Ferromagnetic resonance studies of video tapes

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The magnetic anisotropy fields ($H_a=2K/M$) and damping factors ($\alpha$) of three kinds tapes of metal particle, oxide particle and metal-evaporated tapes for various home-use video systems were studied using 34-GHz ferromagnetic resonance (FMR). The $H_a$ is in the 3-8 kOe range and varies linearly with the value of coercive force ($H_c$). The $\alpha$ value of metal-evaporated tape is the largest (0.24), indicating the small crystallite size. The smallest $\alpha$ is oxide particle tape (0.10), indicating well-aligned particles. Although the switching parameter $S_w/H_c$ tends to increase with $1/\alpha$ in general way, the relation of $S_w/H_c$ vs. $1/\alpha$ is different in particulate tape and thin-film tape in precisely.

Key words: magnetic recording, thin film, particulate tape, ferromagnetic resonance, iron oxide, metal, gyromagnetic ratio, damping factor, relaxation time

1. Introduction

Due to the demand of the high recording density, coercive force ($H_c$) of the recording media increases. The coercive force is controlled mainly by the magnetic anisotropy of the magnetic materials. In recent years, damping factor ($\alpha$) of the magnetic recording media have attracted interests since the parameter has connection with switching speed as was first pointed out by Artman et al. In determining both the anisotropy and/or the damping factor $\alpha$, ferromagnetic resonance (FMR) is known to be a suitable method.

To determine $\alpha$ value of well-aligned particles from the line width ($\Delta H$) of FMR, correction of $\Delta H$ value by particle-axis orientation distribution is known to be necessary. However, the reported switching parameters are measured for the distributed particles and therefore the obtained damping parameter should be compared with the distributed particles or not-well aligned particles. Furthermore, we have no concern for a single particle but we focus on the whole media. In this paper, we obtained the $\alpha$ value without correction by particle-axis distribution and compared with switching parameters.

2. Experimental

The tapes used are commercially-available home video tapes. The tapes are three types: metal particle (MP) tapes for 8mm format, Co-modified-Fe$_3$O$_4$ particle tapes for 16mm format, and ME tapes for 34-GHz FMR. The magnetic film is in the x-y plane and the x-axis is the tape direction. The anisotropy axis k is in the vertical plane.

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tapes for VHS format and metal-evaporated (ME) tapes for 8mm format. Ferromagnetic resonance was measured at 34.48 GHz. The first derivative FMR spectra of the absorption were measured. The applied static fields up to 18 kOe were rotated in (i) the film plane or (ii) the vertical plane normal to the film and along the direction of the tape length. The static magnetic properties were measured using a vibrating sample magnetometer (VSM). All the measurements performed at room temperature.

3. Theoretical

The resonance relation derivation follows the energy method. The equations are the same as in the previous papers. The basic resonance condition is given by

\[ \frac{\omega}{\gamma} = \left( \frac{\delta^2 G/\delta \theta^2}{\delta^2 G/\delta \phi^2} \right) \left( \frac{1}{\chi^2 \sin^2 \theta} \right), \]

where \( \omega \) and \( \gamma \) denote angular frequency and gyromagnetic ratio, respectively. The geometrical coordinates for the analysis is shown in Fig.1 for particulate tape and Fig.2 for ME tape.

The free energy per unit volume \( G \) for particulate tape is,

\[ G = -2\pi M' \sin^2 \theta (1-c) + K \sin^2 \theta \cos \phi (1-c) - MH \cos \phi \sin \theta \sin \phi \cos (\phi - \psi) \]

Here, \( K \) is the magnetic anisotropy constant, and \( c \) is the shape anisotropy contribution factor.

The \( G \) for ME tape is,

\[ G = K \sin^2 \phi (\cos \psi + \sin^2 \phi \sin \psi) - \frac{1}{2} \sin^2 \phi - 2nM' \sin^2 \phi - MH \cos \phi \sin \theta \sin \phi \cos (\phi - \psi) \]

Fig. 4 Changes in \( H_r \) and \( \alpha \) with \( H_c \) of metal particle tape (MP), oxide particle tape and metal evaporated tape (ME).

