

일축이방성물질의 자기이방성상수에 관한 도식적 분석법

한국표준과학연구원 김윤배

吉林大學 金漢民

A graphical method to determine high order anisotropy constants of uniaxial magnetocrystalline anisotropic material

KRISS Y.B.Kim

Jilin University Jin Han-min

1. Introduction

Magnetic materials with uniaxial anisotropy are of interest in permanent magnet or recording applications. Many of rare earth-3d transition metal compounds, especially, show strong uniaxial magnetocrystalline anisotropy with high magnetization and are used as high coercive high energy permanent magnets. The coercivity of a rare earth magnet originates from its strong anisotropy, so that understanding the anisotropy of rare earth-3d transition metal compounds is important.

In this paper, we suggest a method to analyze high order anisotropy constants of a uniaxial anisotropic material. It is an extended form of the Sucksmith and Thompson method [1] to higher order and basal plane anisotropy.

2. Magnetization rotation at the initial stage of magnetization process

If a magnetic field H is applied perpendicular to $\{001\}$ axis of a tetragonal system with the polar angles (θ_h, φ_h) , and if we consider the anisotropy constants up to K_5 , the total free energy is expressed as

$$E = K_1 \sin^2 \theta_m + (K_2 + K_3 \cos 4\varphi_m) \sin^4 \theta_m + (K_4 + K_5 \cos 4\varphi_m) \sin^6 \theta_m - M_s H [\sin \theta_m \sin \theta_h \cos(\varphi_m - \varphi_h) + \cos \theta_m \cos \theta_h] \quad (1)$$

At the initial stage of magnetization of a uniaxial anisotropy system with easy magnetization $\{001\}$

$$\frac{2K_3}{K_1} \theta_m^2 \sin 4\varphi_m = \frac{\sin \theta_h \sin(\varphi_m - \varphi_h)}{\sin \theta_h \cos(\varphi_m - \varphi_h) - \theta_m \cos \theta_h} \quad (2)$$

If θ_m is negligibly small, $\varphi_m \approx \varphi_h$, and special solutions of $\varphi_h = \varphi_m = 0$ and $\varphi_h = \varphi_m = \pi/4$ exist.

3. Analysis of magnetocrystalline anisotropy constants.

For the special case of $\varphi_h = 0$ or $\varphi_h = \pi/4$, in which the field is applied to an easy or hard direction in the basal plane, a special solution of $\varphi_h = \varphi_m = 0$ or $\varphi_h = \varphi_m = \pi/4$ exists. Since $\varphi_h = \varphi_m$ at the initial stage of magnetization process, the magnetization vector keeps the original rotation plane as far as the equation (3) for the second derivative is satisfied:

$$\frac{\partial^2 E}{\partial \phi_m^2} = -16 \left[\frac{K_3}{M_s} \left(\frac{M}{M_s} \right)^3 + \frac{K_5}{M_s} \left(\frac{M}{M_s} \right)^5 \right] + H > 0 \quad (3)$$

If we assume $M_s \approx 10^3$ emu/cm³ and $|K_3| \sim |K_5| \approx 0.5 \times 10^7$ erg/cm³ with the same sign, as the typical values of rare earth-3d transition metal compounds, equation (3) is still positive if the magnetization is below $0.7M_s$ at an applied field of $H \sim 40$ kOe. With the values assumed above and a saturation field of 100 kOe (typical saturation field of rare earth-3d transition metal compounds at room temperature), the deviation of the magnetization vector from the plane made by the c-axis and the applied field is calculated to occur near saturation.

If a magnetic field is applied to [100] or [110] direction, from equilibrium condition,

$$\left[\left(\frac{H}{M^3} \right)_{[100]} - \frac{2K_1}{M_s^2} \left(\frac{1}{M_{[100]}^2} \right) \right] = \frac{4(K_2 + K_3)}{M_s^4} + \frac{6(K_4 + K_5)}{M_s^6} M_{[100]}^2 \quad (4)$$

$$\left[\left(\frac{H}{M^3} \right)_{[110]} - \frac{2K_1}{M_s^2} \left(\frac{1}{M_{[110]}^2} \right) \right] = \frac{4(K_2 - K_3)}{M_s^4} + \frac{6(K_4 - K_5)}{M_s^6} M_{[110]}^2 \quad (5)$$

K_1 may be determined from the slope of initial part of magnetization curves using the relation $M/H = M_s^2/2K_1$. Then, the high order anisotropy constants can be determined from the intercept and slope of $\left[\left(\frac{H}{M^3} \right) - \frac{2K_1}{M_s^2} \left(\frac{1}{M^2} \right) \right]$ vs. M^2 plots. Table 1. shows the anisotropy constants of Pr₂Fe₁₄B determined by the method explained above

Table 1. Magnetocrystalline anisotropy constants of Pr₂Fe₁₄B at 290 K ($\times 10^7$ erg/cm³).

K_1	K_2	K_3	K_4	K_5
5.7	-0.26	0.12	0.21	-0.12

Reference

- [1] W. Sucksmith, F. R. S. and J. E. Thompson, Proc. R. Soc. London Ser., A225 (1954) 362.