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Application of Vector Moving Preisach Model to Longitudinal Thin Film Media

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Vector Moving Preisach model has been applied to the unoriented Co-based alloy thin film media. In the model, the out-of-plane easy axis distribution of the particles was derived directly from the texture coefficient phkl obtained from XRD analysis, which corresponds to the fraction of the grains that have the {hkl} plane lying parallel to in-plane direction. The model was validated, by its prediction of a variety of responses, including major loop, minor loop, and the angular dependence of coercivities.

Ⅰ. Introduction

Vector Moving Preisach (VMP) model which is a combination of Preisach model and Stoner-Wohlfarth (S-W) model has been proposed by Oti and Della Torre [1]. They found the possibility of the application of the model to the commercial tape media. A more sophisticated model modified by Ossart and Charap [2] includes the truncation of S-W asteroid, addition of feed back and extension of the model to 3D. They established the identification procedure and restored the remanence curves of the particulate media. The model has so many model parameters such as the distribution of critical field and interaction field, truncation factor, moving parameter, and easy axis distribution that it causes another problem to obtain the parameters.

In the previous work [3], we introduced the texture coefficients p_{hkl}, defined as the fraction of the grains that have {hkl} plane lying parallel to in-plane direction which gives directly the information on easy axis distribution in out-of-plane direction. And we restored the major loops and the angular variations of coercivities for Co thin film media. The identification procedure was simplified by the introduction of texture coefficients obtained by non-magnetic experimental data, XRD analysis.

The present study extended the previous work, simulation of major loop of thin film media to that of minor loop. Various Co-based alloy thin films were prepared by DC sputtering method, and their magnetic properties were measured by VSM.

Ⅱ. The Model

A. Principle

VMP model is a combined model which combines two earlier approaches to hysteresis modeling: the classical Preisach (CP) model [4], which is a intrinsically scalar model with particle interactions and the Stoner-Wohlfarth (S-W) uniaxial particle assembly model, which is intrinsically a vector model without interactions [5]. The introduction of the Preisach interaction field (H_i) to S-W asteroid as shown in Fig. 1 makes the model describe both particle interaction and vector nature.

In the model, a single point on the Preisach plane corresponds to a pseudo-particle comprising basic particles with different weights and orientations. Positive and negative switching fields in the Preisach plane are replaced by the critical field (H_c) and Preisach interaction field (H_i) in practical use. The direction of the magnetization in each particle, **D** (**H**, H_c, H_i) is determined graphically in S-W asteroid as shown in Fig. 1. The total magnetization of a medium, an assembly of pseudo-particles, is as follows :

$$\mathbf{M} = \iint \mathbf{D}(\mathbf{H}, H_c, H_i)\, P(H_c, H_i)\, dH_c\, dH_i \qquad (1)$$

where **H** is the total field that is vector sum of the interaction field (H_i) and the applied field (H_a), and P is density function.

B. Switching Properties

Ideally Co-based alloy thin film media consist of single domain grains of uniaxial anisotropy with different easy axes. A coercivity mechanism for these grains is coherent rotation magnetization, as in S-W model. In real media, S-W model is often insufficient to predict media coercivity. There should be an accommodation of other switching modes. Thus, the curling mode as suggested by Huang [6] is introduced to modify S-W asteroid as shown in Fig. 1 (full line). Relationship between the anisotropy field and the coercivity is given by

$$H_c = \frac{-1.08s^{-2}(-1.08s^{-2}+1)}{\sqrt{(-1.08s^{-2}+1)^2-(2.16s^{-2}+1)\sin^2\omega}}\,H_k \qquad (2)$$

where s is the fitting parameter and ω is the angle between the easy axis and the applied field. The Preisach density function is given as the product of the anisotropy field density instead of the critical field density and the interaction field density: $P(H_k, H_i) = P(H_k)\,P(H_i)$.

