

Thermomagnetic Data Writing and Erasing in DyCo/NiFe (TbFe/NiFe) Film Structures

V. A. Seredkin*, S. V. Stolyar, G. I. Frolov, and V. Yu. Yakovchuk

Kirensky Institute of Physics, Siberian Division, Russian Academy of Sciences, Krasnoyarsk, Russia

Krasnoyarsk State University, Krasnoyarsk, Russia

* e-mail: sva@iph.krasn.ru

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Abstract—A new principle of data writing and erasing is proposed based on the exchange coupling between magnetic layers with mutually orthogonal orientations of the effective magnetization. The new method provides for a significant decrease in energy consumption. The possibility of using bilayer magnetic films of the (rare earth metal–transition metal)/NiFe type possessing unidirectional anisotropy as the media for thermomagnetic writing and erasing of magneto-optical data is studied. © 2004 MAIK “Nauka/Interperiodica”.

Uniaxial amorphous ferromagnetic films of rare earth and transition (REM–TM) metals with perpendicular magnetic anisotropy (TbFe, TbFeCo, DyCo, DyFeCo, etc.) are now most widely used as the media for thermomagnetic writing and erasing of magneto-optical data [1–4]. Thin films of these compounds with compositions in the compensation region are characterized by high values of perpendicular magnetic anisotropy ($K_{\perp} = 10^5\text{--}10^6$ erg/cm³), sufficiently large magneto-optical parameters, and an acceptable range of temperatures and linear resolution for thermomagnetic writing and erasing of magneto-optical data. However, these media require application of a relatively large external write/erase magnetic field $H_w \sim (3\text{--}6) \times 10^4$ A/m, since lower values do not provide for the magnetic domain saturation in the zone of writing [5]. Another negative factor is a large time of transition from writing to erasing (determined by the coil inductance in the write/erase magnetic field source [4]), which limits the operating speed of devices using such data recording media. Therefore, the search for novel effective magneto-optical materials and new principles of data recording is a currently important task. One possible solution is based on the phenomenon of unidirectional anisotropy in exchange-coupled layers with different magnetic order.

We have obtained for the first time bilayer magnetic film TbFe/NiFe and DyCo/NiFe structures exhibiting unidirectional anisotropy in the sample plane and having mutually orthogonal magnetizations in the DyCo(TbFe) and NiFe layers [6, 7].

The very fact of formation of a unidirectional anisotropy, whereby orientations of the effective magnetization vectors of individual layers are mutually orthogonal and, hence, are not exchange-coupled ($\mathbf{J}\mathbf{M}_1\mathbf{M}_2 = \mathbf{J}M_1M_2\cos(M_1\wedge M_2)$), is rather unusual. For

this reason, the unidirectional anisotropy observed in the proposed bilayer film systems cannot be interpreted within the framework of existing notions [8], although it is clear that the observed effects are related only to the magnetic structure of the REM–TM layer.

The results of our investigations showed that the sign of displacement (ΔH) of the hysteresis loop of the NiFe layer relative to the zero magnetic field at room temperature is unambiguously determined by the direction of magnetization in the REM–TM layer. When the latter layer is demagnetized, the shift of the hysteresis loop of the NiFe layer vanishes, the coercive force (H_c) exhibits a severalfold increase, and the hysteresis loop becomes isotropic in the film plane.

In order to elucidate the nature of this effect, we have performed investigations using the methods of spin wave (SWR) and ferromagnetic (FMR) resonances [9]. It was established that the ferrimagnetic layer (DyCo or TbFe), characterized by the integral perpendicular magnetic anisotropy, represents a nanocrystalline heterophase system consisting of at least two magnetic phases. The magnetization vector of the 3d metal sublattice in one of these phases is parallel to the film plane. We believe that the exchange interaction between magnetizations of the NiFe layer and the in-plane component of the magnetization vector of the heterophase REM–TM layer is precisely what accounts for the appearance of unidirectional anisotropy in such systems. Thus, the unidirectional anisotropy in (REM–TM)/NiFe film structures has an exchange nature.

