Blocking Temperature and Hysteresis Characteristics of the Decay Products TITANOMAGNETITES

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Abstract—**This work is devoted to the theoretical study of the temperature dependence of the blocking, the coercive force of the spontaneous magnetization and the size of the magnetite core core / shell nanoparticles of magnetite / titanomagnenit. It is shown that the coercive force and the saturation magnetization of a spontaneous increase with increasing volume fraction of magnetite core, which is consistent with experimental data.**

This work is devoted to the theoretical study of the temperature dependence of the blocking, the coercive force of the spontaneous magnetization and the size of the magnetite core core / shell nanoparticles of magnetite / titanomagnenit. It is shown that the coercive force and the saturation magnetization of a spontaneous increase with increasing volume fraction of magnetite core, which is consistent with experimental data. (Mogensen, 1968). Later Hjelm-Kwist and Ramdohr (см. [1]) showed that separation of magnetite nano are a common feature of the collapse of the titanomagnetite. For example, at the initial stage of

decay titanomagnetites an increase in the coercive force H_c and the residual saturation magnetization to saturation

magnetization I_{rs}/I_s, some authors [2] show to the small dimensions of the phases. The development process of disintegration increases the size of the phases and a sharp

drop H_c и I_{rs}/I_s.

In this paper, we attempt, within the previously developed model [3.4] two-phase nanoparticles to analyze the effect of decay processes in the hysteresis characteristics titanomagnetite.

I. INTRODUCTION

In accordance with the ideas of [5, 6], we assume that as a result of the collapse of the primary homogeneous titanomagnetite $Fe_{3-x_0}Ti_{x_0}O_4$ formed core/shell nanoparticles in which the magnetite core coated titanomagnetite ($Fe_{3-x}Ti_xO_4/Fe_3O_4$) (fig. 1). During decay of the nuclei of magnetite volume x can be increased, which will increase the concentration of titanium in the shell volume εV.
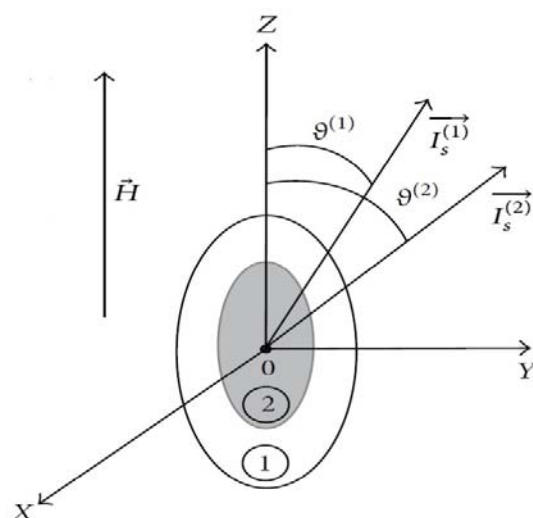

Figure 1. Illustration model core / shell nanoparticles $I_s^{(1)}$ and $I_s^{(2)}$-magnetization vector, $\vartheta^{(1)}$ and $\vartheta^{(2)}$ –angle between $I_s^{(1)}$ and $I_s^{(2)}$ and external field **H**. Uniformly magnetized particle (phase 1) of volume V ellipsoidal and elongated Q contains uniformly magnetized core (phase 2) with volume v = εV ellipsoidal inclusion and elongation q

In the process of disintegration of the amount of magnetite cores can be increased, which will lead to an increase in the concentration of titanium in the shell x volume εV. Based on the conservation of the number of titanium atoms in the nanoparticle volume V and the volume in the shell $(1 - \varepsilon)V$ it can establish a link between the initial concentration of titanium x_0 in nanoparticle with x at any time of the collapse: $N_{Ti} = nVx_0 = n(1 - \varepsilon)Vx$ (n – the concentration of molecules titanomagnetites). Thus

$$x = \frac{x_o}{(1 - \varepsilon)} \quad (1)$$

From (1) should be a limit on the maximum value of the relative volume of magnetite core $\varepsilon_m = 1 - x_0$ appropriate $x = 1$.

