Energy loss during pulsed magnetization reversal of iron borate single crystals

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The relationship between the intensity of shock magnetoelastic oscillations of the magnetization and the time-varying properties of iron borate has been studied for the first time. When the main stage of the magnetization reversal lasts $\leqslant$13–16 ns, there is a sharp decrease in the efficiency of the energy transfer from the magnon system of the crystal to the phonon system. As a result, there is a sharp increase in the rate of magnetization reversal. A change in slope occurs on the curve of the pulsed magnetization reversal.

One of the basic problems in the physics of transition processes in magnetic materials is to incorporate energy losses correctly.[1,2] This is usually done phenomenologically,[3–7] with the help of a Landau–Lifshitz damping constant[3] or a Gilbert damping constant,[4] since the actual mechanism for the transfer of energy out of the spin system of a crystal lattice during pulsed magnetization reversal and magnetization is not clear. In this situation, there is accordingly much interest in an experimental study of transition processes in magnetic materials which have a clearly expressed interaction between magnon and phonon systems. Falling in this category are weak ferromagnets with an easy-plane anisotropy, in which magnetoelastic interactions are the most obvious and the most accessible to study.[8–10] The most suitable material in this class of magnetic materials would be iron borate, $FeBO_3$, which has a high Néel temperature,[9] a low saturation field ($H_{sat} \leqslant 2$ kOe),[11] a low effective anisotropy field in the basal plane,[9] and a high intensity of shock magnetoacoustic vibrations.[12] These vibrations arise during transition processes and characterize the degree of magnetoelastic interaction. These advantages have yet to be realized.

In this letter we are reporting the first study of the intensity of shock magnetoelastic vibrations which arise during the 180° magnetization reversal of iron borate single crystals as a function of the amplitude of the reversal field, H_s. We compare the results with the primary pulsed characteristic of iron borate: the pulsed magnetization-reversal curve, i.e., the plot of the reciprocal of the magnetization reversal time, τ^{-1}, versus the field amplitude H_s.

We studied $FeBO_3$ single crystals, platelets 24 to 110 μm thick with basal plane parallel to their surface. We used several pieces of apparatus to study the behavior of the magnetization of the sample by the induction method[13] and to observe nonequilibrium dynamic domains.[14] The initial state of saturation was reached by means of a static field H_0 ($=1.1H_{sat}$) parallel to the basal plane. The pulsed field H_p was directed opposite H_0. As a measure of the vibration intensity we adopted the modulus (A_1) of the induction signal at the minimum corresponding to the first period of the vibrations

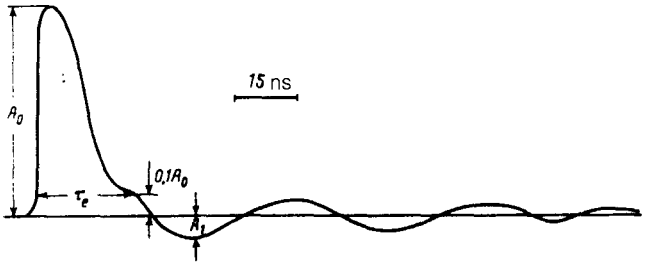

FIG. 1. Induction signal of the magnetization reversal of a $FeBO_3$ single crystal 80 μm thick. $H_s = 2.6$ Oe.

observed after the end of the main part of the induction signal, in which the basic change in magnetization occurs (Fig. 1).

We used the two most common definitions of the magnetization-reversal time.[2,13] According to the first, the magnetization-reversal time τ_e is equal to the interval between the instants at which the signal voltage is equal to 0.1 of its amplitude A_0. The quantity τ_e characterizes the duration of the main stage of the reversal, but it ignores the contribution from the stage involving magnetoelastic vibrations. Accordingly, we also used the definition based on an analysis of the change in the induction flux, $\Delta\Phi(t)$. In this case the magnetization-reversal time τ_Φ was reckoned from the time t_1, at which the flux change $[\Delta\Phi(t_1)]$ reaches 0.1 of the total change $\Delta\Phi_m$, to the time t_2, at which we have $\Delta\Phi(t_2) = 0.9\Delta\Phi_m$. To eliminate the ambiguity stemming from the nonmonotonic change in the magnetization, we constructed an asymptote around which $\Delta\Phi$ oscillated in order to determine the time t_2.

