ORIENTATION OF THE MAGNETIC MOMENTS IN PERPENDICULAR ANISOTROPIC THIN FILMS BY HALL EFFECT

N.T. Minh Hong, N.H. Duc, N.H. Sinh and V. N. Thuc

Department of Physics, College of Science, VNU

Abstract: As a tradition, the magnetization easy direction of a unixial magnetic anisotropic film has usually been determined by using torque magnetometer and vibrating sample magnetometer. In this paper, for the first time, we introduce a novel method to determine the magnetic moment orientation of perpendicular magnetic anisotropic thin films by means of the longitudinal Hall effect study. For the magnetic $Tb(Fe_{0.55}Co_{0.45})_{1.5}$ (known as TerfecoHan) film, the field-dependence of the longitudinal Hall effect is carried out at various angles α between the applied field and the film plane direction. The results showed that the Hall voltage hysteresis curve exhibits a parallelogram type with a positive high-field susceptibility at $\alpha = 90^0$. The Hall voltage susceptibility, futhermore, decreases with decreasing α and changes in sign at $\alpha_m = 70^0$, which is coincided with the magnetic moment orientation. This finding is comparable with Magnetic Force Microscopy (MFM) images as well as Conversion Electron Mossbauer Spectral (CEMS) studies.

1. Introduction

As we known, in magnetic thin films, there always exists the ordinary and extraordinary Hall effect. The former one is due to Lorentz force and the latter one is proportional directly to sample's magnetization [1]. The extraordinary Hall effect (EHE) has been recognized as an useful tool for measuring the magnetic hysteresis M(H) curves of magnetic film having perpendicular anisotropy [2].

Generally, the EHE voltage is governed by the perpendicular component of the magnetization. The final (saturation) magnetization state is, however, determined by the applied field direction. So that the EHE voltage can increase or decrease depending on the relative of the initial magnetic moment direction with respect to the applied magnetic field one. As a consequence, the EHE voltage vs. field curve is expected to be analyzed to determine the magnetic moment direction. This problem is tackled in this paper. This idea is realized for TerfecoHan film.

2. Experiments

The films with thickness of 570 nm were deposited on glass substrates using rf-sputtering technique at room temperature. A vibrating sample magnetometer was used to determine the magnetization M. Domain structure was studied using MFM with magnetic tip that were magnetized perpendicular to the sample plane. The conversion electron Mössbauer spectra (CEMS) at room temperature were recorded using a conventional spectrometer equipped with a home-made helium-methane proportional counter. The Hall effect measurement has been carried out at room temperature by the standard dc four probe method on the square samples of 4×4 mm^2. The longitudinal Hall voltage V_H was measured in direction perpendicular to the currents I, as a function of the applied magnetic field as well as the field direction. α is defined to be the angle between the film plane and field direction.

3. Results and discussions

The perpendicular magnetic anisotropy of the investigated film is clearly evidenced by Magnetic Force Microscopy (MFM) in Fig. 1. At zero fields, MFM image allows us to see a complex structure in which there exists the interlacement of bright and dark color together corresponding to that domains with different polarity. The alternating perpendicular magnetization component gave rise to the contrast of the MFM images since MFM measures force gradient acting on the tip due to the perpendicular component of the surface field. These two stripes were found to have almost the same size and posses equal areas. When having a magnetic field applied on this sample, the magnetization process makes domain structure changed (domain width, geometrical type) until the sample approached saturation state.

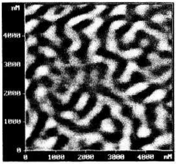

Fig.1. The MFM image of magnetic TerfecoHan film

This magnetic structure is also confirmed by Conversion Electron Mössbauer Spectral (CEMS) in Fig. 2. The result turns out from fit of the Mössbauer Spectrum that the average angle β between TbFeCo magnetic moments and the film normal is equal to 75^0. This demonstrates that the magnetization of TerfecoHan film seems to orientate perpendicular to film plane.

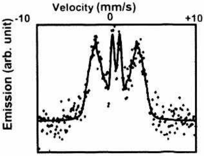

Fig.2. The Mössbauer spectra obtained at room temperature

The normalized V_H/V_{Hmax} and M/M_{max} curves measured in direction perpendicular to the film plane are presented in Fig. 3. Note that the sign of Hall coefficient isn't taken into account. The results showed that the $V_H(H)$ curve and the M(H) curve are well coincidental. The agreement between two experiments is rather good for indicating the coercive force H_c as well as hysteresis curves. However, there still exist the small discrepancies due to the mechanical hysteresis. This is understood as follows. According to the theoretical model proposed by Mc Guire et al, ρ_H closely relates to

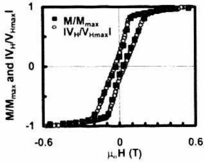

Fig.3. The M/M_{max} and V_H/V_{Hmax} curves of TerfecoHan film

magnetization mechanism [1]. In this case of TerfecoHan with perpendicular magnetic anisotropy, the rotation of magnetic moments in applied field leads to change V_H. The large change of ρ_{H} at low field proves the contribution of perpendicular magnetization component to the longitudinal Hall voltage.

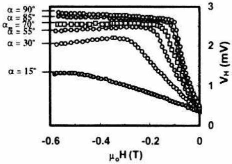

Fig.4. The $V_H(H)$ measured at various angles α

In high fields, the saturation tendency is not obtained for both EHE and M curves. In both case, one observes a rather large EHE and M slope (χ_{EHE} and χ_M in Fig. 4). As α decreases, χ_{EHE} initially decreases, annuls at $\alpha_m = 70^0$ and finally changes in sign (see Fig. 5). At the angle $\alpha_m = 70^0$, only existing a sufficient magnetic field of 0.15 T, all magnetic moments immediately arrange parallel to the field direction. The saturation process reaches completely at low field, while that requires a larger magnetic field for the case of other angles α. We assume that the direction of magnetic field coincides with that of magnetization in this case. The value of $\alpha_m = 70^0$ corresponds to $\beta = 30^0$. This value is somewhat higher than that obtained for the CEMS analysis. The accuracy of these two methods should be verified. However it allows us to explain experimental observation, in particular, the change in sign of χ_{EHE}.

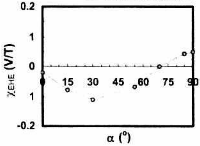

Fig.5. The angular dependence of field susceptibility (χ_{EHE})

In summary, the perpendicular magnetic anisotropy of the TerfecoHan thin film is well evidenced by means of MFM, VSM as well as EHE experiments. Thank to that, the EHE magnetometry is proposed to be used to study magnetization process. Moreover, EHE investigations are quite possible to determine the magnetic moment orientation in the magnetic films having perpendicular anisotropy.

Acknowledgements. This paper is supported by the State Program for Nanoscience and Nanotechnology of Vietnam under the Project 811.204 and the Project 8BS3.

References

1. P. Hansen, *in Handbook of Magnetic Materials*, edited by K. H. J. Buschow, Elsevier, Amsterdam, 1991, Vol. 6, Chap. 4.
2. D. G. Stinson, A. C. Palumbo, B. Brandt, and M. Berger, *J. Appl. Phys.*, **61**(1987), 3816.