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Determination of first and second magnetic anisotropy constants of magnetic recording media

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We propose a simple method to evaluate the first and second magnetic anisotropy constants of high-density magnetic recording media with their easy axis in the film plane. By measuring the magnetization curve along the film normal, uniaxial anisotropy constants K_1 and K_2 can be determined simultaneously. The present method has been applied to $(11\cdot 0)$ oriented CoCrPtTa hard disk media. The measured anisotropy constants are presented along with their temperature dependence. We also point out serious shortcomings of the currently used evaluation methods, such as the rotational hysteresis method and the singular point detection technique, which usually overestimate the magnetic anisotropy constant.
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Magnetic recording is the predominant data storage technology and continues to make rapid advances in data density. In the near future, however, fundamental physical phenomena, such as bit instability due to superparamagnetism, may be encountered that limit the achievable data density. The superparamagnetism is the consequence of random field fluctuations due to overcoming the activation energy Kv by thermal energy $k_B T$, where K is the anisotropy constant per unit volume and v is the volume of a reversal unit. In order to predict thermal stability of recording bits, accurate determination of magnetic anisotropy is indispensable.

Some systematic studies have been carried out to determine the anisotropy constants of Co–X binary and Co–Cr–X (X=Pt, Ta, etc) ternary alloys by using epitaxially grown single crystal films.[1–3] However, it has been very difficult to evaluate the anisotropy constants for the conventional polycrystalline thin film media. Most popular methods now widely used for polycrystalline samples are the rotational hysteresis method,[4] the singular point detection technique (SPD),[5] and utilization of the law of approach to saturation.[6] All these methods give the anisotropy constant K_u for samples with random easy axis orientation. In usual discussions on thermal stability, this K_u has been regarded as the first anisotropy constant K_1 of the energy expression $E = K_1 \sin^2\theta + K_2 \sin^4\theta + \cdots$. It is obvious that K_u does not coincide with K_1 unless $K_2, K_3, \ldots = 0$. For example, a very simple calculation gives $K_u = \Sigma i K_i$ $(i = 1,2, \ldots)$ for the case of the SPD method. If higher-order terms are negligibly small with respect to K_1, the above method gives reasonable values of K_1. However, this approximation is inappropriate for pure Co and Co alloys which usually possess somewhat large K_2, resulting in over- or underestimation of K_1. Therefore, one must determine both K_1 and K_2 separately for more quantitative discussions on the thermal stability. In this letter, we propose a simple method for the evaluation of high-order anisotropy terms of polycrystalline recording media. The present high-density recording medium usually consists of a $(11\cdot 0)$ oriented Co–Cr–Pt (Ta) recording layer on a polycrystalline Cr(100) underlayer. This means that the easy (c) axis of the recording layer lies in the film plane. In this case, it is possible to determine both K_1 and K_2 simultaneously, as previously mentioned. Let us take the coordinate system shown in Fig. 1. For the $(11\cdot 0)$ oriented Co–Cr–Pt (Ta) recording layer, the easy axis distributes randomly in the film ($x-y$) plane. When the film is exposed to an external field H along z direction, the total energy can be expressed by

$$E = K_1 \sin^2\theta + K_2 \sin^4\theta + 2\pi M_s^2 \sin^2\theta - M_s H \sin\theta, \quad (1)$$

where K_1 and K_2 are the first and second anisotropy constants, M_s is the saturation magnetization, and θ is the angle of magnetization with respect to the easy axis in the film plane. By normalizing all terms of Eq. (1) by M_s^2, it can be rewritten as

$$\varepsilon = (k_1 + 2\pi)\sin^2\theta + k_2 \sin^4\theta - h \sin\theta, \quad (2)$$

where $\varepsilon = E/M_s^2$, $k_i = K_i/M_s^2 (i = 1,2)$, and $h = H/M_s$. From the equilibrium condition $d\varepsilon/d\theta = 0$, the following relationship can be derived:

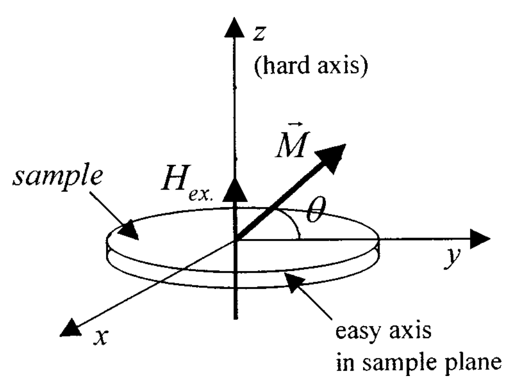

FIG. 1. Coordinate system (x, y, z) for the magnetic film with the easy axis in the film ($x-y$) plane. External field H_{ex} is applied along the film normal (z direction).

