The aim of the present study is the fabrication and investigation of the structural, morphological and magnetic behaviour of magnetically hard 250 - 1000 nm $Co_{50}Pt_{50}$ ordered arrays, patterned by e-beam lithography.

2. Experimental

For the fabrication of the CoPt patterns, the lift off approach was selected to be applied. For the lithographic process, 200 nm PMMA resist (Molecular Weight 996 K, provided from Aldrich) was spin coated on cleaned Si wafers and prebaked at 160 °C for 60 min in an oven (Post Apply Bake step). The exposure was performed with a vector scan e-beam machine EBPG-3 at 50 keV using a 500 pA beam current at 100nm beam diameter. Development was performed in IPA-H_2O 7:3 for high resolution and sensitivity. The $Co_{50}Pt_{50}$ films, 50 nm thick, were deposited by magnetron sputtering using a target power of 30 W and an Ar pressure of 7 mTorr. After the growth, a lift-off step in acetone in ultrasonic bath was applied. For the study of the square dimension effect on the magnetic properties, square-array patterns with side sizes 1000, 500, 250 nm were fabricated. In order to perform magneto-optical measurements each of these patterns covers a 2 mm ×2 mm area. The patterned samples were annealed after the resist removal at 650°C for 30 minutes under ultra high vacuum. The structural and morphological properties of the samples were analysed by X-ray diffraction (XRD), atomic force microscopy (AFM) and scanning electron microscopy (SEM). The

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magnetic properties of the arrays were measured using a magneto-optical Kerr effect magnetometer (MOKE) and magnetic force microscopy (MFM).

Fig. 1 SEM in-plane picture for the (a) 1000 nm, (b) 500 nm and (c) 250 nm CoPt square-arrays after lift-off process and annealing step.

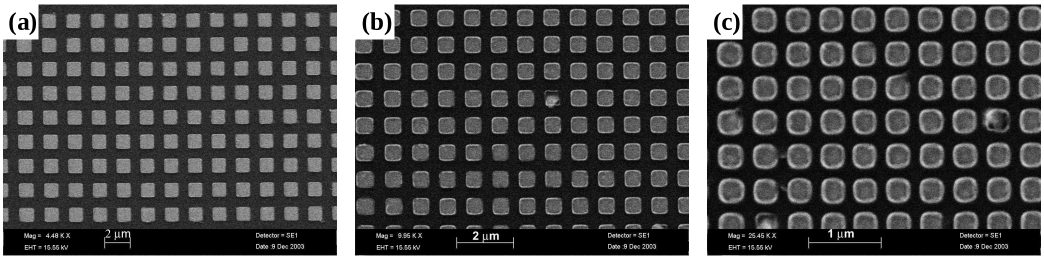

Fig. 1. SEM in-plane picture for the (a) 1000 nm, (b) 500 nm and (c) 250 nm square-arrays.

3. Results and discussion

Fig. 2 shows the XRD patterns for the continuous films. Due to the small interacting volume between the X-ray beam and the patterned area it has not been possible to obtain the correspondent XRD traces for the CoPt patterns. As can be seen, the XRD traces for the as-deposited films (lower line) show a weak peak in the region between the (111) diffraction lines of the disordered cubic phase ($CoPt_3$) and the ordered tetragonal phase (CoPt), suggesting that a satisfactory structural ordering of the nanoparticles in the $L1_0$ ordered phase has not occurred. In order to obtain the crystallization of the magnetically hard $L1_0$ phase [5], the as-deposited samples were annealed at 650 °C for 30 minutes. As expected the thermal annealing (upper line) led to a satisfactory crystallization of the samples in the $L1_0$ ordered structure and to a (111) texturing. The mean grain sizes D_{ave} were estimated by line broadening analysis by applying the Scherrer equation [6]. The D_{ave} for the films are ~ 15 and ~ 30 nm for the as-deposited and annealed samples respectively, considerably below the single domain diameter for the tetragonal CoPt phase [2].

