

Effects of Sweeping Rate on Magnetic Viscosity of Metal Evaporated Tape

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Magnetic viscosities of a commercialized metal evaporated tape were measured as a function of sweeping rate in VSM at room temperature. Within several seconds in the viscosity measurement, curves are downward concave and more concave with increasing sweeping rate when magnetization were plotted as a logarithmic function of time. However, magnetization varied as a logarithmic function of time after several seconds. Magnetic viscosity coefficient gradually increased with increasing sweeping rate and then kept a constant value at a rate faster than 61.5 Oe/s. It was supposed that magnetic viscosity occurs during field sweeping, which was in good agreement with Sharrock's model qualitatively. Activation volume decreased with increasing sweeping rate, which was due to the fact that magnetic viscosity coefficients increased with sweeping rate while irreversible susceptibilities were not affected by sweeping rate.

1. Introduction

Recently magnetic recording density is increasing to meet a very large capacity of information. At a recording density of 10 Gb/in², however, it was pointed out that the recorded information might be lost because of thermal fluctuation [1]. The ratio of anisotropy energy to thermal energy at 10 Gb/in² is 40-100 which is much smaller than the present value of 1000. Therefore a thermal effect must be considered to commercialize the recording media with a high recording density.

Magnetic viscosity measurements are widely used to predict the thermal stability. In magnetic viscosity measurements, magnetization as a function of the time after a sudden increase in the applied magnetic field are measured. Theoretical backgrounds used in this paper are briefly introduced below.

The magnetic viscosity is a common physical phenomenon in all ferromagnetic materials. Magnetization is not constant, but changed as a function of time. This phenomenon can be understood from the physical point of a view as follows. External energy, which is normally Zeeman energy, must be supplied to overcome local energy barriers in order to change magnetization. Thermal energy can be one of the external energy. Neel pointed out that atomic vibrations could be changed by thermal effects, and thus local energy barriers could be also varied due to magnetoelastic effects. Therefore magnetization is varied as a function of the time in various fashions depending on the energy barrier distribution.

The fact that magnetization was varied as a function of time was well known phenomenon, but the reason for that had not been known clearly. Snoek suggested that carbon or nitrogen diffusion is an origin of magnetic viscosity because he observed the phenomenon in a steel containing carbon or nitrogen atoms [2]. However, Street and Woolley proved that the origin of the phenomenon was not diffusion, but the thermal effects considering the results on a pure iron by Ewing [3] in 1889. A study on magnetic viscosity by the thermal effects had been done experimentally and theoretically by Street and Woolley and the equation of $\Delta M = A - S \ln t$ was suggested for the first time on Alnico permanent magnets [3, 4]

A magnetization in M-H loop consists of reversible and irreversible components. It is also for the case of time dependent magnetization, $M(t) = M_{irr}(t) + M_{rev}(t)$, where irreversible magnetization $M_{irr}(t)$ is residual magnetization when a magnetic field is removed at a time, t . Contributions of time-dependent reversible magnetization $M_{rev}(t)$ are small compared to $M_{irr}(t)$ which is originated from demagnetization, for example. Therefore only irreversible magnetization is considered here, because magnetic viscosity by thermal effects is irreversible by nature. Magnetization variation as a function of time is given by equation (1) in a particle with a single energy barrier

$$M_{irr}(t) = A + B \exp(-t/\tau_0) \quad (1)$$

where A , B is arbitrary and τ_0 is the Neel-Arrhenius relaxation time given by

$$\frac{1}{\tau} = f_o e^{-E_B/kT} \quad (2)$$

where k is the Boltzman constant, E_B is the activation energy and f_o is a frequency factor, the order of which is $10^9 \sim 10^{12} \text{ s}^{-1}$. In most ferromagnetic materials magnetization is varied as a logarithmic function of time t ,

$$M_{irr}(t) = M_o - S \ln(t/t_o) \quad (3)$$

where M_o is irreversible magnetization at a time $t=t_o$ and S is a constant called magnetic viscosity coefficient. Street and Woolley showed that magnetization is varied as a logarithmic function of time if energy barrier distribution function $f(E_B)$ is assumed constant [4].

