Natural antiferromagnetic resonance in domain walls of thulium orthoferrite near reorientation temperature

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An investigation was made of the dependences of the intensity and resonance wavelength of intrinsic antiferromagnetic resonance in domain walls of thulium $TmFeO_3$ and dysprosium $DyFeO_3$ orthoferrites in the temperature range 100–500°K. Cooling of $TmFeO_3$ below 120°K revealed a considerable increase of the resonance wavelength and a strong weakening of the resonance absorption intensity. No anomalies were observed for $DyFeO_3$. The characteristics of the resonance in $TmFeO_3$ were explained by changes in the anisotropy constant, spontaneous magnetization, and domain structure near the spin reorientation region ($T_1 = 80$°K, $T_2 = 92$°K). The spin reorientation process in $DyFeO_3$ occurred at 40°K and changes in the constants occurred below the investigated temperature range.

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Zero-field resonance absorption of unknown origin was observed at $\lambda \approx 0.77$ mm at room temperature in $TmFeO_3$ with a maze domain structure. Earlier investigations of this absorption were reported by us in[1,2].

The experimental observations reported in[1,2] did not allow interpretation of the observed absorption as conventional antiferromagnetic resonance or as a result of the interaction of hf radiation with translational oscillations of domain walls. It was suggested that the observed resonance absorption was due to the interaction of submillimeter radiation with hf oscillations in domain walls which could coexist in orthoferrites with lf translational vibrations of the walls themselves.

The possibility of existence of two resonance branches of a transition (wall) layer was demonstrated theoretically in[3] for compensated antiferromagnets. Thus, some antiferromagnets, particularly those with different sublattice anisotropy constants, have an hf branch for the transition layer. It was shown subsequently in[4] that in the case of antiferromagnets exhibiting weak ferromagnetism there are not only two branches of resonance absorption in domains but also two branches characteristic only of the transition layer.

The present paper reports a further study of antiferfomagnetic resonance in domain walls of $TmFeO_3$ and $DyFeO_3$ and it gives results of investigations of the dependence of the resonance wavelength and intensity in the temperature range 100–500°K. It is known that, in the temperature range from $T_1 = 80$°K to $T_2 = 92$°K, a spontaneous reorientation of spins occurs in $TmFeO_3$ and it represents two second-order phase transitions at the beginning and end of the reorientation process.[5] This reorientation rotates the spontaneous magnetic moment from the c to the a axis. Changes in the various properties of a crystal (anisotropy constants, spontaneous magnetization, domain structure) begin outside the range of temperatures in which the spin reorientation takes place. This is due to anisotropic temperature dependences of the lattice parameters.[5–7] Therefore, a study of the resonance absorption in domain walls near the reorientation region is of interest. Dysprosium orthoferrite $DyFeO_3$ also exhibits spin reorientation: it occurs at 40°K and represents a first-order phase transition; however, the changes in the constants associated with this spin reorientation process in $DyFeO_3$ occur below the range of temperatures which we investigated.[8] Therefore, it would be interesting to compare the resonance properties of $TmFeO_3$ and $DyFeO_3$.

Our investigation was carried out using a quasioptic spectrometer similar to that described in Ref. 2.

Single crystal samples of $TmFeO_3$ were grown by the floating zone method employing radiation heating.[9] We investigated two samples with maze and stripe domain structures. The sample with a maze structure was a plate of $5 \times 5 \times 1.2$ mm dimensions cut at right-angles to the c axis (the last dimension is that along the c axis). The sample with a stripe structure was a plate of 10×7 mm area and 1 mm thick cut at a small angle relative to the c axis. Above the reorientation region the domain structure in $TmFeO_3$ was of the "up-and-down" type with domain walls parallel to the c axis; the domain size D was proportional to $\sqrt{L_c}$, where L_c is the size of the sample along the c axis,[4] and for $L_c = 1$ mm at room temperature we found that $D \approx 0.6$ mm.

