Stabilization of microdomain configurations in two-layer magnetic films

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The problems considered relate to antiparallel reorientation of the magnetization of local regions, of diameter from 150 to 3 μm, in two-layer Mn-NiFe magnetic films with unidirectional anisotropy. The films are heated rapidly, in the presence of an external magnetic field $H_3 > H_c + \Delta H$, over a time $\sim 10^{-8}$ sec. It is observed that in reoriented regions of diameter $d > 80$ μm, the magnetization can be in only a single stable state. On decrease of the diameter of the microdomains from 70 to 3μm, two stable states of magnetization are produced in them. A physical explanation of the observed phenomenon is proposed.

New physical phenomena in film media with magnetic ordering are of definite interest from the point of view of practical application of them as memory elements in modern computational technology. Of special interest are thin magnetic films (TMF) coupled by ferro-antiferromagnetic exchange interaction and possessing unidirectional anisotropy. In such films, application of a magnetic field antiparallel to the unidirectional anisotropy produces a spiral spin configuration through the thickness[1]. A number of physical peculiarities of the ferromagnetic resonance and spin-wave resonance, in particular in the presence of quasi-Bloch boundaries through the film thickness, are described in[2-4]. Later, Glazer et al.[5] described the possibility, in principle, of obtaining local domains with the direction of the magnetization M antiparallel to the M of the whole film, by using a dynamic change of the spin configuration through the film thickness in an antiferro-paramagnetic second-order phase transition. These domains were obtained under simultaneous action of static thermal and magnetic fields on the TMF. The minimum dimension of domains formed in this manner was 100 μm.

But the prospect for application of these peculiarities of two-layer magnetic films, with unidirectional anisotropy, in computational technology can be developed only under the condition of rapid formation of antiparallel magnetization of separate regions, sufficiently localized and of sufficient density. Described below are the results of investigations of the physical peculiarities of microdomain configurations in two-layer magnetic films with ferro-antiferromagnetic exchange interaction, for the purpose of elucidating the prospect for applying them practically.

Two-layer Mn-82 NiFe magnetic films were used in the research; they were deposited on glass substrates, heated to 200° C, in a vacuum $\sim 10^{-6}$ mm of mercury. The thicknesses of the manganese and permalloy layers were 800 and 1000 Å respectively. The unidirectional anisotropy was produced by annealing in a magnetic field of 20 Oe at temperature 360° C. In order to stabilize the basic static magnetic parameters—the coercive force H_C and the field displacement of the hysteresis loop ΔH—of the films, they were subjected to a thermomagnetic treatment. Rapid heating of local regions of the TMF was accomplished by a pulsed laser of type LGI-21. By means of the meridional magnetooptic Kerr effect, it was possible to record the state of magnetization of separate regions of the films, with diameters down to 2—3 μm.

The necessary microdomain configurations are obtained as follows. In the initial state, the magnetic film finds itself in the presence of an external constant magnetic field $H_3 = 60$ Oe, applied antiparallel to the direction of the unidirectional anisotropy of the TMF. Under these conditions there is a gradual rotation of the magnetization through the thickness of the ferromagnetic layer of the film, from the direction of the unidirectional anisotropy to the direction of the external magnetic field H_3, since the spin system of the ferromagnet is pinned in the ferro-antiferromagnetic boundary layer; that is, there is formed a spiral magnetic structure through the thickness (Fig. 1a)[1,6]. By a pulse of focused light beam of duration $\sim 10^{-8}$ sec, a microregion of the film was heated to a temperature T_2 above the Néel point T_N of the antiferromagnet but below the Curie temperature T_C of the ferromagnet. Since the antiferromagnet goes over in the heated region to the paramagnetic state, the pinning of the spins of the ferromagnet in the boundary layer disappears; a new direction of magnetization is established through the whole thickness of the ferromagnetic layer within the region and is determined by the external magnetic field H_3 (Fig. 1b). On lowering of the temperature of the region to T_N, an ordering of the spin system of the antiferromagnet occurs; the direction of the ordering in the boundary layer is determined by the exchange interaction of the spin system of the antiferromagnet with the spin system of the reoriented ferromagnetic region. After removal of H_3, the magnetization of the reoriented region, because of the exchange interaction, remains antiparallel to the unidirectional anisotropy of the film as a whole. In accordance with the method described, experiments were conducted on the formation of local domains with antiparallel magnetization, with diameter d from 150 to 3 μm. The hysteresis