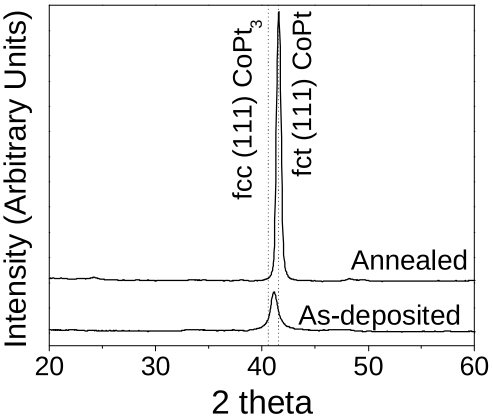

Fig. 2. XRD patterns for the as-deposited and annealed continuous films.

Fig. 2 shows the in-plane SEM pictures of the square-arrays soon after the resist removal. As can be seen the patterned samples exhibit a satisfactory ordering of the arrays and an acceptable in-plane profile of the squares after the lift-off process.The profile the annealed 1000 nm square arrays as obtained by AFM is illustrated in Fig. 3. As can be seen, in general the dots exhibit a sharp squared profile except for the presence of kinks on the edge of the squares. The reason of this behavior is due to the lateral growth of the film on the walls of the resist. Although the lift-off process results in the removal of the resist, part of the coating contributes to the formation of the kink on the edge of the patterned squares [7].

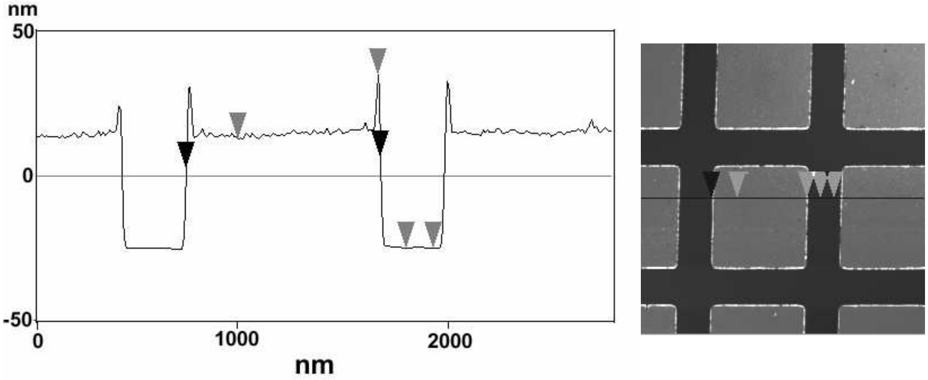

Fig. 3. AFM profile image for the 1000 nm square-arrays.

Fig. 4 shows the AFM (left) and MFM (right) image of the annealed 1000 nm square arrays. As can be seen from the MFM pictures the squares exhibit magnetic domains, whose sizes (~ 100 nm) are larger than the D_{ave} (~ 30 nm) of the annealed samples. This behaviour suggests that the magnetic domains encompass several nanograins leading to the occurrence of intergranular exchange coupling. Similar magnetic domain patterns have been observed in all arrays.

The as-deposited continuous films were ferromagnetically soft. Such results are consistent with their structural properties observed by XRD (Fig. 1), which indicate a low degree of formation of the ferromagnetically hard CoPt fct phase. The parallel magnetization curves were obtained only for the continuous films because of the small interacting volume between the patterned area and the laser beam of the MOKE.

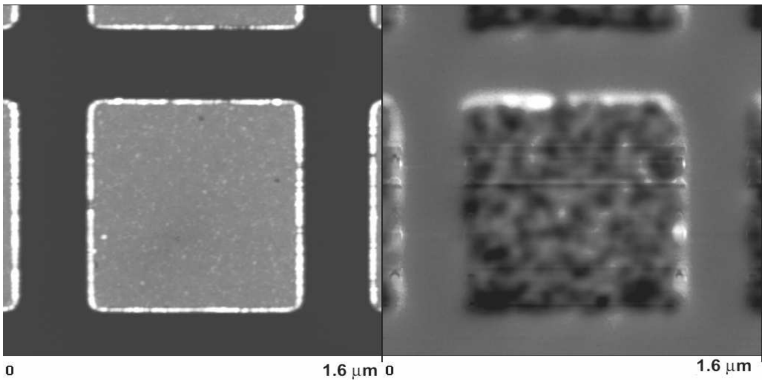

Fig. 4. In-plane AFM and MFM image of the 1000 nm square arrays.

