PARTICLE ORIENTATION DISTRIBUTION IN $\gamma\text{-Fe}_2\text{O}_3$ MAGNETIC TAPES
BY MOSSBAUER AND HYSTERESIS LOOP MEASUREMENTS

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Abstract

The particle orientation in several $\gamma\text{-Fe}_2\text{O}_3$ magnetic tapes has been quantitatively evaluated by using the data of both Mössbauer and hysteresis loop measurements performed in the three orthogonal directions.

A texture function has been obtained as a development of real harmonics. The profile of the texture function gives the quality of the different magnetic tapes. A different degree of particle orientation at the surface of the tape is evidenced by means of conversion electron Mössbauer spectra.

Introduction

Acicular $\gamma\text{-Fe}_2\text{O}_3$ are the most widely used magnetic material for magnetic recording media. The orientation of the easy magnetization axis of magnetic particles is one of the key parameters of the recording media performances.

It is well known that acicular $\gamma\text{-Fe}_2\text{O}_3$ particles have the easy magnetization axis along the major axis of the needle¹ and the particles are oriented as uniformly as possible in the recording direction of the tape^{2,3}.

We present in this work an experimental determination of the texture function of several $\gamma\text{-Fe}_2\text{O}_3$ magnetic tapes using a combination of data obtained from Mössbauer and hysteresis loop measurements. By means of Mössbauer spectroscopy the angle between the direction of propagation of the γ -rays and the direction of the local magnetic moment ($\cos \theta_R$) can be measured^{3,4}.

The squareness of the hysteresis loop, in a sample of single domain particles, directly gives the orientation of the particles respect to the direction of the applied magnetic field^{5,6}.

The combination of both data, Mössbauer and hysteresis loop measurements, gives a more accurate determination of the texture function of the magnetic particles in the tape.

Experimental and Results

a) Mössbauer spectroscopy:

The Mössbauer spectra were recorded at room temperature using a conventional spectrometer. The films used as Mössbauer absorbers were cut from three stacks of three different Co-adsorbed $\gamma\text{-Fe}_2\text{O}_3$ commercial recording films (to be denoted as 1, 2 and 3 respectively).

Figure 1: Geometrical arrangements used for obtaining the Mössbauer spectra.

Figure 1 indicates the three geometrical arrangements used to record the Mössbauer spectra. Mössbauer conversion electron spectra were also recorded by using a home-made acetone detector. The geometry used for the C.E.M. spectra is that corresponding to the γ -rays perpendicular to the tape.

b) Magnetic measurements:

The hysteresis loop measurements were done by using a home-made Weiss coercimeter. The external magnetic field, H , was applied along three directions which correspond to $H \parallel X$ (A), $H \parallel Y$ (B) and $H \parallel Z$ (C), respectively, where the directions X, Y, Z are defined in Figure 1.

Figure 2: Mössbauer spectra for sample 2 in the three different directions and C.E.M. spectra for the three samples.

In Figure 2, we show the recorded Mössbauer spectra for sample 2 in the three different geometrical arrangements and C.E.M. spectra for the three different samples.

In Table I we summarize the ratio of the intensities of outer lines to the inner lines ($A_{1,6}:A_{2,5}$) of the six pattern lines spectra and the values of the squareness of the hysteresis loop.

Table I

SAMPLE	GEOMETRY	SQUARENESS TRANSMISSION		C.E.M.S. <cos ² θ _R >
		<cosθ _R >	<cos ² θ _R >	
1	A	0.50(1)	0.32(1)	0.14(1)
	B	0.77(1)	0.34(1)	
	C	0.22(1)	0.17(1)	
2	A	0.45(1)	0.23(1)	0.06(1)
	B	0.85(1)	0.40(1)	
	C	0.19(1)	0.11(1)	
3	A	0.42(1)	0.29(1)	0.12(1)
	B	0.78(1)	0.40(1)	
	C	0.19(1)	0.18(1)	

Discussion

Our unique assumption in the analysis of the experimental results is that the differences among <cosθ_R> and <cos²θ_R>^{1/2} measured by hysteresis loop and Mössbauer spectroscopy respectively, are due to the texture function of the particles. This means, for example, that the demagnetizing field associated with the remanence does not modify the magnetic moment orientation.

We have verified this point by recording Mössbauer spectra of magnetized and demagnetized samples and no differences were observed.

The particles texture function $D(\theta_M, \phi_M)$ may be written in terms of real harmonics Z_l^m as:

$$D(\theta_M, \phi_M) = \sum_{l=0}^{\infty} \sum_{m=0}^l D_l^m Z_l^m(\theta_M, \phi_M) \quad (1)$$

where θ_M and ϕ_M are the polar and azimuthal angles between the magnetic moment and the reference axis of the tape (figure 1). We assumed that a magnetic tape has orthorhombic symmetry and so only even l terms appear in the development. The contribution of the different terms of eq. (1) depends on the experimental technique.