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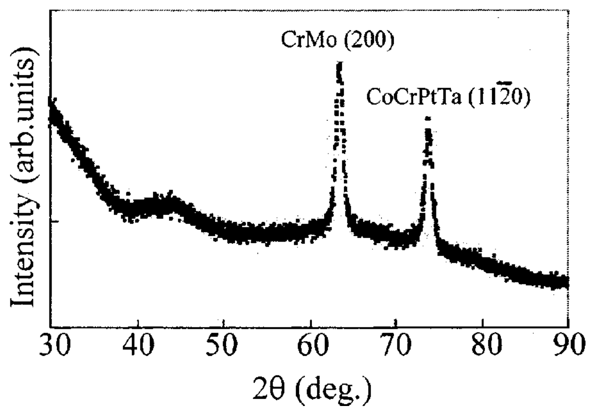

FIG. 2. X-ray diffraction scan of CoCrPtTa/CrMo hard disk media. The line source is Cu $K\alpha$ line. It is clearly noticed that the sample shows excellent $(11\cdot0)$ orientation of hcp-CoCrPtTa on bcc-CrMo (100).

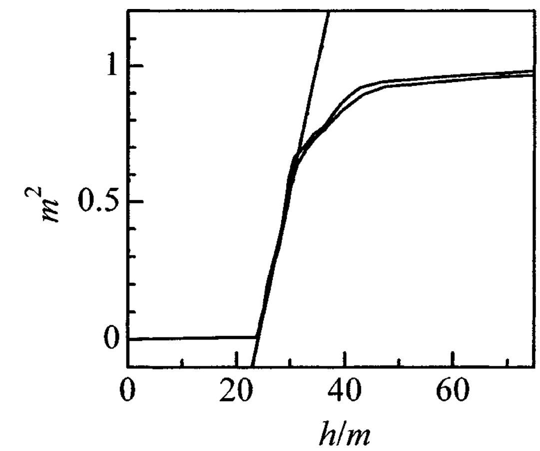

FIG. 4. m^2 vs h/m plot for the CoCrPtTa/CrMo hard disk medium shown in Figs. 2 and 3.

$$m^2=\frac{1}{4k_2}\frac{h}{m}-\frac{k_1+2\pi}{2k_2}, \tag{3}$$

where $m(=\sin\theta)$ is the normalized magnetization along the film normal. By plotting m^2 vs h/m, one can determine both K_1 and K_2. At the saturation point $(m=1)$, the saturation field becomes $h_s=2(k_1+2k_2)+4\pi$, which is the singular point detected by the SPD method.[5] The same results can also be obtained from susceptibility measurements by using the following expression from Eq. (3):

$$\chi=\frac{1}{2}\frac{1}{(k_1+2\pi)+6k_2m^2}. \tag{4}$$

We apply this method to typical longitudinal recording media for hard disk drives. The media comprise a Ni–P seed layer, a CrMo underlayer, the CoCrPtTa magnetic layer, and a carbon overcoat. The magnetic layer has a thickness of 20 nm and exhibits good magnetic properties; $M_s=440$ G, H_c (in plane)$=2750$ Oe, $M_r/M_s=0.78$. Figure 2 shows the x-ray diffraction scan measured using the Cu $K\alpha$ line. It is clearly noticed that the sample shows excellent $(11\cdot0)$ orientation of hexagonal-close-packed (hcp)-CoCrPtTa on body-centered-cubic (bcc)-CrMo (100), meaning that the c-axes lie in the film plane almost perfectly. For magnetic measurements along the film normal, we used both a vibrating sample magnetometer and a superconducting quantum interference device (SQUID) with maximum field of 1.5 and 5.0 T, respectively. Both equipments gave the same results. The following data shown below are collected using a SQUID. After very careful adjustment of the sample plane normal to the external field, we measured the magnetization curves in the temperature range of 250–350 K. Figure 3 shows the magnetization curve along the film normal at $T=250$ K. No remanence is observed, reflecting that the easy axes are mostly in the film plane as expected from Fig. 2. Using this magnetization curve, m^2 is plotted against h/m, as shown in Fig. 4. From Eq. (3), the slope and the intersection with the m^2 axis should be equal to $1/4k_2$ and $-(k_1+2\pi)/2k_2$, respectively. From this relationship we can determine the magnetic anisotropy constants K_1 and K_2 as 1.1×10^6 and 0.52×10^6 erg/cc at $T=250$ K. Figure 5 shows the temperature dependence of K_1, K_2, and K_1+2K_2. As the temperature increases, K_1 decreases more rapidly than K_2. This behavior is very similar to that of hcp-Co.[6] The usefulness of the present method was also confirmed for various kinds of recording media; for example, K_1 and K_2 of a very low coercivity CoCrPt medium ($H_c=1580$ Oe, $M_r/M_s=0.73$) were determined as 0.87×10^6 and 0.58×10^6 erg/cc, respectively. In order to check the accuracy of this method, we repeated the same measurement five times

