Experimental Report

Proposal: **5-54-129** **Council:** 10/2012

Title: Polarized neutron reflectivity study of the magnetization profile in anisotropy graded FePt films by ionirradiation.

This proposal is a new proposal

Researh Area: Physics

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Samples: FePt

Instrument	Req. Days	All. Days	From	To
D17	5	5	22/05/2013	27/05/2013

Abstract:

To achieve high recording density, current technology demands for magnetic media with magnetization perpendicular to the film plane, high thermal stability and moderate coercivity. There is no known single phase materials that show all of these requisites. We have shown that Ar+ irradiation can be effectively used to transform a single phase, high coercivity, chemically ordered, FePt L10 thin film into a graded-anisotropy, exchange-coupled, composite media with tunable magnetic response. This can be exploited to produce a magnetic media with the desired magnetic behavior. We propose to use polarized neutron reflectivity measurements to determine the magnetic depth profile in the FePt irradiated films and consequently determining the dependence of the magnetic anisotropy with thickness and the ion beam parameters.

Title: Polarized neutron reflectivity study of the magnetization profile in anisotropy graded FePt films by ion irradiation.

The $L1_0$ phase of FePt is an ordered alloy constituted of Fe and Pt sublattices, assembled as alternate Fe and Pt planes in the fcc cubic where Pt plays a primary role in determining the huge values of magnetocrystalline anisotropy (in excess of 1 MJ m^{-3}) [1]. Since the beginning of the nineties, FePt $L1_0$ has been widely studied for potential applications as perpendicular magnetic recording media because the large magnetocrystalline anisotropy allows the ferromagnetic stability in particles of few nanometers in diameter, and consequently the achievement of ultrahigh density of information.

Large anisotropy is only one aspect of the problem of magnetic recording. High-density recording requires a magnetic media with small grain size to control the noise, high anisotropy for improving thermal stability of the grains and low or moderate coercivity because of the limited magnetic field that the write head can produce. The well-known magnetic recording "trilemma" [2] shows up that all these desirable properties for a magnetic media are conflicting requisites in a single-phase material. Two broad groups of systems have been proposed to solve this problem: layered composite systems comprised of two or more magnetically hard and soft films coupled by exchange interaction at their interfaces, also known as exchange coupled composite (ECC) media and graded systems, *i.e.* magnetic materials where the magnetocrystalline anisotropy changes continuously as a function of the thickness.

The huge magnetocrystalline anisotropy of FePt in the $L1_0$ phase is strictly related to the chemical order. Actually, the alternating stacking of Fe and Pt layers induce a slight (+2.8%) tetragonal strain in the face-centered cubic (*fct*) lattice along the stacking direction (namely the *c*-axis) that, together with the large spin-orbit coupling in Pt and the strong hybridization between Pt 5d and Fe 3d states, cause the large (uniaxial) structural magnetic anisotropy of the $L1_0$ phase. On the other hand, FePt in the chemically disordered phase, called the A1 phase, *i.e.* a *fcc* lattice where the occupancy probability of the atomic sites is 50% for Fe or is magnetically soft due to the lack of tetragonal distortion, even if the atomic composition and coordination of A1 is identical to $L1_0$.

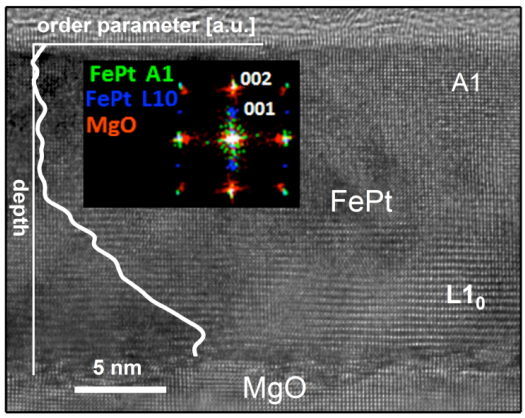

Figure1.- High Resolution (HR) TEM image of the 20 nm thick FePt film irradiated with a dose of $5 \cdot 10^{14}$ ions cm^{-2}, in cross section. Irradiation is from top to bottom. Inset: superposition of the Fast Fourier Transform magnitude of the MgO (red), bottom-FePt (blue) and top-FePt (green); Line graph: square root of the intensity of the Fourier filtered images obtained by selecting the (001) superstructure spots, proportional to the chemical ordering parameter.

Using this difference between the magnetic anisotropy of the chemically ordered $L1_0$ phase and disordered phase a new method has been recently developed to fabricate FePt films with graded chemical order and consequently graded magnetocrystalline anisotropy [3]. Ion irradiation induces atomic displacements in the crystal structure and consequently can modify the chemical order of the material. Actually, ion irradiation has been found to be effective in turning the $L1_0$ chemically ordered, magnetically hard phase, into the A1 chemically disordered, magnetically soft phase (see Figure 1). In general, the chemical disordering induced by ion irradiation occurs within the ion penetration depth, while the level of disordering is controlled by the ion beam parameters (*e.g.* ion dose, ion energy and incidence angle) results in an anisotropy graded magnetic media whose anisotropy profile can be, to some extent, designed on purpose. In particular we can tune the width of the transition region to a length scale that is effective in reducing the switching field of the graded system while the underlying magnetically hard material, not affected by ion irradiation, grants for thermal stability. The main advantage in using ion irradiation is that the most significant irradiation parameters are largely uncritical and can be tightly controlled and easily reproduced in different fabrication systems. Furthermore, the method is simple, fast and can be scaled-up to large area samples.