Figure 1 shows the resonance curves of $TmFeO_3$ obtained using Bryans 26000 A3 X–Y recorder when the temperature of the sample was varied smoothly. Each of the curves represents the temperature dependence of the relative transmission of a sample for a constant wavelength of the incident radiation. An analysis of many curves of the type shown in Fig. 1 yields the temperature dependences of the resonance wavelength and intensity of the resonance absorption (Figs. 2 and 3). Figure 2 gives the temperature dependence of the resonance wavelength for a sample of $TmFeO_3$ with a stripe domain structure. When temperature is reduced below 120–110°K, the resonance wavelength λ_{res} rises steeply. In the range 110–100°K the value of λ_{res} changes by a factor exceeding 2.5, whereas in the range 300–150°K this wavelength varies only slowly (by ~10%). It should be pointed out that the resonance wavelengths (frequencies) of the samples with stripe and maze structures

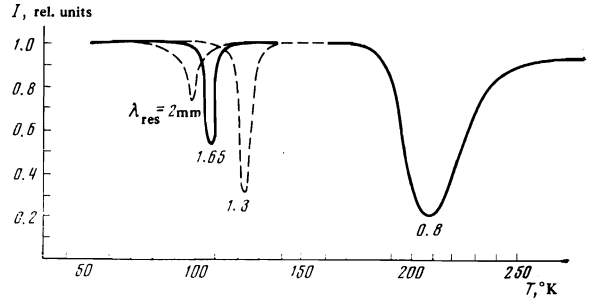

FIG 1. Resonance curves of $TmFeO_3$ samples with stripe (continuous curve) and maze (dashed curve) domain structures.

agree within the limits of the resonance curve width. Figure 3 shows the temperature dependences of the resonance absorption intensity $I_s = I_0/I_{res}$ (I_0 is the transmission of a sample outside the resonance region and I_{res} is the transmission at the resonance wavelength) obtained for samples with stripe and maze domain structures. We can see from Fig. 3 that the absorption intensity is almost constant in the range 130–300 °K. When temperature is reduced below 130 °K the resonance absorption intensity falls steeply and reduction of the temperature of a sample by 20 °K in this range reduces the resonance intensity by a factor of almost three, so that at 100 °K the resonance becomes difficult to observe ($I_s \approx 1.2$).

Thus, the experiments carried out on various samples of $TmFeO_3$ show that there is a narrow temperature range near the limiting temperatures T of the reorientation process in which the intensity of the resonance absorption in domain walls falls steeply and there is a strong rise of the resonance wavelength.

Similar experiments were carried out also on single-crystal samples of dysprosium orthoferrite $DyFeO_3$, grown by the floating zone method with radiation heating. A sample of $DyFeO_3$ was a disk, whose diameter was 7 mm and thickness 0.5 mm, cut at right-angles to the c axis. Zero-field resonance absorption in a sample of $DyFeO_3$ with a maze domain structure was observed at the wavelength of 0.79 mm. The resonance absorption in $DyFeO_3$ exists only in the presence of a domain structure and its characteristics are related to the parameters of this structure. The application of an external static (parallel to the c axis) magnetic field reduces the number of domains (increases the domain size) and also weakens the resonance absorption without

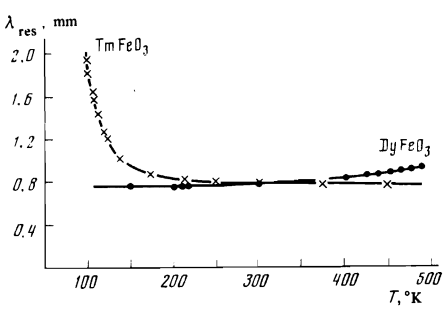

FIG. 2. Temperature dependences of the resonance wavelength: ×) $TmFeO_3$ with stripe domain structure; ●) $DyFeO_3$.

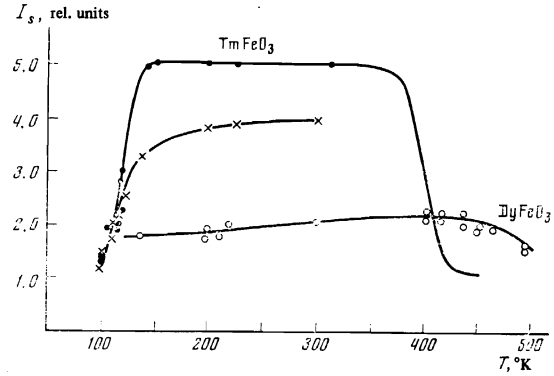

FIG. 3. Temperature dependences of the resonance absorption intensity: ×) $TmFeO_3$ with stripe domain structure; ●) $TmFeO_3$ with maze domain structure; ○) $DyFeO_3$.