The described process of decay can lead to a change in hysteresis characteristics of nanoparticles (coercive force

$$l(t) = c\left[\left(n_1(t) - n_3(t)\right)\left((1-\varepsilon)l^{(1)}{}_s + \varepsilon l^{(2)}{}_s\right) + \left(n_2(t) - n_4(t)\right)\left|(1-\varepsilon)l^{(1)}{}_s - \varepsilon l^{(2)}{}_s\right|\right] \quad (2)$$

Where $n(t) - \{n_1(t), n_2(t), n_3(t), n_4(t)\}$ vector populations of the states of two-phase nanoparticles with components $n_i(t)$ can be regarded as the probability of finding nanocha¬stitsy in one of four conditions: first «(↑↑)» and third «(↓↓)» – with parallel orientation of

$$\frac{d n_i(t)}{d t} = \sum_{k \neq i}^{4} \left(-W_{ik} n_i(t) + W_{ik} n_k(t)\right), \quad n_i(0) = n_{0i} \quad (3)$$

Where $W_{ik} = f_0 exp\left(-E_{ik}/k_B T\right)$ – elements of the matrix of transition probabilities i – th equilibrium in k - th, $f_0 = 10^{10} c^{-1}$ the frequency factor, $E_{ik} = E_{ik\,max} - E_{i\,min}$ – energy barriers separating i – th и k – th equilibrium states ($E_{ik\,max}$ – the smallest of the maximum values of power sharing i – th и k – the states, $E_{i\,min}$ – energy i – th equilibrium). A detailed calculation of energy barriers presented in the book [4].

II. NANOPARTICLES BLOCKING TEMPERATURE TITANOMAGNETITE / MAGNETITE

Since the eigenvalues W_{ik} determine the inverse times of transition from one state to another τ_m, чтобы estimate the time of the transition to the equilibrium state will use the maximum of them: $\tau = (\tau_m)_{max}$. We define the temperature block T_B as the temperature at which the relaxation time of $\tau = 1\,c$.

The simulation results of temperature block T_B cspherical nanoparticles $Fe_{2,0}Ti_{0,2}O_4 / Fe_3O_4$ size 100 nm from radius magnetite core titanomagnetite, which can be considered as a measure of decay titanomagnetites, showed on fig. 2. The figure shows that the temperature of blocking virtually unchanged until $r\sim20$ nm and rapidly increases with the size of the magnetite core.

H_r, residual saturation magnetization I_{rs}, and saturation magnetization I_s) and the blocking temperature T_B.

For a description of the magnetic properties of nanoparticles titanomagnetites use the results of [3]. According to [3], the magnetization is defined as the ratio of titanomagnetite

magnetic moments of the two phases, the second «(↑↓)» and fourth «(↓↑)» – with antiparallel magnetic moments of the phase (see. Fig. 1). Change the vector population of two-phase nanoparticles can be described by the following equation [4]:
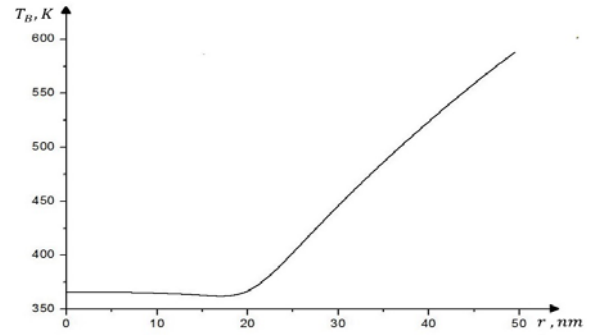

Figure 2. Temperature dependence of the blocking nanoparticles from the size of magnetite core r.

This behavior is determined by the dependence T_B potential barrier height of the size of the nucleus (see. Fig. 3). Fig. 3 shows the potential barriers, defining the reversal nanoparticles being in the first state. It can be done in two ways: by the magnetic moments of the coup or phase synchronous magnetic reversal of the magnetic moment of the nanoparticle. In the first case, a transition occurs from the first state «(↑↑)» second «(↑↓)» – through the barrier E_{12} (or fourth «(↓↑)» – through the barrier E_{14}), and then the third «(↓↓)» – through the barrier E_{23} or E_{43}. In the second - from the first «(↑↑)» to third «(↓↓)» – through the barrier E_{13}. From fig. 3 that for nanoparticles from simulated all of the above transition occurs transitions from the first to the fourth, and then a third state. Moreover, the potential barrier E_{14}, defining the reversal of nanoparticles c $r < 20$ нм, practically independent of size of the nucleus, whereas the magnetization reversal nanoparticles $r > 20$ nm controlled barrier E_{43}, which increases rapidly with increasing r.
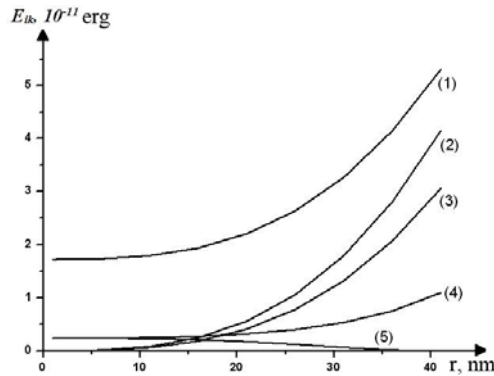
Figure 3. The dependence of the potential barriers E_{ik} on the size of the magnetite core r. curves: $1 - E_{12}$, $2 - E_{42}$, $3 - E_{32}$, $4 - E_{14}$, $5 - E_{22}$.