Fig. 5 (a) shows the parallel (dotted line) and perpendicular (continuous line) hysteresis loops for the annealed continuous films. As can be seen, the annealing resulted in significant ferromagnetic hardening of the samples with a high coercivity both in the parallel (6.2 kOe) and in the perpendicular (4.1 kOe) direction with respect to the plane of the film.

Fig. 5 (b) shows the comparison between the perpendicular loops for the patterned samples. As can be seen, the perpendicular hysteretic properties of the arrays within the dot size range of 250 - 1000 nm do not exhibit a significant change with respect the continuous films. This result indicates that the lift-off process did not affect sensitively the magnetic properties of the samples after the annealing in relationship with the magnetic behavior of the continuous films. Our results suggest that in the perpendicular direction the possible presence of dipolar interaction or the surface properties of the dots do not influence significantly the hysteretic properties of the arrays. A lot of studies have been performed, until now, on longitudinal inter-dot magnetostatic interactions for sub-micron ferromagnetic structures [8,9]. Most of such studies concern materials with a low magnetocrystalline anisotropy constant and, consequently, a critical single domain diameter larger than the dot size. Such investigations involve, thus, the study of interactions between single domain dots and no studies have been performed until now on interactions between ferromagnetic dots, which exhibit multidomain behaviour. For this reason, it is not clear in which extent the parallel and perpendicular inter-dot magnetostatic interactions play a role in the hysteretic properties of the CoPt arrays, therefore further studies have to be performed in order to elucidate better this aspect.

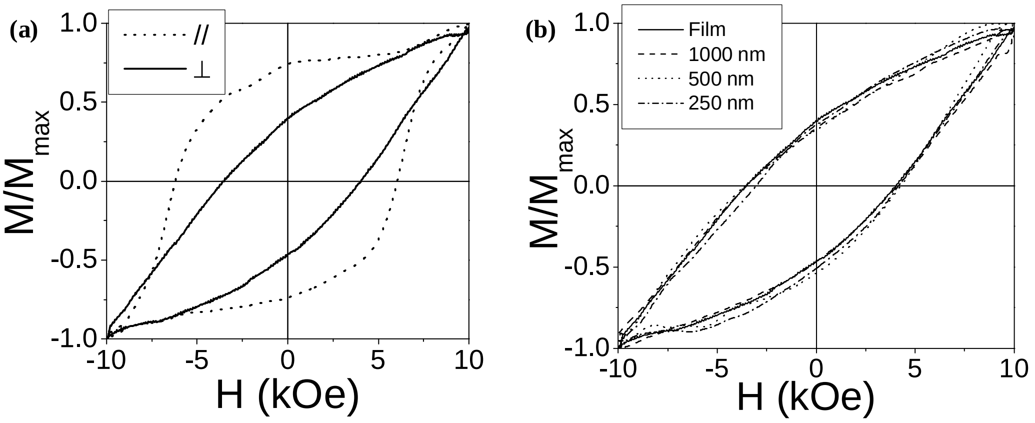

Fig. 5. Comparison between the (a) parallel (dotted line) and perpendicular (continuous line) hysteresis loops for the annealed continuous films and (b) the perpendicular hysteresis loops for the annealed continuous films (continuous line) and the arrays (dotted and broken lines) after thermal annealing.

4. Conclusion

Magnetically hard $Co_{50}Pt_{50}$ ordered sub-micron square arrays were prepared. The patterning process performed by e-beam nanolithography and the deposition by sputtering resulted in the formation of $Co_{50}Pt_{50}$ ordered arrays 250-1000 nm sized. The thermal annealing of the samples at 650 ºC for 30 minutes led to the crystallization of the specimen in the $L1_0$ phase and to their consequent magnetic hardening both in the parallel (H_c = 6.2 kOe) and in the perpendicular (H_c = 4.1 kOe) direction with respect to the film plane. The comparison of the perpendicular hysteresis loops between the continuous film and the patterned samples suggests that, in the 250-1000 dot size range, the magnetic properties of the samples do not exhibit significant changes.

Acknowledgments

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