Neel also pointed out that the irreversible magnetization can be made by internal field fluctuation. The relation between the Neel's fluctuation field and the magnetic viscosity coefficient is given by the equation (4) [5].

$$H_f = \frac{kT}{\left(\frac{\partial E}{\partial H}\right)} = S\chi_{irr} \quad (4)$$

Wohlfarth derived the equation for the fluctuation field by assuming that the thermal energy is comparative with the magnetic energy [6].

$$E = v_{ac} M_S H_f = kT \quad (5)$$

$$H_f = \frac{kT}{V_{ac} M_S} \quad (6)$$

where V_{ac} is called activation volume. The activation volume is defined as the largest particle volume that must be rotated magnetically in the process of overcoming energy barrier. In case of wall motion it is defined as a volume swept by one jump. From the above equations the fluctuation field can be calculated from magnetic viscosity and irreversible susceptibility, and thus the activation volume can be calculated.

$$V_{ac} = \frac{kT}{M_S H_f} \quad (7)$$

Measurement temperature, field, time and others are varied to analyze the magnetic behaviors.

No experimental data on sweeping rate, however, at which magnetic field was increased from zero to a measuring field were reported. In this study effects of sweeping rate on the magnetic viscosity were investigated.

2. Experimental procedure

SONY metal evaporated (Hi-8 ME, E6-60) tape was used. Thickness, coercivity and remanence of the tape were 0.16 m, 1100 Oe and 3980 G, respectively. The composition of the tape is Co-Ni-O (Co:Ni = 8 : 2).

EG&G VSM (Model 155) was used to measure magnetic viscosity. The measurement procedure is as follows. Magnetic field of 10 kOe was applied in a positive direction and then reduced to zero gradually. After reversing the polarity of the magnetic field, field was increased to a measuring field and then the magnetization changes as a function of time were measured for 100 seconds. After the measurement same processes were repeated for different measuring fields. Magnetic field was measured by Lakeshore gaussmeter and the stabilities of magnetic fields were within 2.7 Oe in a low field and 4.2 Oe in a field higher than 2000 Oe.

Magnetic viscosities were measured in fields from 500 to 2500 Oe. The sweeping rate at which fields were increased from zero to measuring fields was varied from 16 to 76 Oe/s. Irreversible magnetic susceptibilities were measured by differentiating DC remanence curves with applied field and the results were compared with those obtained from switching field distribution.

3. Results and discussion

Figure 1 shows the variation of magnetization of ME tape with time, i.e., magnetic viscosity, in which field was

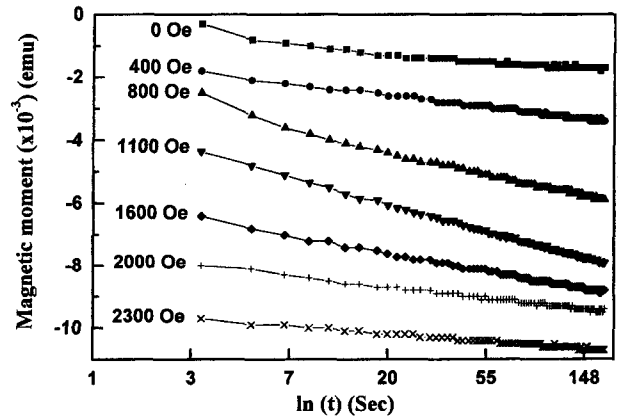


Fig. 1. Time dependence of magnetization of ME tape (Sweeping rate : 16.4 Oe/s).