4. Results and Discussion

The coercive force \( (H_c) \) are 0.73 kOe for oxide particle, 1.05 kOe for ME and 1.55 kOe for metal particle.

Figure 3 shows FMR spectra of the three tapes along the tape longitudinal direction (\( \theta = \pi/2, \phi = 0 \)). From the angular dependence of the resonance fields \( (H_r) \), anisotropy field \( (H_A = 2K/M) \) for three tapes and saturation magnetization \( (4\pi M) \) for ME tape were obtained. The obtained values and used parameters of \( \omega/\gamma \) and \( 4\pi M \) are listed in Table 1. The used \( 4\pi M \) value of MP is

<table>
<thead>
<tr>
<th>Material</th>
<th>( H_c ) (kOe)</th>
<th>( 4\pi M ) (kG)</th>
<th>( \Delta H ) (kOe)</th>
<th>( \gamma/2\pi )</th>
<th>( \alpha ) (GHz/kOe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxide</td>
<td>0.73</td>
<td>3.5</td>
<td>4.50</td>
<td>1.46</td>
<td>2.80</td>
</tr>
<tr>
<td>ME</td>
<td>1.05</td>
<td>4.9</td>
<td>5.34</td>
<td>3.50</td>
<td>2.80</td>
</tr>
<tr>
<td>MP</td>
<td>1.55</td>
<td>7.6</td>
<td>21.4</td>
<td>2.33</td>
<td>2.93</td>
</tr>
</tbody>
</table>
the same as the bulk Fe since the core part of the iron particle was found to be close to the pure Fe. Hc increases with Hc as shown in Fig. 4. For the metal-evaporated tape, the tilt angle $\delta$ of the anisotropy axis is also obtained as 50.6°.

From the linewidth ($\Delta H$) along the tape longitudinal direction, we obtain damping parameter $\alpha$. $\alpha$ does not simply depend on $H_c$. However, as far as particulate tapes, $\alpha$ tends to depend on $H_c$. The $\alpha$ value of metal-evaporated tape is the largest (0.24), indicating the small crystallite size, which is observed as 20A. The smallest $\alpha$ is Co-modified Fe$_3$O$_4$ tape (0.10), indicating well-aligned particles. The obtained $\alpha$ value of 0.17 of MP tape is far smaller than that (0.92) by Yu and Harrell. The reason for the difference is not clear. By the correction with distribution function, however, $\alpha$ decreases. One reason may be due to the difference of $\Delta H$ determining method: we obtained from absorption derivative and they obtained from absorption curve. The switching constant ($S_a$) of the media were reported by Thomley and Doyle group and they conclude the figure of merit $S_a/H_c$ is a good parameter describing the switching speed. Also, the relaxation time $\tau$ in the resonance is roughly written as $\tau=1/(2\pi \alpha)$, we plot $S_a/H_c$ as a function of $1/\alpha$ as shown in Fig. 5. Since the $S_a/H_c$ value of Co-Fe$_3$O$_4$ is not known, we used that of Co-Fe$_3$O$_4$. Although it looks like that the $S_a/H_c$ tends to increase with $1/\alpha$, the relation is not simple. As was clearly shown in Fig. 4, $\alpha$ values are different between particulate tapes (MP, oxide) and thin-film tape (ME). Therefore, damping mechanism is different in the two-type tapes. This difference in the two-type tapes and further difference in the origins of damping and switching mechanisms make non-linearity in $S_a/H_c$ vs. $1/\alpha$.

5. Conclusions

The magnetic properties of metal particle(MP), oxide particle and metal-evaporated (ME) tapes for various home-use video systems were studied using ferromagnetic resonance at 34 GHz. The $H_c$ value varies with $H_c$. However, $\alpha$ does not. The $\alpha$ value of ME tape is the largest (0.24), indicating the small crystallite size. The smallest $\alpha$ is Co-modified Fe$_3$O$_4$ tape (0.10), indicating well-aligned particles. Although the switching parameter $S_a/H_c$ tends to increase with $1/\alpha$ in general way, the relation of $S_a/H_c$ vs. $1/\alpha$ is different in particulate tape and thin-film tape in precisely.

References