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ORDER, DISORDER, AND PHASE TRANSITION IN CONDENSED SYSTEM

Variety of the Pulsed Magnetization Reversal of an Inhomogeneous Lattice of Anisotropic Nanoparticles

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Abstract—The responses of the magnetic moment of an isolated nanoparticle having a uniaxial anisotropy and the magnetic moment of a planar lattice made of such nanoparticles to a Gaussian magnetic field pulse are studied by computer simulation. The influence of the anisotropy and the field pulse parameters on the precession dynamics is investigated. The periodic dependence of the response time and the final orientation of the magnetic moments on the pulse duration is revealed and analyzed. For a lattice consisting of different types of nanoparticles, the number of final lattice configurations induced by pulsed magnetization reversal is shown to be larger than the number of the types of nanoparticles more than twofold.

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1. INTRODUCTION

The magnetic superstructures and the ensembles of magnetic nanoparticles, the interaction of the magnetic moments of which mainly has a dipole–dipole character, that are created by nanotechnologies have been extensively studied in recent years [1–6]. As a result of the discreteness of such structures, their equilibrium and dynamic states differ substantially from the states of macroscopic single-domain objects. In particular, these differences include bistable lattice states, which are caused by the presence of differently oriented configurations with different total magnetic moments, possible controlled transitions between the configurations, and dynamic oscillation modes of the magnetic moment of a system during their magnetization reversal [7–10].

Regular ensembles of magnetic nanoparticles of different dimensions can serve as a medium for ultrahigh-density data recording and storage. The recording of information on magnetic dipole lattices is based on a change in the equilibrium configuration of magnetic moments, which is induced by radio-frequency magnetic field pulses, and reading is provided by the excitation of an appeared configuration a low-energy radio-frequency pulse at the ferromagnetic resonance frequency and by scanning the response frequency of a dipole system [11–13]. In [14], we studied the dynamic conditions and the magnetization reversal of the lattices of nanoparticles having a cubic crystalline anisotropy in ac magnetic fields. A fundamentally different situation appears in the most widely used case of a uniaxial magnetic anisotropy of lattice elements. This type of anisotropy is also important for data recording and storage systems.

The pulsed (ultrafast) magnetization reversal of various magnetic systems was studied in many theoretical and experimental works [15–24]. In particular, the authors of [15] experimentally detected periodic magnetization reversal of a planar layered structure when the pulse duration or amplitude was changed, which was explained by the key role of phase coherence between magnetization precession and a field pulse in switching. The precession response of the magnetization of a microscopic memory cell to a pulsed action was experimentally investigated in [16], and short switchings of the cell were detected when long-wavelength magnetic excitations were suppressed after the decay of a field pulse. The magnetization dynamics of antiferromagnetic systems under ultrafast magnetic field pulses was studied in [17–20]. In particular, the authors of [17] demonstrated the possibility of magnetization reversal of a system with a long relaxation process, and the possibility of magnetization reversal without a long relaxation process when a field signal of a specific shape was used was shown in [20]. Based on the Landau–Lifshitz–Gilbert equation, Sukhov and Berakdar [21] considered the magnetization reversal of single-domain nanoparticles and proposed a scheme for reaching a given state of magnetization using ultrashort magnetic pulses. The influence of a planar magnetic field on the pulsed magnetization reversal and the magnetization relaxation in single-crystal films was studied in [22], and the pulsed magnetization reversal of iron garnet films with an easy-plane anisotropy was analyzed in [23]. The

authors of [24] investigated the dynamic hysteresis loops and the relaxation effects during the pulsed magnetization reversal of nanoparticles.

The purpose of this work is to solve dynamic equations numerically to study the response of the magnetic field of an isolated nanoparticle with a uniaxial anisotropy and a planar lattice made of such nanoparticles to a Gaussian pulse. We revealed the conditions of pulsed magnetization reversal of dipoles and the influence of the dipole–dipole interaction between lattice elements on the response dynamics. When considering a wide pulse duration range and plotting magnetic moment response diagrams, we were able to use computer simulation to reveal periodic dependences of the precession response time of the system on the pulse and lattice parameters and the presence of 180° magnetization reversal. It was found that, when a lattice is made of nanoparticles having different anisotropy constants, various sets of lattice subsystems the magnetization of which is reversed by one pulse acting on the entire system can be specified at retained initial orientations of other lattice subsystems. A set of the systems to be subjected to magnetization reversal is changed by changing the pulse duration. The revealed periodic dependence of the response of the system on the pulse duration can be used to significantly increase the variety of the pulse-controlled configurations of an inhomogeneous nanoparticle lattice.

2. INITIAL EQUATIONS

We consider a planar array of nanoparticles with identical (in magnitude) magnetic moments $|\mathbf{m}_i| = m$. Each nanoparticle is taken to have a uniaxial magnetic anisotropy and is in a single-domain state. The energy of the ith nanoparticle is written as the sum of the Zeeman energy in an applied magnetic field $\mathbf{H}$, the dipole–dipole interaction energy, and the anisotropy energy,

$$W(\mathbf{m}_i) = -\mathbf{m}_i \cdot \mathbf{H} + \sum_n W_d(\mathbf{m}_i, \mathbf{m}_n) - \frac{K_u(\mathbf{m}_i \cdot \mathbf{n})^2}{2}, \quad (1)$$

where K_u and $\mathbf{n}$ are the uniaxial anisotropy constant and the unit vector of the easy magnetization axis. The dipole–dipole interaction energy is

$$W_d(\mathbf{m}_i) = \sum_{n\neq i}\left(\frac{\mathbf{m}_i \cdot \mathbf{m}_n r_{\text{in}}^2 - 3(\mathbf{m}_i \cdot \mathbf{r}_{\text{in}})(\mathbf{m}_n \cdot \mathbf{r}_{\text{in}})}{r_{\text{in}}^5}\right), \quad (2)$$

where $\mathbf{r}_{\text{in}}$ and r_{in} are the radius vector and the distance between the ith and nth dipoles, respectively.