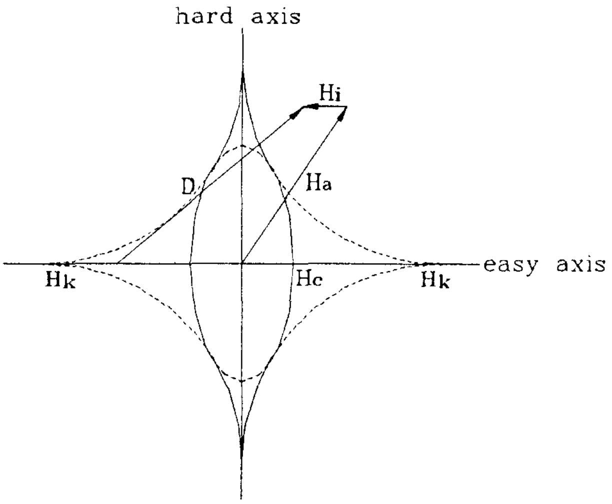

Fig. 1. Determination of Vector **D** and switching characteristics in S-W asteroid.

C. Moving Properties

Thin film media have close packed structure which results in complex inter-particle interactions. One of the methods to scale these interactions is to measure the delta-M curves, and a phenomenological moving constant or a feedback constant which is proportional to magnetization is adopted to describe the positive interaction in delta-M curves. Total magnetization is obtained by the iteration procedure and given by

$$M = f(H_a + kM), \qquad H_{int} = kM \qquad (3)$$

where H_a is the applied field, and k is the feedback constant. In the VMP model, the moving constant k is replaced by the feedback tensor [k] whose off-diagonal components are neglected [2]. The effective field in each particle is given by the sum of applied field H_a, mean interaction field H_{int}, which are globally constant over the medium and Preisach interaction field H_i which is locally dispersed over the medium.

D. Easy Axis Distribution

Co thin film media with uniaxial anisotropy have three kinds of principal planes, i. e., $(11\bar{2}0)$, $(10\bar{1}0)$, $(10\bar{1}1)$, and (0002) planes, and easy axis (c-axis) in each plane makes 0°, 23.6°, 90° with respect to film plane direction, respectively. Relative amount of grains with three different directions of easy axes can be obtained directly by texture coefficient phkl which is the fraction of the grains that have {hkl} plane lying parallel to in-plane direction. It is defined as follows.

$$P_{hkl} = \frac{I_{hkl}/I_{r,hkl}}{\sum I_{hkl}/I_{r,hkl}} \qquad (4)$$

where I_{hkl}, $I_{r,hkl}$ are x-ray peak intensities of {hkl} plane of specimen and powder standard samples, respectively. Integral intensities of 4 Co peaks are obtained by Lorentzian curve fitting as in Fig. 2. In-plane easy axes are assumed to be randomly distributed. Thus, the three dimensional easy axis distribution can be obtained completely by the product of in-plane distribution $w(\phi_i)$, and out-of-plane distribution $w(\theta_i)$ which is identical to p_{hkl}.

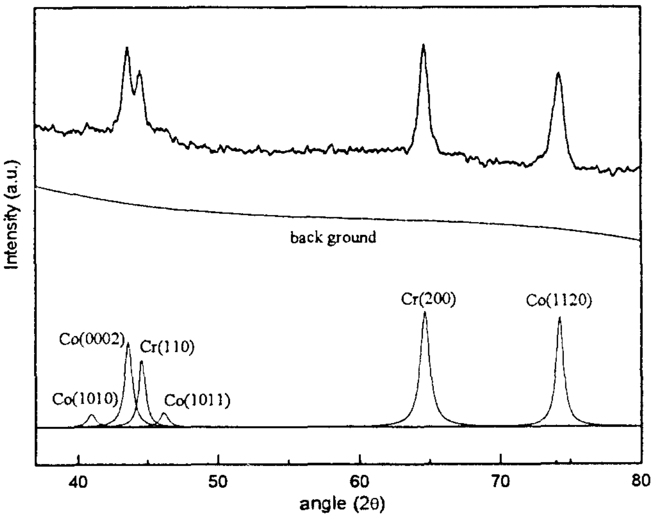

Fig. 2. XRD patterns of CoCrPtTa/Cr thin film.

E. Identification

Gaussian which is given by mean value and standard deviation was used as both anisotropy field distribution and interaction field distribution. Interaction field is assumed to act along the particles' easy axes. Since mean Preisach interaction field is zero, the model have six model parameters, mean anisotropy field $H_{k,m}$, standard deviation of anisotropy field σ_{Hk}, standard deviation of Preisach interaction field σ_{Hi}, curling parameter s, feedback constant k_x and easy axis distribution. Five model parameters except for easy axis distribution which has been directly obtained from texture coefficient should be identified by experimental data. For identification, we used Ossart's identification strategy which is fundamentally trial and error method [2].

