SIMULATION OF THERMAL FLUCTUATION IN MAGNETIZATION OF LONGITUDINAL AND PERPENDICULAR RECORDING MEDIA WITH GRAIN SIZE DISTRIBUTION

Yasutaro UESAKA¹, Yoshinobu NAKATANI², Nobuo HAYASHI²,
Yoshio TAKAHASHI³, and Hiroshi FUKUSHIMA⁴,

1) Nihon University, College of Engineering, Kohriyama, Fukushima 963, Japan

2) University of Electro-communications, Chofu, Tokyo 182, Japan

3) Central Research Laboratory, Hitachi Ltd., Kokubunji, Tokyo, 185, Japan

4) Honda-cho, Midori-ku, Chiba City, Chiba 266, Japan

Abstract Thermal fluctuations in magnetization of longitudinal and perpendicular magnetic recording media was calculated using the Monte Carlo simulation method. From the simulation results and by considering that thick media (>30 nm) can be used in perpendicular recording, we concluded that perpendicular recording is superior to longitudinal recording in terms of thermal fluctuations. Signal decay due to thermal fluctuations increases with increasing grain size distribution when decay is small, but decreases with increasing grain size distribution when decay is large. The signal decay is larger at higher density in longitudinal recording, and it is smaller at higher density in perpendicular recording.

I. INTRODUCTION

Recently, the density of magnetic recording is increasing very rapidly. One of the key technologies in achieving high density is the exploitation of small grain size in magnetic recording. Generally, small grain size can reduce noise, but when grains are too small, they reduce the signal and increase the noise because of thermal fluctuations in magnetization.

Monte Carlo simulation has been used to study thermal fluctuations in magnetization of longitudinal and perpendicular media [1-7]. In most of these simulations, the grain size in the medium was uniform. However, the grain size in a medium in an actual magnetic recording system is not uniform.

In this study, we investigate the effect of grain size distribution on thermal fluctuations in longitudinal and perpendicular media. We also

investigate the effect of recording density on thermal fluctuations in the magnetization of longitudinal and perpendicular recording media.

II. GRAIN SIZE DISTRIBUTION

The grain size distribution of sputtered magnetic films was studied using a modified Hitachi HF-2000 FE TEM [8,9]. The specimens we studied were in-plane-oriented CoCrPt films sputtered on Cr or Cr-alloy layers, which were thinned by ion milling to permit transmission electron microscopy (TEM). To measure the grain size, lattice images were taken at a magnification of about 2,000,000. Grain boundaries were manually traced on the TEM micrographs (Fig. 1 (a)), and boundary trace images (Fig. 1 (b)) were produced. They were analyzed in a computer, and we obtained the mean diameter and the standard deviation using from 100 to 200 grains. Here, grain diameter was defined as the diameter of a circle with the same area as each grain (circle equivalent diameter).

Figure 2 shows a histogram of grain size distribution in a CoCrPt film. This distribution has a long tail toward the side with the larger grain. We found that the following D²-Gauss distribution fitted the histogram [7].

$$f(x) = x^2 \exp[-(1/2)((x - \mu)/v)^2]. \quad (1)$$

Here, x stands for grain diameter, and μ and v are the parameters to characterize the function.

(a)

(b)

Fig. 1 TEM micrograph (a) and boundary trace image (b) of a CoCr film [7].

Fig. 2 Histogram of grain size distribution of a CoCrPt film [7].

III. CALCULATION METHOD

The simulation method in our study was the same as that explained in a previous paper [7]. In order to take into account the distribution in grain size, the following method was used in this paper. (1) The center of each grain was regularly placed, as shown in Fig. 3. The width between adjacent grains was zero when there was no grain size distribution. (2) In calculating the magnetostatic field from the cell itself and from the first and second nearest neighbor cells, the

Fig. 3 Model of distributed grain size.

precise effect of grain size was considered. (3) In calculating the magnetostatic field from the other cells, the distribution of grain was represented by the magnetization strength. (4) In calculating the energy barrier in the Monte Carlo step, the volume of each grain was taken into account.

In calculating the magnetostatic field from all other cells, in a previous paper [7], step (3) was used, that is, the distribution of grain was represented by the magnetization strength.

In Fig. 3, large grains overlap adjacent grains, and small grains have large grain boundaries. These do not occur in real material. However, we adopted the above model to reduce

computation time.

We used Eq. (1) for the grain size distribution in simulation.

In calculating the energy barrier of perpendicular recording media, the easy direction of the crystalline anisotropy of a grain was assumed to coincide with that of grain's shape anisotropy.