The dynamics of each moment of the dipole lattice is described by the Landau–Lifshitz equation with the Gilbert relaxation term [25],

$$\frac{\partial \mathbf{m}_i}{\partial t} = -\gamma \mathbf{m}_i \times \mathbf{H}_i^{\text{eff}} - \frac{\alpha}{m_i}\mathbf{m}_i \times \frac{\partial \mathbf{m}_i}{\partial t}, \quad (3)$$

where γ is the gyromagnetic ratio and α is the dissipation parameter, which is the same for all particles. With allowance for Eq. (1), the magnetic field created at the site of the ith dipole has the form

$$\mathbf{H}_i^{\text{eff}} = -\frac{\partial W_i}{\partial \mathbf{m}_i} = \mathbf{H} + K_u \mathbf{n}(\mathbf{m}_i \cdot \mathbf{n}) + \sum_{n\neq i}\frac{3(\mathbf{m}_n \cdot \mathbf{r}_{\text{in}})\mathbf{r}_{\text{in}} - \mathbf{m}_n r_{\text{in}}^2}{r_{\text{in}}^5}. \quad (4)$$

We now pass to the following dimensionless parameters: $\boldsymbol{\mu}_i = \mathbf{m}_i/m$, $\mathbf{e}_{\text{in}} = \mathbf{r}_{\text{in}}/r_{\text{in}}$, $\tau = (m\gamma/d^3)t$ (where d is the nanoparticle diameter), and $l_{\text{in}} = r_{\text{in}}/d$. In the dimensionless parameters, Eq. (3) take the form

$$\frac{\partial \boldsymbol{\mu}_i}{\partial \tau} = -\boldsymbol{\mu}_i \times \mathbf{h}_i^{\text{eff}} - \alpha \boldsymbol{\mu}_i \times \frac{\partial \boldsymbol{\mu}_i}{\partial \tau}, \quad (5)$$

where $\mathbf{h}_i^{\text{eff}} = \eta + k_u \mathbf{n}(\boldsymbol{\mu}_i \cdot \mathbf{n}) + \sum_{n\neq i}\left[\frac{3(\boldsymbol{\mu}_n \cdot \mathbf{e}_{\text{in}})\mathbf{e}_{\text{in}} - \boldsymbol{\mu}_n}{l_{\text{in}}^3}\right]$.

Here, the applied magnetic field is $\mathbf{h} = \mathbf{H}d^3/m$ and the uniaxial anisotropy constant is $k_u = K_u d^3$.

We now pass from the dimensionless quantities to dimension ones for a dipole lattice of iron nanoparticles: the magnetic moment of a nanoparticle is $m \approx 2.2\mu_B N$, where N is the number of atoms in it. For $N = 561$, the nanoparticle diameter is $d = 2.728 \times 10^{-7}$ cm and the magnetic moment is $m \approx 1.145 \times 10^{-17}$ erg/Oe. Allowing for $\gamma = 1.76 \times 10^7$ (Oe s)$^{-1}$, we obtain the following numerical estimates for the time, the magnetic field, and the anisotropy constant: $t = (d^3/\gamma m)\tau \approx 10^{-10}\tau$ s, $H = (m/d^3)h \approx 564h$ Oe, and $K_u = (1/d^3)k_u \approx 5 \times 10^{19} k_u$ cm^{-3}, respectively.

For a further analysis, we represent vector equation (5) as three scalar equations. For example, for x components $\partial \boldsymbol{\mu}_i/\partial\tau$, we have

$$(1+\alpha^2)\frac{\partial \mu_{ix}}{\partial \tau} = (\mu_{iz} + \alpha\mu_{ix}\mu_{iy})\mathbf{h}_{iy}^{\text{eff}} - (\mu_{iy} - \alpha\mu_{iz}\mu_{ix})\mathbf{h}_{iz}^{\text{eff}} - \alpha(1-\mu_{ix}^2)\mathbf{h}_{ix}^{\text{eff}}. \quad (6)$$

Equations for the remaining components have an analogous form and can be derived by the circular permutation of the components.

We now consider both an isolated nanoparticle and a lattice of 6 × 6 nanoparticles having different uniaxial anisotropy constants. The coordinate system is chosen so that axis x is perpendicular to the lattice plane and two other axes are parallel to the lattice sides. The easy axis of the magnetic anisotropy coincides with axis y. The normalized magnetic moment is taken to be unity, $|\boldsymbol{\mu}_i| = 1$, and the dissipation parameter is $\alpha \approx 0.01$. The equilibrium orientations and the precession dynamic modes of the total magnetic moment of the entire lattice are determined numerically using the fourth-order Runge–Kutta method.

3. RESPONSE OF AN ISOLATED MAGNETIC MOMENT

We first consider the dependence of the response of the magnetic moment of an isolated dipole on the parameters of a Gaussian magnetic field pulse,

$$h(\tau) = h_0 \exp[-(\tau - \tau_i)^2/2\tau_0^2], \quad (7)$$

where h_0, τ_i, and τ_0 are the peak field, the time shift, and the pulse duration, respectively. The pulse field is considered to be polarized along axis x and its peak value is taken to be $h_0 = 2$. The initial orientation of the magnetic moment of a nanoparticle is considered to be along the positive direction of axis y.

For a nanoparticle with a uniaxial anisotropy constant $k_u = 1$, Fig. 1a shows the diagrams that determine the dependence of the y component of the magnetic moment on the pulse duration at $\tau = 250$ (diagram *1*) and after relaxation (horizontal diagrams *2*, *3*). At an initial value $\mu_y = 1$, diagrams *2* and *3* reveal the pulse duration ranges that correspond to the absence of magnetization reversal ($\mu_y = 1$) and the reversal of the magnetic moment ($\mu_y = -1$). As follows from these diagrams, the magnetic moment rapidly reaches the final direction (y or $-y$ depending on the τ_0 range) in the central zones of the parameter τ_0 ranges, which correspond to the magnetization reversal (or no magnetization reversal) of a nanoparticle, since the y component is approximately ± 1 V at $\tau = 250$. As a result, the response of the magnetic moment to a pulsed action turns out to be short. However, near the boundaries of the given ranges at $\tau = 250$, we have $|\mu_y| \ll 1$. Therefore, the precession of the magnetic moment (after the action of a pulse) in pane xz has a high amplitude at the given time; that is, the response to a pulse is long. Figures 1b and 1c show the time dependences of the y and x components of the magnetic moment, respectively, at pulse durations $\tau_0 = 0.3$, 0.35, 0.7, and 1.5 (curves *1*–*4*) for the case considered above. Curves *1* and *2* correspond to the zone near the edge of magnetization reversal (*1*) and non-reversal (*2*) ranges. As a result, the y component slowly approaches an equilibrium position and the precession in plane xz has a high amplitude for a long time. Curves *3* and *4* correspond to the centers of magnetization reversal (*3*) and non-reversal (*4*) ranges; therefore, the response of the magnetic moment to a pulse is very short.

