INFLUENCE OF THE SHAPE OF MAGNETIC PARTICLES AND DIELECTRIC PERMITTIVITY OF THE MEDIUM ON MAGNETO-OPTICAL PROPERTIES OF NANO-DISPERSIVE COBALT

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The influence of the shape of magnetic particles and dielectric permittivity of the medium is investigated on the magneto-optical properties of the nano-dispersive structures using the thin discontinuous Co films. The behaviour of the magneto-optical spectra of thin Co films was explained in the framework of the effective medium approximation. The results have confirmed the significant change of the components of the tensor of effective dielectric permittivity and subsequently of the magneto-optical and optical properties which brought about the change of the shape of magnetic particles. These calculations proved that a good agreement between the experimental results and the theoretical calculations is achieved if the shape of the particles is taken into account

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Introduction

The advance in technology requires magnetic materials with new properties. It is for this reason that intensive experimental and theoretical research on the magnetic substances is being pursued worldwide with a view to creating cutting-edge materials. The exploration of the mutual influence of the microstructure and the structural content on magnetic, magneto-optical and optical properties of nanoheterostructures has become the focus of intensive research. Therefore, experimental methods of magneto-optical researches are extremely relevant to study, as they allow the study of their inner electronic structures, and especially of their magnetic interactions. Optical and magneto-optical research methods are one of the simplest, the most effective and informative way of studying of the nanostructures and the modern materials.

Nowadays, magneto-optical research methods are widely used for examination of ultrafine magnetic structures such as: magnetic fluids, thin discontinuous metal films, heterogenic glasses, ferrite-garnet films, implanted magnetic surfaces, etc. Ultrafine medium is an ensemble of particles having smaller size than 100 nm. They have unique qualities compared to bulk ferromagnetic. This appears to be a result of the fact that the particles with identical properties and materials of particles are destroyed at a diapason covering size till 100 nm.[1,2]

There is no doubt that any experimental or theoretical research done in this direction revives a strong interest as many aspects still remain enigmatic.

Theory

In general, the magneto-optical properties of nano-dispersive magnetic structures are very different from the properties of the bulk ferromagnetic and depend on the structural parameters: the occupancy of the volume of the ultrafine medium with metal, the size and shape of the particles, the order of the particles, the properties of the medium, surrounding metal particles.[3,4]

The tensor of effective dielectric permittivity of magnetized ultrafine ferromagnetic material, by analogy with the tensor for bulk ferromagnetic materials, is represented as

$$\varepsilon_{eff} = \begin{bmatrix} \varepsilon_{eff} & -i\varepsilon'_{eff} & 0 \\ i\varepsilon'_{eff} & \varepsilon_{eff} & 0 \\ 0 & 0 & \varepsilon_{eff0} \end{bmatrix}, \quad (1)$$

where

$$\varepsilon_{eff} = \varepsilon_{1eff} - i\varepsilon_{2eff},$$
$$\varepsilon_{0eff} = \varepsilon_{01eff} - i\varepsilon_{02eff},$$
$$\varepsilon'_{eff} = \varepsilon'_{1eff} - i\varepsilon'_{2eff}.$$

In this case the tensor components depend on both the properties of magnetic colloidal particles themselves, and the properties of the medium in which they find themselves. The knowledge of tensor components enables us to calculate any type of magneto-optical effect. The next step is to establish the link between the components of the tensor of effective dielectric permittivity and the components of the tensor of the according bulk materials. This task was first brought in 1985.[5]

For ultrafine magnetic medium with a low concentration of magnetic colloidal particles and with no direct contact between them the tensor components of the effective dielectric permittivity within the framework of theoretical models of an effective medium, extended to include the case of magnetic media, can be written as:

1.The model of averaged characteristics:

$$\varepsilon_{\rm eff} = q\varepsilon_{\rm m} + (1-q)\varepsilon_0\,; \quad \varepsilon'_{\rm eff} = q\varepsilon'_{\rm m} \tag{2}$$

2. The Maxwell–Garnett model:

$$\varepsilon_{\rm eff} = \frac{2q(\varepsilon_{\rm m}-\varepsilon_0)+(\varepsilon_{\rm m}+2\varepsilon_0)}{(\varepsilon_{\rm m}+2\varepsilon_0)-q(\varepsilon_{\rm m}-\varepsilon_0)},$$

$$\varepsilon'_{\rm eff} = \frac{9q\varepsilon_0^2\varepsilon'_{\rm m}}{(\varepsilon_{\rm m}(1-q)+\varepsilon_0(2+q))^2}. \tag{3}$$

