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BRIEF COMMUNICATIONS

Enhancement of the Kerr Effect in Magnetooptical DyFeCo/GeO Carriers

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Abstract—The optimum parameters of a dielectric layer near the substrate in the interference multilayer structure are calculated. The calculations showed that this layer should have the index of refraction $n \sim 3$. The results are presented of measuring the Kerr angle of magnetooptical rotation in the multilayer structure, in which GeO films were used as dielectric layers for the first time. The maximum Kerr angle of rotation and magnetooptical quality observed in this system were 0.75° and 0.34°, respectively. These values exceed those inherent in the known information carriers, which demonstrates the advantage of this structure for use in magnetooptical discs.

At present, rare earth–transition metal amorphous films are extensively used for manufacturing magnetooptical (MO) discs [1]. For this reason, the search for methods of increasing the Kerr polar effect, which determines the magnitude of the detected signal, is urgent. One of the methods is the deposition of a dielectric layer (DL) [2], which, according to the theory [3], allows one to increase the Kerr rotation by a factor of n^2 due to interference effects, where n is its index of refraction. According to the ISO International Standard, information should be read from the substrate side of the MO disc. In this case, the DL is placed between the substrate and the magnetic layer and the MO rotation substantially depends on the difference between the indices of refraction of the substrate and the DL, which means that the latter should have large n [4]. As a storage medium in the MO discs, a multilayer interference structure is used, which consists of a magnetoactive layer embedded between the dielectric layers and of a reflection layer. The systems with SiO [4], ZnS [5], and AlN [4, 6] used as DLs were studied. They demonstrated an increase in the Kerr rotation angle by factors of 1.6, 1.75, and 1.9 compared to a single-layer film. Theoretical calculations showed that the Kerr effect can be enhanced up to 90° by selecting optimum parameters of the DL [7].

In this paper, we present the calculation and the experimental study of a multilayer structure in which GeO films were used as DLs for the first time and amorphous DyFeCo films were used as the magnetoactive and reflecting layers.

Samples were prepared by thermal evaporation in vacuum (3×10^{-4} Pa). The interfering dielectric GeO layer, the magnetoactive DyFeCo layer (10 nm thick), the dielectric GeO layer (34 nm thick), and the reflecting DyFeCo layer were successively deposited on glass substrates whose temperature was 20–30°C. The structure thus obtained was covered with a protective GeO layer 150 nm thick. The thickness of the dielectric GeO layer near the substrate was varied from 60 to 102 nm. The reflecting layer was selected to be larger than the skin layer for the wavelength range from 780 to 820 nm used in the MO storage and was 70 nm thick. The schematic of this system is presented in Fig. 1.

The DyFeCo magnetic layers contained 20 at.% of Dy and 80 at.% of FeCo, the ratio of Fe to Co being 2 : 1. This provided perpendicular anisotropy in the films, the optimum value of the coercive force ($H_c \approx 3$ kOe), and the maximum Kerr angle of rotation per layer $\theta_k \approx 0.17°$.

The MO parameters were measured on an MO setup with zero compensation in fields up to 16 kOe. The coercive force was measured from the MO hysteresis loops. The reflection coefficient R was measured with a Specord UV-VIS modernized spectrophotometer. To find optimum parameters of the DL near the substrate at which the Kerr angle of rotation should resonantly

Air	0	$N_0 = n_0 = 1$
Glass substrate	1	$N_1 = n_1 = 1.52$
Dielectric layer	2	$N_2 = n_2 = ?$
Magnetoactive DyFeCo layer	3	$N_3 = 2.4 - i2.6$
Dielectric GeO interlayer	4	$N_4 = n_4 \sim 2.8$
Reflecting DyFeCo layer	5	$N_5 = 2.4 - i2.6$
Protective GeO layer	6	$N_6 = n_6 \sim 2.8$

$Q_3 = Q_5 = 0.0149 + i0.006$

Fig. 1.