These data support the experimentally detected periodicity of magnetization reversal when the field pulse parameters change [15] for other anisotropic systems and the conditions of formation of a short or long precession response of the magnetic moment to a pulsed action [16, 17].

Figure 2 shows the projections of the magnetic moment trajectories onto the yz plane, which is perpendicular to the anisotropy axis (parameters correspond to Figs. 1b, 1c). We conventionally designate

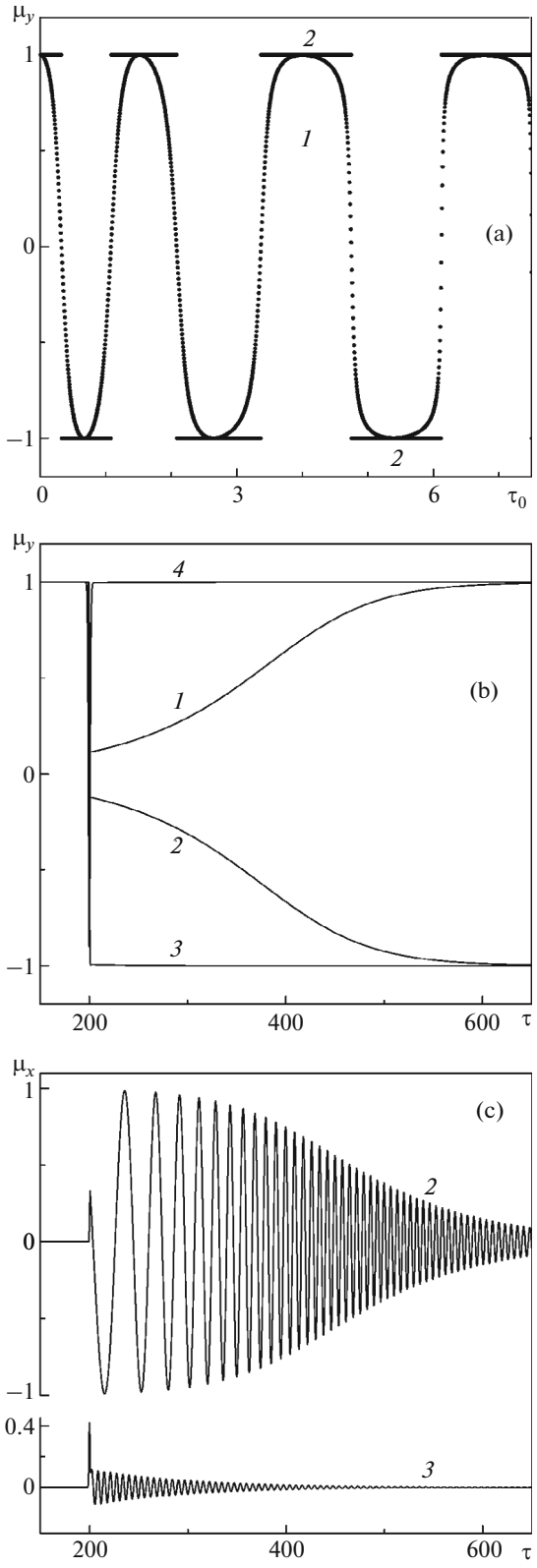

Fig. 1. (a) y component of an isolated magnetic moment vs. the pulse duration at $h_0 = 2$ for $\tau =$ (*1*) 250 and (*2*, *3*) after relaxation. Time dependences of the (b) y and (c) x components of the magnetic moment for a pulse duration $\tau_0 =$ (*1*) 0.3, (*2*) 0.35, (*3*) 0.7, and (*4*) 1.5. The anisotropy constant is $k_u = 1$ and $\alpha = 0.01$.

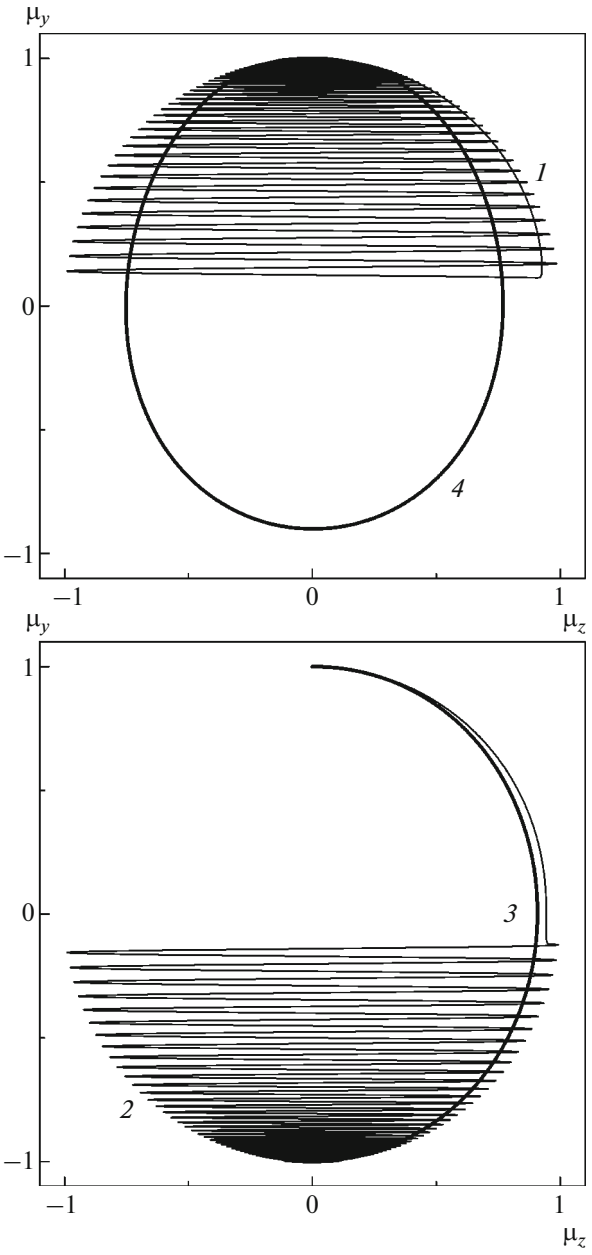

Fig. 2. Projection of magnetic moment trajectories for pulse durations τ_0 = (*1*) 0.3, (*2*) 0.35, (*3*) 0.7, and (*4*) 1.5 at $h_0 = 2$ onto the plane that is perpendicular to the anisotropy axis.