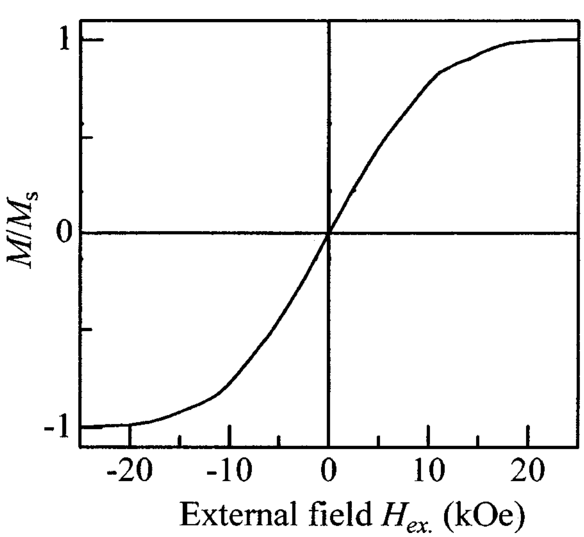

FIG. 3. Magnetization curve of a CoCrPtTa/CrMo hard disk medium measured along the film normal.

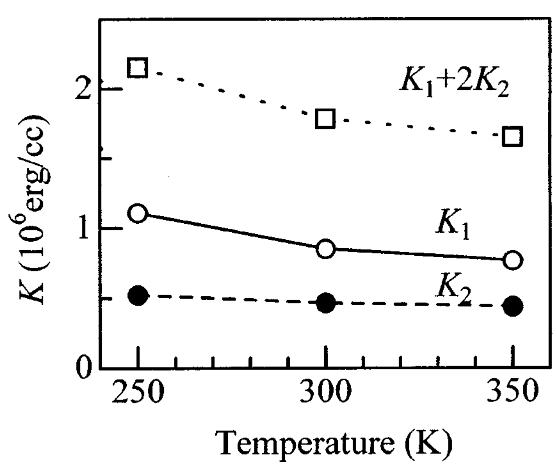

FIG. 5. Temperature dependence of K_1, K_2, and K_1+2K_2.

for the CoCrPtTa medium previously mentioned. The measurement error both for K_1 and K_2 was less than 10%.

In contrast to the present method, the SPD method detects $K_u = K_1 + 2K_2$, which is about two times larger than K_1 for the case of the CoCrPtTa medium mentioned above. In the case of the rotational hysteresis method, which is the most popular one, the evaluated K_u value is claimed to be severely influenced by exchange and dipolar interactions between grains.[7] Under the assumption that there are no interactions between grains, rotational hysteresis would diminish at $H = 2(K_1 + 2K_2)/M_s$, yielding the same K_u as the SPD method. Thus, these two conventional methods have obviously overestimated the first anisotropy constant K_1, because the measured K_u has been treated as the coefficient of the $\sin^2\theta$ term in the energy expression for uniaxial magnetic anisotropy. This very rough approximation might cause misleading discussions on magnetic and thermal behaviors of recording media when K_2 is not negligibly small compared with K_1. One may say that it is also possible to determine both K_1 and K_2 from the conventional torque curve measured in the normal plane. In this case, however, a very laborious procedure is required to correct the unsaturation effect due to the insufficient external field. Moreover, since the torque imposed on each grain is governed by the angle between the external field and its easy axis, one must know the *c* axis distribution in the film plane. This difficulty can be completely removed in the present method, because the external field is always orthogonal to the *c* axes of all constituent grains.

In summary, we have proposed a very simple method for the evaluation of high-order anisotropy terms of polycrystalline recording media with the easy axes in the film plane. This enables us to evaluate the magnetic anisotropy constants K_1 and K_2 separately and gives more useful information for quantitative discussions on the thermal stability of recording media.

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