Rate of growth of domains in a thin ferrite plate

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It is found that in the change of shape of magnetic domains in an external magnetic field H, the velocity of motion of a domain boundary during the change of length of the domains in their growth stage exceeds by an order of magnitude the velocity of motion of a boundary during the widening of the domains that occurs after the growth is completed. The measured velocity of growth of the domains exceeds the theoretical limit for the velocity of uniform motion of a 180° plane Bloch boundary.

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It is known that the magnetization of a ferromagnetic plate by an external magnetic field, directed along an easy axis, occurs in two stages: first the width of the energetically unfavorable domains decreases, and then, at a certain characteristic width, these domains burst or tear away from the edge of the crystal, and thereafter there occurs only a decrease of length of the domains that have formed.[1,2] On decrease of the field, the process goes in reverse sequence. The velocity of motion of a domain boundary during a change of length of domains was measured earlier—regarding the rate of remagnetization of whiskers (iron single crystals), see [3]. The velocity of motion of a boundary during a change of width of domains has been the subject of intensive experimental and theoretical investigation in recent years in connection with the problem of cylindrical magnetic domains.

The aim of the present work was to make comparative measurements of the velocities V_g and V of domain boundaries: V_g is the velocity of translation of the vertex of a domain in its change-of-length stage (growth), V the velocity of a plane boundary in the change-of-width stage of a domain.

The objects of investigation were plates of single crystals of yttrium iron garnet (YIG, ($Y_3Fe_5O_{12}$) of thickness 25 and 40 μm, cut in a (110) plane, and plates of single crystals, with growth-induced uniaxial anisotropy, of yttrium-gadolinium-thulium garnet (YGTG, $YGdTmFe_{4.3}Ga_{0.7}O_{12}$) of thickness 80 μm, cut in a (111) plane. The crystals were grown by the solution-in-melt method by L. G. Godes and I. G. Avaeva. The plates were optically polished, and then were annealed to remove stresses produced by the mechanical working. The coercivity (H_c) of the walls was measured by the method described in [4] and was: $H_c < 0.2$ Oe in YIG and $H_c < 0.6$ Oe in YGTG.

Photographs of the domain structure are shown in Fig. 1. The domain structure in the YIG plates had the form of stripes a few hundreds of microns wide, with magnetic moment **M** lying in the plane of the plate, so that the domains were visible (in a polarizing microscope by transillumination) only under oblique incidence of the light. In the YGTG plates there were ranges with a maze domain structure and **M** normal to the surface, and ranges with a stripe domain structure, in which **M** was directed at angle $71° \pm 1.5°$ to the surface normal; measurements were made in both ranges. A biasing magnetizing field, with a component $\mathbf{H}_0$ parallel to **M**, was produced by a permanent magnet.

The velocity measurement was made by a pulse method, with magneto-optic apparatus that used the Faraday effect. A pulsed magnetic field **H**, coinciding in direction with $\mathbf{H}_0$, was produced by coils of a few turns of conductor of diameter 100 μm. The rise time of the field was 15 nsec, the duration of the pulses up to 50 μsec. A plane-polarized beam of light from a laser ($\lambda = 0.63$ μm) was focused on the plate (a spot of diameter 120 μm); then, after the analyzer, it fell on a photoelectron multiplier (PEM). Motion of a domain on the area occupied by the spot of light led to a change of intensity of the light falling on the PEM. Increase of the "signal-to-noise" ratio by more than an order of magnitude was accomplished by the method described in [5]. It was possible to move the specimen under study by means of a micrometer feed, and thereby to shift the spot of light with respect to the domains.

It is possible to calculate the velocity V_g of a boundary if one knows the distance between two positions of the spot and the lag time between the response pulses of the PEM corresponding to these spot positions. First the spot was moved along the domain to a position where an accurate record could be made of the lag of the pulse response of the PEM with respect to the field pulse; here the distance from the visible vertex of the domain to the nearest edge of the spot of light was usually 40 to 100 μm. Then the spot was shifted successively 20, 40, 60 μm, and so on, and each time the lag was measured. The measured values of the velocity were averaged over a time corresponding to shift of the domain vertex by a distance of 40 to 80 μm. The total shift of the vertex over a time equal to the duration of the pulse was: in YIG, 300 μm or more; in YGTG, 700 μm in the range of stripe domain structure and 200 μm in the range of maze domain structure. It is clear that the mean velocity thus measured is less than the maximum.

The velocity V of motion of a boundary during a change of width of the domain was measured on the basis of the form of the PEM response, as in [5]. In YGTG a measurement was also made of the velocity of collapse of cylindrical magnetic domains [6] in that region of the plate in which a maze domain structure was observed.