the positive and negative directions of axis *y* as "initial" and "opposite" configuration poles and the *xz* plane as "equatorial" and can state the following. A long response without magnetization reversal takes place in the case where, after the end of a pulse, the magnetic moment is oriented near the equatorial plane on the side of the initial pole (curve *1*). If the magnetic moment after the end of a pulse action is near the equatorial plane on the side of the positive pole, a long response wit magnetization reversal occurs (curve *2*). If a pulse moves the magnetic moment to the region near one of the poles, the response is short. If the magnetic moment passes through the opposite pole under the action of a pulse and stops near the initial pole, no magnetization reversal takes place (curve *4*). If the magnetic moment only reaches the opposite pole, a short response with magnetization reversal occurs (curve *3*). Thus, if the action of a pulse terminates at low values of the *y* component of the magnetic moment, the magnetic moment begins to precess and approaches axis *y* under the action of the anisotropy field. As a result, a long-term response of the magnetic moment forms. If the action of a pulse ends when the *y* component is close to ±1, the precession motion under the action of the anisotropy field is very weak and the response is short.

4. RESPONSE TO A LATTICE OF NANOPARTICLES

Similar dependences were also obtained in the case of a lattice of nanoparticles at a weak dipole–dipole interaction. Figure 3 shows the time dependence of the *y* component of the total magnetic moment of the lattice $\mathbf{M} = \Sigma\boldsymbol{\mu}_i$ for a 6 × 6 lattice with a parameter d = 10 at $k_u = 1$, and Fig. 4 shows the dependence of the *x* component for a pulse duration $\tau_0 = 0.3$, 0.35, 0.4, 0.7, and 1.5 (curves *1*–*5*). As in the case of an isolated dipole, the response of the system to a pulsed action is long at the boundaries of the magnetization reversal ranges (curves *1*–*3*) and is short at the centers of these ranges. It has a high amplitude in the form of an individual burst only during the pulse (curves *4*, *5*). Here, the influence of a dipole–dipole interaction manifests itself only in the case of a long response as the modulation of precession motion.

When the parameters move toward the boundaries of the magnetization reversal/non-reversal ranges, the response time becomes longer and the final configuration of the system begins to depend even on a weak dipole–dipole interaction. The final orientation of individual dipoles turns out to be rather random (lattice is divided into domains) and the total magnetic moment of the system becomes small or near-zero. For a lattice with a parameter d = 10 and an initial dipole orientation along axis *y*, Fig. 5 depicts the time dependences of the *x* and *y* components of the total magnetic moment and the final configuration of the system after a pulse of duration $\tau_0 = 2.1$ (which is close to the boundary of the ranges, $\tau_0 \approx 2.08$; see the diagram in Fig. 1a). The response of the system is seen to become very long and chaotic.

5. SELECTIVE MAGNETIZATION REVERSAL OF A LATTICE OF NANOPARTICLES

Since a weak dipole–dipole interaction was found to weakly affect magnetization reversal processes in

most cases, we first consider the pulsed magnetization reversal of isolated dipoles having different anisotropies and then transfer the results obtained to an inhomogeneous lattice made of such dipoles.

Figure 6 shows the magnetization reversal pulse of isolated nanoparticles with different uniaxial anisotropies vs. the pulse duration. The anisotropy constant is k_u = 1, 1.2, 1.4, 1.6, 1.8, and 2 (diagrams I–VI), and different constants can be achieved in practice using different nanoparticle shapes, i.e., different ellipsoid sizes along a chosen direction. Since the initial dipole orientation is taken to be the positive direction of axis y, $\mu_y = 1$ in the diagrams reveals the pulse duration ranges corresponding to the absence of magnetization reversal and $\mu_y = -1$ reveals the τ_0 ranges corresponding to the magnetization reversal of a nanoparticle. It is seen that, when the uniaxial anisotropy constant decreases (i.e., as the pulse amplitude increases with respect to the anisotropy constant, as was shown by additional analysis), the magnetization reversal/nonreversal ranges narrow and the number of the ranges increases correspondingly. When the equality $h_0 = k_u$ is satisfied, only one narrow range of parameter τ_0 takes place. It corresponds to the non-magnetization reversal of a dipole and magnetization reversal occurs in all other cases. When h_0 is slightly higher than k_u, the range corresponding to magnetization reversal becomes bounded from the side of high values of τ_0, where only magnetization reversal takes place. When the difference between parameters h_0 and k_u increases further, new alternating magnetization reversal/nonreversal ranges appear and become narrower.

Note that the anisotropy constant exceeds the pulse amplitude, magnetization reversal occurs only in one limited pulse duration range. At the difference between h_0 and k_u increases, this range narrows and disappears. For example, for $h_0 = 1$, the pulse duration range corresponding to the magnetization reversal of dipoles exists at $1 < k_u \le 1.3$; at $h_0 = 2$, for $2 < k_u \le 2.7$ (higher anisotropy constants), magnetization reversal is absent.

When a heterogeneous lattice made of the six types of nanoparticles under study is subjected to the action of one pulse, only the part of the lattice corresponding to the diagrams for the given pulse duration undergoes magnetization reversal. In particular, the dashed lines in Fig. 6 illustrate the following thirteen pulse durations corresponding to characteristic sets of the lattice subsystems undergoing magnetization reversal: in the first case, the entire lattice undergoes magnetization reversal; in the second case, subsystems IV, V, and VI; in the third case, I, V, and VI; in the fourth case, I, II, V, and VI; and so on.

