Simulation of Magnetic Transition under Influence of Perpendicular Anisotropy Component in Thin Film Longitudinal Recording Media

Toshikazu NISHIHARA, Toshiro ABE, Toshio ANDO, Makoto MIZUKAMI and Masaru SEGAWA

Central R&D Center, JVC
58-7, Shinmei-cho, Yokosuka, Kanagawa 239, Japan

Abstract—Hysteresis properties and transition configurations as related to intergranular exchange coupling and out-of-plane angle of grain's magnetic easy axis have been studied with 3D-static simulation model in longitudinal thin film media. The out-of-plane angle of easy axis contributes to release the bridgings in large exchange coupled thin film media.

I. INTRODUCTION

The studies of magnetic transition noise in thin film recording media have been widely performed with experiments and computer simulations. Particularly the simulation studies based on the full dynamic model^{(1) (2)} have been very successful. However the calculations are extremely computationally intensive. Therefore we have developed static 3D-simulation model for micromagnetic studies.

It is now understood that the transition noise is strongly affected by the degree of exchange coupling between grains^{(3) (4)} in polycrystalline films. Further, present studies have shown that the transition noise is influenced by magnetic longitudinal orientation^{(5) (6)} and oblique orientation⁽⁷⁾. Now it is expected that oblique orientation or perpendicular anisotropy component is significant to reduce demagnetization field in thin film longitudinal recording media.

In this paper we describe a newly developed static 3D-simulation method and its application on transition configuration in thin film longitudinal recording media with/without perpendicular anisotropy component and intergranular exchange coupling.

II. MODEL & METHOD

We used basically the Hughes model⁽⁸⁾ for grain arrangement and characterization with some modifications. The modeled thin film medium is composed of 25x41 grains by a two dimensional array. Each grain is a single domain with uniaxial anisotropy and uniform magnetization. The easy axis of each grain is 3D-randomly assigned under specific conditions.

Fig.1 shows grain's calculation plane. E_{ij} is a grain's easy axis unit vector and H_{ij} is a external magnetic field's vector. Magnetic unit vector M_{ij} is in the plane made from E_{ij} and H_{ij} . Curling magnetization model

⁽⁹⁾ and Stoner-Wohlfarth eq. are used for calculation to magnetic reversal and resulting magnetic direction, respectively.

The external magnetic field H_{ij} consists of long range magnetostatic field H_s , nearest neighbor exchange coupling field H_e and Karqvist-2D head field H_h .

Fig.1 Grain's Calculation Plane

(The direction of plane varies at every calculation step depending on the direction of external magnetic field until convergence is reached. E is a grain's easy axis unit vector. H is a external magnetic field vector. M is a magnetic directional unit vector.)

$$H_{ij} = H_{sij} + H_{eij} + H_{hij}$$

In case of hysteresis loop calculation, H_h is de/escalated constantly. The dipole-dipole interaction eq. is used for the long range magnetostatic field H_s

$$H_{sij} = \sum (-1/4\pi \mu_0 r_j^3) \{ M_j - 3(M_j \cdot r_j)r_j/r_j^2 \}$$

The nearest neighbor exchange coupling field H_{eij} is set to be the same equation form as H_{sij}

$$H_{eij} = E_c * H_{sij}$$

Here E_c is an exchange coupling constant parameter. In this work E_c is varied from 0 to 0.57 for the study. E_c is selected to be positive or negative value so as to

cause a magnetic coupling.

The direction of each plane is changed at every calculation step depending on the external magnetic field. The value of unit direction vector $M_{i,j}$ is obtained by solving the eqs. of the Stoner–Wohlfarth eq., $dE/d\theta = 0$ and $d^2E/d\theta^2 > 0$. To obtain $M_{i,j}$, self-consistent method⁽¹⁰⁾ is used, and the calculation allows to continue until convergence is reached. The convergence is decided by that all of the value of $M_{i,j}(x,y,z)$ is within 2% of prior value of $M_{i,j}(x,y,z)$.

Numerical conditions are settled as grain size of 20nm, head gap length g_l of $0.3\mu\text{m}$ and head medium spacing of 50nm.

III. RESULTS AND DISCUSSIONS

Hysteresis properties and transition configuration results are obtained under the conditions which are varied in ranges of the exchange coupling constant parameter E_c of $0 \sim 0.57$ and the average out-of-plane angle of easy axis $\theta_z = \pm 0, \pm 20, \pm 30, \pm 40$ degrees. This structure is based on actual Co-alloy/Cr sputtered film media. As for each grain, individual K_u and out-of-plane angle of easy axis $\theta_{z,i}$ are arranged as Gaussian distribution with an average value of K_u and θ_z , respectively. In x-y plane they are set to be oriented randomly. Individual grain's M_s , K_u , standard deviations of K_u and θ_z , randomness in x-y plane and head field are settled to be constant in this work as $M_s=4000(\text{G})$, $K_u=4 \times 10^6$ (erg/cc), standard deviation σ of distributed value's K_u and $\theta_z = 25\%$ of each average.

A. Hysteresis Properties

Fig.2 shows some examples of calculated hysteresis loops for the exchange coupling parameter $E_c=0.29$ and for four different out-of-plane angle θ_z . The values of M_s and H_c are normalized. Since the number of grains is limited, lines of hysteresis loops are wobbling.

