Journal of Optoelectronics and Advanced Materials Vol. 4, No. 2, June 2002, p. 307 - 310

MAGNETIZATION PROCESSES SIMULATIONS FOR INTERACTING NANOPARTICULATE SYSTEMS USING A PREISACH-NÉEL MODEL

I. D. Borcia, L. Spinu[a], Al. Stancu

Faculty of Physics, "Al. I. Cuza" University, Iasi, 6600, Romania
[a]AMRI, University of New Orleans, LA 70148, USA

Magnetization processes of nanoparticulate magnetic media are simulated using a Preisach-Néel type model with thermal variable variance. A lattice of representative particles distributed in the Preisach plane describes the magnetic behavior of the ensemble. Each representative particle corresponds to the same total magnetic moment. The effect of dynamic interactions was taken into account by modifying the position of the maximum of the Preisach distribution to higher coercitive fields when the number of superparamagnetic particles increases. We also considered the dependence of the statistical interactions on the number of the superparamagnetic particles. The movement of the critical curves in the Preisach plane in constant and variable magnetic field processes is taken into consideration in respect with the results of the simulations using a model with the master equation distributed in the Preisach plane. Using this model we have simulated in-field and remanent magnetization curves and the deltaM curves.

(Received February 27, 2002; accepted May 15, 2002)

Keywords: Hysteresis, Preisach-Néel model, Superparamagnetism, Time- and temperature-dependent models, DeltaM curves, Interacting nanoparticulate systems

1. Introduction

In order to explain the magnetic properties when the dimensions of the magnetic entities became smaller, time and temperature dependent models have been developed in the last few years ([1]-[5]). A phenomenological theory, based on intrinsic energy barrier, has been described by Chantrell et al. [1]. In order to simplify the calculations, linear energy barrier versus field were used in [2], [3]. This gives straight critical lines, separating superparamagnetic and blocked particles. Considering in the calculus of the energy barrier the Stoner–Wohlfarth model, nonlinear critical curves are obtained, as one can see in Ref. [4] and [5]. This approach allows the evaluation of the angular dependence of the curves computed for oriented nanoparticle systems. The analysis of the movement of the critical curves in the Preisach plane was done by us [6] using a model in which the dynamic of all subsystems in the Preisach plane (particles associated to a certain point in the Preisach plane) is described by the master equation.

In Preisach modeling it has been shown that the static interactions distribution is strongly dependent on the magnetic state of the sample [7]. In systems in which the relaxation has an important role, such as the nanoparticulate ferromagnetic ensembles, the interactions variance is changing due this factor too. In order to take into account the increase of the energy barriers height as an effect of dynamic interactions, the coercive field distribution is shifted in function of the superparamagnetic fraction of the magnetic moment. We shall refer to those effects as to the thermal variable variance. Some particular processes are studied using this model.

2. The model

We consider a distribution of ultrafine ferromagnetic particles in the Preisach plane with aligned easy axis, making an angle ψ with the applied field. For a given particle there are two positions of stable equilibrium for the polarization in the Stoner-Wohlfarth model [8] corresponding to angles θ_+ and θ_- between the easy axis and the polarization vector, separated by unstable equilibrium position θ_m. The corresponding values of the magnetic moment are:

$$m_\pm = VP_S \cos(\psi - \theta_\pm) \tag{1}$$

where V is the particle volume, P_S is the saturation polarization of the particle. The expressions of the energy barrier corresponding to the polarization vector in and out of the field direction are those given by Pfeiffer [9]:

$$\Delta E_\pm(H,\psi) = \frac{VP_S H_K}{2}\left[1 \mp \frac{H}{H_c(\psi)}\right]^{g(\psi)} \tag{2}$$

with

$$g(\psi) = 0.86 + 1.14\frac{H_c(\psi)}{H_k}. \tag{3}$$

where H_K, H_c denote the anisotropy and the coercive field respectively.
For the relaxation times, τ_+ and τ_- we use the expression given by Néel [10]:

$$\tau_\pm = \tau_0 \exp\left(\frac{\Delta E \pm}{kT}\right). \tag{4}$$

where τ_0^{-1} is a microscopic attempt frequency which is about $10^9 s^{-1}$.

In our model the distribution of ultrafine ferromagnetic particles is described by a matrix of representative points in the Preisach plane. The representative points are chosen in order to correspond to the same magnetic moment. The higher is the value of the Preisach distribution, the denser are the representative points. The position of the critical curves in processes with constant or variable field and temperature are that given by the result of the simulations using the master equation distributed in the Preisach plane [6]:

$$\frac{dn_+}{dt} = \frac{n_-}{\tau_-} - \frac{n_+}{\tau_+}. \tag{5}$$

with n_+ and n_- –the relative number of particles in and out of the field direction, respectively.