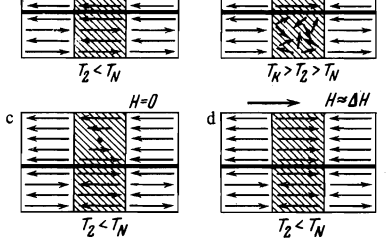
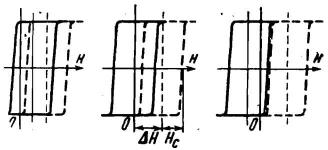


FIG. 1.

loops from regions d $\gtrsim$ 80 μm have the form characteristic of films with unidirectional anisotropy; the magnetization can be in only one stable state. Thus is demonstrated the possibility of rapid formation of local domains with d $\approx$ 80 μm or more, with a single stable state of magnetization, upon pulsed heating over a time $\sim 10^{-8}$ sec. To change the direction of magnetization of the regions in the initial state requires simultaneous action upon it of thermal and magnetic fields.

On decrease of the dimensions of the local domains, it turned out that in the microdomains of diameter $3 < d < 70$ that were formed, it was possible to obtain two stable states of magnetization by varying only the sign of the magnetic field when $T_2 < T_N$. To explain this phenomenon, static remagnetization curves were taken from the surface of the microregions obtained. In Figs. 2a–c it is seen that ΔH changes its magnitude and sign with decrease of the dimension of the magnetic domains formed. This can be explained as follows. A microdomain after formation is in an internal field, nonuniform through the thickness, that strives to unwind its magnetization along the easy direction of the TMF. On the other hand, the forces of exchange interaction with the antiferromagnet strive to keep the magnetization of the ferromagnetic region antiparallel to the easy direction of the whole film. The part subject to the strongest influence of the antiferromagnet is the boundary layer of the ferromagnetic region, whose magnetization is rigidly pinned. But the influence of the antiferromagnet is appreciably weakened at the surface layer, and this leads to a partial or complete rotation of the magnetic moments of the surface layer into the easy direction of the TMF. It is natural that with decrease of the dimensions of the region at fixed thickness, the possibility of such rotation increases. In consequence of this, upon further decrease of the dimensions of the microdomains formed (d < 3 μm) no microdomain configuration of the magnetization at the surface of the TMF is observed after removal of the external magnetic field H_3 (Fig. 1c). But application of an external constant magnetic field $H \approx \Delta H$ (here ΔH is the field displacement of the hysteresis loop of the ferromagnetic region being considered), antiparallel to the direction of the unidirectional anisotropy of the film as a whole, lowers its effective internal field; and this promotes rotation of the spins in the ferromagnetic region, through its whole thickness, into the direction of the effective pinning field in the boundary layer, and a microdomain structure on the surface of the TMF after removal of the field H_3 appears (Fig. 1d).

Thus in the pulsed formation of microdomains with d < 70 μm by the thermomagnetic method, two stable states of magnetization are obtained in them. Thereafter, by the action of external magnetic fields alone on the TMF, it is possible consciously to control the magnetic state of the regions obtained (bits). This physical phenomenon can find practical application in the use of unidirectional TMF, with ferro-antiferromagnetic exchange interaction, as elements of either a magnetic or a magnetooptic operative memory of great capacity, with writing and erasing of information by a thermomagnetic or magnetic method (for example, address buses in an integrated execution).



a b c

FIG. 2. Static remagnetization curves of microregions of a TMF: a, d = 5 μm; b, d = 40 μm; c, d = 70 μm. The dotted curve is for the initial state of the microregion.

On the basis of the results of the investigations on stabilization of microdomain configurations, experiments were conducted on the speed of writing and erasing of magnetooptic information by the thermomagnetic method with minimum dimensions of the bits and maximum bit density. For the conduct of these experiments, 10 specimens were selected, having approximately the same static magnetic parameters: $H_c = 11.2$ Oe, $\Delta H = 14$ Oe. The minimum bit dimension obtained for various films, in which there were still two stable states of magnetization in the absence of an external field H, was 3–5 μm; the corresponding density $\sim 2 \times 10^6$ bit/cm^2. The surface density of light energy in writing and erasing of the bits ~ 4 J/cm^2 at $\lambda = 3370$ Å. Up to 30 write-erase cycles were carried out at each point of a TMF, of diameter 5–7 μm. The resulting change of the magnetic parameters H_c and ΔH was insignificant.

The data obtained enable us to state the possibility of using thin magnetic films of the Mn-NiFe type, with exchange interaction, as elements of an operative memory of large capacity and high speed of introduction and manipulation of information.

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