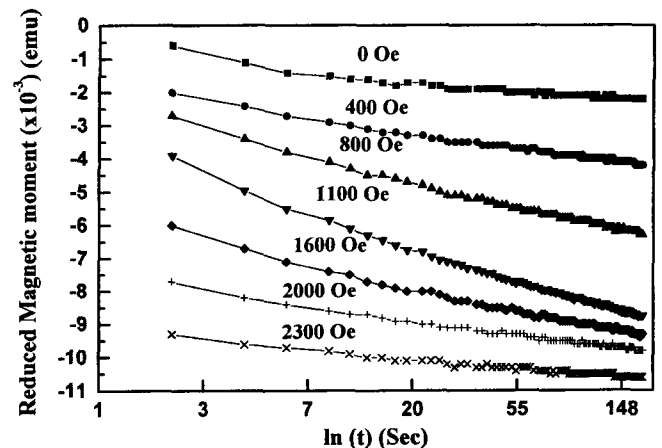


Fig. 2. Time dependence of magnetization of ME tape (Sweeping rate : 76.5 Oe/s).

increased at a rate of 16.4 Oe/s. Magnetization was varied as a logarithmic function of time. However, it did not show logarithmic behavior within several seconds, where the curves are upward concave and more concave with increasing the sweeping rate (Fig. 2). Viscosity coefficient S was largest near coercivity and the coefficients became smaller as the field became away from coercivity.

The most important fact determining the magnetic viscosity phenomena is the activation energy (barrier) distribution, to which particle volume, anisotropy field (both magnitude and direction of anisotropy field) and others contribute. Assuming a single average barrier distribution, magnetization decreased exponentially. However, if a constant activation energy distribution is assumed, magnetization decreased logarithmically [4, 5, 7]. O'Grady who considered the particle volume distribution only, showed that magnetization were varied as in equation (8) [8].

$$\Delta M = -2 \frac{kT}{KV_m(1-H/H_K)^2} f(y_p(H, t)) \ln(t/t_0) \quad (8)$$

where $y_p(H, t) = kT \ln(t/t_0)/KV_m(1-H/H_K)^2$ and V_m are normalized particle volume and average particle volume, respectively. Equation (8) shows that the viscosity coefficient is proportional to the distribution function [9]. Therefore it can be supposed that the distribution function decreases in the beginning of measurement and then remains constant with time in this experiment.

The variation of the viscosity coefficient after 10 seconds measured at different sweeping rates are shown in Fig. 2. The coefficient was maximum near the coercivity. And the coefficients were increased with increasing sweeping rate and kept constant at a rate faster than 61.5 Oe/s. This means that magnetic viscosity phenomenon is affected by the sweeping rates. Therefore in order to measure magnetic viscosity the sweeping rate of the magnetic field must be considered.

Because the magnetic viscosity occurs during the field sweeping, shapes of M-H loops are varied depending on the sweeping rate, thus leading to different coercivities. This means that coercivity is a function of sweeping rate, i.e., frequency. Sharrock derived a time dependency of coercivities for the Stoner-Wohlfarth particle [10].

$$H_c(t) = H_o(1 - [(kT/KV) \ln(At)]^n) \quad (9)$$

where $H_o = 2Kx/M$, $n = 1 / (0.86 + 1.14x)$, $x = [\cos^{2/3}(\varphi) + \sin^{2/3}(\varphi)]^{-3/2}$, and t are the angle between easy direction and applied field, and characteristic time of the experiment, respectively. For example, if a field value of 3000 Oe at 60 Hz is used, maximum slope at coercivity is around $1.1 \cdot 10^6$ Oe/s, leading to the characteristic time of 10^{-5} . The characteristic time of VSM is around 1 s. From equation (9), it can be shown that coercivity increases with decreasing characteristic time. Therefore the result of Fig. 3