It should be noted that the use of the revealed periodic dependence of the magnetization reversal of an anisotropic nanoparticle on the pulse duration makes it possible to increase the number of configurations to

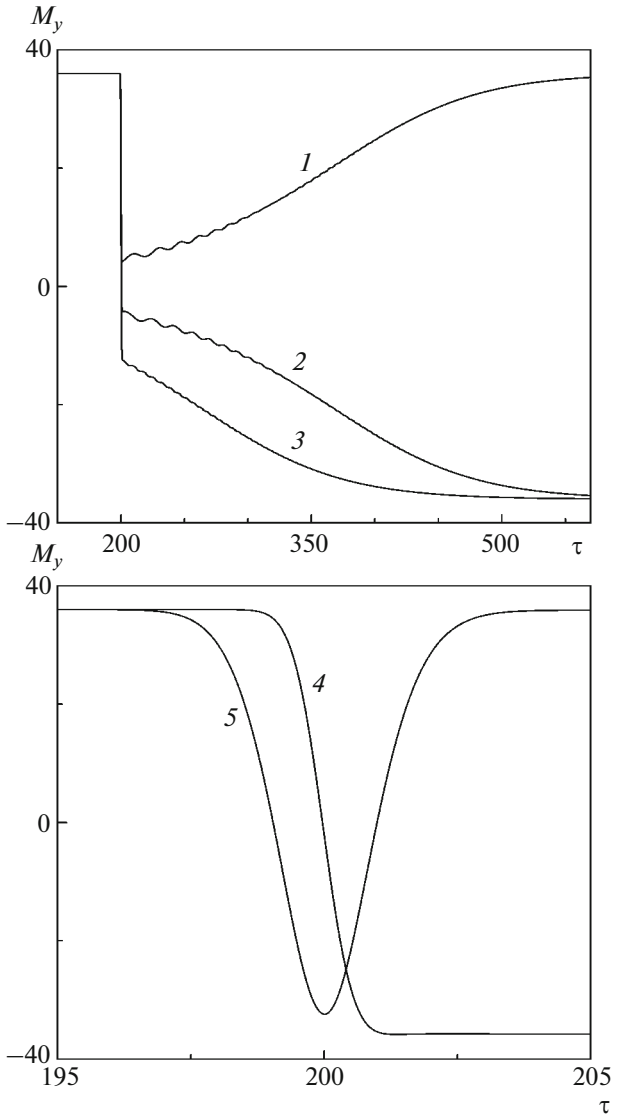

Fig. 3. Time dependences of the y component of the total magnetic moment of an inhomogeneous 6 × 6 lattice with parameter d = 10 (at k_u = 1) after the action of a pulse with h_0 = 2 and τ_0 = (*1*) 0.3, (*2*) 0.35, (*3*) 0.4, (*4*) 0.7, and (*5*) 1.5.

be formed after pulsed magnetization reversal more than twofold (with respect to the number of the types of nanoparticles forming a lattice). The variety of the appearing states can be widened if we use the dependence of the response time on the pulse duration. In particular, the processes where the precession response of a certain lattice subsystem is short and the response of another subsystem is long (longer by two orders of magnitude; see Fig. 4) at the same pulse duration or vice versa at another pulse duration.

Figure 7 shows the time dependences of the x and y components of the total magnetic moment of an inhomogeneous 6 × 6 lattice with parameter d = 10 subjected to a pulse with an amplitude h_0 = 2 and a dura-

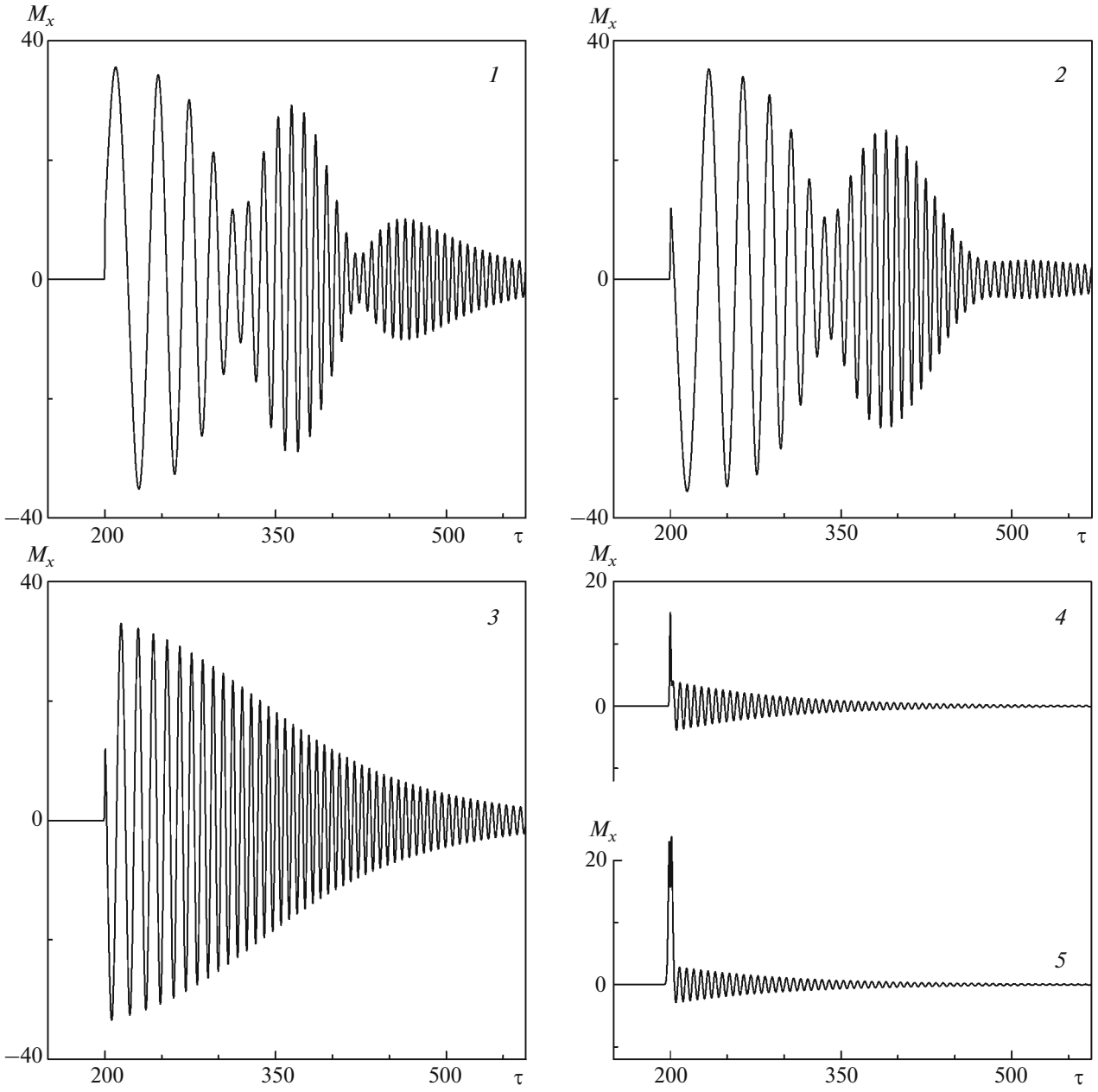

Fig. 4. Time dependences of the x component of the magnetic moment of an inhomogeneous 6 × 6 lattice with $d = 10$ after the action of a pulse with $h_0 = 2$ and $\tau_0 =$ (*1*) 0.3, (*2*) 0.35, (*3*) 0.4, (*4*) 0.7, and (*5*) 1.5.

