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Spin-wave resonance and magnetic anisotropy in FePt thin films

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Abstract

Ferromagnetic Resonance (FMR) measurements at room temperature and X-band microwave frequency were performed on polycrystalline FePt thin films with face-centered cubic structure. With the external field perpendicular to the film plane, the absorption fields H_n of the odd and even spin-wave resonance modes n detected for the $Fe_{0.44}Pt_{0.56}$(45 nm)/Si(1 0 0) and $Fe_{0.51}Pt_{0.49}$(105 nm)/Pt(55 nm)/MgO(1 0 0) films, were found to obey the well-known $H_n \times n^2$ ratio, giving for these films the exchange stiffness constant values of 3.9×10^{-8} and 4.4×10^{-7} erg/cm, respectively. The study of the out-of-plane angular dependence of the absorption field of the uniform FMR mode allowed the measurement of the effective magnetic anisotropy constants of 5.3×10^6, 6.4×10^6, and 6.7×10^6 erg/cm^3, related, respectively, to the [1 1 1], [1 0 0], and [1 1 0] textures present in the films.

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Keywords: FMR; FePt thin films; SWR; Magnetic thin films

1. Introduction

Spin waves are intrinsic excitations in magnetic materials and have attracted considerable attention in the last decades. They arise from collective excitations in arrays of spins and can be detected in ferromagnetic resonance (FMR) experiments. In ferromagnetic films of suitable thickness (10–1000 nm) they are indeed standing spin waves across the film excited by the microwave field [1,2]. FMR is also a very convenient technique to study the properties of magnetic thin films in general, including near-equiatomic polycrystalline FePt thin films because under the most common growth conditions they grow into a magnetically soft face-centered cubic (FCC) structure [3,4]. For FePt films with $L1_o$ (type face-centered tetragonal-FCT) structure and high uniaxial magnetic anisotropy ($K_u \approx 4$–10×10^7 erg/cm^3) [5], FMR would be a more-restricted technique due to the need of very high magnetic fields to attain the resonance conditions. In this work, we report the FMR study of spin-wave resonance (SWR) modes in FCC near-equiatomic FePt films. The analysis of the dependence of the resonance field H_n on the spin-wave mode number n allows the measurement of the exchange stiffness constant. Besides this, the study of the out-of-plane angular dependence of the absorption field of the uniform mode gives the magnetic anisotropy of the corresponding crystallographic texture present in the film.

2. Experimental procedure

The polycrystalline Fe_xPt_{1-x} films investigated in this work were prepared by DC magnetron sputtering from pure targets of elemental Fe and Pt, onto pure Si(1 0 0) substrates, and onto a Pt(1 0 0) FCC buffer layer pre-deposited on top of MgO(1 0 0) substrates, at the temperature of 200 °C. The base pressure in the deposition chamber was $\sim 10^{-5}$ Pa and high purity Ar gas at the pressure of 0.6 Pa and flow of 20 sccm was used. Rutherford Backscattering Spectroscopy (RBS) was used to study the thickness and composition of the films, and the structural phases were identified by X-ray diffraction (XRD) measurements. We report here the FMR study

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of $Fe_{0.44}Pt_{0.56}$(45 nm)/Si(1 0 0) and $Fe_{0.51}Pt_{0.49}$(105 nm)/Pt(55 nm)/MgO(1 0 0) FCC films. The FMR data were taken at room temperature using a commercial electron spin resonance spectrometer (Bruker ESP-300) operating at the X-band microwave frequency, with the sample located at the center of a standard TE_{102} microwave resonant cavity and fixed to a goniometer, allowing the study of in-plane and out-of-plane angular dependence of the absorption field and linewidth. The FMR spectra were taken using standard phase-sensitive detection techniques, applying modulation fields of up to 20 Oe, modulation frequency of 100 kHz, and microwave power of up to 10 mW. The direction of the applied field in the plane of the film or with respect to its normal was measured with an error of $\pm 0.5^\circ$, and the absorption field and linewidth, with an error of ± 5 Oe.