In addition, we have studied the temperature dependence of the coercive force H_c and the displacement field ΔH for the bilayer films. Figure 1 shows the typical curves for a film structure of the DyCo/NiFe type. For the structures with TbFe ferrimagnetic layer, the curves are analogous. As can be seen from these data,

the H_c and ΔH values sharply change in the temperature interval 350–370 K (Fig. 1, region II), where the coercive force exhibits a tenfold increase, while the shift of the hysteresis loop vanishes completely. This state is roughly retained in the adjacent temperature interval 370–430 K (region III). As the temperature grows further, the H_c of the NiFe layer decreases down to almost the initial level (region IV).

From the standpoint of practical applications of the (REM-TM)/NiFe films with unidirectional anisotropy, the most important temperature intervals correspond to regions I and III (Fig. 1). In the former region extending from 290 to 345 K (which is the working range of magneto-optical data storage), the values of static magnetic parameters H_c and ΔH exhibit no significant variation and the initial magnetic state of the REM-TM layer is not altered by remagnetization of the NiFe layer. The increase in H_c of the NiFe layer in region III is explained as follows. At temperatures in the interval ~370–430 K, the exchange interaction between REM-TM and NiFe layers is still retained, but the coercive force of the REM-TM layer decreases to such a level that the exchange interaction energy becomes sufficient to remagnetize this layer in the normal direction during remagnetization of the NiFe layer. This is reliably monitored by the polar magneto-optical Kerr effect. Obviously, this is not accompanied by a shift of the hysteresis loop, so that $\Delta H = 0$.

This phenomenon underlies the new principle of thermomagnetic data writing and erasing in bilayer (REM-TM)/NiFe film structures with unidirectional anisotropy. The recorded data are read from the REM-TM layer by means of the polar magneto-optical Kerr effect.

The above principle of writing data is illustrated in Fig. 2-I. In the initial state (Fig. 2-Ia), the REM-TM layer 2 occurs in the saturated state with the magnetization vector oriented, for example, downward (ground state). Due to the exchange coupling, the NiFe layer 3 also occurs in the saturated state with the magnetization vector oriented, for example, leftward. When an external writing magnetic field $H_w \geq H_c + \Delta H$ is applied antiparallel to the initial magnetization vector of layer 3 (Fig. 2-Ib), the magnetization direction in this layer changes to the opposite, while the magnetization state of layer 2 is not affected because H_w is much smaller than the anisotropic field ($H_u \geq 8 \times 10^5$ A/m) in this layer. Heating the local magnetized zone (Fig. 2-Ic) to any temperature within region III (Fig. 1) does not change the magnetic state of this zone in layer 3, whose Curie temperature is much higher (~835 K). As was noted above, the energy of the exchange interaction between layers 2 and 3 changes the direction of magnetization in layer 2 to the opposite (upward). On cooling the given zone, this state is retained even upon removal of the external writing field H_w ; the magnetization in layer 3 acquires a nonequilibrium helicoidal structure (Fig. 2-Id) [10]. This state corresponds to recording one

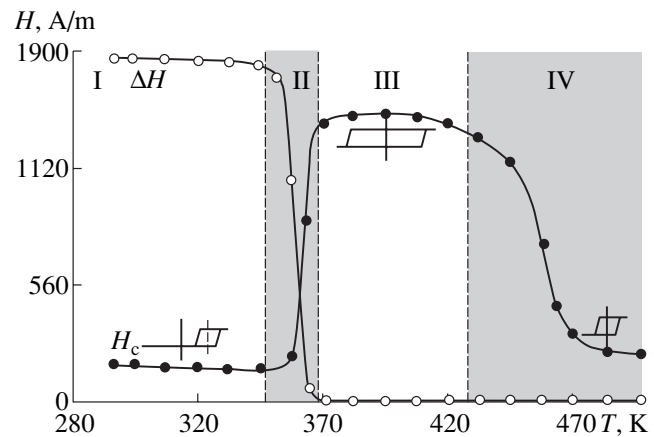


Fig. 1. Temperature dependences of the coercive force H_c and the displacement field ΔH in the NiFe layer of a bilayer DyCo/NiFe (TbFe/NiFe) film structure (see the text for explanations).

bit of data in layer 2. The domain formed in the magnetized zone will always occur in the saturated state, which is maintained by a mechanism different from that described in [5]. In our case, the exchange interaction between homogeneously magnetized layer 3 and layer 2 prevents the formation of a multidomain structure in the course of formation of the data-bearing domain.