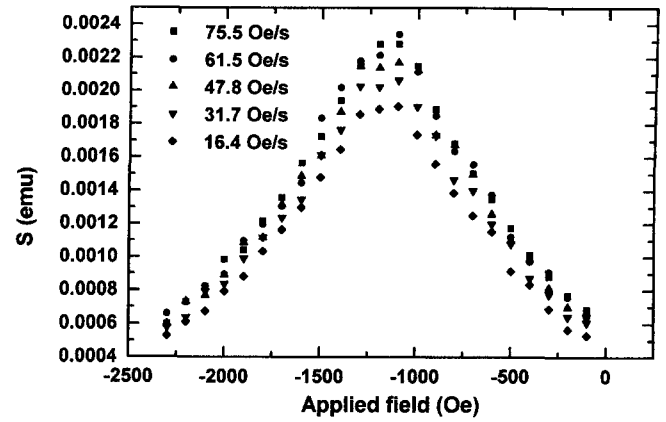


Fig. 3. Magnetic viscosity coefficient of ME tape measured at different sweeping rate.

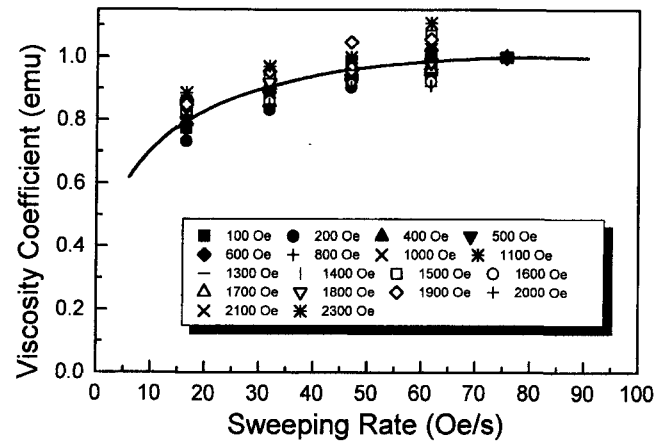


Fig. 4. Effects of sweeping rate on the viscosity coefficient normalized to that of 75.7 Oe/s.

is consistent with Sharrock's equation qualitatively. Eddy current effects were not considered in the above calculation.

Effects of sweeping rate on the viscosity coefficient were replotted in Fig. 4, in which coefficients were normalized to those of 75.7 Oe/s. The trend is more clear that viscosity coefficients drop more sharply in a low sweeping rate and are saturated at the rate higher than 61.5 Oe/s.

Magnetic viscosity coefficient S is proportional to fluctuation field H_f and its proportional constant is irreversible susceptibility χ_{irr} as suggested by Street and Woolley. Irreversible susceptibility is normally measured from DC remanence curve or switching field distribution. Irreversible susceptibilities are plotted as a function of sweeping rate in Fig. 5. Sweeping rates did not affect irreversible susceptibilities. The processes for obtaining DC remanence curves are very similar to those for magnetic viscosity. In DC remanence curve measurement sweeping rate from zero to measuring fields was varied, but fields were immediately removed as soon as measuring fields were reached. It is supposed that some magnetization variations induced by different sweeping rate were removed or annihilated in the process of returning to a remanence state. Irreversible susceptibilities obtained from switching field distribution were

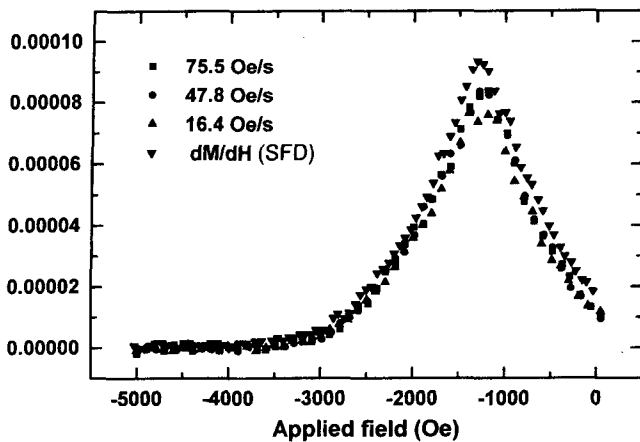


Fig. 5. Irreversible susceptibility of ME tape measured at different sweeping rate.