Hysteresis loops of as-deposited film with field applied parallel and perpendicular to the film plane (Figure 2(a)) show that the easy magnetic axis is perpendicular to the film plane (*c*-axis of the *fct* structure). After irradiation at 40°, a significant reduction (-50%) of the coercive field (Hc) and a positive nucleation field are observed (Figure 2(c)). This is due to the formation of an exchange coupling between the A1 and $L1_0$ phases. By changing the ion incidence angle to 85° it is possible to change the ion penetration depth and therefore the relative thickness of soft, anisotropy-graded and hard layers. The

magnetic behavior can be consequently tuned: the irradiation at 85° still reduces Hc (-39%) but to a lower extent (Figure (b)).

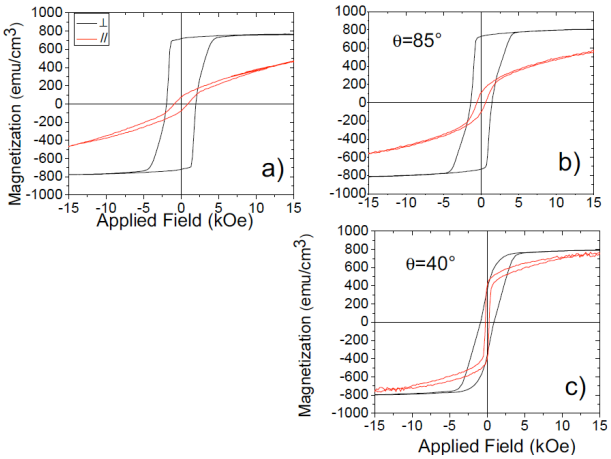

Figure2.- Hysteresis loops of 15 nm thick films parallel (red line) and perpendicular to the film plane: before (a) and after ion irradiation ($5 \cdot 10^{14}$ ions cm^{-2} dose) at 85º(b) and 40º(c) incidence angle.

We have performed polarized neutron reflectivity (PNR) experiments to understand the magnetic behaviour of the irradiated FePt thin films. In a PNR experiment a scan over a suitable range of q_z provides excellent information on the magnetic depth profile of the film. PNR measurements will give us the magnetization in the film plane as a function of depth in the film. As the magnetization component pointing perpendicular to the film plane cannot be measured in a PNR experiment, no signal is expected in a film that was 100 % in the $L1_0$ phase. On the other hand, the magnetization of the A1 phase will be in the film plane (M_s= 796 emu/cm^3). Assuming that the atomic number density of the FePt is not changed on irradiation, neutron reflectivity should show a clear magnetic signal in the irradiated samples that could be modelled with a magnetization that was decreasing as a function of depth, as the crystallographic phase is changing fro the A1 disordered soft-phase to the $L1_0$ ordered hard-phase (see figure 1).

As an example we show in figure 3 the experimental results obtained for the sample irradiated at a dose of 5.10^4 ions cm^{-2} and an at incident angle of 85º at different applied magnetic fields (22 Oe, 1.6 kOe, 5.2 kOe and 11 kOe). The experimental data has been fitted assuming the existence of 2 layers with different magnetic anisotropy. For the fits, the structural parameters have been preserved for all the applied magnetic fields and only the magnetization of the different layers has been changed.

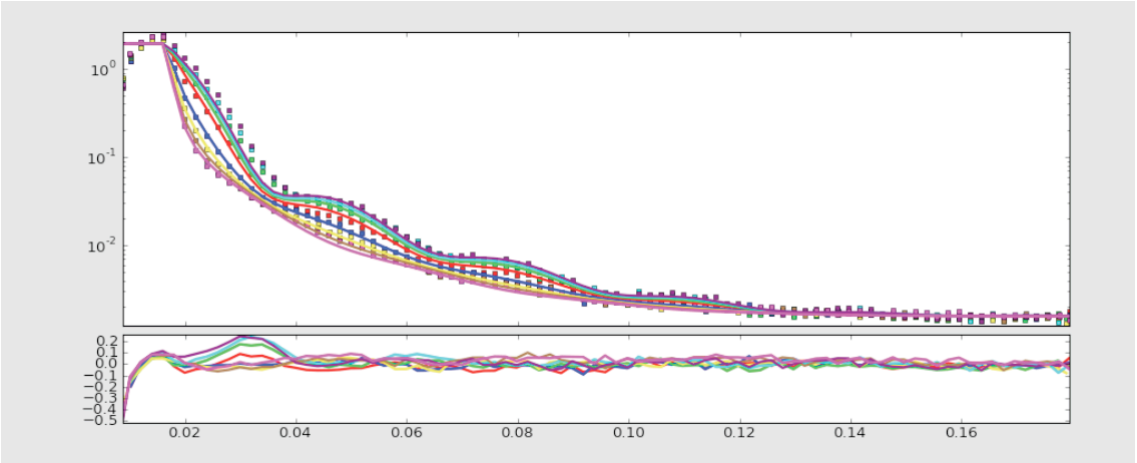

Figure 3.- Polarized neutrons reflectivity measurements of a irradiated FePt thin film at several in-plane applied magnetic fields at T=300 K. The symbols represent the up-up and down-down reflectivity curves. The numerical adjustments are plotted in solid lines.

