Abstract

$Fe_{50}Pt_{50}$ [2] ferromagnetic thin films fabricated by sputtering methods at room temperature tend to grow in a relatively soft magnetic phase, chemically disordered with the atoms randomly arranged in an fcc structure. This alloy shows several unique magnetic properties that makes it particularly interesting for a deeper study of the physical behavior. The main characteristic is the presence of a critical thickness above which the magnetic domain structure changes from planar to a periodic pattern of parallel in-plane magnetized regions, in which the magnetization has a relatively small component that points alternatively in different directions normal to the film plane. This domain pattern is usually known as stripe magnetic domain or simply "stripes". The perpendicular component of the magnetization is induced by the presence of a magnetic anisotropy with the easy axis normal to the film plane, which originates in the joint contribution of magnetoelastic and magnetocrystalline effects.

In the first part of this work, we present different studies in a set of thin films with thicknesses in the range 9 nm $\leq d \leq$ 94 nm in which we maintained the same growing conditions. As expected, a transition in the magnetic domain structure occurs at a critical thickness d_{cr}, which is accompanied by significant changes in the magnetic response of the films. The critical thickness for this transition (in this particular set of samples, we found $d_{\rm cr} \sim 30$ nm) depends on the Q-factor, $Q = \frac{K_\perp}{2\pi M_s^2}$, defined as the ratio between the perpendicular magnetic anisotropy, $K_\perp$, and the demagnetizing energy. Therefore, a change in the domain structure is expected when the perpendicular anisotropy or the saturation magnetization, M_s, changes. Due to the different thermal expansion of the FePt alloy and the Si wafers used as substrates, and also the dependence of M_s with the temperature T, a reduction in Q is predicted when the temperature is lowered. From magnetic experiments measured at temperatures between 4 K $\leq T \leq$ 300 K, we have effectively observed a variation in the coercive field, presenting a maximum value which can be associated to a transition from a structure of magnetic domains with the magnetization that stays essentially in the plane of the film, generally called in-plane domains, to stripe-like

[2]From now on, we are going to simply call the equiatomic composition FePt.

domains. The transition temperature range is broad and proportional to the film thickness, consistently with a change in the perpendicular anisotropy caused by an interfacial induced stress. A model that includes the temperature dependence of the strain and the magnetization, predicts correctly the observation of a larger critical thickness at lower temperatures. In order to have a better understanding of the dominant type of interaction in each kind of domain structure, we used the well known DC demagnetization (DCD) and isothermal remanent magnetization (IRM) remanence protocols, δM plots and magnetic viscosity measurements. We have observed a strong correlation between the domain configuration and the sign of the magnetic interactions. Planar domains are associated with positive exchange-like interactions, while stripe domains have a strong negative dipolar-like contribution. The dynamical behavior of the same set of films has been characterized using ferromagnetic resonance spectroscopy in a broad range of frequencies, from 1 to 100 GHz. As expected, the increase in frequency is accompanied by larger resonance fields and linewidths, displaying an anisotropic response when the external applied field is rotated from the in-plane to the out-of-plane direction. In order to determine the dependence of the damping parameter of the magnetization with the excitation frequency, we analyzed the linewidths in different geometries and found an anisotropic damping parameter, $\alpha_{\parallel} = 0.025(1)$ when the field is applied parallel to the plane of the film and $\alpha_{\perp} = 0.021(1)$ in the perpendicular case.

In the second part of this work, with the aim of analyzing the effects of residual stresses in the magnetic properties, we fabricated a second set of FePt thin films in which we varied the growing conditions. In this case, we kept the nominal thickness constant $d \sim 100$ nm but varied the Ar pressure (P_{Ar}) in the sputtering chamber in the range $3 \leq P_{\mathrm{Ar}} \leq 13$ mTorr. In this series we performed a thorough structural characterization, which allowed us to obtain information about the size and microstrain of the grains, texture and the evolution of residual strain in the films. We have found that by varying the growing conditions it is possible to maintain approximately constant the crystalline texture but to relax the residual in-plane stresses. The films deposited at lower argon pressures are subjected to biaxial compressive stresses. The corresponding strain produces a component of the anisotropy in the direction normal to the film plane which gives rise to stripe-like magnetic domains. For higher P_{Ar}, stresses are relaxed and the magnetic configuration changes to a planar structure.

Although there are systematic studies on FePt thin films in which the thicknesses or the residual stress are individually changed, up to now there were no investigations of the dependence of d_{cr} with the induced residual stress. The ability to modify in a controlled manner the deformation in the film, allowed us to study in detail the transition from in-plane magnetic domains to a stripe-like structure and its dependence on these parameters. For this purpose a new series of films were fabricated, in which we modified not only the deposition conditions, but also the range of thicknesses for each Ar pressure. In addition to performing a detailed microstructural characterization, we investigated the magnetic response through DC magnetization experiments and images taken with a magnetic force microscope (MFM), which helped us to determine the critical thickness dependence on P_{Ar}. We correlated these results with the structural characterization, which allowed us to construct a phase diagram of magnetic domains, where the critical thickness is plotted as a function of Q. Most of the obtained experimental results could be satisfactorily explained by using a theoretical model that takes into account the energy contribution of exchange, shape, domain walls and perpendicular anisotropy.

Finally, having established the mechanisms that give rise to a stripe-like domain pattern, we grew another set of samples with the aim of a better understanding of the properties of this kind of systems. The alloy $Fe_{20}Ni_{80}$ (called Permalloy, or simply Py in the abbreviated form) also presents a stripe-like domain structure above a certain critical thickness, also caused by a perpendicular component of the magnetic anisotropy. Despite this similarity with FePt, some properties of Py, such as the value of the critical thickness and the period of the stripes, are significantly larger than in FePt. These differences suggest the need to investigate the magnetic behavior of FePt/Py bilayers with smaller and larger thicknesses than the critical value in which the domain structure changes. For this study we deposited two sets of bilayers in which the thickness of one of the alloys was fixed while the other was varied. The growing sequence of the films composing the bilayer was investigated in samples in which either FePt or Py was in contact with the Si substrate. Through MFM microscopy measurements we have observed a single stripe domain structure in most films, but for some combinations of thicknesses we could find a configuration of two coupled stripe structures rotated approximately 45°. Vibrating sample and Magneto-optic Kerr effect magnetometry, allowed us to separate the magnetic behavior of the top layer (MOKE is only sensitive to a penetration depth $\sim 10-20$ nm). In general, we found a singular magnetic behavior, with a relatively strong exchange coupling near the interface with a magnitude that decreases near the sample surface, allowing the stripe structure in the top part of the upper layer to behave differently than the coupled bilayer.

In summary, in the course of this thesis we have characterized the transition in the structure of magnetic domains and its dependence with the perpendicular anisotropy through the quality factor Q. From the various studies on FePt thin films, we have been able to modify the critical thickness of the magnetic transition in a controlled manner, either through modifying the deposition conditions, by varying the temperature variation or even by coupling the sample with a layer of a material with similar magnetic characteristics.