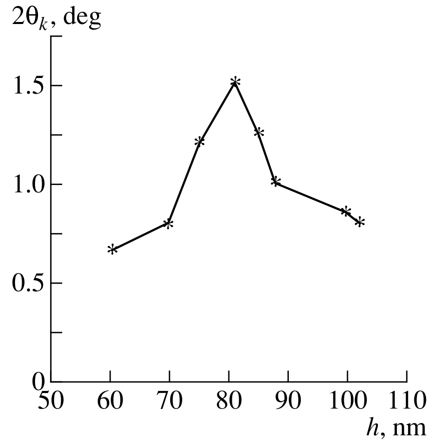

Fig. 2. Dependence of the Kerr angle of rotation on the thickness of the dielectric layer near the substrate.

increase due to interference effects, we calculated the index of refraction and thickness of this layer from the expressions [7]

$$n_2^2 = n_1 n_3 + (n_3 k_1^2 - n_1 k_3^2)/(n_1 - n_3), \quad (1)$$

$$\tan\delta_2 = -n_2(n_1 - n_3)/(n_1 k_3 + n_3 k_1), \quad (2)$$

where $\delta_2 = 2\pi n_2 h_2/\lambda$ is the phase incursion in a layer of thickness h_2; $N_j = n_j - ik_j$ is the complex index of refraction of the jth layer, where n_j is the real index of refraction and k_j is the absorption coefficient; and the subscripts correspond to the situation when the dielectric layer (j = 2) is adjacent, on one side, to the external medium (j = 1) and to the magnetic layer (j = 3) on the other side.

The calculations were performed for the structure presented in Fig. 1. Here, the media on both sides of the DL providing the interference themselves consist of a set of layers; n_1, k_1, n_3, k_3 correspond to the effective values, which in turn were determined from coefficients of reflection from corresponding interfaces.

Taking into account that the glass substrate is transparent ($N_2 = n_2$), we can write the amplitude reflectance from the substrate side in the form [8]

$$r_{02} = (r_{01} + r_{12}\cos 4\pi n_1 h_1/\lambda) \times (1 + r_{01} r_{12} \cos 4\pi n_1 h_1/\lambda)^{-1} \quad (3)$$

and the reflection coefficient of the system will be described by the expression

$$R_{02} = \frac{r_{01}^2 + r_{12}^2 + 2 r_{01} r_{12} \cos(-\Delta_{01} + \Delta_{12} - 4\pi n_1 h_1/\lambda)}{1 + r_{01}^2 r_{12}^2 + 2 r_{01} r_{12} \cos(\Delta_{01} + \Delta_{12} - 4\pi n_1 h_1/\lambda)}, \quad (4)$$

where $r_{ij} = (N_i - N_j)/(N_i + N_j)$ and Δ_{01} and Δ_{12} are the changes in the phase at the interfaces, which are equal to 0 or π, depending on whether r_{01} and r_{12} positive or negative; i.e., in this case, $\Delta_{01} = \Delta_{12} = \pi$. Thus, the calculation of R_{02} results in the replacement of the two interfaces on the substrate side relative to the DL by one effective surface. The effective value $n_{1\,\mathrm{eff}}$ of the real index of refraction of the medium on the substrate side was obtained from the expression [8]

$$R_{02} = (n_{1\,\mathrm{eff}} - n_2)^2 (n_{1\,\mathrm{eff}} + n_2)^{-2}, \quad (5)$$

$$n_{1\,\mathrm{eff}} = n_2(1 + R_{02} \pm 2\sqrt{R_{02}})(1 - R_{02})^{-1}. \quad (6)$$

The effective value of the index of refraction $n_{3\,\mathrm{eff}}$ and the absorption coefficient $k_{3\,\mathrm{eff}}$ on the side of the magnetoactive layer were obtained from the measured amplitude reflection coefficient of the effective surface, which replaced two neighboring interfaces, starting with the protecting GeO layer. To simplify the calculations, we neglected complex magnetooptical parameters in the index of refraction of the DyFeCo films because of their smallness. Based on the general expression for the amplitude reflection coefficient [7], we can write the following expressions:

$$\begin{aligned} r_{46} &= [r_{45} + r_{56}\exp(-i4\pi n_5 h_5/\lambda)] \\ &\times [1 + r_{45} r_{56} \exp(-i4\pi n_5 h_5/\lambda)]^{-1}, \\ r_{45} &= (N_4 - N_5)/(N_4 + N_5), \\ r_{56} &= (N_5 - N_6)/(N_5 + N_6); \end{aligned} \quad (7)$$