The principle of erasing data from the domains formed as described above is illustrated in Fig. 2-II. The erasing magnetic field (H_e) in this case is not used. When the zone with a data-bearing domain (see the initial state of the magnetic structure in Fig. 2-IIa) is heated to a temperature close to the Curie point T_c of layer 2 (Fig. 1, region IV), this zone passes to a paramagnetic state and the direction of magnetization in the given zone of layer 3 is reoriented (due to the direct exchange interaction in the NiFe layer) in accordance with the magnetization of the surrounding material (leftward), thus passing to the equilibrium state (Fig. 2-IIb). On cooling, the zone in layer 2 will change the direction of magnetization to the opposite (due to the energy of exchange interaction with layer 3) and the data-bearing domain will disappear (Fig. 2-IIc).

Since the magnetic field required for writing data ($H_w \geq (H_c + \Delta H) \approx 2 \times 10^3$ A/m) is much smaller than that used in [5] and the data erasing needs no magnetic field at all, the total magnetic field energy consumed for data writing/erasing is significantly reduced. Relatively low values of the magnetic field used for writing data allow the pulses of magnetic field H_w to be very short (several nanoseconds), which provides for a very high operating speed. The operating speed additionally increases because there is no need for commutation of the magnetic field during write/erase cycles. It should be noted that all the aforementioned advantages of

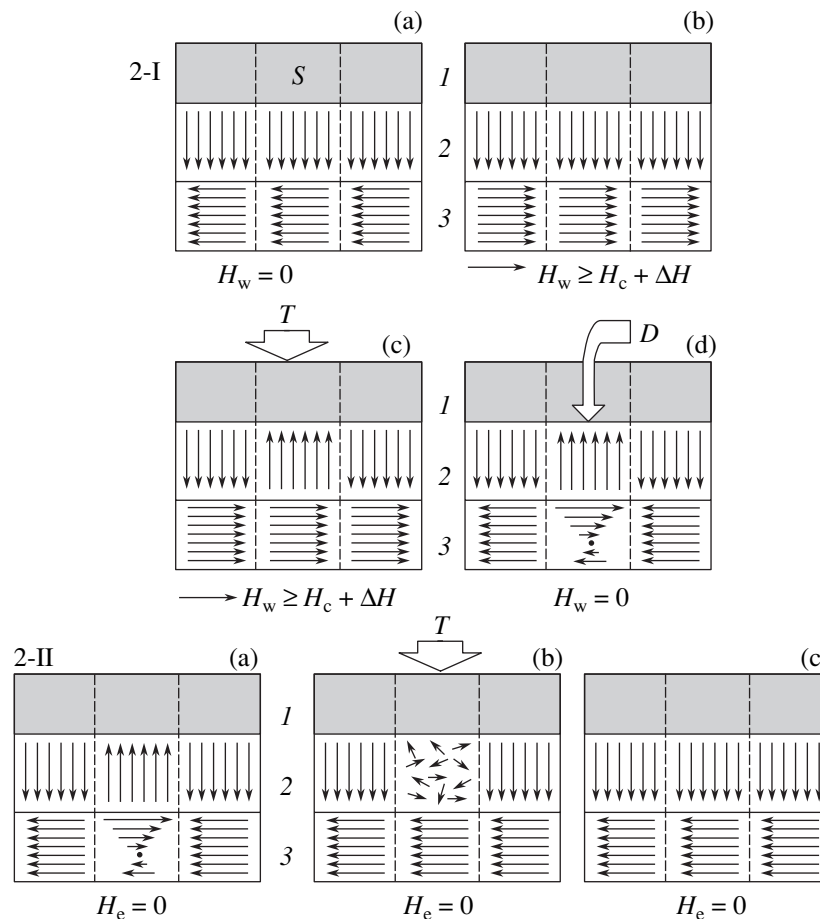


Fig. 2. Schematic diagrams illustrating the principles of writing (2-I) and erasing (2-II) of magneto-optical data in a bilayer DyCo/NiFe (TbFe/NiFe) film structure (see the text for explanations): (S) substrate; (T) heating; (D) domain.

REM–TM layers as the data recording media are retained.

In conclusion, the results of our investigations showed that the proposed (REM–TM)/NiFe film structures make possible the use of data writing and erasing principles different from the existing ones, which provides for a significant decrease in the energy consumed.

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