VECTOR MAGNETIZATION OF RECORDING MEDIA

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Abstract-- Advanced magnetic recording media may be oriented with a preferred direction of magnetization in or out of the plane. The angular dependence of the magnetic properties of the media provides important information for determining the mechanism of magnetization reversal and for analyzing the recording process, since the head field incorporates parallel and perpendicular components in its interaction with the recording media. To obtain the intrinsic magnetic properties, it is necessary to compensate the demagnetizing fields, and for this purpose, we have added orthogonal biaxial detecting coils to our VSM for the simultaneous measurement of the vector magnetization components. In this paper, we report on vector magnetization measurements on most of the commonly used magnetic recording media, including SVHS, 8 mm video, CrO_2 , Ba-ferrite, Co-Ni-P thin film, and CoCr.

INTRODUCTION

Magnetic recording media are typically in the form of thin films or thin coatings of particulate assemblies. The anisotropy of the individual particles or crystallites may be oriented in the plane, out of the plane, or random. A very fundamental question pertaining to these media is the mechanism of magnetization reversal, and one way to experimentally investigate it is by measuring the angular dependence of the magnetic properties of the media [1,2]. For media oriented in the plane, it is quite simple to measure the angular dependence of the magnetic properties in the plane, since we do not have to contend with any demagnetizing fields. The field of a typical ring-type recording head, however, changes from purely horizontal over the center of the gap to purely perpendicular far away from the gap edge. Furthermore, many advanced media, such as CoCr perpendicular anisotropy media [3] and Ba-ferrite particulate media [4], may have a preferred direction of magnetization perpendicular to the media plane. In such cases, the measurement of the intrinsic magnetic properties out of the media plane is obscured by the

demagnetizing fields which arise on account of the sample shape when the external field is applied at any angle away from the plane. In this respect, it is particularly useful to measure the vector magnetization [5] in order to determine the demagnetizing field, and thus provide the appropriate corrections to the applied field in order to obtain the correct amplitude and direction of the effective applied field.

To perform the vector magnetization measurements, we have added vector (two-dimensional) capability to the DMS Model 880 VSM, which also incorporates computer-controlled angular sample positioning. The vector magnetization is measured by orthogonal pairs of pickup coils, one along x (the direction of the applied field H_a) and the other along y . In this magnetometer, a field feedback loop permits the precise digital setting of the field before the magnetization is measured. Therefore, both the M_x and M_y components of the magnetization can be measured successively for each field setting using the same signal processor.

In this paper, we report on the vector magnetization of various recording media, both thin film and

particulate, with different anisotropies and orientations.

EXPERIMENTAL SYSTEM AND ANALYSIS

The vector coil arrangement for the biaxial VSM is shown schematically in Figure 1, along with the various angles for the magnetization $\vec{M}$, the applied field H_a (assumed along the x axis), and the effective field H_e (corrected for the demagnetizing field). The sample is shown in a vertical plane, so the applied field rotates out of the plane of the sample.

Fig. 1 Schematic diagram of the vector quantities and angles shown as a top view of biaxial (xy) VSM.

The other case, where the sample plane is horizontal (xy), is also of interest for samples that are oriented in the plane, but is quite simple to analyze since there are no corrections required (there are no demagnetizing fields).

The basic relations can be easily derived from Figure 1, which shows the sample plane rotated by an angle Ω from the x axis.

The magnetization $\vec{M}$ makes an angle ψ with the x axis and an angle ϕ with the sample plane. Therefore,

$$\psi = \tan^{-1}(M_y/M_x) \text{ and } \phi = \Omega - \psi$$

$$\text{and } M = |\vec{M}| = (M_x^2 + M_y^2)^{1/2}.$$

If we denote the components of $\vec{M}$ parallel and perpendicular to the sample plane as M_l and M_v , respectively, we have:

$$M_l = M \cos \phi \text{ and } M_v = M \sin \phi.$$

Therefore, the demagnetizing field H_d can be determined from:

$$H_d = |\vec{H}_d| = 4\pi N M_v = 4\pi N M \sin \phi$$

where $4\pi N$ is the demagnetizing factor.

Consequently, the effective field H_e can be determined from the expression:

$$H_e = |\vec{H}_e| = |\vec{H}_d + \vec{H}_a| = (H_{e,x}^2 + H_{e,y}^2)^{1/2}$$

where

$$H_{e,x} = H_a - 4\pi N \cdot M \cdot \sin \phi \cdot \sin \Omega$$

$$H_{e,y} = 4\pi N \cdot M \cdot \sin \phi \cdot \cos \Omega.$$

The effective field $\vec{H}_e$ is at an angle θ with respect to the x axis, where $\theta = \tan^{-1}(H_{e,y}/H_{e,x})$.

We may also easily obtain the components of H_e parallel and perpendicular to the sample plane:

$$H_{e,l} = H_e \cdot \cos(\Omega - \theta)$$

$$H_{e,v} = H_e \cdot \sin(\Omega - \theta).$$

What we measure experimentally is $M_x(H_a)$ and $M_y(H_a)$ at various values of Ω . To obtain the intrinsic M-H loops without the demagnetizing field, we may use the above expressions to obtain $M_x(H_{e,x})$ and $M_y(H_{e,x})$ at various values of Ω . As was pointed out by Ouchi and Iwasaki [5], in the $M_x(H_a)$ curve at $H_a = H_c$, we have $M_x = 0$, but $M_y \neq 0$, except at $\Omega = 0^\circ$ and $\Omega = 90^\circ$, and the demagnetizing field reflects on the $M_x(H_{e,x})$ curve, resulting in a different $H_c(\Omega)$. It is this intrinsic $H_c(\Omega)$ curve that is of importance in determining the mechanism of magnetization reversal.

