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Precision Determination of Anisotropy Constant K_1 from Magnetization Curve of Partially Aligned Unaxial Anisotropy System

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A method to deduce the rotational magnetization curve from experimental magnetization of partially aligned uniaxial anisotropy system has been investigated. The curve obtained by this process has been evaluated quite close to the theoretical magnetization curve compared to that obtained by linear extrapolation from high field data. This new approach offers better accuracy for the determination of magnetic anisotropy by fitting a calculated magnetization curve to the obversed one.

Key words : anisotropy, magnetization curve, fitting method, rotational magnetization, rare earth compound

1. Introduction

Magnetic anisotropy is an important parameter for the alloy design of magnetic materials. The anisotorpy constants are usually measured by torque magnetometry or calculated from magnetization curves (magnetization method). The materials with strong anisotropy such as rare earth-3d transition metal compounds have several or a few tens tesla of anisotropy field, and the magnetization method is usually applied for the evaluation of their magnetic anisotropy [1-6].

Permanent magnet materials or high density recording media are required to posses a strong uniaxial anisotropy for high coercivity. If specimen is single crystal, under the assumption of homogeneous magnetization rotation, the anisotropy constants can be determined by fitting a calculated magnetization curve along magnetization hard direction to the observed one. In case of partially aligned system, however, the experimental magnetization curves near zero applied field include domain wall motion component, and the magnetization originated by magnetization rotation is indistinguishable. Analysis of the magnetic anisotropy by the fitting is then ambiguous and inaccurate. Most of works [7-12] on partially aligned system, therefore, have excluded the low field data by extending the magnetization curve measured at high field to low field region. In principle, this extension results in higher magnetization than that of rotational magnetization, and the anisotropy is always over estimated. For an example, if a linear extrapolation is taken from a field $H = J_s/\mu_0$ to $H = 0$, the over estimation of the K_1 of $Nd_2Fe_{14}B$ and $BaO{\cdot}6Fe_2O_3$ (for loose powders with Gaussian distribution width $\theta_0 = 10^{\circ}$) are estimated to be about 13% and 17%, respectively [13]. In addition, the over estimation increases seriously if J_s^2/K_1 or K_2/K_1 increases. For the precision evaluation of magnetic anisotropy, therefore, an ideal method to deduce the rotational magnetization curve from experimental magnetization is needed.

2. Determination of K_1

Fig. 1 shows the magnetization curves of partially aligned uniaxial powders having different K_1 but same in K_2 and J_s. Here, the magnetization curves parallel (||) and perpendicular ($\perp$) to the alignment direction (AD) were calculated using energy minimization of Eq. (1). In this case, the magnetization easy axis (MEA) of each powder was assumed to have a Gaussian distribution around the AD, as expressed by Eq. (2), and the total magnetization was calculated by summing the magnetization of each powder.

$$E = K_1 \sin^2\theta + K_2 \sin^4\theta - \vec{J_s} \cdot \vec{H} \tag{1}$$

$$f(\theta_c) = \frac{\exp(-\theta_c^2/2\theta_c^2)\sin\theta_c}{N} \tag{2}$$

Here, K_1 and K_2 are the first and second order magnetic anisotropy constant, respectively. The notation θ is the angle between MEA and J_s, and θ_c is the angle between MEA and AD. The angle θ_0 is the width of the Gaussian distribution and N is the normalizing factor (See Fig. 2).

As can be seen in Fig. 1(a), the curvature of magnetization curve near $H = 0$ is severe when K_1 is low. If a linear

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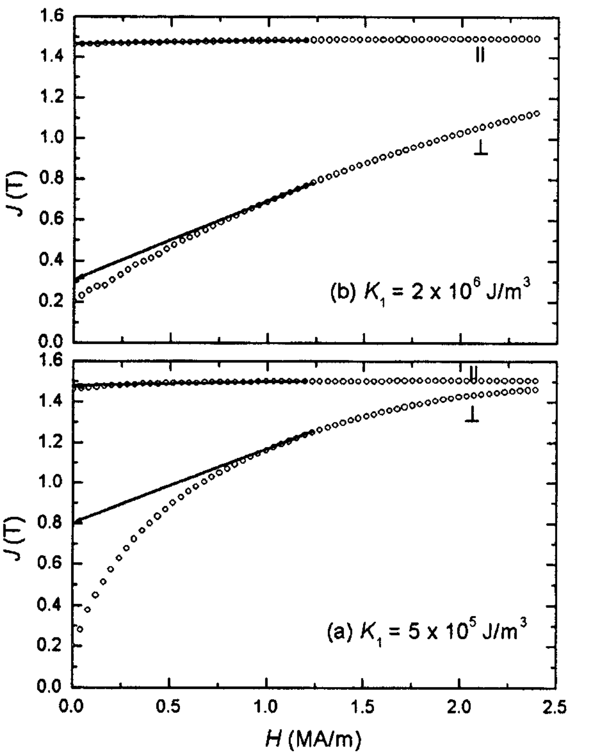

Fig. 1. Magnetization curves of partially aligned uniaxial anisotropy system for (a) $K_1 = 5 \times 10^5$ J/m^3, $K_2 = 5 \times 10^5$ J/m^3, J_s = 1.5 T and (b) $K_1 = 2 \times 10^6$ J/m^3, $K_2 = 5 \times 10^5$ J/m^3, J_s = 1.5 T.

