FERROMAGNETIC RESONANCE IN FILMS WITH UNIAXIAL OBLIQUE ANISOTROPY

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1. Introduction

The effective fields in magnetic thin films, their origins and peculiarities are described by Heinrich, Cochran and Kowalewski in this chapter. A particular attention is focused on FMR and Brillouin light scattering (BLS) techniques, which are used for the study of effective fields in films and multilayers. In the theoretical description the effective field is believed being an admixture of the interface and bulk effective fields. Dipole (demagnetizing) field, in-plane and perpendicular uniaxial anisotropies fields as well as magnetocrystalline anisotropy field has been considered as main contributions. The advantages of their investigation and measurements by means of FMR and BLS were also shown in [1].

Our work is dealt with the special type of magnetic anisotropy, the so-called uniaxial oblique anisotropy (OA), which was not considered in above mentioned chapter by Heinrich et al., but can often occur in films under deposition. The way of OA testing in thin films by FMR as well as the determination of OA field/energy and angle of the anisotropy axis inclination from the film normal has been proposed.

It is well known that the uniaxial oblique anisotropy (OA) whose axis makes an angle 0<α<90° with respect to the film normal can be spontaneously formed during the deposition of ferromagnetic films. This fact is often out of consideration because either OA presence is not detected by traditional measurements or it is believed that the OA influence is insignificant. But in many cases the OA presence should be taken into account both for determination of true magnetic parameters of the films and for an adequate description of torque or FMR field angular dependences. For example the study of the films with a large value perpendicular anisotropy (PA) (anisotropy field $H_{pa}=4\pi M_s$, where $M_s$ is the saturation magnetization) was paid much attention recently. A series of effects (the appearance of the additional maxima on FMR field angular dependence, their displacement etc.) has been observed. As it was impossible to describe their behavior using the first-order anisotropy constants only, the authors of [2,3] asserted that the influence of higher-order anisotropy terms was important and should be taken into account. As a result they have obtained a good agreement of theoretical and experimental data. But similar description is not unique. Some of "complicated" experimental dependences can be easily simulated assuming the first-order anisotropy energy terms only. In this case it should be supposed that PA axis is
canted and in fact the sample possess oblique anisotropy instead of perpendicular. Even at a small deviation of the axis from the film normal, angular dependences of the resonance field can be modified noticeably. The OA presence in the film and the values of its parameters are determined in this work by computer simulation of the experimental FMR data in the following way.

2. Theoretical description

Let us consider a magnetic film with oblique uniaxial anisotropy. Spherical coordinate system \(\rho \eta \xi\) (where \(\xi\) and \(\eta\) are polar and azimuthal angles respectively) is chosen so that the anisotropy easy axis lies in \((\rho \eta 0)\) plane and \((\rho \frac{\pi}{2} \xi)\) is a film plane (see Fig.1). \(\theta\) and \(\varphi\) are equilibrium polar and azimuthal angles of the magnetization \(M\) and \(\varphi_H\) and \(\theta_H\) characterize the direction of external field \(H\). Free energy of the system is

\[
F = -MH \sin \delta + 2\pi M^2 \cos^2 \theta + \frac{MH_{OA}}{2} \sin^2 \beta.
\]  

(1)

Here \(H_{OA}\) is OA field. Magnetization makes \(\beta(\theta, \varphi, \alpha)\) and \(\delta(\theta, \varphi, \theta_H, \varphi_H)\) angles with OA easy axis and magnetic field directions respectively:

\[
\sin \delta = \sin \theta_H \cos \varphi_H \sin \theta \cos \varphi + \sin \theta_H \sin \varphi_H \sin \theta \sin \varphi + \cos \theta_H \cos \theta
\]
\[
\sin^2 \beta = \sin^2 \theta \sin^2 \varphi + \sin^2 \alpha \cos^2 \theta + \cos^2 \alpha \sin^2 \theta \sin^2 \varphi - 2 \sin \alpha \cos \alpha \cos \theta \sin \varphi
\]