$$\begin{aligned} r_{36} &= [r_{34} + r_{46}\exp(-i4\pi n_4 h_4/\lambda)] \\ &\times [1 + r_{34} r_{46} \exp(-i4\pi n_4 h_4/\lambda)]^{-1}, \\ r_{34} &= (N_3 - N_4)/(N_3 + N_4); \end{aligned} \quad (8)$$

$$\begin{aligned} r_{26} &= [r_{23} + r_{36}\exp(-i4\pi n_3 h_3/\lambda)] \\ &\times [1 + r_{23} r_{36} \exp(-i4\pi n_3 h_3/\lambda)]^{-1}, \\ r_{23} &= (N_2 - N_3)/(N_2 + N_3); \end{aligned} \quad (9)$$

$$R_{26} = r_{26}^2, \quad (10)$$

$$N_{3\,\mathrm{eff}} = n_2(1 + R_{26} \pm 2\sqrt{R_{26}})(1 - R_{26})^{-1}, \quad (11)$$

$$N_{3\,\mathrm{eff}} = n_{3\,\mathrm{eff}} - ik_{3\,\mathrm{eff}}. \quad (12)$$

Our calculations showed that the DL should have the index of refraction $n = 3$. The GeO films are the best candidates for such layers, because the measurement showed that their index of refraction is $n \sim 2.8$. Calculated from (2), the optimum thickness h_2 of the GeO film in the structure considered was ~95 nm.

The Kerr angle of rotation in the dielectric GeO film with optimum thickness can be evaluated from the polarization of light reflected from the external surface of this multilayer structure. In the approximation linear in magnetization, this angle is [9]

$$\theta_k = \mathrm{Im}(\chi/r), \text{ if } |\chi| \ll |r|, \quad (13)$$

where $r^{\pm} = r \pm \chi$ is the amplitude reflection coefficients for circularly polarized components with right (+) and left (–) directions of rotation, respectively.

These coefficients were determined using the scheme described above, but using the index of refraction for circularly polarized waves in the magnetoactive medium, which is described by the expression [9]

$$N_j^{\pm} = N_j\sqrt{1 \pm Q_j}, \tag{14}$$

where N_j is the complex index of refraction, which is determined by the diagonal component of the dielectric constant tensor, and Q_j is the complex MO parameter related to the gyrotropy of the magnetic medium.

In contrast to the above calculations, we should consider the entire system, so that expressions (7)–(9) should be supplemented by the expressions

$$r_{16} = [r_{12} + r_{26}\exp(-i4\pi n_2 h_2/\lambda)]$$
$$\times [1 + r_{12}r_{26}\exp(-i4\pi n_2 h_2/\lambda)]^{-1}, \tag{15}$$
$$r_{12} = (N_1 - N_2)/(N_1 + N_2);$$
$$r_{06} = [r_{01} + r_{16}\exp(-i4\pi n_1 h_1/\lambda)]$$
$$\times [1 + r_{01}r_{16}\exp(-i4\pi n_1 h_1/\lambda)]^{-1}, \tag{16}$$
$$r_{01} = (N_0 - N_1)/(N_0 + N_1).$$

Having thus obtained r_{06}^{+} and r_{06}^{-}, we can determine θ_k from (13). The necessary values of MO and optical parameters of the DyFeCo films (Fig. 1) were taken from the data for amorphous TbFe films [10, 11]. The Kerr angle of rotation was measured to be ~0.7°.

The experimental dependence of the Kerr angle of rotation on the DL thickness for the multilayer structure is shown in Fig. 2. This dependence exhibits a resonance, which suggests that the interference effect increases the MO rotation. One can see from Fig. 2 that the maximum angle of rotation $2\theta_k = 1.5°$ corresponds to the structure with the DL thickness ~81 nm, in good agreement with calculations. Such an angle of rotation is 4.5 times larger than that for a single-layer magnetic film, and the corresponding MO quality $\sqrt{R}\,\theta_k$ is 0.34°. These values exceed the corresponding parameters for known information carriers, made of rare earth–transition metal films. Thus, GeO films of optimum thickness used as the DL in multilayer film structures increase the Kerr angle of rotation by several times compared to a single-layer film. These are promising media structures for use in MO discs. The calculations based on the interference effects are in good agreement with the experimental data and can be used for the evaluation of optimum parameters of the dielectric layer.

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