Thus, as expected, with increasing magnetite core temperature rise occurs blocking nanoparticles. Nanoparticles with a high content of magnetite are more stable against thermal stress, which is consistent with experimental data [6, 7].

III. THE COERCIVE FORCE AND SATURATION MAGNETIZATION

The coercive force H_c and saturation magnetization I_s the system of nanoparticles titanomagnetites $Fe_{2.8}Ti_{0.2}O_4/Fe_3O_4$ o determined from the hysteresis loop, which built by the relations (2) – (3). Naturally, H_c and I_s nanoparticles increase with increasing magnetite nanoparticle (see. Fig.4). It should be noted the area in which the growth of magnetite core has no significant effect on the coercive force of the system.
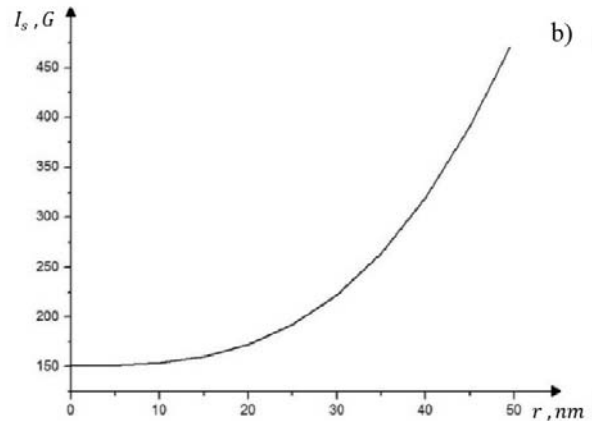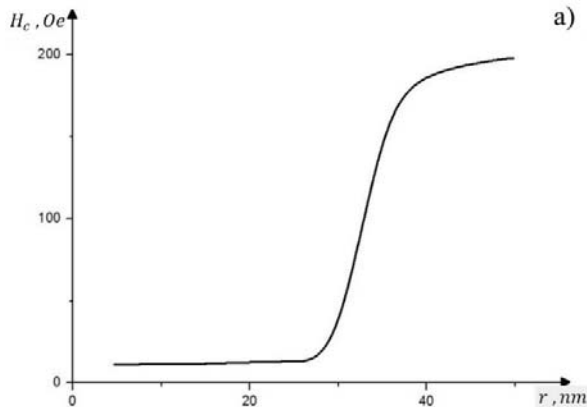

Figure. 4. The dependence of the saturation magnetization Is (a) and the coercive force Hc (b) the radius of the nanoparticles $Fe_{2.8}Ti_{0.2}O_4/Fe_3O_4$.

Obviously, this is due to the low values of the potential barriers E_{14} и E_{43} when the size of the magnetite core $r < 30$ nm, which do not exceed 10^{-11} Erg (see. Fig. 3). The sharp increase in coercive force of up to a maximum value corresponding to H_c magnetite nanoparticles with an increase in the core $r > 30$ nm, associated with a significant (5 - fold) increase in potential barriers (see. fig. 3). Obviously, a slight change in potential barriers in the $20 < r < 30$ nm can not neutralize the thermal fluctuations of the magnetic moments of the phase nanoparticles, which determines the weak growth of the coercive force in the above area. The dependence of the coercive force of the size of the magnetite core is in good agreement with the experimental results [2, 6].

IV. CONCLUSION

In the model core / shell nanoparticles [3] studied the temperature dependence of the blocking, the coercive and the saturation magnetization of the size of the magnetite core. It is shown that an increase in the particle core temperature of blocking does not change up to a value of 20 nm, and then begins to increase rapidly. The coercive force and spontaneous saturation magnetization increases with increasing volume fraction of magnetite core. These results are in good agreement with the experimental data [2, 6].

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