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A PREISACH-NÉEL MODEL WITH THERMAL VARIABLE VARIANCE: SENSIBILITY TO THE PARAMETERS

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We performed simulations of magnetization curves in field, remnant and also with variable temperature. The simulations were done using a Preisach-Néel model for nanoparticulate media. The model includes the reversible and the irreversible part of the magnetization. There are taken into account the variations of the Preisach distribution due to the mean field and to the thermals effects as well as the movements of the thermal boundary in processes with variable field and temperature. Because the identification problem is a very important point in our simulations, the study of the model sensibility to the parameters can allow for choosing a better identification procedure. In the paper the variation of the magnetization curves with parameters values is analyzed.

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1. Introduction

The Preisach-Néel type models are efficient tools for studying magnetic properties of nanoparticles assemblies. The models include both the irreversible and the thermal effects, being thus capable to describe a large diversity of field dependent magnetization processes such as first magnetization (FM), major hysterezis loop (MHL), isothermal remnant magnetization (IRM), DC demagnetization (DCD), relaxation processes or phenomena with variable temperature as field-cooled (FC) and zero-field-cooled (ZFC) [1-4]. We have developed a realistic Preisach-Néel model that includes a non-linear energy barrier expression, able to describe the previous mentioned magnetization processes with the same set of parameters, for a large scale of fields and temperatures [5, 6]. In order to fit experimental data, an important problem consists in the indentification of the model parameters. The goal of this paper is to analyze the sensibility of the simulated curves to different parameter sets which will be useful for improving the identification strategy.

2. Model and simulations results

For our Preisach-Néel type model we have considered an assembly of uniaxial single-domain particles distributed in the Preisach plane. The magnetic response of each particle is considered to be in accordance with the Stoner-Wohlfarth model [7]. The starting point of the model is presented in [5] and [6]. A nonlinear expression of the energy barrier was used on the bases of the energy interpolation expression [8]:

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

with

$$g(\psi)=0.86+1.14\frac{H_c(\psi)}{H_K}. \tag{2}$$

and H is the applied field; H_K the anisotropy field, H_c the critical field, v – the particle's volume, P_s – the particle's polarisation. This expression allow us to describe the dependence of the magnetization processes as function of the angle between the applied field and the particle easy axis.

In our model a grill of 100 × 100 representative points corresponding to the same magnetic moment is considered, in order to describe the full Preisach distribution. The model takes into account the movement of the critical lines in field- and time-depdendnet magnetization processes as it was found using the numerical solution of the master equation distributed in the Preisach plane [5, 6]. The Preisach distribution is usually not stable during a magnetization process of the most known magnetic media. Similar with [9] a shift of the Preisach distribution along the coercivity axis is considered as an effect of the dynamic interactions between the superparamagnetic particles:

$$H_{c0}=H_{co,static}+m_{sp}\Delta H_{c0} \tag{3}$$

where m_{sp} represents the superparamagnetic fraction of the magnetic moment, $H_{c0,static}$ the most probable coercive field at low temperature, and ΔH_{c0} is a parameter proportional with the dynamic interactions strength.

The dynamic interactions determine a change of the interaction field distribution variance. Similarly with the Variable Variance Preisach Model [10], for the static case, our Preisach-Néel model considers a temperature dependent variance of the interaction field distribution:

$$\sigma_i=m_{sp}\sigma_{i,sp}+\left(1-m_{sp}\right)\sigma_{i,bk} \tag{4}$$

where $\sigma_{i,sp}$ and $\sigma_{i,bk}$ are the values of the interaction field variance, when all the system's particle are in the superparamagnetic and, respectively, in the blocked state. This will be referred as Thermal Variable Variance (TVV) Preisach-Néel Model. The spontaneous polarization of the particles is considered as in [4]:

$$P_s=P_{s0}\left(1-\frac{T}{T_c}\right)^{\Gamma} \tag{5}$$

A main field interaction field can be also considered in our model. With our model equipped with these entire dependences, one can simulate the field-, time- and temperature-dependent magnetization processes for a wide range of values time, magnetic field and temperature. Simulations of the IRM, DCD, MHL, ZFC curves were made for different values of the model parameters. Due to the large number of model's parameters some problemes are expected to occur and one need to identify the effect of each parameter on the final result.

One observes that all the curves are very sensitive to the direction of the applied field relative to particles easy axis (see Figs. 1 and 2). On the MHL plots the increase of the angle ψ leads to a decrease of the cycle rectangularity. The maximum of ZFC curves grows up with the angle increasing. This effect is more pronounced for small values of ψ. In the same time, as the angle ψ increases, for values between 0° and 45° the maximum of ZFC curves shifts toward higher temperatures and for values larger than 45° the maximum of ZFC curves shifts back to lower temperatures. Unlike the Preisach-Néel models with non-linear energy barriers, the models with linear energy barriers are not able to take into account the easy axis orientation dependence, fact that makes difficult, if not impossible, the data fitting process.

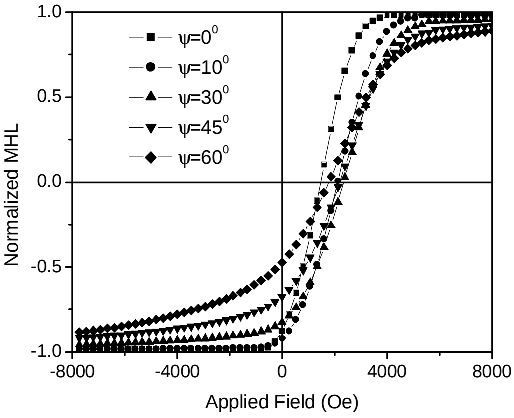

Fig. 1. Simulated MHL plots for different values of the angle between the applied field and the particle easy axis.

