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Fine Particle Magnetic Recording Media

E. D. DANIEL*
Memorex Corporation, Santa Clara
California, U.S.A.
AND
E. P. WOHLFARTH
Department of Mathematics, Imperial College
London, England

The coercivity and remanence curves of γFe_2O_3 particles used as coatings of magnetic recording tapes are discussed on the basis of fine particle theory.

1. Introduction

Although the physical principles underlying the operation of recording tapes are of great interest, their discussion in fundamental magnetic terms is a rare event[1]. It seems appropriate, therefore, to give a brief account of these principles in terms of fine particle theory.

Present day tapes are coated with dispersed particles of γFe_2O_3, usually elongated (about $0.6\times0.1\times0.1\,\mu$), but sometimes isotropic (about $0.1\,\mu$ diameter) and containing small amounts of cobalt. The powders are easy to produce in bulk (e.g. by thermal conversion from αFe_2O_3 powders) and their properties are suitable for recording purposes, although the saturation magnetization I_0 is only about 400 gauss.

Other materials may prove to be equally or even more suitable for recording. These include the reduced Fe-Co-Ni alloy powders investigated by Professor K. Nagai. Alternatives are elongated Fe particles and particles with fairly large uniaxial, magnetocrystalline anisotropy; although these are presumably under investigation, no details have been published.

2. Coercivity of γFe_2O_3 Powders

The coercive force H_c of tapes made from elongated γFe_2O_3 particles is about 250 oersted. If H_c were determined entirely by shape anisotropy and the magnetization reversals were coherent, the expected value should approach $2\pi I_0$, i.e. about 2500 oersted. This difference by a factor 10 is probably caused mainly by (i) particle interactions and other assembly effects, (ii) incoherent magnetization reversals. The first were eliminated in the measurements of Morrish and Yu[2] on a single γFe_2O_3 particle which was found to have H_c about 800 oersted. The remaining factor about 3 may be ascribed to incoherent magnetization reversals. If these are of the fanning type[3], H_c is calculated[4] to approach about 650 oersted. If the incoherent reversals are of the curling type[5], then on the assumption of infinite cylinders with radius R, the value $H_c/2\pi I_0=1/3$ demands $R=1.8\sqrt{A}/I_0$, where A is the exchange constant, i.e. if $R=0.05\mu$ it demands $A=10^{-6}$ erg/cm (no measurements of A are available, but the accepted value for pure iron is 2×10^{-6} erg/cm).

Incoherent reversals in these particles are demonstrated indirectly by other measurements. Bate[6] measured H_c for a partially aligned assembly as a function of the angle Ω between the alignment direction and that of measurement. For dilute specimens the H_c, Ω curves have maxima at about 50°, characteristic[3,5] of incoherent reversals. The measured rotational hysteresis integral[7], 1.6, is similarly characteristic; for curling it corresponds[5] to about the same value of $RI_0/\sqrt{A}$ as that given by H_c. Another demonstration of incoherent magnetization reversals in γFe_2O_3, and a method of eliminating them in favour of coherent reversals, is described by Flanders and Shtrikman[8].

For isotropic γFe_2O_3 particles the coercive force is presumably determined mainly by magnetocrystalline anisotropy. This has never been measured accurately for pure or Co doped γFe_2O_3. One old measurement gives[4] an estimated H_c about 100 oersted for the pure material, agreeing roughly with

* formerly with Ampex Electronics Ltd., Reading, Berkshire, England.

observation. Cobalt doping increases H_c to much larger values, certainly as a result of the increase of the anisotropy constant K to large positive values, analogously to its increase in Co doped magnetite[9]. With large K the reduced saturation remanence $J_r = I_r(\infty)/I_0$ is expected to approach the theoretical value[10] 0.831, and this is indeed found. A slight admixture of shape anisotropy is, however, expected[11] to reduce j_r inordinately towards 0.5.

3. Remanence Curves

Curves relevant to the recording process include the static remanence curve $I_r(H)$, the D. C. and A. C. demagnetization remanence curves $I_D(H)$ and $I'_D(H)$, and, most important, the anhysteretic remanence curve $I_{ar}(H)$.