The Preisach distribution was considered as a product of two Gaussian distributions:

$$P(H_c H_i) = \frac{1}{2\pi H_{c0} H_{i0}} \exp\left(-\frac{(H_c - H_{c0})^2}{2\sigma_c^2}\right)\exp\left(-\frac{H_i^2}{2\sigma_i^2}\right). \tag{6}$$

where H_c, H_i are the coercive and interaction fields, H_{c0}, H_{i0} – the coordinates of the distribution maximum, σ_c and σ_i – the standard deviations.

The Preisach distribution is considered not to be constant, a thermal variable variance is considered. The increase of the energy barrier height as an effect of the dynamic interactions is taken into account:

$$H_{c0} = H_{c0,static} + m_{superpara}\Delta H_{c0}. \tag{7}$$

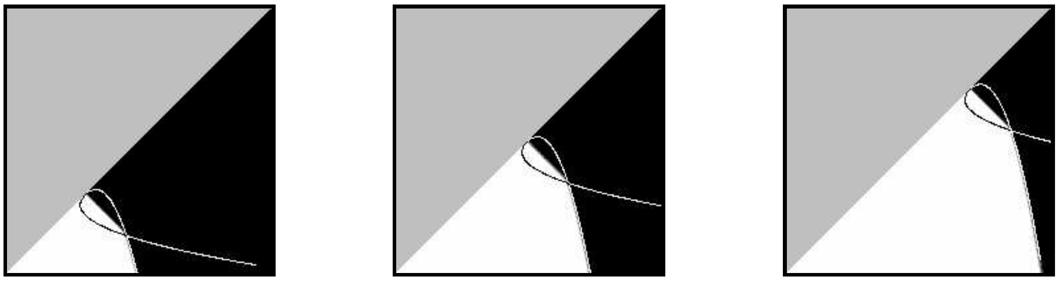
$$\sigma_i = \sigma_{i,static} - m_{superpara}\Delta\sigma_i \tag{8}$$

3. Simulations

The results of the simulations using the master equation distributed in the Preisach plane whose coordinates are the switching fields (H_α, H_β) during a magnetization process with constant field rate are represented in Fig. 1. In the white zones n_+=1 and in the black ones n_+=0. We have founded the expression of the equivalent time that better fits all our simulations. This equivalent time is given by the expression [6]:

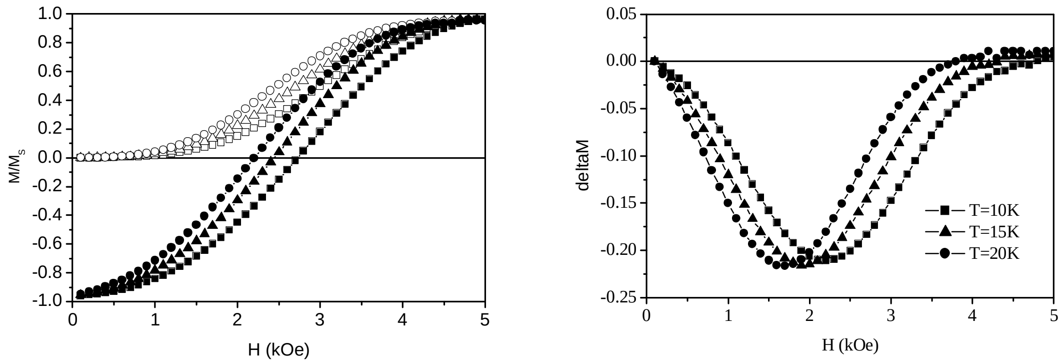
$$t_{eq} = H_f / (\partial H / \partial t) \tag{9}$$

where $H_f = k_B T / P_S V$ is the fluctuation field [11].



a) b) c)

Fig. 1. The Preisach plane during magnetization processes with the field rate r=8 A/m/s (a-c).