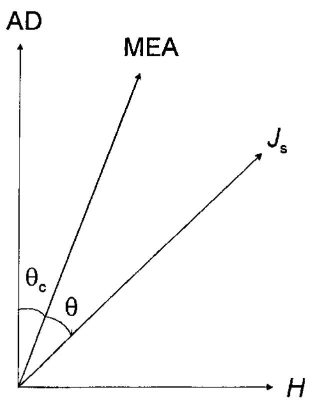

Fig. 2. The relation between AD, MEA, J_s, H, θ_c and theta.

extrapolation is taken from a high field region, for the exclusion of domain wall effect, it will result in a big difference between the magnetization at $H = 0$, $J_0^{extp}(\perp)$ and $J_0^{rot}(\perp)$. Moreover, the difference increases according to the increase of J_s^2/K_1 and K_2/K_1, and a big error will be made if the anisotropy is analyzed on the extrapolated curve.

On the other hand, the extrapolation on the parallel magnetization curve shows no big difference between $J_0^{extp}(\|)$ and $J_0^{rot}(\|)$ with the change of K_2/K_1 and J_s^2/K_1. (See the arrows on parallel magnetization curves in Fig. 1.). Since the θ_0 can be determined using $J_0^{extp}(\|)$ and J_s from the Table 1 in the article [14], the $J_0^{rot}(\perp)$ can be calculated with a good approximation using equation (3)

$$J_r(\perp) = J_s \frac{2}{\pi} \frac{\int_{\theta=0}^{\theta=\pi/2} \sin^2\theta \exp\left(-\frac{\theta^2}{2\theta_0^2}\right) d\theta}{\int_{\theta=0}^{\theta=\pi/2} \exp\left(-\frac{\theta^2}{2\theta_0^2}\right) \sin\theta d\theta} \qquad (3)$$

Table 1 compares the values obtained by the two method mentioned above for the two cases with high (A) and low (B) anisotropy. The $J_0^{rot}(\perp)$ values obtained by this work are fairly close to the theoretical values compared to those obtained by the linear extrapolation.

Fig. 3 shows the experimental magnetization curve (soild curve) of $Nd_2Fe_{14}B$ powder which was aligned in a magnetic field and measured perpendicular to the alignment direction at 250 K. As shown in the figure, the magnetization curve drops rapidly near $H = 0$ due to the domain wall moving effect. Here, the J_0^{rot} was estimated by equation (3), and $J_0^{rot} - J_r$ corresponds to the total decrement in magnetization by the domain wall motion. The domain wall contribution decreases according to the increase of H, and it is considered negligible at $H = J_s/\mu_0$ because this field overcomes the demagnetizing field of specimen. Therefore, the rotational magnetization curve should connect the two points J_0^{rot} and $J_{h=J_s/\mu_0}$. So, the line extrapolated from a high field region and the experimental magnetization curve are the upper and low limit for rotational magnetization curve, respectively. In the intermediate range of $0 \le H \le J_s/\mu_0$, the contribution of wall motion is thought

Table 1. Comparison with teoretical values for the rotational magnetization at $H = 0$ determined by linear extrapolation method and by equaion (3). The values after the oblique stroke are the ratio to the theory

	$J_0^{rot}(\|)$		θ_0		$J_0^{rot}(\perp)$	
	A	B	A	B	A	B
theory	1.46		10		0.21	
extrapolation	–	–	–	–	0.31+/1.48	0.80+/3.94
this work	1.47+/1.007	1.48+/1.014	9.3/0.93	7.6/0.76	0.20/0.95	0.16/0.76

A: J_s = 1.5 T, $K_1 = 2 \times 10^6$ J/m^3, $K_2 = 5 \times 10^5$ J/m^3
B: J_s = 1.5 T, $K_1 = 5 \times 10^5$ J/m^3, $K_2 = 5 \times 10^5$ J/m^3
+Obtained by extrapolation from high field region.

