Abstract

Time ($t$) dependence of the change in relative magnetization ($\Delta M_{\text{rela}}$) for a period of 1000 h was investigated for advanced data storage metal particulate (MP) tape and Ba-ferrite (BF) sheets prepared from ultrafine particles at 295 to 338 K. Time dependence of $\Delta M_{\text{rela}}$ at 295 K in all samples obeyed a logarithmic law for 1000 h. $\Delta M_{\text{rela}}/\log t$ at all temperatures for BF sheet was much larger than that of MP tape because of lower anisotropy field component. Relative permanent magnetization loss due to the oxidation for MP tape at 295 K was negligibly, however it increased as temperature increased.

Keywords: Anisotropy field distribution; Ba-ferrite media; data storage tape; long-term stability; magnetization; metal particulate tape; permanent magnetization loss; thermal fluctuation.

1. Introduction

In recent years, advanced data storage tapes have been made to achieve a high recording density with low noise [1], [2]. There has been a growing interest in the aging [3], the durability [4], the storage stability [5], and thermal demagnetization effects [6] of data storage tapes. Magnetization stability over a long period of time is particularly important to secure high reliability for advanced data storage tapes with high coercivity ($H_c$). In high-density magnetic recording media, the time dependence of magnetization obeys a logarithmic law and is dependent upon the fluctuation field ($H_f$) and the irreversible susceptibility ($X_{\text{irr}}$) [7], [8]. A change in magnetization ($\Delta M$), which is caused by thermal fluctuation, for the time interval from $t_1$ to $t_2$ can be expressed as follows [7], [8]:

$$\Delta M = H_f X_{\text{irr}} (\ln t_1 - \ln t_2).$$

(1)

It is assumed to be excluded the relative permanent magnetization loss ($M_{\text{loss}}$) due to the oxidation from the relative...
magnetization ($M_{\text{rela}}$) [9]. This paper reports on the time dependence of $M_{\text{rela}}$ over a long period of time for advanced data storage tapes prepared from ultrafine metal particulate (MP) composite and sheet samples prepared from ultrafine Ba-ferrite (BF) particles at various preserving temperatures.

2. Experimental details

The sample used was data storage tape prepared from ultrafine acicular MP composite that was made by trial production and sheet samples prepared from hexagonal platelet BF particles with different average volume ($V_{\text{phy}}$). The MP particles were covered with a magnetic oxide layer approximately 1.5 nm thick, which had much lower magnetic property values than the Co$_{25}$Fe$_{75}$ main part [10]. Table 1 shows the average particle diameter ($D$) and length ($L$) obtained by transmission electron microscopy, $V_{\text{phy}}$, saturation magnetization of particles ($\sigma$), thickness of magnetic layer ($t_{\text{mag}}$), and fundamental magnetic properties of samples used in this study. The listed magnetic properties at 295 K are squareness in the direction of easy magnetization (SQ), orientation ratio (OR) obtained by dividing SQ by squareness in the direction of hard magnetization, $H_c$, anisotropy field ($H_A$) obtained by Flanders and Shtrikman’s method described later [10]-[12], switching field distribution (SFD), rotational hysteresis integral ($R_b$), which corresponds to the mechanism of magnetization reversal, and maximum value of delta $M$ plots (delta $M_{\text{max}}$), which is used to investigate the interactions between particles. These samples are the longitudinal recording media, the directions of easy magnetization of sample and external field are parallel to each other. The volume content of particles for samples was approximately 40%. Table 2 shows $H_f$ at 295 K and $K_A V_{\text{act}}/k_B T$ for the factors of thermal stability in the reverse field of 0.5 kOe, where $K_A$, $V_{\text{act}}$, $k_B$, and $T$ are anisotropy constant, activation volume, Boltzmann constant, and the absolute temperature, respectively. The magnetic properties and $M_{\text{rela}}$ in the direction of easy magnetization were measured using a vibrating sample magnetometer (VSM). Samples of 8 × 8 mm were cut from the original MP-3 tape and BF sheets, and 5-20 sheets were layered on top of each other. The sample was then fixed to a specimen holder with vibrating rod of VSM.