The static and demagnetization curves have either been calculated explicitly[12,5] for assumed magnetization reversal processes and critical field spectra (the last being in principle derivable by this means[13]), or relations between them have been derived[14] which hold under rather general conditions but not if particle interactions are important or if the anisotropy is non-uniaxial. For elongated γFe_2O_3 powders these relations are not obeyed very closely[13,15]; Bate found the best agreement for $I_r(H)$ and $I_D(H)$ measured parallel to the preferred orientation where the interactions are thus least important. It should be possible to analyze these deviations from the relations of reference (14) more quantitatively in terms of particle interactions. For example[16], the area between the $I'_D(H)$ curves derived from either $I_r(H)$ or $I_D(H)$, which is zero in the absence of interactions, is, on the basis of the theoretical 'pair model'[17], equal to $\frac{1}{2}(H_1 - H_2)I_r(\infty)$, where H_1 and H_2 are the two critical fields for this model. The area between the $I_{ar}(H)$ curve and the lines $I_{ar}(H) = I_r(\infty)$ and $H=0$ is, for this model, also equal to this value. This theoretical relation between areas, which holds for all spectral distributions of H_1 and H_2 in an assembly, should be tested experimentally.

As just implied, the initial susceptibility c of the $I_{ar}(H)$ curve is infinite in the absence of particle interactions. The observed finite value of c, governing the recording sensitivity of the tape under A.C. biasing conditions, thus arises as a result of these interactions. These have been discussed using two approximations, neither of which is fully satisfactory: (i) The interactions are formally represented by the effect of a demagnetizing field with coefficient $N = N_e + N_i$, where N_e is the external and N_i the internal

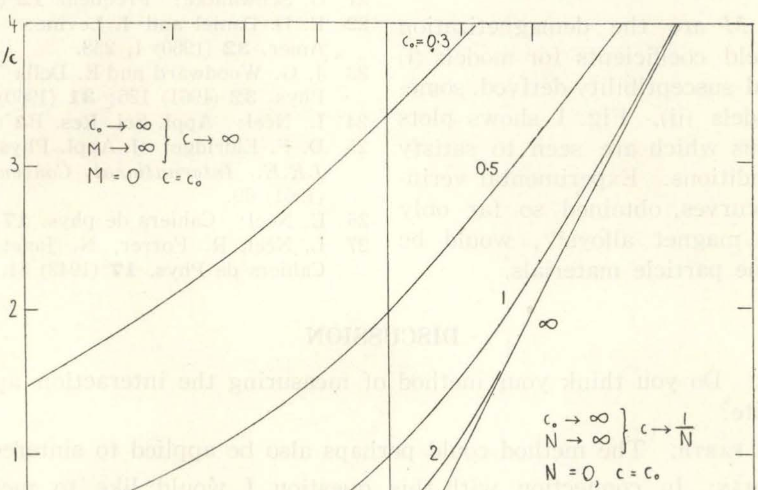

Fig. 1. Initial anhysteretic susceptibility. c, susceptibility; c_0, value of c if $N = M = 0$; N, demagnetization coefficient; M Lorentz field coefficient. See relations (1), due to Néel.[26]

demagnetization coefficient[18,19,20]. For a thin tape specimen N_e is negligible and $c=1/N_i$, depending, as observed, on the particle dispersion and alignment. If the interactions are represented more closely by a Lorentz type field, coefficient M, then c is still infinite. (ii) For the approximation just discussed the interactions were taken to be magnetization *dependent*, this dependence being represented in a particularly simple and formal way. Alternatively, they may be taken to be magnetization *independent* and to be represented by a model such as the pair model[17], the related Preisach model[21,22,23] or that based on the effect of the R.M.S. dipole interactions between particles[24,25]. For the last model Eldridge showed that, for a given distribution of dipole interaction fields, c is a constant, independent of I_0, H_c and the packing factor.

It may be that a combination of magnetization dependent and independent effects is a better approximation than is provided by either effect separately. By considering how $I_{ar}(H)$ is built up ('*gelée*') during the steady reduction of the A.C. field, Néel[26] showed that

$$c=N^{-1}[1-\exp(-Nc_0)]\ , \qquad (1)$$

giving also

$$c=M^{-1}[\exp(Mc_0)-1]\ ,$$

where N and M are the demagnetization and Lorentz field coefficients for models (i) and c_0 the initial susceptibility derived, somehow, from models (ii). Fig. 1 shows plots of these relations which are seen to satisfy all limiting conditions. Experimental verification of such curves, obtained so far only for permanent magnet alloys[27], would be desirable for fine particle materials.

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DISCUSSION

G. HEIMKE: Do you think your method of measuring the interaction applicable to barium ferrite?

E. P. WOHLFARTH: The method could perhaps also be applied to sintered ferrite.

S. SHTRIKMAN: In connection with this question I would like to mention some measurements of remanence curves on $BaFe_{12}O_{19}$ carried out by P. Flanders. Here he found that the static remanence was related to the DC demagnetization remanence according to Wohlfarth's relations. This suggests, as expected, that interactions are not very important in $BaFe_{12}O_{19}$. Details of this work will be presented before the Conference on Magnetism, Phoenix, November 1961.