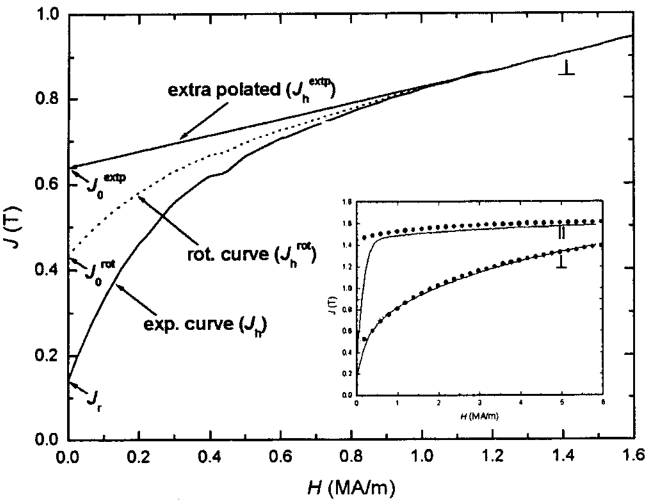

Fig. 3. Magnetization curve of partially aligned $Nd_2Fe_{14}B$ powder along perpendicular to AD. Experimental curve (solid) measured at 250 K and the rotational curve (dotted) deduced by calculation. The inset is the high field magnetization curves measured (solid) and calculated (solid circles).

proportional to $J_h^{extp} - J_h$, and the relation $(J_0^{rot} - J_r)/(J_0^{extp} - J_r) = (J_h^{rot} - J_h)/(J_h^{extp} - J_h)$ is assumed to maintain roughly. Then, the rotational magnetization at $0 \le H \le J_s/\mu_0$ can be calculated using the following equation;

$$J_h^{rot} = J_h + \frac{(J_0^{rot} - J_r)(J_h^{extp} - J_h)}{J_0^{extp} - J_r} \tag{4}$$

where,

J_0^{rot} : rotational magnetization at $H = 0$ calculated from θ_0

J_0^{extp} : magnetization at $H = 0$ obtained by the extrapolation from $H = J_0/\mu_0$.

J_h^{rot} : rotational magnetization at a given field.

J_h^{extp} : magnetization at a given field obtained by the extrapolation from $H = J_0/\mu_0$

J_h : experimental magnetization at a given field.

J_r : remanent magnetization.

The dotted curve shown in Fig. 3 is the rotational magnetization estimated from experimental magnetization curve using the equation (4). The rotational curve connects the two points J_h^{rot} and $J_{h=J_s/\mu_0}$, and it reflects the experiments smoothly. The magnetocrystalline anisotropy constants calculated by fitting method for the rotational magnetization curve are $K_1 = 2.4 \times 10^6$ J/m^3 and $K_2 = 3.0 \times 10^6$ J/m^3. The solid circles in the inset are the magnetizations calculated by applying those anisotropy constants, and they reproduce well the rotational magnetization curves.

3. Conclusion

A method to deduce a magnetization curve originated by magnetization rotation has been investigated for partially aligned uniaxial anisotropy system. The curve is quite close to the theoretical magnetization curve compared to that obtained by the linear extrapolation method. This approach offers a clue to calculate the magnetic anisotropy constants with higher accuracy.

References

[1] D. Givord, H. S. Li, and R. Perrier de la Bathie, Solid State Commun. **51**(11), 857 (1984).
[2] H. Hiroyoshi, H. Yamauchi, Y. Yamaguchi. H. Yamamoto, Y. Nakagawa, and M. Sagawa, Solid State. Commun. **54**(1), 41 (1985).
[3] M. Sagawa, S. Fujimura, H. Yamamoto, Y. Matsuura, and S. Hirosawa, J. Appl. Phys. **57**, 4094 (1985).
[4] J. J. M. Franse, F. R. de Boer, P. H. Frings, R. Gersdorf, A. Menovsky, F. A. Muller, R. J. Radwanski, and S.Sinnema, Phy. Rev. B **31**(7), 4347 (1985).
[5] R. Verhoef, Q. Wang, and J. J. M. Franse, Physica B **177**, 211 (1992).
[6] H. Yamauchi, M. Yamada, Y. Yamaguchi, H. Yamamoto, S. Hirosawa, and M. Sagawa, J. Magn. Magn. Mater. **54-57**, 575 (1985).
[7] M. Katter, J. Wecker, C. Kuhrt, L. Schultz, and R. Grossinger, J. Magn. Magn. Mater. **114**, 35 (1992).
[8] Zhi-gang Zhao, Wang Qun, X. K. Sun, Y. C. Chuang, and F. R. de Boer, J. Magn. Magn. Mater. **104**, 1287 (1992).
[9] R. Grossinger, R. Krewenka, H. R. Kirchmayr, S. Sinnema, Yang Fu-Ming, Huang Ying-Kai, and F. R. de Boer, and K. H. J. Buschow, J. Less-Common Metals, **132**, 265 (1987).
[10] H. T. Kim Y. B. Kim, C. S. Kim, T. K. Kim, and Hanmin Jin, J. Magn. Magn. Mater. **152**, 387 (1996).
[11] D. H. Kim, T. K. Kim, W. S. Park, and Y. B. Kim, J. Magn. Magn. Mater. **163**, 373 (1996).
[12] Y. B. Kim and Jin Han-min, J. Magn. Magn. Mater. **189**, 241 (1997).
[13] M. J. Kim, Y. B. Kim, and T. K. Kim, J. Magn. Magn. Mater. **217**, 106 (1997).
[14] Y. B. Kim and Jin Han-min, J. Magn. Magn. Mater. **169**, 114 (1997).