The results of the measurements of the dependence of the velocity of motion of a boundary on the field amplitude H in YIG are shown in Fig. 2: a for V_g and b for V. From theory, a limiting velocity V_W (shown in the figure by the dotted line) is known for uniform motion of a 180° plane Bloch boundary [7]. From Fig. 2 it is evident that t the velocity of the boundary in the change-of-domain-width stage does not exceed V_W; the mobility $\mu = V/H$ of a boundary in small fields is $\mu = 7 \cdot 10^3$ cm/sec Oe $\pm$ 10%. The velocity of a wall in the growth stage is almost an order of magnitude larger than in the change-of-domain-width stage and exceeds the limiting velocity

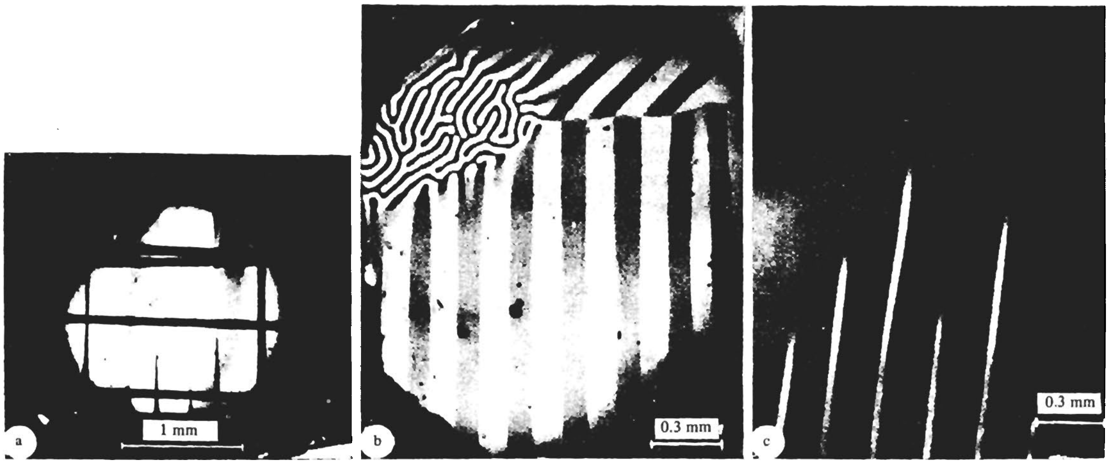

FIG. 1. Domain structure in a constant magnetic field H_0: a–YIG (the heavy lines across the domains are turns of the pulse coil); b–YGTG, $H_0 = 0$; c–YGTG, $H_0 \neq 0$, range of stripe domain structure. In cases a and c the growing domains are clearly evident.

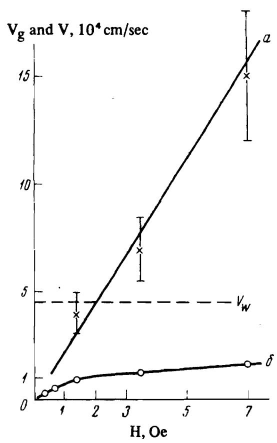

FIG. 2. Dependence of the velocity of a domain boundary on the amplitude H of the pulsed field in YIG, in the growth stage (a) and in the change-of-domain-width stage (b). The dotted line shows $V^{max} = V_W$ according to Walker.

V_W. Here the mobility of a boundary is $\mu_g = 2.5 \times 10^4$ cm/sec Oe ± 20%. These results are independent, within the limits of measurement error, of the value of the biasing field, and they were verified on a large number of domains in several plates: V_g and V varied within the limits 100% for different specimens, but their ratio was constant.

Similar measurements (with the same error) on YGTG gave for the boundary mobility during domain growth the value $\mu_g = 500$ cm/sec Oe, during change of width the value $\mu = 100$ cm/sec Oe in the range of stripe domain structure and 450 and 85 cm/sec Oe, respectively, in the range of maze domain structure. On increase of the biasing field, the maze domains contracted to cylindrical magnetic domains. We made comparative measurements of the velocity V_c of collapse of cylindrical magnetic domains and of the velocity V_g of growth. It was found that the ratio of the mobilities was $\mu_g/\mu_c \approx 6$. The mobility of a boundary during collapse, $\mu_c = 70$ cm/sec Oe, was obtained as a result of an averaging of the data from repeated measurements on a group of sixty domains; the spread in the values of μ_c for individual domains was as much as 50%. It is to be expected that the radius of curvature of the vertex of a growing domain will be equal to the radius of a cylindrical domains.

Thus as a result of the investigations made, it is clarified that the velocity of a domain boundary in the growth stage is almost an order of magnitude larger than in the change-of-domain-width stage, and exceeds the Walker limit [7]. The results of measurements made in crystals with high (YIG) and low (YGTG) domain-boundary mobility provide a basis for supposing that the velocity difference in different stages of reorganization of the domain structure is not an accidental result. At present there is no satisfactory explanation of the observed effect. It is possible that a correct calculation of the local demagnetizing field will permit clearing up of the question.

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Note in proof (March 19, 1975). In [3], measurements were made on a wedge-shaped domain (i.e., only in the growth stage) of the velocities V_g and V_n (V_n normal to the generators of the wedge). It was discovered for the first time that $V_g \gg V_n$, and an attempt was made to explain this on the assumption of conservation of the form of the wedge. This reason is unacceptable when one has to do with velocities V_g and V ($\neq V_n$) in different stages of reorganization of the domain structure (for example, for YGTG $V_n = 0$).

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196