tion τ_0 = 0.8, 1.1, 1.6, 3.0, 3.8, 4.5, 6.5, and 8.8 (curves *1*–*8*). Since curve *8* in Fig. 7a would be close to curves *4* and *5*, it is not shown. Each lattice column consists of identical nanoparticles, and nanoparticles from different columns have different uniaxial anisotropy constants and correspond to the six different cases from the previous figure ($k_u = 1$, 1.2, 1.4, 1.6, 1.8, 2). This distribution of different nanoparticles was chosen for convenience and can be arbitrary. Here, curves *2* are most interesting: the pulse duration for one of the lattice subsystems is very close to the boundary between magnetization reversal/non-reversal ranges, and the response of the entire system turns out to be longest and chaotic. An increase in the pulse duration also leads to an increase in the first burst time of the x component of the magnetic moment (see curve *8*). For all cases under study, Fig. 8 presents dipole lattice configurations after selective magnetization reversal of dipoles (numerals at the configurations indicate the pulse durations).

In conclusion, we consider the following problem: at which lattice parameters d given selective magneti-

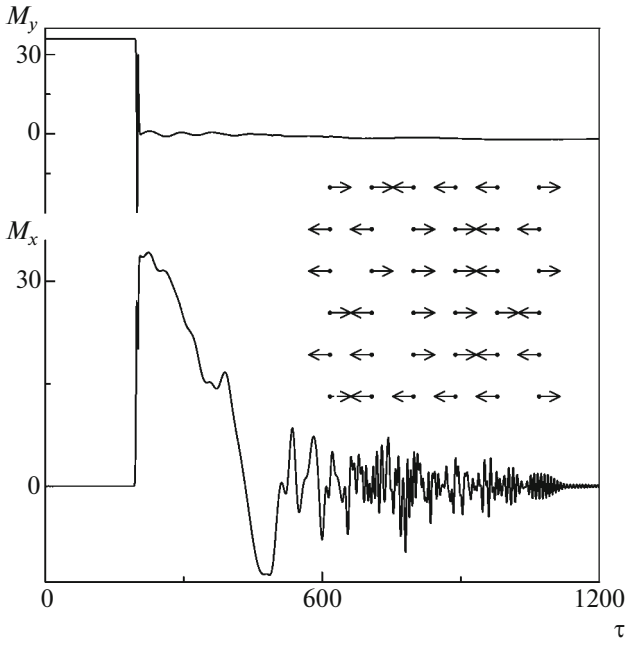

Fig. 5. Time dependences of the x and y components of the total magnetic moment of an inhomogeneous 6 4 6 lattice with $d = 10$ and its final configuration after the action of a pulse with $h_0 = 2$ and $\tau_0 = 2.1$.

zation reversal takes place. Figure 9 shows the time dependence of the y component of the magnetic moment of the lattice and its final configurations after the action of a pulse with $h_0 = 2$ and a duration $\tau_0 = 3$ at lattice parameters $d = 2.5$, 3, 3.5, and 4 (curves *1–5* and the corresponding configurations). Here, we consider a binary lattice consisting of two types of nanoparticles with $k_u = 1$ and 1.4, which are staggered in a lattice. The nanoparticles are chosen so that, in an isolated case, the first subsystem ($k_u = 1$) undergoes magnetization reversal by a pulse with chosen parameters and the second subsystem ($k_u = 1.4$) does not. It is seen that, at $d < 4$, the dipole–dipole interaction is too high for exact selective magnetization reversal of the lattice (however, 14 of the 18 dipoles chosen for magnetization reversal underwent this process even at $d = 3.5$). Exact selective magnetization reversal can be performed when the interdipole distance in the lattice is $d \geq 4$, since the dipole–dipole interaction is too weak, all other things being equal.

6. CONCLUSIONS

When studying the response of the magnetic moment of a nanoparticle with a uniaxial magnetic anisotropy to a Gaussian pulse, we revealed a strong dependence of the precession dynamics time on the pulse duration and amplitude. When the pulse duration changes, the response time of the magnetic moment periodically reaches its maximum and minimum values. The number of such periods increases

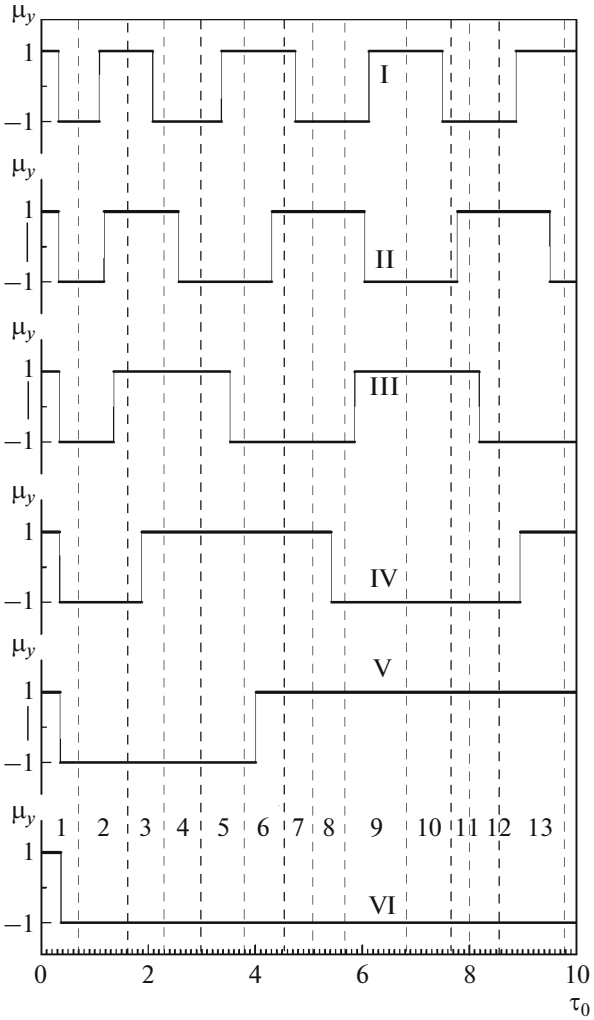

Fig. 6. Effect of the duration of a pulse with $h_0 = 2$ on the magnetization reversal of isolated magnetic nanoparticles with k_u = (I) 1, (II) 1.2, (III) 1.4, (IV) 1.6, (V) 1.8, and (VI) 2 and the pulse durations corresponding to various sets of nanoparticles subjected to magnetization reversal after the action of a pulse.

with the difference between the pulse peak and the uniaxial anisotropy constant. A phase trajectory rapidly approaches an equilibrium state after a very short burst of precession dynamics under the conditions that correspond to the minimum response of the magnetic moment to a pulse.