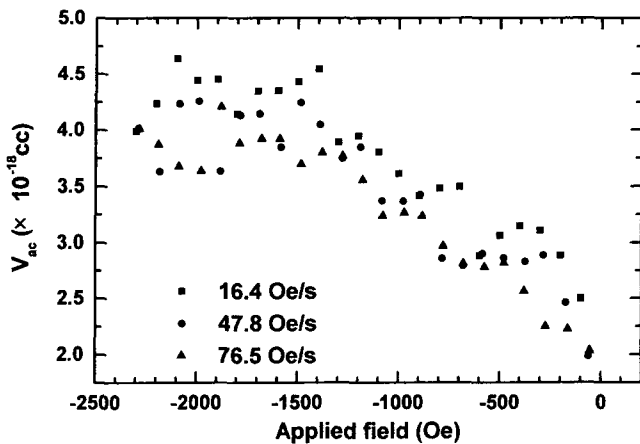


Fig. 6. Activation volume of ME tape measured at different sweeping rate.

almost same as those of Fig. 4 as reported by others.

Activation volumes were calculated as a function of applied field and sweeping rate (Fig. 5). Activation volumes increased with increasing field and kept constant above 1500 Oe. Increasing trend of activation volume with increasing field might be due to higher magnetic (Zeeman) energy. If external field was increased, particles with larger volume could reverse magnetization because more energy could be obtained to overcome the energy barrier. Activation volumes were decreased with increasing sweeping rate, which was due to the fact that irreversible susceptibilities

were not affected by sweeping rate while viscosity coefficients were increased with increasing the sweeping rate.

4. Conclusion

Magnetic viscosities of commercialized ME tape were measured as a function of sweeping rate and the results are as follows.

1) Within several seconds in the viscosity measurement, curves are downward concave and more concave with increasing sweeping rate when magnetization were plotted as a logarithmic function of time. However, magnetization varied as a logarithmic function of time after several seconds.

2) Magnetic viscosity coefficient gradually increased with increasing sweeping rate and then kept constant at a rate faster than 61.5 Oe/s. It was supposed that the magnetic viscosity occurs during field sweeping, which was in good agreement with Sharrock's model qualitatively.

3) Activation volume decreased with increasing sweeping rate. This was due to the fact that magnetic viscosity coefficients increased with sweeping rate while irreversible susceptibilities were not affected by sweeping rate.

References

- [1] Pu-Ling and Stanley H. Charap, *IEEE Trans. Magn.*, **30**(6), 4230(1994).
- [2] J. L. Snoek, *Physica*, **5**, 663(1938).
- [3] R. Street and J. C. Woolley, *Proc. Phys. Soc. B*, **62**, 141 (1949).
- [4] R. Street and J. C. Woolley, *Proc. Phys. Soc. A*, **62**, 562 (1949).
- [5] R. Street, J. C. Woolley and P. B. Smith, *Proc. Phys. Soc. B*, **65**, 679(1952).
- [6] E. P. Wohlfarth, *J. Phys. F*, **14**, L155(1984).
- [7] M. El-Hilo, S. Uren, K. O'Grady, J. Popplewell and R. W. Chantrell, *IEEE Trans. Magn.*, **26**(1), 244(1990).
- [8] K. O'Grady, R. W. Chantrell, J. Popplewell and S. W. Charles, *IEEE Trans. Magn.*, **17**(1), 2943(1981).
- [9] M. El-Hilo et al., *J. Magn. Magn. Mater.*, **109**, L164(1992).
- [10] M. P. Sharrock, *J. Appl. Phys.*, **76**(10), 6413(1994).