As is well known, the uniform FMR mode is due to a spatially uniform precession of the magnetization over the whole film. However, when the exciting microwave field varies in phase or amplitude across the film, the magnetization depends on space and time (the local moments are no longer parallel inside the film) and several SWR modes, at lower absorption fields, can be excited [6]. At a critical angle of the applied field with respect to the film normal they all converge to the uniform mode [2,7–9]. In this work, in perpendicular FMR ($\theta_H = 0^\circ$) and for directions of the applied field up to a critical angle $\theta_H = 5^\circ$ from the normal, SWR modes were detected for both films (Figs. 1 and 2). In parallel FMR ($\theta_H = 90^\circ$), the spectrum of the $Fe_{0.51}Pt_{0.49}$(105 nm)/Pt(55 nm)/MgO(1 0 0) film (Fig. 2) shows only the uniform mode, while the spectrum of the $Fe_{0.44}Pt_{0.56}$(45 nm)/Si(1 0 0) film (Fig. 1), besides the uniform mode, gives evidence also of a second and much weaker FMR mode at a lower absorption field. The out-of-plane angular dependence of the absorption fields for these two modes (Fig. 3) shows a crossover point at which they are superposed and have the same absorption field; in perpendicular FMR, the second mode was not detected due to the lack of sufficiently high magnetic field to attend the resonance condition. We attribute these two FMR modes to the presence of two magnetic phases A and B in this film, due to crystallites with different textures. Another evidence of this is given by the XRD pattern in Fig. 4a, where the FePt(1 1 1) peak at $2\theta = 40.85^\circ$ and the FePt(1 1 0) peak at $2\theta = 32.90^\circ$ characterize the presence of two textures in the film [10,11]. The XRD pattern of the second $Fe_{0.51}Pt_{0.49}$(105 nm)/Pt(55 nm)/MgO(1 0 0) film (Fig. 4b) shows only the FePt(2 0 0) peak at $2\theta = 47.85^\circ$, giving evidence of a predominant FCC structure with [1 0 0] texture [10]. The out-of-plane angular dependence of the absorption field of this film is also shown overlapped in Fig. 3.

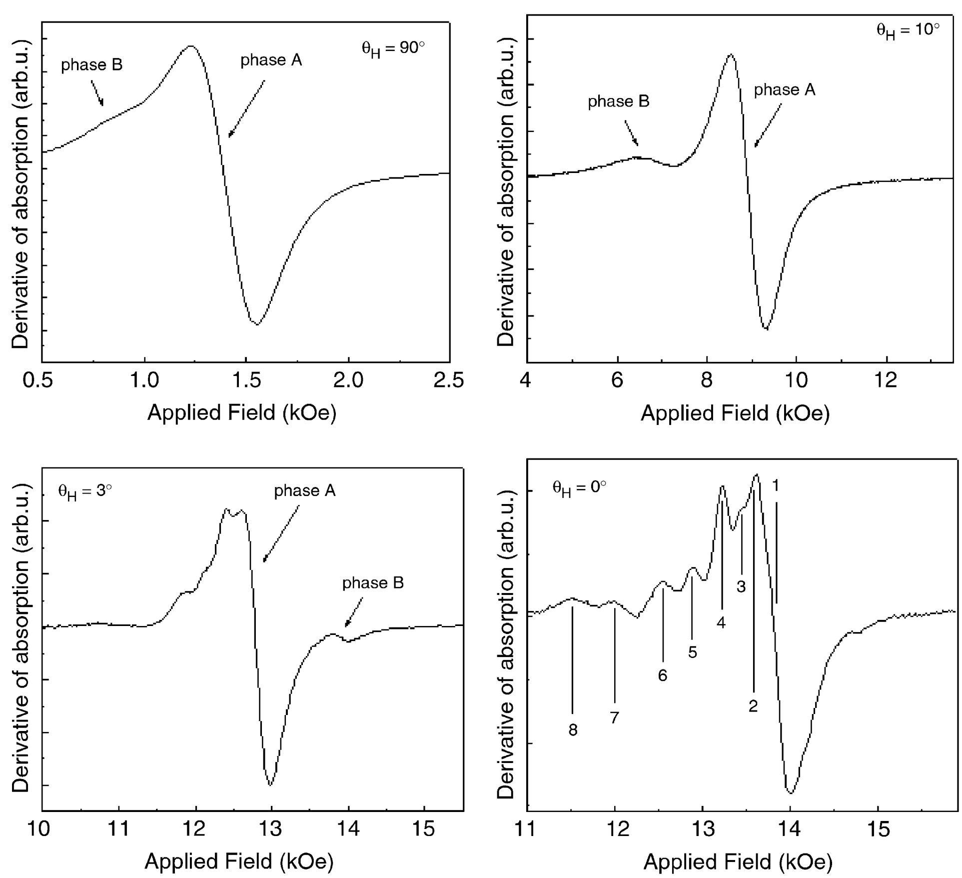

Fig. 1. FMR spectra of the $Fe_{0.44}Pt_{0.56}$(45 nm)/Si(1 0 0) film. The angle θ_H gives the direction of the applied field H with respect to the film normal.