The peculiarities of spectral dependences of the transverse Kerr effect of Au-Co nanostructures

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Abstract. The paper is concerned with the experimental spectral dependence of the magneto-optic Kerr effect for samples of nano-layered films of Co-Au. Theoretical spectral dependences of the 'Transversal Kerr Effect' are constructed. Spectral dependences taking into account the size effect are given. Theoretical and experimental data are compared. There is good agreement between experimental and simulated results. The relevance of this research area and the results obtained are noted. Discussed the possibility of using such nano-layered thin films structures.

1. Introduction and background
Currently studies of magneto-optic properties of multilayer structures are very important [1-2]. In such structures it is possible to have promising optical, transport and magneto-optic effects, such as giant magnetoresistance, anomalous Hall effect, transverse Kerr effect (TKE), etc. These effects are of both fundamental and practical interest in a wide range of applications of nanostructures.

2. Experimental technique
This article solves a critical problem of modeling spectral dependences of TKE and comparing them with experimental data using the example of cobalt-gold nanolayer structures. The spectral dependences of the TKE of cobalt-gold layered nanofilms (figure 1) were obtained in [3]. The relative change in the intensity of p - polarized electromagnetic radiation reflected from the samples was measured:

\[ \rho_{\omega}(\lambda) = \frac{I(H) - I(0)}{I(0)} \]

where I(H) and I(0) is the intensity of the reflected radiation when a magnetic field is applied and without a magnetic field, respectively.

The samples under study are nanolayer cobalt films of different thicknesses deposited on a silicon substrate. To protect against oxidation, a gold layer with a thickness of \( d_{Au} = 0.9 \) nm was deposited on all the investigated cobalt samples.
Figure 1. Spectral dependences of the TKE for different Co-Au films (dots) at different thickness of the cobalt layer and pure cobalt (solid line) [3].

Thus, based on figure 1, it is obvious that with an increase in the thickness of the cobalt layer, an increase in the Kerr effect value is observed. Also, a sharp change in the spectral dependences is worthy noting when the thickness of the cobalt layer is more than 5 nm. This effect is associated with the formation of the crystal structure of cobalt.

3. Experimental results and discussion

The magnetic optical properties of Co-Au nanofilms was studied on the samples with the thickness of the cobalt layer $d_{Co} = 1.5, 2.5$ and $15$ nm. The TKE was calculated by the following formulas [4]:

$$\rho_\omega = 2\text{Re}\rho;$$

$$g_j = \sqrt{n_j^2 - n_1^2 \sin^2 \phi}, \quad F_k = \exp(-2\pi\lambda^{-1}g_k d_k)$$

where $r_i$ is the reflection coefficient, $n_1$ is the refractive index of the external environment; $\phi$ is the angle of light incidence; $j, k, l$ are the numbers of environments; $dk$ is the thickness of the respective medium; $\lambda$ is the wavelength of light; $Q=\text{i}\varepsilon_{xy}\text{eff}/\varepsilon_{xx}\text{eff}$ is the magnetic optical parameter, $\varepsilon_{xy}\text{eff}, \varepsilon_{xx}\text{eff}$ are diagonal and non-diagonal components of the effective medium tensor of the dielectric permittivity; $\varepsilon_{xy}$ for the case of transverse magnetization equal to 1.

It is important to note that in the near infrared region of the spectrum the dimensional effect must be accounted for. It is assumed that the cobalt layer consists of the same size $r_0$ granules. Thus, taking into account the dimensional effect, the permittivity tensor $\varepsilon_{\text{mod}}$ is calculated as follows:

$$\varepsilon_{\text{mod}} = \varepsilon_0 + \frac{\omega_\text{p}^2}{\omega(\omega + i/\tau_{\text{bulk}})} - \frac{\omega_\text{p}^2}{\omega(\omega + i/\tau_{\text{part}})}$$

where $\tau_{\text{part}}$ and $\tau_{\text{bulk}}$ are the free path of electrons in a cobalt granule and the free path of electrons in a massive sample, respectively. Taking into account the Drude-Lorentz law, the nondiagonal $\varepsilon_{xy}=-i\gamma$ components of $\varepsilon_{\text{mod}}$ are determined from the following expressions:
\[ \gamma_{\text{mod}} = \gamma_0 + \frac{4\pi\sigma_{xy}^{\text{bulk}} / \tau_{\text{bulk}}^2}{\omega(\omega + i/\tau_{\text{bulk}})^2} - \frac{4\pi\sigma_{xy}^{\text{gr}} / \tau_{\text{part}}^2}{\omega(\omega + i/\tau_{\text{part}})^2} \] 

\[ R_{\text{gr}} = R_{\text{bulk}} + 0.2 R_s \frac{l}{l_0} (1 + \frac{l}{l_0}) \] 

where \( \omega \) is the frequency of light, \( \omega_p \) is the plasma frequency, \( R_{\text{gr}} \) is the coefficient of anomalous Hall effect, \( \rho_{\text{bulk}} \) is the resistivity of the massive sample, \( \rho_{\text{gr}} \) is the resistivity of the granule, \( R_s \) is the value of the anomalous Hall effect coefficient of the material of the granule surface, and \( \sigma \) is conductivity.

The spectral dependences of the TKE of the Co-Au nanoscale films under study were calculated using (2) - (4) and taking into account the size effect. The obtained dependences are shown in figure 2.

![Figure 2](image-url)  
**Figure 2.** Calculated spectral dependences of the TKE with account for the size effect at \( d_{\text{Co}} = 1.5 \) nm – dotted line, 2.5 nm – point line, 15 nm – solid line in comparison with experimental data (points) at \( d_{\text{Co}} = 1.5 \) nm - stars, 2.5 nm – triangles and 15nm - squares.

Thus, as can be seen from figure 2, there is a good agreement between the experimental and theoretical data of the TKE for nanoscale films with cobalt thickness \( d_{\text{Co}} = 1.5 \) and 2.5 nm. However, at \( d_{\text{Co}} = 15 \) nm there is a strong divergence of theoretical and experimental dependences. This may be due to the heterogeneity of the distribution of cobalt granules and the formation of the crystal structure of cobalt. Other approximation methods should be used to describe the magneto-optic properties of such crystal structures.

### 4. Conclusion

The simulation carried out in this paper analyzed and predicted the optical and magneto-optic properties of nanoscale films, which is important for the selection of materials with the desired properties. Such samples can be used as highly sensitive magnetoresistive sensors and miniature magnetic heads, and the methods of magneto-optic spectroscopy are non-contact methods of non-destructive testing. Thus, the results are of both fundamental and practical interest in a wide range of applications [5-8].

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