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Three-dimensional analysis of the magnetization process of thin-film media

E. Miyashita, Y. Yoneda, and J. Numazawa
NHK Science and Technical Research Labs, 1-10-11 Kinuta, Setagaya-ku, Tokyo 157, Japan

A calculation model in which the medium is considered as a set of many fine magnetic particles is applied to thin-film media. The magnetic characteristics are calculated for a particle with an initial layer, a particle without an initial layer, and media composed of the particles of either type. The results show that the switching mode of both particles is a quasi-coherent rotation but the switching field dependence of the particle with an initial layer has curlinglike characteristics. The perpendicular medium with an initial layer is over corrected by $4\pi M_s$ demagnetization correction. © *1996 American Institute of Physics.* [S0021-8979(96)21008-3]

I. INTRODUCTION

All kinds of recording media have intrinsic particle structures, sizes and shapes, and interactions between them. When analyzing media, we must consider the characteristics of fine magnetic particles of which they are constituted. In order to analyze a medium microscopically the authors have proposed a new medium model for calculating the magnetic characteristics of recording media.[1] Several calculation models have been proposed,[2,3] but they have assumed either that the magnetization in a particle is uniform or that the switching field characteristics of a particle are curling. In this model, no assumptions are made about either the magnetization in a particle or the reversal mode. The medium is considered as a many-body system of fine magnetic particles and the magnetic characteristics of the media are calculated from the magnetic properties of the isolated fine particles and interparticle interactions. The authors have previously calculated the characteristics of metal-particle and barium–ferrite-particle media and showed the effect of the interactive field on the magnetization process.[1]

We have now improved this model for application to thin-film media. In the improved model, the initial layer of a fine particle can be considered for calculation of the switching process. To calculate the medium magnetization process, the exchange and demagnetization fields are also considered. Using this model, we calculate the magnetization curves for perpendicular thin-film media. Perpendicular media have an initial layer which is semihard and has easy axis in the plane, because the surface roughness or adatoms of the substrate throw an initial crystal growth into disorder. In order to study the effect of initial layer on the magnetization process, we calculate the magnetization curves of perpendicular media both with and without an initial layer. The validity of a demagnetization correction for perpendicular media is also discussed.

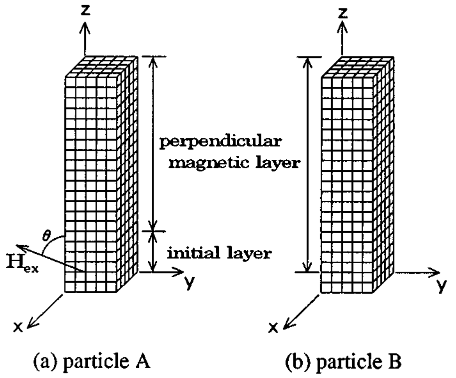
II. CALCULATION MODEL

A. Calculation model for the switching process of an isolated fine particle

The switching process of an isolated fine particle was calculated numerically by use of the Landau–Lifshitz–Gilbert equation.[4] The fine particles are assumed to be hexahedral, as shown in Fig. 1. The particle is divided into $n_x \times n_y \times n_z$ cubic cells. The cell size is set sufficiently small for the magnetization in the cell to be considered uniform. The easy axis of each cell can be set independently for consideration of not only the perpendicular layer but also the initial layer. The forward differential method was used because the algorithms are simple and the free boundary condition was imposed. The calculation parameters are shown in Table I.

B. Calculation model for magnetization process of the medium

The medium model is shown in Fig. 2. The thin-film medium is composed of fine particles located on $N_x \times N_y$



(a) particle A (b) particle B

FIG. 1. Calculated particles.

TABLE I. Calculation parameters of particles.

	Particle A	Particle B
Division number $n_x \times n_y \times n_z$	5×5×26	5×5×26
Cell size [nm]	9	9
Exchange in a particle A [$\times 10^{-6}$ erg/cm]	0.6	0.6
Magnetocrystalline anisotropic constant		
K_{u1} [$\times 10^4$ erg/cc]	142–342	142–342
K_{u2} [$\times 10^4$ erg/cc]	36–85	36–85
Initial layer		
K_{u1} [$\times 10^4$ erg/cc]	48–114	
K_{u2} [$\times 10^4$ erg/cc]	12–28	
Saturation magnetization M_s [emu/cc]	570	570

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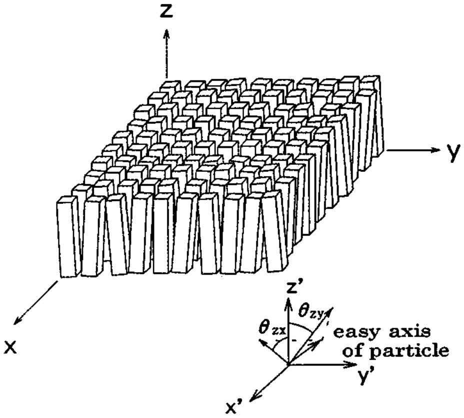


FIG. 2. Medium model.

lattice points with each easy axis direction. The characteristics of the isolated particle have already been calculated in (a), and now the interactive field must be calculated. This includes considerations of the magnetostatic interactive field from other particles, the exchange field from the nearest neighboring particles, and the demagnetization field. For simplicity, the magnetostatic field was calculated on the assumption that the magnetization of the particles is uniform. The demagnetization field coefficient in the z-axis direction is equal to 1. The calculation range of the magnetostatic interactive field is to the sixth nearest neighboring particles. The periodic boundary condition was imposed. The calculation's parameters are shown in Table II. All distribution is assumed to be Gaussian.