Figure 2 shows the oscillation amplitude A_1 versus the field H_s for a single crystal 80 μm thick with $H_{sat} = 1.8$ Oe. Also shown here are $\tau_e^{-1}(H_s)$ and $\tau_\Phi^{-1}(H_s)$. According to the results of Ref. 11, the $\tau_e^{-1}(H_s)$ curve consists of two characteristic regions. The switch to the other definition of the magnetization-reversal time τ_Φ does not alter the structure of the pulsed magnetization-reversal curve; it simply changes the ordinates of

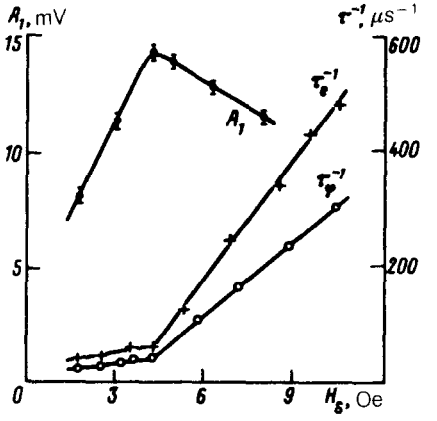

FIG. 2. Curves of the pulsed magnetization reversal obtained through the use of two methods for defining the magnetization-reversal time, τ_e and τ_Φ; plot of the oscillation amplitude A_1 vs the field H_s.

the experimental points. Furthermore, there is no significant change in the field $H_s = H^*$, at which the changes in slopes are observed on both magnetization-reversal curves. Analysis of the behavior of the magnetization reveals that the magnetization reversal occurs through a nonuniform rotation of the magnetization within each region of the magnetization-reversal curves.

It was found (Fig. 2) that as the field amplitude H_s is increased, the quantity A_1 at first increases and then begins to decrease. The field H_s, at which the maximum amplitude is reached, is close to the field of the slope change of the magnetization-reversal curve, H^*. A study of the set of six samples at our disposal revealed that the duration of the main stage of the magnetization reversal at the point of the slope change, $\tau_e(H^*)$, depends weakly on the thickness of the crystal and on the period of the magnetoelastic oscillations, which is determined by this thickness. As the thickness is varied over the range specified above, the period changes from ~ 13 to ~ 56 ns, while $\tau_e(H^*)$ remains in the interval 13–16 ns.

The initial increase in oscillation amplitude can evidently be explained by an increase in the excess energy obtained by the magnon system of the crystal from the external field, $2M_sH_s$. At $H_s > H^*$, the efficiency of the energy transfer from the magnon system to the phonon system drops sharply, and the oscillation intensity decreases significantly, despite the further increase in the energy in the magnon system. It may be that when the main stage lasts less than 13–16 ns, the phonon system "lags" behind the magnon system, or (in the terminology of Refs. 8 and 9) there is a partial "freezing" of the crystal lattice. A complete freezing of the crystal lattice has been observed previously in fields varying sinusoidally at a frequency $\sim 10^3$–10^4 MHz, e.g., in experiments on antiferromagnetic resonance.[8,9]

In summary, when the length of the main stage of the magnetization reversal is $\leqslant$13–16 ns, there is a sharp decrease in the losses in the magnon system due to the excitation of acoustic vibrations of the crystal lattice. As a result, there is a sharp increase in the rate of magnetization reversal, as is seen, in particular, in a slope change on the curve of the pulsed magnetization reversal. This is the first reported case in magnetodynamics in which the structure of the curve of pulsed magnetization reversal has been determined by a change in energy losses. In other magnetic materials which have been studied in any detail at all—Fe–Ni polycrystalline films,[15,16] iron garnet films,[17] and amorphous magnetically soft films[18]—the structure of this curve has been associated with sharp changes in the nature of the spatial-temporal behavior of the magnetization.

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