The saturation magnetization of each grain was 400 emu/cm^3 , the uniaxial anisotropy energy constant was $2 \times 10^6 \text{ erg/cm}^3$, and the exchange interaction between adjacent grains was zero. The easy directions of the grains in the longitudinal recording media were randomly oriented in the film plane (2D random) and the easy directions in the perpendicular recording media were oriented almost perpendicular to the film plane. (The easy directions were oriented according to a Gaussian distribution with a standard deviation of 1° .) The number of cells were 64×32 . The output signal from the recorded magnetization was calculated using the reciprocity principle. The initial states were ideally recorded states.

IV. RESULTS AND DISCUSSIONS

Figures 4 and 5 show the time dependence of output signals for longitudinal and perpendicular recording media. The vertical axes are the output signals at a setting time normalized by the output signal just after recording, and the parameters are recording density. The grain size distribution was not taken into account in these calculations. In longitudinal recording, the normalized signal at higher density is smaller than that at lower density, but in perpendicular recording, the normalized signal at lower density is smaller than that at higher density. This is because the reversal of magnetic moments begins near the transition region in longitudinal recording media, and in perpendicular recording media it begins from the saturation region [7].

Figures 6-8 show the output signals of longitudinal recording media after three years' decay at various grain size distributions. The parameter, σ , in the figures is the standard deviation of grain size distribution (units are nm).

The vertical axes are the ratio of output signal after three years' decay to that just after recording. Figures 9 to 11 show the output signals of perpendicular recording media after three years' decay. When the average grain is large, the residual ratio of the output signal decreases with increasing grain size distribution, but it decreases with decreasing grain size distribution when the average grain is small. In other words, the residual ratio of the output signal begins decreasing at smaller average grain size with decreasing grain size distribution.

Fig. 4 Signal decay of a longitudinal medium with time. $V=10 \times 10 \times 10 \text{ nm}$. $T=300 \text{ K}$.

Fig. 5 Signal decay of a perpendicular medium with time. $V=10 \times 10 \times 10 \text{ nm}$. $T=300 \text{ K}$.

Fig. 6 Residual ratio of output signal of 15 nm thick longitudinal media after three years decay. Density=408 kfcf.

Fig. 9 Residual ratio of output signal of 15 nm thick perpendicular media after three years decay. Density=408 kfcf.

Fig. 7 Residual ratio of output signal of 30 nm thick longitudinal media after three years decay. Density=408 kfcf.

Fig. 10 Residual ratio of output signal of 30 nm thick perpendicular media after three years decay. Density=408 kfcf.

Fig. 8 Residual ratio of output signal of 60 nm thick longitudinal media after three years decay. Density=408 kfcf.

Fig. 11 Residual ratio of output signal of 60 nm thick perpendicular media after three years decay. Density=408 kfcf.

The residual ratio of output signals for 15 nm thick longitudinal media is similar to that of 15 nm perpendicular media (Figs. 6 and 9). The residual ratio of both media becomes larger with increasing thickness, but the residual ratio of the perpendicular media increases more rapidly than that of the longitudinal media. The residual rate of an output signal for 60 nm thick perpendicular media with an average grain size more than 8 nm is larger than 0.95 even at σ (standard deviation) = 5 nm. Suppose that a residual output ratio of 0.95 is allowed for use in a recording medium. The average grain size is larger than 10 nm and the standard deviation in grain size is about 5 nm in usual recording media. Therefore, 60 nm thick perpendicular film can be used as a recording medium without further reducing the standard deviation in grain size. Considering the above results and that 50 to 100 nm thick media are used in perpendicular recording (around 20 nm thick media are used in longitudinal recording), we concluded that perpendicular recording is superior to longitudinal recording in terms of thermal fluctuations.

The above results were obtained assuming that the magnetic moment of each grain reversed coherently. This assumption should be valid for a grain in a longitudinal medium, because a particle which is smaller than 30 nm x 30 nm x 30 nm reverses almost coherently [10]. However, this is not clear for a grain in a perpendicular medium. Therefore, we investigated the switching mechanism for the magnetic moment of a single particle. The crystalline easy direction of a particle is in the long direction. When a particle switches coherently, the switching field with the field applied in the easy direction and that in the hard direction coincide. If a moment switches incoherently, the switching field with the field applied in the easy direction is smaller than that in the hard direction. Therefore, the ratio of a switching field with the field applied in the easy direction to that in the hard direction is a parameter to describe the extent of coherent switching (coherency). Figure 12 shows the ratio of various single particles. The horizontal axis shows the length of particles in the long direction and the parameters in the figure are the length in

the short direction (units are nm). The ratio decreases with increasing the length in the short direction (diameter) when the length in the long direction is large, but vice versa when the length in the long direction is small. The ratio decreases with increasing length in the long direction, and it is larger than 0.9 even in 200 nm long particles with 30 nm diameters. This suggests that our assumption is valid for a particle with lengths shorter than 200 nm and with diameters smaller than 30 nm.

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