In the case of an anisotropic nanoparticle, the maxima of the response of the magnetic moment to a magnetic field pulse oriented along axis x divide the pulse duration range into intervals, where a nanoparticle undergoes magnetization reversal (from initial direction $\pm y$ to the opposite direction $\mp y$), alternating with intervals without magnetization reversal. The central regions of these intervals are characterized by a short response of the magnetic moment, and the edge regions, by a long response. Depending on the ratio of

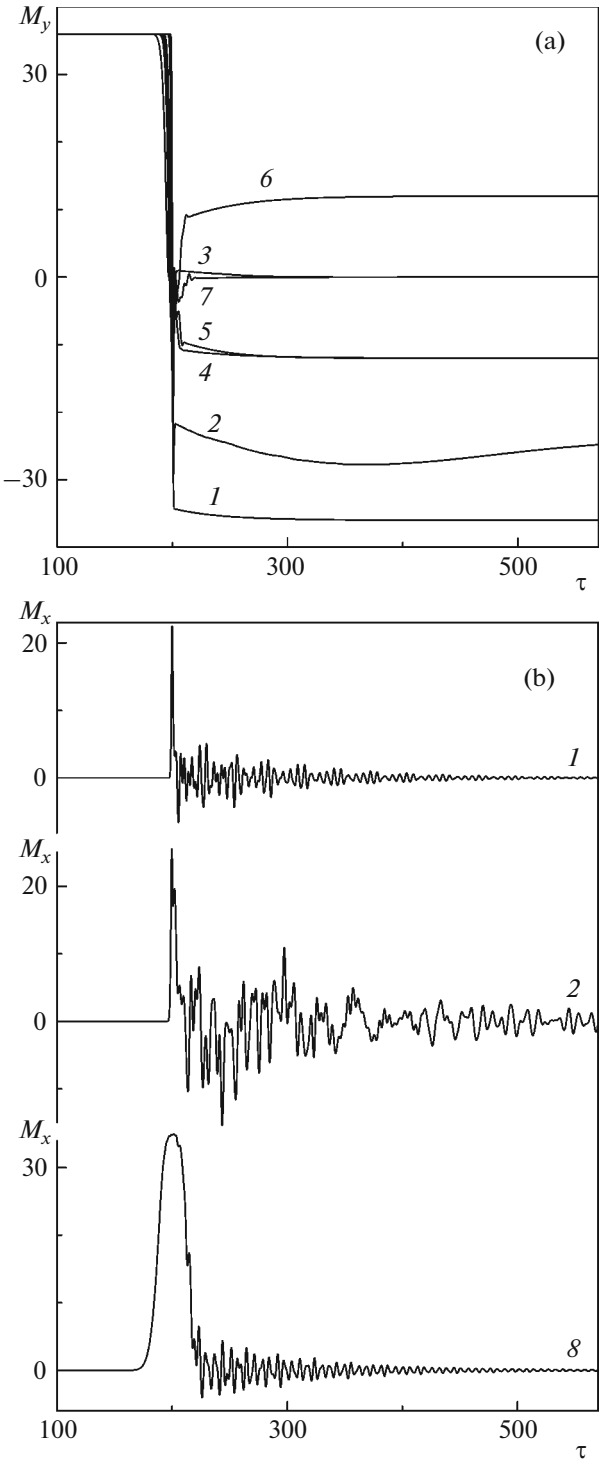

Fig. 7. Time dependences of the x and y components of the total magnetic moment of an inhomogeneous 6 × 6 lattice with $d = 10$ during the action of a pulse with $h_0 = 2$ and $\tau_0 =$ (*1*) 0.8, (*2*) 1.1, (*3*) 1.6, (*4*) 3.0, (*5*) 3.8, (*6*) 4.5, (*7*) 6.5, and (*8*) 8.8. The lattice columns have different anisotropies of nanoparticles: $k_u = 1$, 1.2, 1.4, 1.6, 1.8, and 2.