Using the above equations, we can also obtain the following relationships:

$$M_l(H_{e,l}), M_l(H_{e,v}), \\ M_v(H_{e,l}), \text{ and } M_v(H_{e,v}).$$

These relationships are very useful in analyzing the fundamental vector magnetization and field interactions in the recording process.

Finally, as again was shown by Ouchi and Iwasaki [5], it is possible from the vector magnetization data to obtain the intrinsic torque curve corrected for the effect of demagnetization, and thus be able to determine the anisotropy constant of the media:

$$T_i = |T_i| = M_x H_e \\ T_i = M \cdot H_e \cdot \sin(\psi - \theta).$$

RESULTS AND DISCUSSION

We measured the vector magnetization in the plane and out of the plane for various media of current interest, including longitudinally oriented particulate media (SVHS, CrO₂, and metal particle (MP)), non-oriented and perpendicularly oriented Ba-ferrite (BF) media, and longitudinal and perpendicular thin film media (Co-Ni-P and CoCr). Since the amount of data obtained could not be presented within the limited size of this paper, we decided to present some important general vector results for all of these media and leave the further analysis and interpretation to a future publication.

We selected an angle $\Omega = 60^\circ$ from the plane for comparing the uncorrected ($M-H_a$) and corrected ($M-H_e$) loops of the various media. Figures 2-4 show the results for SVHS, CrO₂, and MP (8 mm video) tapes. Clearly, at $H_a = H_c$, there is a very large M_y component, resulting in a large correction for the intrinsic $M-H_e$ curves. The Co-Ni-P thin film media exhibit similar behavior, as shown in Figure 5.

Fig. 2 M_x-H_a and M_y-H_a loops (left) and $M_x-H_{e,x}$ and $M_y-H_{e,x}$ loops (right) of SVHS Co-gamma media for $\Omega = 60^\circ$.

Fig. 3 M_x-H_a and M_y-H_a loops (left) and $M_x-H_{e,x}$ and $M_y-H_{e,x}$ loops (right) of advanced CrO₂ media for $\Omega = 60^\circ$.

Fig. 4 M_x-H_a and M_y-H_a loops (left) and $M_x-H_{e,x}$ and $M_y-H_{e,x}$ loops (right) of 8 mm MP media for $\Omega = 60^\circ$.

The isotropic Ba-ferrite media shown in Figure 6 have a smaller M_y component, while the perpendicularly oriented Ba-ferrite (Figure 7) and the CoCr (Figure 8) media have a small and distinctly different M_y curve.

Using the above transformations, we calculated the intrinsic

Fig. 5 M_x - H_a and M_y - H_a loops (left) and M_x - $H_{e,x}$ and M_y - $H_{e,x}$ loops (right) of 8 mm thin film media for $\Omega = 60^\circ$.

Fig. 6 M_x - H_a and M_y - H_a loops (left) and M_x - $H_{e,x}$ and M_y - $H_{e,x}$ loops (right) of isotropic Ba-ferrite floppy disk media for $\Omega = 60^\circ$.

Fig. 7 M_x - H_a and M_y - H_a loops (left) and M_x - $H_{e,x}$ and M_y - $H_{e,x}$ loops (right) of perpendicularly oriented Ba-ferrite tape media for $\Omega = 60^\circ$.

angular dependence $H_C(\Omega)$ for the various media, and the results are shown in Figures 9-15, along with the uncorrected values of H_C . We observe that the SVHS tape and the Co-Ni-P longitudinal thin film have a similar $H_C(\Omega)$ dependence

Fig. 8 M_x - H_a and M_y - H_a loops (left) and M_x - $H_{e,x}$ and M_y - $H_{e,x}$ loops (right) of CoCr perpendicular anisotropy media for $\Omega = 60^\circ$.

decreasing monotonically with Ω . On the other hand, the CrO_2 and the MP tapes have a very different $H_C(\Omega)$ dependence, exhibiting a slight peak at about 60° , which is reminiscent of a curling mode of magnetization reversal []. The isotropic Ba-ferrite has its intrinsic H_C essentially independent of Ω , as we would expect. In all of these cases, the corrected H_C is lower than the uncorrected H_C at all values of Ω , except for 0° and 90° where the two are equal. Figures 14 and

Fig. 9 Angular variation of H_C of SVHS media before and after demagnetization correction.

15 show the corresponding results for the perpendicularly oriented media (Ba-ferrite and CoCr). In this case, the corrected H_C is

Fig. 10 Angular variation of H_c of CrO_2 media before and after demagnetization correction.

Fig. 11 Angular variation of H_c of 8 mm MP media before and after demagnetization correction.

Fig. 12 Angular variation of H_c of 8 mm thin film media before and after demagnetization correction.

Fig. 13 Angular variation of H_c of isotropic Ba-ferrite floppy disk media before and after demagnetization correction.

Fig. 14 Angular variation of H_c of perpendicularly oriented Ba-ferrite tape media before and after demagnetization correction.

Fig. 15 Angular variation of H_c of CoCr perpendicular anisotropy media before and after demagnetization correction.

higher than the uncorrected H_C . Otherwise, the shape of the intrinsic $H_C(\Omega)$ curves resembles that of the SVHS and Co-Ni-P, except for the 90° angular displacement of the perpendicular anisotropy media.

To draw some conclusions regarding the mechanism of magnetization reversal in these media, it is necessary to normalize the $H_C(\Omega)$ curves to the average anisotropy field H_k . This will form the subject of a subsequent publication.

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