The results obtained from the analysis of the experimental results are summarized in the Table I. We show the thickness of the different magnetic layers together the magnetization of each layer.

Neutron Reflectivity	Thickness (nm)	Roughness (nm)	magnetic moment(22Oe)	magnetic moment (1.62kOe)	magnetic moment (5.2kOe)	magnetic moment (11kOe)	err
layer_1_top	3,4	0,5	0,57	1,19	1,55	1,80	
layer_2	16,5	0,7	0,66	1,2	1,60	1,92	
Total	19,9		0,615	1,195	1,575	1,860	
Magnetization (emu/cc)			198	384	508	600	±2.5%

Table I.- Magnetic and structural properties of the irradiated FePt thin films obateined from the PNR experiments

For this film, the magnetization of both layers is almost the same, within the experimental error, indicating the irradiation has produced a magnetically homogeneous film with a reduction of the magneto-crystalline anisotropy.

The results obtained from the fit of the polarized neutrons reflectivity measurements are in good agreement with the magnetization macroscopic measurement performed with an AGFM experimental set-up (Alternative Gradient Field Magnetometer). In Figure 4 the comparison between the hysteresis loop obtained with the AGFM and the magnetization obtained from the PNR experiments are shown.

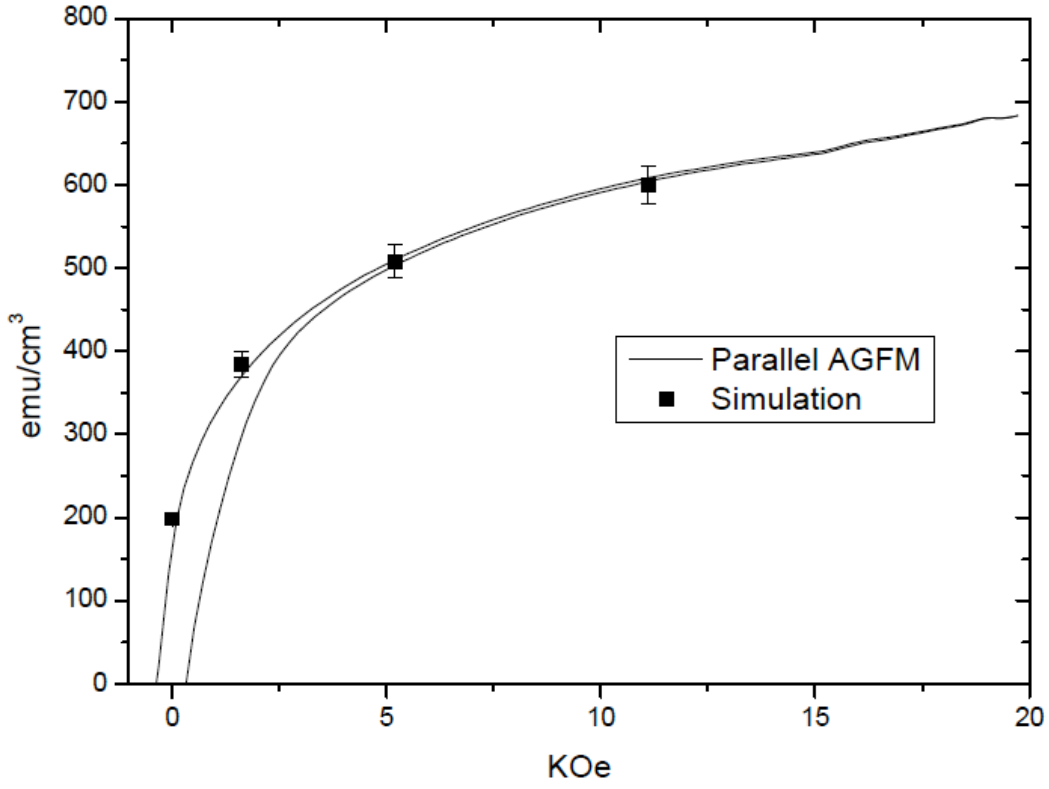

Figure 4.- Magnetic hysteresis loop obtained at 300 K with a AGFM (solid line) and magnetization values obtained from the analysis of the PNR experiments (symbols) at the different applied magnetic fields, as determined in Table I.

References.-

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2.- H. J. Richter and A. Y. Dobin, *J. Magn. Magn. Mater.* **2005**, *287*, 41.

3.- A di Bona, P Luches, F Albertini, F Casoli, P Lupo, L Nasi, S D'Addato and S Valeri, Acta Materalia **61** (13) 4840 (2013)