Table 1. Average particle sizes, volume, and fundamental magnetic properties of samples used in this study.

| Sample     | $D \times L$ (nm) | $V_{\text{phy}}$ ($10^{-18}$ cm$^3$) | $\sigma$ (emu/g) | $t_{\text{mag}}$ (µm) | SQ/OR | $H_c$ (kOe) | $H_A$ (kOe) | SFD | $R_b$ | delta $M_{\text{max}}$ |
|------------|-------------------|-------------------------------------|-----------------|----------------------|-------|-------------|-------------|-----|------|-------------------|
| MP-3 tape  | 10×35             | 2.7                                 | 96              | 0.13                 | 0.81/2.7 | 2.35        | 4.3         | 0.60 | 0.88 | -0.10               |
| BF-1 sheet | 20×6.5            | 2.0                                 | 53              | 1.8                  | 0.57/1.3 | 2.54        | 4.7         | 0.56 | 0.82 | 0.14               |
| BF-3 sheet | 23×7.0            | 2.9                                 | 57              | 1.8                  | 0.69/2.1 | 3.00        | 5.1         | 0.34 | 0.67 | 0.06               |

The long-term time dependence of $M_{\text{rela}}$ and $M_{\text{loss}}$ for MP tape and BF sheets was measured by the method described below. The samples were initially magnetized to saturate by field of +20 kOe. These were preserved for a period of 1 to 1000 h at 295, 323, and 338 K with no reverse field and a constant reverse field of 0.5 kOe using the magnetic circuit with a highly-uniform magnetic field provided by the anisotropic Sr-La-Co ferrite magnet and soft iron yoke. Relative humidity in the preserving oven was approximately 55 ± 10%. The magnetization value of VSM was calibrated at 10 kOe using saturation magnetization of Ni (99.99%) sheet with the same sample size and the sample was centred exactly on the VSM search coils with spacing of 40 mm in every experiment. The external field in the neighbouring of sample was exactly kept constant at 0 ± 0.2 Oe in every measurement of $M_{\text{rela}}$ and $M_{\text{loss}}$. All the measurements were made at 295 ± 3 K. The value of $M_{\text{rela}}$ was measured as a function of the fixed time elapsed. The samples prepared for every experiment were remagnetized at +20 kOe, and their $M_{\text{loss}}$ were measured as the same conditions of time as above. Magnetization of 0.2 h later at 295 ± 3 K with no reverse field was taken as the initial value ($M_0$). Both $M_{\text{rela}}$ and $M_{\text{loss}}$ of samples were normalized to $M_0$.

The anisotropy field ($H_A$) distribution in the direction of easy magnetization for MP tape and BF sheets was measured with Flanders and Shtrikman’s method using a torque magnetometer as follows [10]-[12]. A saturating field of +20 kOe is applied at the angle $\theta = 85^\circ$ from the direction of easy magnetization ($\theta = 0^\circ$), then the direction of the magnetic field is rotated through $10^\circ$ and the field ($H_A$) is applied. The magnetization in the direction between $85^\circ$ and $95^\circ$ with respect to the field direction reverses when the field reaches a certain magnitude, which corresponds to $H_A$. This reversal of magnetization is detected by torque with a scanning field every 0.1 kOe as follows: 0→0.1→0.2→0.3→0.4→0.5→0.6→0.7→0.8→0.9→1.0→0.9→0.8→0.7→0.6→0.5→0.4→0.3→0.2→0.1→0.0→0.0→0.0→0.0→0.0→0.0→0.0 kOe.
Thus, the reversed magnetization can be obtained as a function of $H_n$, that is, $H_A$ distribution. The area ($A$) enclosed by a plot of torque versus field gives a reversed magnetization value or corresponding volume ($V$) with $H_A$ in the range of $H_n>H_A>H_{n-1}$ from the following equation [10]-[12].

$$A = (1/3)M_s V H_A^2$$  \hspace{1cm} (2)

Here, $(H_{n-1}+H_n)/2$ was used as $H_A$.

Fig. 1 shows magnetic torque versus field curves in the direction of easy magnetization (-5° to +5°) for MP-3 tape at 295 K as representative of all the samples. The area $A$ was calculated every 0.5 kOe. The $V$ value of all the samples was obtained from the magnetic field dependence of area $A$ given by Eq. (2).

### Table 2. Fluctuation field and thermal stability factor of samples used in this study.

| Sample     | $H_f$ (Oe) | $K_A V_{act}/k_B T$ |
|------------|------------|---------------------|
| MP-3 tape  | 25.5       | 70                  |
| BF-1 sheet | 57.6       | 45                  |
| BF-3 sheet | 51.3       | 62                  |

