Magnetic Viscosity of Sr-Na-Zn W-Type Hexagonal Ferrite Magnets

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Abstract. The temperature dependence of the magnetic viscosity coefficient (S_v), the activation volume (v), and the anisotropy field (H_A) were examined for Sr-Na-Zn W-type hexagonal ferrite magnet from 77 to 623 K. Samples with different coercive forces (H_{cJ}) were prepared, and the dependence of S_v and v on H_{cJ} was studied at 300 K. The results show that the temperature dependence of S_v is the same as that of H_{cJ} . The value of v is inversely proportional to H_A . The logarithm of S_v is proportional to $\ln H_{cJ}$ and H_{cJ} is proportional to $v^{-2.1}$, as in the case of $\text{Sm}_2\text{Fe}_{17}\text{N}_x$ and SrM particles used in magnets and BaM fine particles used for high density recording media. They are considered to have a similar coercive force mechanism.

1. INTRODUCTION

In recent years, there has been a growing interest in W-type hexagonal ferrite which has a saturation magnetization (J_s) about 10% greater than that of M-type hexagonal ferrite. Many reports on the magnetism of W-type Hexagonal ferrites have been published[1,2], though studies on their magnetic viscosity are particularly few. The magnetic viscosity in permanent magnets belongs to the Jordan-type aftereffect phenomenon and is caused by thermal fluctuations[3,4]. It is known to depend on the magnetic viscosity coefficient (S_v), the irreversible susceptibility (X_{irr}) and the logarithmic time ($\ln t$) [3-5]. When the change in magnetization from time t_1 to t_2 (ΔJ) is considered, S_v can be expressed using the following equation[3-5]:

$$S_v = \Delta J / X_{irr} (\ln t_1 - \ln t_2) = k T / (\partial E / \partial H)_T = k T / v J_s \quad (1)$$

where k is the Boltzman constant, E is the activation energy, v is the activation volume and H is the magnetic field. This paper reports on studies of the temperature dependence of S_v and the anisotropy field (H_A) for a Sr-Na-Zn W-type hexagonal ferrite in the temperature range from 77 to 623 K. Also, the relationships between the coercive force (H_{cJ}) and both S_v and v were investigated at 300 K.

2. EXPERIMENTAL

Sr-Zn W-type hexagonal ferrite was investigated with 1.33 wt% Na_2O and 0.67 wt% SrO , which were added after semisintering treatment. Table 1 shows sintering conditions, grain size (D) and the magnetic properties of Sr-Na-Zn W-type hexagonal ferrite magnets. These samples were spherical with diameters of 4 mm. After the application of 1.6 MA/m, the samples were subjected to a constant external field (H_{ex}) for 1000 s and ΔJ was measured using a vibrating sample magnetometer (VSM). The apparent reversible susceptibility (X_{rev}) and the total differential susceptibility (X_{tot}), obtained by differentiating the demagnetizing curve with respect to H_{ex} , were also measured using a VSM. X_{irr} can be expressed as $X_{tot} - X_{rev}$, where the prime indicates the values before correcting for the demagnetizing field. Corrections were made for the demagnetizing field using a demagnetizing factor of $N=1/3$. The uniaxial anisotropy constant (K_A) is obtained from unsaturated torque curves. For the torque magnetometer used, fields were available in the range of 0.8 to 2 MA/m. The coefficient of the $\sin^2 \theta$ term was extrapolated to infinite H by plotting against $1/H$. The uniaxial anisotropy constants and the anisotropy fields are related by $H_A=2K_A/J_s$.