Ⅲ. Results and Discussions

VMP model was applied to CoCrPtP/Cr/glass and CoCr PtTa/Cr/glass thin films whose magnetic properties are shown in Table Ⅰ. Particles with easy axes of 32 (in-plane) × 5 (out-of-plane) sets or 64 × 5 sets are used in the model. Model parameters of two different Co thin film media are listed in Table Ⅱ.

Table Ⅰ. Magnetic properties of thin film media

sample	Hc (Oe)	S	S*
$CoCr_{4.6}P_{5.6}Pt_{12.1}/Cr$	2180	0.90	0.84
$CoCr_{5.8}Pt_{10.1}/Cr$	1550	0.89	0.87
$CoCr_{12}Pt_{11}Ta_2/Cr$	1740	0.85	0.82

Table Ⅱ. Parameters of the model

	$CoCr_{4.6}P_{5.6}Pt_{12.1}/Cr$	$CoCr_{5.8}Pt_{10.1}/Cr$	$CoCr_{12}Pt_{11}Ta_2/Cr$
$H_{c,mean}$ (Oe)	2200	1420	1910
σH_c (× $H_{c,mean}$)	0.25	0.25	0.34
σH_i (× $H_{c,mean}$)	0.1	0.1	0.25
k_x (× 4π)	0.05	0.19	0.25
s	2.25	2.41	2.1
$w(\theta_1)$, $\theta_1 = 0$	77.7	73.6	71.1
$w(\theta_2)$, $\theta_2 = 23.6$	8.4	11.6	15.1
$w(\theta_3)$, $\theta_3 = 90$	13.9	14.8	13.8

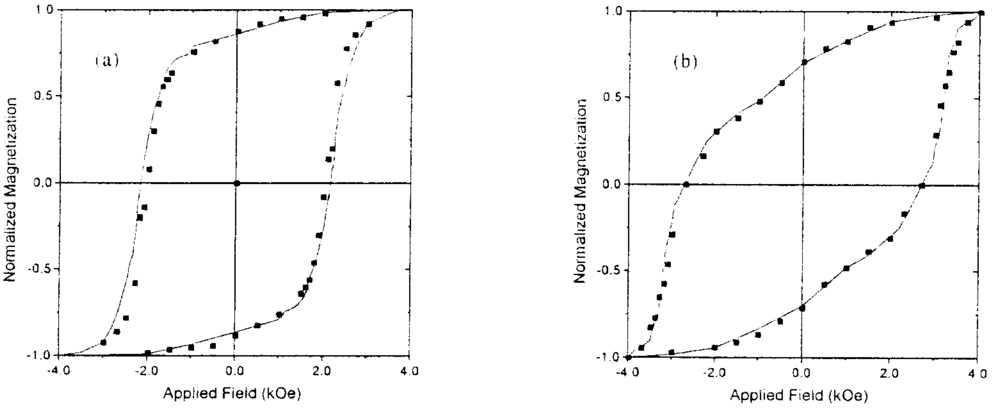

Fig. 3. Major loop of $CoCr_{4.6}P_{5.6}Pt_{12.1}/Cr$ thin film media
(a) Field is applied parallel to in-plane direction.
(b) Field makes 40° with respect to in-plane direction.
(square : measured data line : simulated data)