Fig.3 and Fig.4 show the calculated results of squareness ratio R_s and coercivity H_c , respectively, as the functions of out-of-plane angle θ_z and exchange coupling parameter E_c . R_s and H_c values are sensitive to intergranular exchange coupling⁽¹⁾. The larger the exchange coupling, the larger the R_s and H_c in these conditions. The R_s and H_c values are also sensitive to the amount of θ_z . These values decrease in proportion to the grain's out-of-plane angle θ_z , especially in the case of smaller E_c , as shown in Fig.3 and Fig.4. This is caused by the fact that the large θ_z weakens positive interaction among grains.

Fig.2 Examples of Calculated Hysteresis Loops (Exchange coupling parameter $E_c=0.29$, out-of-plane angle $\theta_z=0 \sim 40$ degrees)

Fig.3 Squareness ratio on out-of-plane angle θ_z

Fig.4 Coercivity on out-of-plane angle θ_z

B. Transition Configurations

Transition configurations are studied by simulating the recording of one bit and four-bits transitions. Prior to the recording, the magnetization of each grain is saturated along the recording direction. The head field is set to be about 2.5 times the calculated film coercivity. Periodic boundary conditions are used both in the track direction and in the transverse direction.

Fig.5 and Fig.6 show two typical examples of calculated transition configuration of x-y plane for the parameter of $E_c=0$ and 0.29, respectively. In these cases out-of-plane angle θ_z is 0 degree. In the value of $E_c=0$ (Fig.5), obscure pattern can be observed, while in the value of $E_c=0.29$ (Fig.6) magnetic clusters can be observed. And small bridging also can be observed (pointed with an arrow in Fig.6). Fig.7 shows width of zig-zag domain as the function of exchange coupling parameter E_c from one bit transition configurations. As studied experimentally⁽¹¹⁾ and numerically⁽³⁾, the stronger the E_c , magnetic clusters are formed more distinguished and the wider the width of zig-zag domain.

Fig.8 shows an example of calculated transition configuration of x-y plane for the parameter of $E_c=0.29$ and $\theta_z=20$ degrees. In this case calculated conditions are same as the case of Fig.6 except the value of θ_z . In the value of $\theta_z=20$ degrees the bridging pattern from cluster to cluster cannot be observed. And the maximum bit width approaches normal length (marked as $\blacktriangle\blacktriangle$). The maximum bit width is defined as a length pointed with " $\blacktriangleright\blacktriangleleft$ " in Fig.6 and Fig.8.

Fig.9 shows the width of zig-zag domain calculated by one bit transition as the functions of θ_z and E_c . Three different patterns are observed in this result. On the first pattern [A], the transition configuration of magnetic media is almost close to that of particulate media that is the case of $E_c=0\sim0.07$. In these cases of $E_c=0$ and 0.07 the width of zig-zag domain cannot be calculated because of obscure configuration in all values of θ_z . The larger value of θ_z causes only the larger randomness of magnetic easy axis distribution in the film plane. The cases of $E_c=0.14$, and $\theta_z=30, 40$ degrees are same as the cases of $E_c<0.07$.

Second pattern [B] is the case that E_c has a middle value (~ 0.43). Grains are formed to magnetic clusters. But the width of zig-zag domain in the value of $\theta_z>20$ degrees is smaller than the case of $\theta_z=0$ degree. Fig.10(a)(b) show cross sectional view of magnetic vector of each grain at the line #18 in Fig.6 and Fig.8 marked "-" in each figure, respectively. It can be derived from Fig.10(a)(b) that in the case of $\theta_z=0$, magnetic energy can be relaxed only in x-y plane. But in the case of larger θ_z , magnetic energy can be relaxed not

only in the x-y plane but also in the x-z plane as shown in Fig.10(b) and Fig.8. It is considered that the θ_z of 20 degrees causes the reason of the maximum bit width

Fig.5 Calculated Transition Configuration (I)

Out-of-plane angle $\theta_z=0$ degree. Exchange coupling parameter $E_c=0$. An empty circle with a tail represents a magnetization vector with a negative x component and a solid circle with a tail represents a magnetization vector with a positive x component.

Fig.6 Calculated Transition Configuration (II)

Out-of-plane angle $\theta_z=0$ degree. Exchange coupling parameter $E_c=0.29$. An arrow indicates a bridging from cluster to cluster. Figures of right side show line number. Cross sectional view of #18 is shown in Fig.10(a).

Fig.7 Width of zig-zag domain as a function of E_c ($\theta_z=0$ degree)

approaching the normal bit length and eliminating the bridging patterns.

In the third case [C] of large E_c (~ 0.57), large θ_z does not shorten the maximum bit width and eliminate the bridging because of the excessive value of E_c .

Fig.8 Calculated Transition Configuration (III)

Out-of-plane angle $\theta_z = 20$ degrees. Exchange coupling parameter $E_c = 0.29$. Cross sectional view of #18 is shown in Fig.10(b).

Fig.9 Width of zig-zag domain as a function of θ_z

(a) line #18 in Fig.6

(b) line #18 in Fig.8

Fig.10 Magnetic M_x and M_z component display
(a) line #18 in Fig.6, (b) line #18 in Fig.8

IV. CONCLUSION

The effect of out-of-plane angle of grain's easy axis and intergranular exchange coupling has been studied in thin longitudinal recording film media with the newly developed 3D-static simulation model. In the case of 0 or small value of the exchange coupling, transition configuration is constructed as obscure in planely randomness media. In this case magnetic orientation is important for high density and high S/N recording. In the case of larger exchange coupling, grains have formed to magnetic clusters with bridging. In this case out-of-plane angle of grain's easy axis contributes to shorten the zig-zag width and to eliminate the bridging because of relaxation of magnetic energy.

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