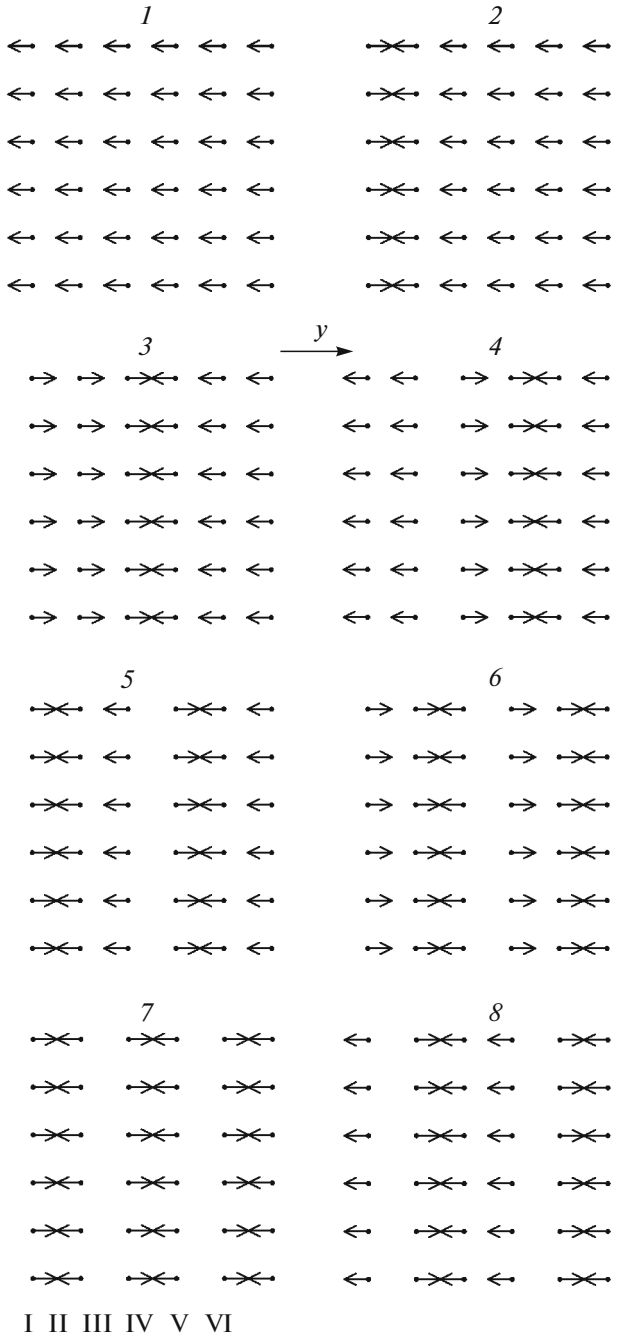

Fig. 8. Final configurations of a lattice consisting of nanoparticles with $k_u = 1$, 1.2, 1.4, 1.6, 1.8, and 2 (correspond to columns) after the action of a pulse with $h_0 = 2$ and $\tau_0 =$ (*1*) 0.8, (*2*) 1.1, (*3*) 1.6, (*4*) 3.0, (*5*) 3.8, (*6*) 4.5, (*7*) 6.5, and (*8*) 8.8.

the pulse amplitude to the uniaxial anisotropy constant, the conditions that correspond to the magnetization reversal or non-reversal of a dipole can be met at a long pulse duration (beginning from a certain characteristic value).

The revealed specific features of the response of the magnetic moment to a pulsed action are caused by the precession attractors of the phase space of the nonlinear system under study. The response time and the presence of magnetization reversal are determined by

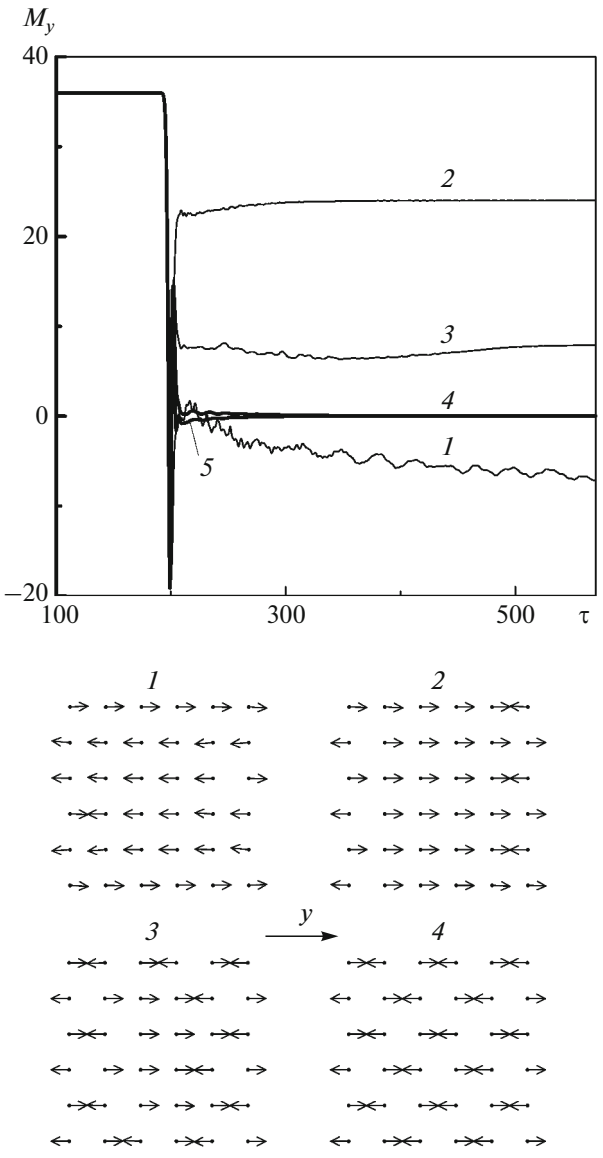

Fig. 9. Time dependences of the y component of the magnetic moment of a binary lattice (alternating nanoparticles with $k_u = 1$ and 1.4) and its final configurations after the action of a pulse with $h_0 = 2$ and $\tau_0 = 3$ for a lattice parameter $d =$ (*1*) 2.5, (*2*) 3, (*3*) 3.5, (*4*) 4, and (*5*) 5.

the position of the magnetic moment with respect to an anisotropy axis during the termination (significant weakening) of the pulsed action. The closer the magnetic moment to the perpendicular to the anisotropy axis, the longer the response. The magnetic moment precesses under the action of an anisotropy field to the initial or opposite direction. The resonance properties of a nanoparticle determine the precession frequency. It should be noted that, when a perturbation (white noise) is turned on, the specific features of the response of the magnetic moment to the pulsed action remain unchanged.

In a lattice of nanoparticles, a weak dipole–dipole interaction affect magnetization reversal processes only near the boundaries of the pulse duration ranges: the lattice is chaotically divided into domains and the total magnetic moment of the system becomes small or near-zero. At other pulse durations, the dipole–dipole interaction only modulates the precession dynamics of the total magnetic moment.

The dependence of the reversal of magnetic moments on the ratio of the pulse amplitude to the anisotropy constant of nanoparticles and on the pulse duration allows us to use one pulse to perform selective magnetization reversal of a dipole lattice consisting of nanoparticles with different uniaxial anisotropy constants. When choosing the pulse duration, we can execute magnetization reversal of certain lattice subsystems, with other subsystems remaining unchanged. The variety of lattice configurations thus formed can exceed the number of the types of the nanoparticles making up a lattice more than two fold. This possibility was demonstrated for a 6×6 lattice divided into six subsystems having different uniaxial anisotropy constants: during pulsed magnetization reversal, various pulse durations lead to the formation of thirteen configurations characterized by specific sets of subsystems subjected to magnetization reversal. Exact selective magnetization reversal can be achieved in lattices with a parameter $d \geq 4$, where the dipole–dipole interaction is sufficiently weak.

Thus, when an inhomogeneous lattice of the magnetic dipoles of anisotropic nanoparticles is subjected to the action of one pulse, only a certain given part of the lattice undergoes magnetization reversal. The results obtained are valid for a wide class of dynamic systems and reveal a general character of their response to a pulsed action.

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