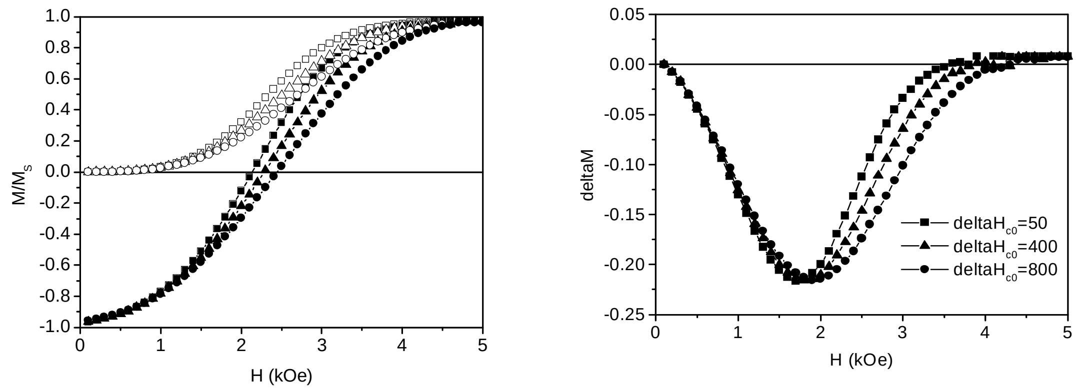


a) b)

Fig. 2. a) Simulated IRM (open symbols) and DCD (filled symbols) curves for different temperatures (T = 10K - squares, T = 15K– triangles, T = 20K - circles); b) Calculated DeltaM curves with the values of IRM and DCD from figure a).

During a magnetization process the critical curves and the positions of the representative points are moving in the same time. In our model the magnetization state of a lattice of representative points depends on their relative motion. We have made the supposition that the modification of the Preisach distribution has a weak influence on the motion of the critical curves, so we didn't take into account this influence. In our thermal variable variance model the movement of the critical curves was taken exactly the same as in the distributed master equation simulations.

In Fig. 2a are represented the simulated IRM (isothermal remanent magnetization) and DCD (DC demagnetization) curves for different values of the temperature. One can observe that the magnetization arrive more rapid at the saturation when the temperature increases. The effect of the temperature on the deltaM curves ($deltaM(H) = 2IRM(H) - (DCD(H) + M_{rs})$) is the shift of the minimum to lower values of the field (see Fig. 2b). The effect in considering the thermal variable variance in the model is shown in Fig. 3. When ΔH_{c0} increases IRM and DCD curves arrive more difficultly at saturation (Fig. 3a). The influence in deltaM curves is shown in Fig. 3b. One can observe that the effect of increasing deltaH_{c0} is a shift to right for the deltaM curves.



a) b)

Fig. 3. a) Simulated IRM (open symbols) and DCD (filled symbols) curves for different values of the variable variance parameter (ΔH_{c0}=50 Oe - squares, ΔH_{c0}=400 Oe – triangles, ΔH_{c0}=800 Oe - circles); b) Calculated deltaM curves with the values of IRM and DCD from figure a).

4. Conclusions

A thermal variable variance Preisach-Néel model was developed. The model can explain magnetization processes when both interactions and relaxation phenomena are important. IRM, DCD and deltaM curves are simulated and the influence of the temperature and of the variable variance was discussed. In the actual paper we present only magnetization processes with constant temperature and in our following researches we will try to simulate with the same model magnetization processes with variable temperature such as FC and ZFC processes.

References

[1] R. W. Chantrell, A. Lyberatos, M. El-Hilo, K. O'Grady, J. Appl. Phys. **76**, 6407 (1994).
[2] P. D. Mitchler, E. Dan Dahlberg, E. E. Wesseling, R. M. Roshko, IEEE Trans. Magn. **32**, 3185 (1996).
[3] T. Song, R. M. Roshko, IEEE Trans. Magn. **36**, 223 (2000).
[4] L. Spinu, A. Stancu, J. Magn. Magn. Mater. **189**, 106 (1998).
[5] A. Stancu, L. Spinu, IEEE Trans. Magn. **34**, 3867 (1998).
[6] L. Spinu, I. D. Borcia, A. Stancu, C. J. O'Connor, "Time and temperature dependent Presiach models", accepted for publication in Physica B, 2001.
[7] M. Pardovi-Horvath, E. Della Torre, F. Vajda, G. Vertesy, IEEE Trans. Magn. 29, 3793 (1993).
[8] E. C. Stoner, E. P. Wohlfarth, Philos. Trans. R. Soc., **A240**, 599 (1948).
[9] H. Pfeiffer, Phys. Stat. Sol. (a), **118**, 295 (1990).
[10] L. Néel, Annales Géophysique **5**, 99 (1949).
[11] V. Basso, C. Beatrice, M. LoBue, P. Tiberto, C. Bertotti, Phys. Rev. B **61**, 1278 (2000).