In the case of Mössbauer spectroscopy we must evaluate the expression:

$$\langle \cos^2 \theta_R \rangle = \int_0^{2\pi} \int_0^\pi \cos^2 \theta_R D(\theta_M, \phi_M) \sin \theta_M d\theta_M d\phi_M \quad (2)$$

The corresponding expression to be evaluated in the case of hysteresis loop measurements is:

$$\langle \cos \theta_R \rangle = 2 \int_0^{2\pi} \int_0^{\pi/2} \cos \theta_R D(\theta_M, \phi_M) \sin \theta_M d\theta_M d\phi_M \quad (3)$$

In both cases $\cos \theta_R$ must be referred to the principal axis of the tape as:

$$\cos \theta_R = \cos \theta \cos \phi + \sin \theta \sin \phi \cos \phi_M + \sin \theta \sin \phi \sin \phi_M \sin \phi_M \quad (4)$$

where θ and ϕ define the geometry used in the experiment.

Introducing eq.(4) in eq.(2) and (3) and performing the corresponding integrals we obtain a set of 6 equations corresponding to the 6 independent experimental measurements. Taking into account both, that in the hysteresis loop measurements the external magnetic field produces an orientation in the positive hemisphere of all magnetic moments, and the spatial isotropy of this distribution, the D_l^m coefficients determined from the hysteresis loop measurements are 4 times greater than those obtained from the Mössbauer experiments. Therefore it can be written:

$$\langle \cos^2 \theta_R \rangle = a_0^0(1) D_0^0 + \sum_{m=0}^2 a_2^m(1) D_2^m \quad (5)$$

$$\langle \cos \theta_R \rangle = a_0^0(2) D_0^0 + \sum_{m=0}^2 4a_2^m(2) D_2^m + \sum_{m=0}^2 a_4^m(2) D_4^m$$

where the development of <cos²θ_R> is limited up to $l=2$ by symmetry arguments³ while the <cosθ_R> development is limited up to $l=4$ because the $a_1^m(2)$ coefficients corresponding to $l=6$ are already one order of magnitude smaller⁷.

We note that the equation system (5) is overdetermined because the D_0^0 coefficient is fixed by normalization, hence we solved it by a least squares fitting procedure. The calculated coefficients $a_1^m(1)$ and $a_1^m(2)$ are reported in Table II. In Table III we give the resulting D_2^m parameters obtained by the above method. The D_4^m parameters are not reported because they were smaller than 10^{-3} . In Figure 3 we show a representation of the obtained texture function for the 3 samples. Clearly, a similar trend is apparent for all the samples but sample 2 has a more pronounced peak in the recording direction. This corresponds to a more effective orientation process and hence to a better recording performance.

Table II: $a_1^m(1)$ and $a_1^m(2)$ coefficients

l m	MOSSBAUER (θ, φ)			SQUARENESS (θ, φ)		
	(0, any)	(π/2, 0)	(π/2, π/2)	(0, any)	(π/2, 0)	(π/2, π/2)
0 0	1.18	1.18	1.18	1.77	1.77	1.77
2 0	1.06	-0.53	-0.53	0.99	-0.50	-0.50
2 2	-	0.92	-0.92	0.	0.86	-0.86
4 0	-	-	-	-0.22	0.08	0.08
4 2	-	-	-	0	0.12	-0.12
4 4	-	-	-	0	-0.33	-0.33

Table III: D_2^m parameters

SAMPLE	D_0^0	D_2^0	D_2^2
1	0.2821	-0.132	-0.065
2	0.2821	-0.148	-0.109
3	0.2821	-0.131	-0.098

Figure 3: Representation of the texture function for the three samples.

We remark that even if the hysteresis loop measurements do not add new coefficients to the development of $D(\theta_M, \phi_M)$, the consideration of both measurements simultaneously gives a different set of D_{z^n} coefficients.

We want finally to emphasize that the $\langle \cos^2 \theta_R \rangle$ values observed in the C.E.M. spectra for the C geometry, are smaller than those observed in the transmission Mössbauer experiments. This means that a better alignment in the X-Y plane is obtained for the particles located near the surface of the tape. This is so because the electrons of the C.E.M. spectra are only sensible to a layer of about $1000 \text{ \AA}$ from the surface of the tape while the total thickness of the magnetic coating in the tape is several microns.

The existence of a better orientation in the surface of the coating may be understood as an effect of the drying process which is more effective in the surface than in the bulk of the tape.

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