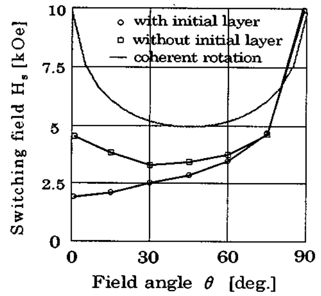
III RESULTS AND DISCUSSION

A. Switching process of an isolated fine particle

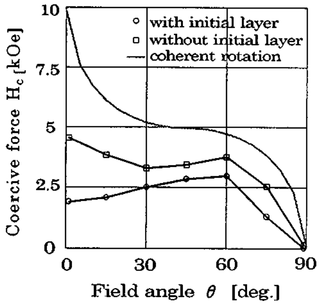
Figure 3 shows the dependence of the switching field and coercive force on the angle of the external field with a crystalline anisotropic field strength of 8000 Oe. The switching mode of both particle **A** with an initial layer and particle **B** without an initial layer is a quasi-coherent rotation. The curve of particle **A**, however, is similar to a curling mode curve. Magnetization reversal of both particles starts at one end of the particle, with the reversal then gradually moving to the other end. This switching mode is taken because in the case of long and thin particles less total energy is used than in other switching modes. The switching field of particle **A** is much smaller than that of particle **B** in the small field angle. For particle **A**, the magnetization layer is in-plane by the easy axis in the plane in the initial layer and out of plane by the easy axis out of the plane in the perpendicular. The angle of magnetization in both layers is nearly 90°. Accordingly, a large torque acts on the initial layer in the low field angle.

TABLE II. Calculation parameters of media.

	Medium A	Medium B
Particle number $N_x \times N_y$	50×50	50×50
Lattice distance $dx \times dy$ [nm]	50×50	50×50
Interparticle exchange		
A_{pmean} [$\times 10^{-6}$ erg/cm]	0.2	0.2
σ_{Ap} [$\times 10^{-6}$ erg/cm]	0.2	0.2
Easy axis dispersion		
σ_{zx}, σ_{zy} [deg]	4,4	4,4
Average anisotropic field		
H_{kmean} [Oe]	7500	7500
Anisotropic field dispersion		
σ_{Hk} [Oe]	500	500



(a) Switching field of particles



(b) Coercive force of particles

FIG. 3. Switching field and coercive force.

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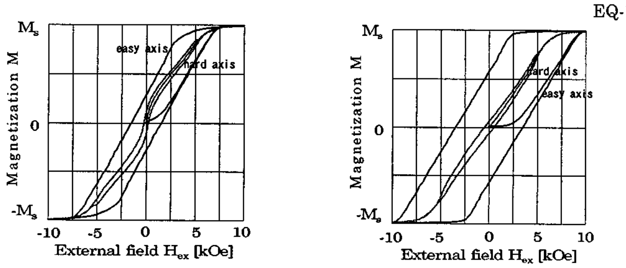
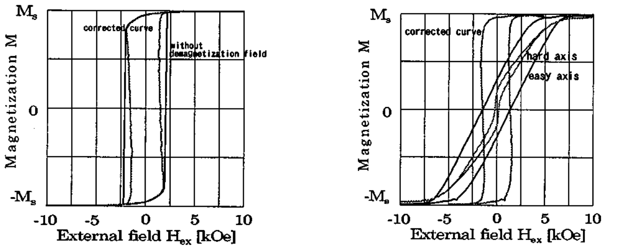


(a) Medium A with initial layer

(b) Medium B without initial layer



(c) Medium A without demagnetization field and demagnetization corrected curve

(d) Measured Co-Cr-Ta medium

FIG. 4. Calculated and measured magnetization curves.

B. Magnetization curves of the media

These magnetization curves were calculated for perpendicular medium **A** composed of particle **A** and medium **B** composed of particle **B**. Figure 4(a) and 4(b) show the magnetization curves of media **A** and **B** with the demagnetization field. Figure 4(c) shows magnetization curves of medium A both without the demagnetization field and after demagnetization correction of the curve in Fig. 4(a). (The curve of medium **A** is shown (c) without the demagnetization field and the corrected curve (a) is shown after demagnetization field correction.) Calculated magnetization curves (a) agree quite well with the measured curves. The coercive force of medium **A** is much smaller than that of **B**. The measured magnetization curves of the perpendicular Co–Cr–Ta film media are also shown in Fig. 4(d) for comparison with the calculated curves. The magnetization curve in the hard axis direction jumps near the zero field shown in Fig. 4(d) because the real perpendicular medium has an initial layer. The curve of the easy axis direction has a slope of nearly $4\pi M_s$ because of the demagnetization field. The dashed line in Fig. 4(d) is the corrected measured curve. Both corrected curves are over corrected after simple demagnetization correction. The switching field of the fine particle depends on not only the strength of the field but also on the angle between the magnetization and the field. The magnetostatic and exchange fields take various directions, so the switching field of each particle in the medium varies. The demagnetization field is uniform but the total field applied to particles exhibits various strengths and directions. The result is that the magnetization curve is not corrected precisely by simple demagnetization. The reason for over correction is that the magnetization process depends strongly on both the switching field characteristics and the magnetostatic interactive field.

IV. CONCLUSION

The improved fine particle model was applied to thin-film media and the magnetization curves were calculated. The following results were obtained:

(1) The switching field characteristics of the particle with the initial layer has curlinglike characteristics.
(2) The coercive force in the perpendicular direction of the medium is considerably reduced by the initial layer.
(3) The perpendicular medium with initial layer is over corrected by $4\pi M_s$ demagnetization.

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