3. Results and discussion

The long-term time dependence of $M_{rela}$ for MP tape and BF sheets was measured at 295, 323, and 338 K. Figs. 2 and 3 show the time dependence of $M_{rela}$ of MP-3 tape, BF-1 and BF-3 sheets for 1000 h at various preserving temperatures. These are the time dependence of $M_{rela}$ with no reverse field and a constant reverse field of 0.5 kOe. The value of $\Delta M_{rela}/\log t$ for all samples at preserving temperature of 295 K was in substantial agreement with $\Delta M/(M_r \log t)$ measured for 1000 s as in Ref. 13, where $M_r$ is the residual magnetization. The time dependence of the change in $M_{rela}$ for MP-3 tape at 295 K was very small (0.17 - 0.25 %/decade) because of small $H_f$ value as shown in Table 2 [13]. The value of $H_f$ is a major factor affecting the media noise and the recorded signal decay. In comparison to MP-3 tape and BF-3 sheet with approximately same $V_{phy}$, the value of $\Delta M_{rela}/\log t$ at 295 K for BF-3 sheet was much larger than that of MP-3 tape. These values of MP-3 tape, BF-1 and BF-3 sheets at 295 K with a constant reverse field of 0.5 kOe were 0.25, 1.29, and 0.54%/decade, respectively. It was found that the time dependence of $\Delta M_{rela}$ in all samples obeyed a logarithmic law mentioned Eq. (1) for a period of 1000 h. The values of $M_{loss}$ for MP-3 tape increased as the preserving temperature increased at the same lapse of time [14]. The value at 295 K for 1000 h was negligibly small. However, the values at temperatures above 323 K increased rapidly after 100 h had elapsed. On the other hand, the values of $M_{loss}$ for BF sheets were very few at all preserving temperatures.

In the case of a constant reverse field of 0.5 kOe, the initial magnetization drop 1 h after for BF-1 sheet was much larger than that of the no reverse field at every preserving temperatures, because the degree of particle orientation which have direct effects upon the values of SQ and OR, was insufficient as shown in Table 1. In the case of small SQ, the value of magnetization does not spring back to the original $M_r$ in demagnetizing curve. In order to decrease the initial magnetization drop in the reverse field of approximately 0.5 kOe or more, it is important to improve the degree of particle orientation.
Fig. 2 Time dependence of the relative magnetization of (a) MP-3 tape, (b) BF-1 sheet, and (c) BF-3 sheet for 1000 h at various preserving temperatures with no reverse field.

Fig. 3 Time dependence of the relative magnetization of (a) MP-3 tape, (b) BF-1 sheet, and (c) BF-3 sheet for 1000 h at various preserving temperatures with a constant reverse field of 0.5 kOe.

In Flanders and Shtrikman’s method, magnetization reversal in a field corresponding to $H_A$ is detected by torque measurement in the same way as in Ref. 12. Relative volumes of MP-3 tape, BF-1 and BF-3 sheets in the direction of easy magnetization are plotted as a function of the magnetic field in Fig. 4, showing the distribution of $H_A$ at 295, 323, and 338 K. Comparing MP-3 tape (a) and BF-3 sheet (c) with BF-1 sheet (b), the temperature dependencies of $H_A$ distribution for MP-3 tape and BF-3 sheet were very small and similar to each other. Both of $V_{phy}$ for MP-3 tape and BF-3 sheet were larger than that of BF-1 sheet as shown in Table 1. It can be seen from Fig. 4(b) that relative volume was detectable in the low field for BF-1 sheet at 323 and 338 K, indicating that some fraction of particles had low $H_A$ values. The distribution of $H_A$ for BF-3 sheet is more desirable than that of BF-1 sheet with smaller $V_{phy}$. In order to decrease the value of $\Delta M_{rel}/\log t$ for Ba-ferrite media, it is particularly important to improve the distribution of $H_A$ and the degree of particle orientation.

Fig. 4 Anisotropy field distribution of (a) MP-3 tape, (b) BF-1 sheet, and (c) BF-3 sheet in the direction of easy magnetization ($\theta$: $-5^\circ$ to $+5^\circ$).
4. Conclusion

This paper reports on the time dependence of $M_{\text{rela}}$ over a long period of time for advanced MP tape and BF sheets prepared from ultrafine particles at various preserving temperatures. The time dependence of $\Delta M_{\text{rela}}$ at 295 K in all samples obeyed a logarithmic law for a period of 1000 h, and the value of MP tape was very small. In comparison to MP tape and BF sheet with approximately same average particle volume, the value of $\Delta M_{\text{rela}}/\log t$ at 295 K for BF sheet was much larger than that of MP tape. The value of $M_{\text{loss}}$ due to the oxidation for MP tape at 295 K for 1000 h was negligibly small. However, the value increased as preserving temperature increased. On the other hand, the values of $M_{\text{loss}}$ for BF sheets were very few at all preserving temperatures. The initial magnetization drop for BF sheet with smaller $V_{\text{phy}}$ was large at every preserving temperature. The volume of lower $H_A$ was detected for BF sheet with smaller $V_{\text{phy}}$ at 323 and 338 K. In order to decrease the value of $\Delta M_{\text{rela}}/\log t$ for Ba-ferrite media, it is particularly important to improve the distribution of $H_A$ and the degree of particle orientation.

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