Table 1. Sintering conditions, grain size D and the magnetic properties of Sr-Na-Zn W-type hexagonal ferrites

Sample	Sintering conditions	D (μ m)	J_s (T)	Br (T)	H_{cJ} (kA/m)	$(BH)_{max}$ (kJ/m ³)
A	1225°C x 0.5 h	0.5 - 1.5	0.407	0.335	138	19.3
B	1275°C x 1.0 h	1.1 - 2.0	0.407	0.349	82	15.3
C	1300°C x 0.5 h	1.8 - 4.0	0.456	0.395	36	5.4
D	1300°C x 1.0 h	3 - 40	0.456	0.414	18	2.4
E	1300°C x 2.0 h	3 - 60	0.456	0.417	14	1.2

3. RESULTS AND DISCUSSION

Similar curvatures of the magnetic field dependencies of $\Delta J'/(ln t_1 - ln t_2)$ and X'_{irr} were observed for Sample A and these had maximum values around the H_{CJ} point for each temperature. Figure 1 shows the magnetic field dependence of S_v for Sample A obtained from Eq.(1), using the values of $\Delta J'/(ln t_1 - ln t_2)$ and X'_{irr} . The range in which S_v stays constant with H_{ex} is very wide at each temperature. For Sample A, J_s and K_A both decreased as temperature increased. The temperature dependence of S_v and H_{CJ} is shown in Figure 2 for Sample A. The temperature dependence of S_v is the same as that of H_{CJ} . S_v and H_{CJ} increase with the increase in the temperature between 77 K and 500 K, as in the case of SrM and BaM magnets[6]. The values of S_v and H_{CJ} are maximized near 520 K and decrease suddenly after that. The temperature dependence of the anisotropy field (H_A) obtained using the values of K_A is shown in Figure 3 along with the activation volume (v) calculated from S_v . The value of v is inversely proportional to H_A in the temperature range from 77 K to 623 K. Figure 4 shows the dependence of S_v and v on H_{CJ} at 300 K for Sr-Na-Zn W-type hexagonal ferrite samples A, B, C, D and E. The logarithm of S_v is proportional to the logarithm of H_{CJ} and H_{CJ} is proportional to $v^{-2.1}$, as in the case of $Sm_2Fe_{17}N_x$ and SrM particles used in permanent magnets and BaM fine particles used for high density magnetic recording media[7-9]. It is believed that they have a similar coercive force mechanism.

Figure 1. External field dependence of the magnetic viscosity coefficient S_v for Sample A at various temperature.

Figure 2. Temperature dependence of coercive force H_{CJ} and the magnetic viscosity coefficient S_v for Sample A in the temperature range between 77 and 623 K.

Figure 3. Temperature dependence of the anisotropy field H_A and the activation volume v for Sample A in the temperature range between 77 and 623 K.

Figure 4. Plots of the magnetic viscosity coefficient S_v and the activation volume v against coercive force H_{CJ} for Sr-Na-Zn W-type hexagonal ferrites.

References

- [1] Collomb A. and Mignot J.P., *J. Magn. Magn. Mat.*, **69** (1987) 330-336.
- [2] Collomb A., Litsardakis G., Samaras D. and Pannetier J., *J. Magn. Magn. Mat.*, **78** (1989) 219-225.
- [3] Street R. and Woolley J.C., *Proc. Phys. Soc.*, **A62** (1949) 562-572.
- [4] Neel L., *J. Phys. Rad.*, **12** (1951) 339-351.
- [5] Gaunt P., *Philos. Mag.*, **34** (1976) 775-780.
- [6] Nishio H., Taguchi H. and Yamamoto H., "Magnetic aftereffects of anisotropy M-type hexagonal ferrite magnets", *Proc. 6th Int. Conf. on Ferrite (ICF6)*, Tokyo 29 September - 02 October 1992, pp. 1129-1132.
- [7] Nishio H., Ishizaka C., Hidaka T., Fukuno A. and Yoneyama T., "Magnetic viscosity in powder and compacted powder magnets of $Sm_2Fe_{17}N_x$ ", *Proc. 8th Int. Symp. on Magnetic Anisotropy and Coercivity in RE-TM Alloys*, Birmingham 15 September 1994, pp. 423-435.
- [8] Nishio H., Taguchi H., Hirata F. and Takeishi T., *IEEE Trans. Magn.*, **29** (1993) 2637-2639.
- [9] Nishio H., *J. Magn. Soc. Jpn.*, **13 S1**, (1989) 697-702.