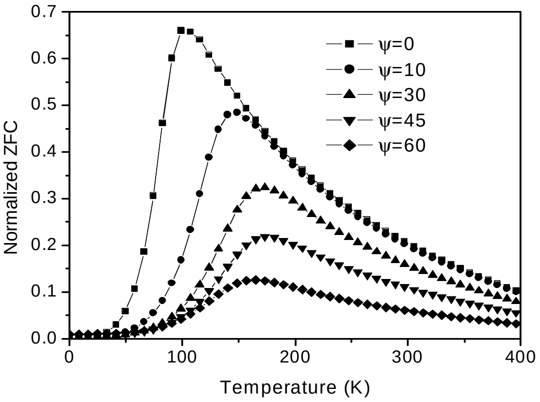

Fig. 2. Simulated ZFC plots for different values of the angle between the applied field and the particle easy axis.

The most probable value of the coercive field also influences the simulated curves of all above mentioned magnetization processes. For MHL and DCD the effect is a modification of the cycle’s width. For FM and IRM a higher most probable coercive field drives to a higher saturation field. On the ZFC curves the increase of $H_{c0,static}$ shifts the maximum toward higher values and decreases their maximum value.

The variance of the coercive field influences the rectangularity of the MHL loop and the remanent saturation moment and field for IRM and DCD. The shape of the ZFC curves is also influenced by this parameter.

An interesting influence on FC and ZFC curves has the value of the magnetic moment of the particles vP_s. This parameter induces only a modification in the temperature scale of the two curves. The maximum value of the ZFC and the value of FC at 0 K are not modified by this parameter, as observed from the data presented in Fig. 3. The interaction field variance can produce modifications of the FC value at 0 K (see Fig. 4). For high values the FC curves can even have a maximum. As the dynamic interactions drive to a change in the interaction variance, it will also have an effect on the ZFC curves, as it is shown in Fig. 5. But the magnetization curves at constant temperature are almost unaffected by this parameter.

ZFC curves are very sensitive to all the tested parameters excepting ΔH_c, which have a weak influence in all the studied curves (the strongest influence appears upon the remnant curves (see Fig. 6)).

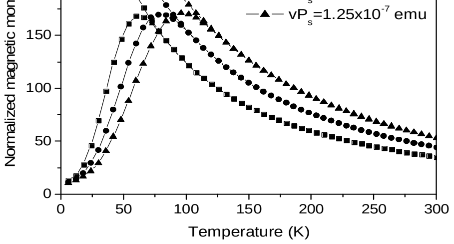

Fig. 3. Simulated ZFC plots for different values of the particle magnetic moment.

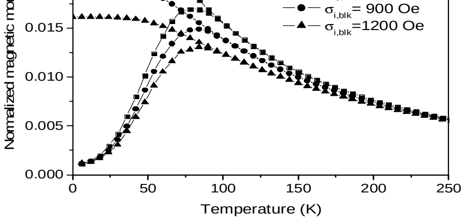

Fig. 4. Simulated ZFC plots for different values of the blocked state interaction field variance and the same ratio between the blocked and super-paramagnetic interaction field variances.

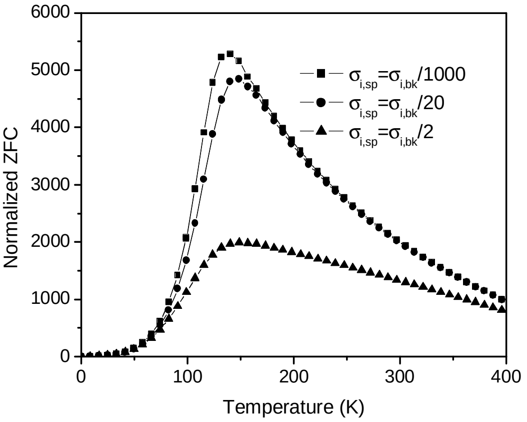

Fig. 5. Simulated ZFC plots for different values of the superparamagnetic interaction field variance.

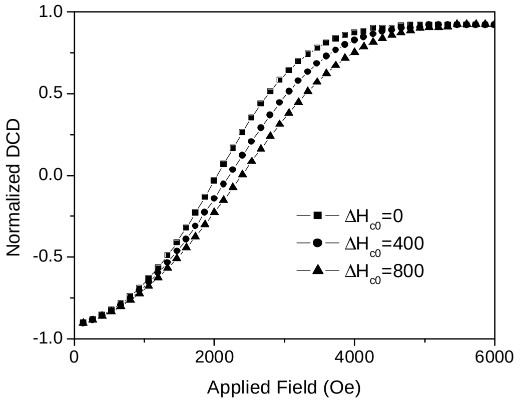

Fig. 6. Simulated DCD plots for different values of ΔH_{c0}.

3. Conclusions

The model presented in this paper is able to simulate various magnetization curves in a wide range of fields and temperatures, using the same set of parameters. In order to obtain the values of the parameters, which describe the magnetic behaviour of an individual sample it is important to correlate these values with the characteristics of the experimental curves. To this purpose we have studied the influence of all model's parameters on the simulated curves. One of the most important parameter that influences all the simulated curves is the angle between the applied field and the particle easy axis, ψ. This parameter appears only in the Preisach-Néel model with non-linear energy barriers and seems to be essential for good fitting of the experimental data. The next step in our researches is to develop a parameter identification procedure for the described model. The results of the study of the influence of each parameter will enable us to optimize the fit procedure.

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