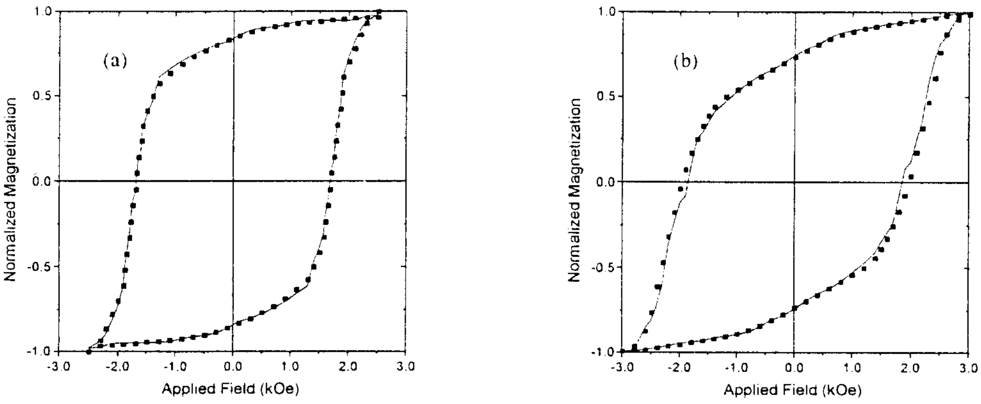

Fig. 4. Major loop of $CoCr_{12}Pt_{11}Ta_2/Cr$ thin film media
(a) Field is applied parallel to in-plane direction.
(b) Field makes 40° with respect to in-plane direction.
(square : measured data line : simulated data)

Their major loops were restored in Figs. 3 and 4. Simulated major loops showed a good agreement with the measured loops even though the field was not applied parallel to film plane direction as shown in Figs. 3 (b) and 4 (b). These results led us to believe that the model is useful to simulate the magnetic recording process where the head field is applied to media in a semi-circular form. And, also, it was believed that the model can be applied to various Co based alloy longitudinal thin film media.

The angular variation of coercivities which is strongly correlated with the switching mechanism and the easy axis distribution [6] was simulated and compared with measured data. CoCrPPt thin film media with two different compositions are used. Good agreements with measured data as shown in Fig. 5 guarantee that texture coefficients are useful as the easy axis distribution in thin film media.

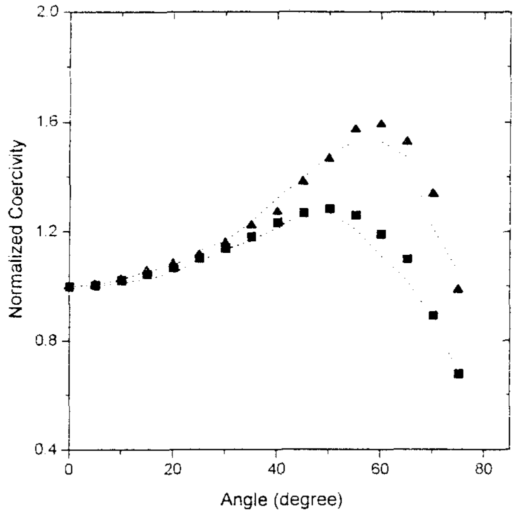

Fig. 5. Angular dependence of coercivities in CoCrPPt/Cr thin film media
(line : simulated data square : $CoCr_{4.6}P_{5.6}Pt_{12.1}$ triangle : $CoCr_{5.8}Pt_{10.1}$)

In the previous work, it was found that minor loop modeling plays an important role for the simulation of high density recording [7]. In this work, we tried to simulate the minor loop of CoCrPtTa thin film media. As shown in Fig. 6, the simulated minor loop was a little different from measured one, which might result from the deficiency of identification of remanence loop including delta M curve which is strongly correlated to two model parameters, feedback and standard deviation of interaction field.

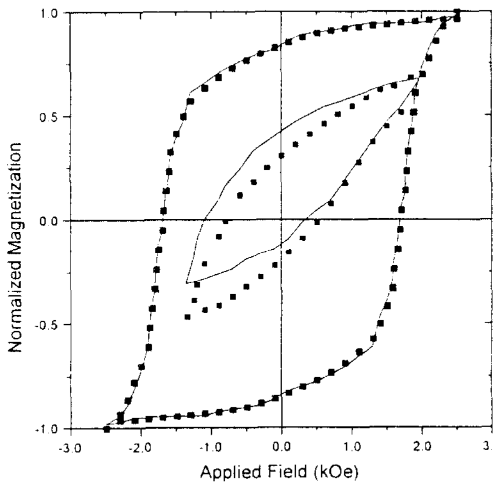

Fig. 6. Minor loop of $CoCr_{12}Pt_{11}Ta_{2}$/Cr thin film media
(square : measured data line : simulated data)

Using the model, we predicted the major loop and the angular variation of coercivities precisely while the modeling of minor loop which is strongly affected by particle interaction was not fulfilled with satisfaction. We will investigate the identification of the delta M curve for the better matching.

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