altering its frequency. Fields $H_0 \approx 100$ Oe destroy domain structure and the resonance absorption (Fig. 4). The influence of H_0 is manifested only in the resonance absorption region and it reduces to its weakening. A transverse magnetic field has no influence on the resonance in question. Hence, we can interpret the resonance absorption in the same way as that observed in thulium orthoferrite $TmFeO_3$. It is clear from Fig. 2 that in the temperature range 200–500 °K the dysprosium orthoferrite $DyFeO_3$ exhibits some rise of the resonance wavelength λ_{res} when temperature is increased and this rise is proportional to a reduction in the spontaneous magnetization in the same temperature range.

The experimentally observed features of the resonance absorption in $TmFeO_3$ near the reorientation region can be explained as follows. As shown in[4], the relevant equations cannot be solved exactly for rare-earth orthoferrites (in contrast to compensated antiferromagnets). The results of an approximate solution of the equations obtained by a direct variational method are reported in[4]. It is assumed there that in weak ferromagnets the nature of the excitations is the same as in conventional antiferromagnets and the existence of weak ferromagnetism influences only the energy spectrum. Therefore, the equations are solved using the same functions as in the case of compensated antiferromagnets. According to[3], the hf branch of a transition layer in compensated antiferromagnets is described by

$$\omega = \frac{\gamma}{2M_0}\{[B + b_2 - a_2][a_1 - a_2 + a_2 e_{11} s_1]\}^{1/2}, \qquad (1)$$

where B is the exchange interaction parameter; M_0 is the magnetization of the sublattices under saturation

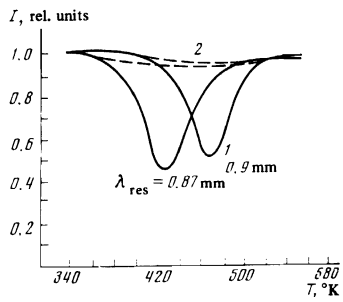

FIG. 4. Resonance curves of $DyFeO_3$: 1) $H_0 = 0$; 2) $H_0 = 100$ Oe.

conditions; a_1, a_2, b_1, and b_2 are the anisotropy constants; and

$$\varepsilon_1 \ll 1,\ s_1 = {}^1/_3.$$

The first anisotropy constant K_1 of orthoferrites can be described, to within fourth-order relativistic interactions, by the following expression

$$K_1 = \frac{1}{2}\left[a_1 - a_2 + \frac{2d_1}{B}(d_1 - d_2)\right],$$

where d_1 and d_2 are the Dzyaloshinskiĭ parameters.

It is known from magnetic measurements that the first anisotropy constant of the orthoferrites exhibiting the spin reorientation effect depends strongly on temperature. Near the reorientation region this temperature dependence of the constant is linear but reorientation changes the sign of the anisotropy constant.[5] Moreover, investigations of the temperature dependence of the spontaneous magnetization of $TmFeO_3$ have demonstrated that cooling a sample from 110°K to the reorientation point results in a steep fall (almost to zero) of the spontaneous magnetization σ along the c axis.[6] Since near the reorientation region we have $K_1 \to 0$ and $d_1 = \sigma B/M_0 \to 0$, the difference $(a_1 - a_2)$ between the anisotropy constants of the sublattices should also tend to zero.

Thus, the experimentally observed steep rise of the resonance wavelength near the reorientation region can be explained, as demonstrated by Eq. (1), by the circumstance that at these temperatures the difference $(a_1 - a_2)$ tends to zero.

The domain structure also changes drastically near the reorientation region: below 150°K the energy of the domain boundaries falls steeply (in the reorientation region this energy becomes zero) and the domain wall width increases.[7] In the reorientation region ($T_1 = 80$°K, $T_2 = 92$°K) there is a transition to a new type of domain structure (domains oriented at an angle with respect to the c axis).[10] Below T_1, when the magnetic moment becomes parallel to the a axis, the domain structure in the investigated $TmFeO_3$ plates cut at right-angles to the c axis has an unfavorable configuration, so that the domain wall energy exceeds the demagnetization energy. The resonance absorption, due to the interaction of submillimeter radiation with hf oscillations in domain walls, should not be observed at these temperatures in such a configuration. Our results do indicate a weakening of the resonance absorption which begins near the reorientation region.

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