3. The Bruggeman model:

$$\varepsilon_{\rm eff} = \varepsilon_{\rm o}(1+3q\frac{\varepsilon_{\rm m}-\varepsilon_{\rm o}}{\varepsilon_{\rm m}+2\varepsilon_{\rm o}})\,; \quad \varepsilon'_{\rm eff} = \frac{9q\varepsilon_{\rm o}^2\varepsilon'_{\rm m}}{(\varepsilon_{\rm m}+2\varepsilon_{\rm O})^2}, \tag{4}$$

where

$\varepsilon_m=\varepsilon_{1m}-i\varepsilon_{2m}$ and $\varepsilon'_m=\varepsilon'_{1m}-i\varepsilon'_{2m}$, are the diagonal and nondiagonal tensor components of the dielectric permittivity of the material of magnetic colloidal particles,

ε_0 is the dielectric permittivity of the non-magnetic phase, and q is the ratio of the volume, occupied by magnetic particles, to the total volume of the magnetic fluid.

After generalization of this theory we arrive at a formula to calculate tensor components for non-spherical ultrafine particles:

$$\varepsilon_{\rm eff} = \varepsilon_0\left(1+\frac{q(\varepsilon_{\rm m}-\varepsilon_0)}{y\varepsilon_{\rm m}+(1-y)\varepsilon_0}\right),$$

$$\varepsilon'_{\rm eff} = \frac{\varepsilon_0^2\varepsilon'_{\rm m}}{[y\varepsilon_{\rm m}+(1-y)\varepsilon_0]^2}, \tag{5}$$

where

$y=f(1-q)$, whilst f is the factor of the shape of the ultrafine particles.[5]

These formulae (5) can be used to investigate which structural parameter has more influence on the optical and magneto-optical properties of the ultrafine medium.

The equatorial Kerr effect under consideration, which consists in a change in the intensity of linearly polarized light reflected from the sample in the case reversal of magnetization of the sample, can be written as

$$\delta_{\rm p} = \frac{2\sin 2\varphi}{A^2+B^2}\left(A\varepsilon'_{1\rm eff}+B\varepsilon'_{2\rm eff}\right), \tag{6}$$

where

$A=\varepsilon_{2eff}(2\varepsilon_{1eff}f\cos^2\varphi-1)$

$B=(\varepsilon^2_{2eff}-e^2_{1eff}+1)\cos^2\varphi+e_{1eff}-1$

φ is the angle of light incidence.

Experimentals

The magneto-optical properties of discontinuous cobalt films, the weight thickness d ($d=m/\rho S$), where m -film mass, ρ -metal density and S -film square) of which falls within the interval 1-30 nm is investigated. Discontinuous films were obtained by evaporation in vacuum of 10^{-5} Torr on glass substrates with a rate of 0.1 to 0.5 nm s^{-1}. The magneto-optical properties were measured at room temperature using the equatorial Kerr effect in the energy range 1.5 - 5.0 eV, the light incident angle being $\varphi=70^0$. The optical constants were determined using the Avery method.[6]

Results and Discussion

Fig. 1 presents the spectral dependences of the equatorial Kerr effect for the nano-dispersive cobalt with different weight thicknesses d and for polycrystalline cobalt.

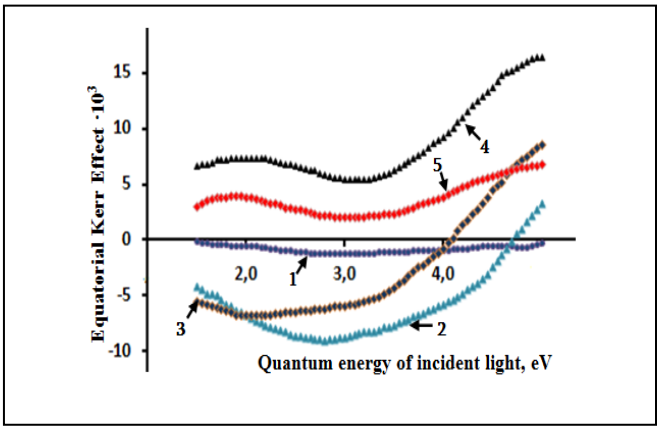

Figure 1. Experimental dependences of the equatorial Kerr effect on $\hbar\omega$ for Co films with weight thicknesses d=1.2 (1); 2.3 (2); 4.9 (3); 30 nm (4) and for polycrystalline Co films (5); (φ=70°).

It can be seen from the Figure 1 that for the films with different weight thickness the frequency dependences of the equatorial Kerr effect is significantly different from that of the similar dependences for bulk cobalt and depends on the film's effective thickness.

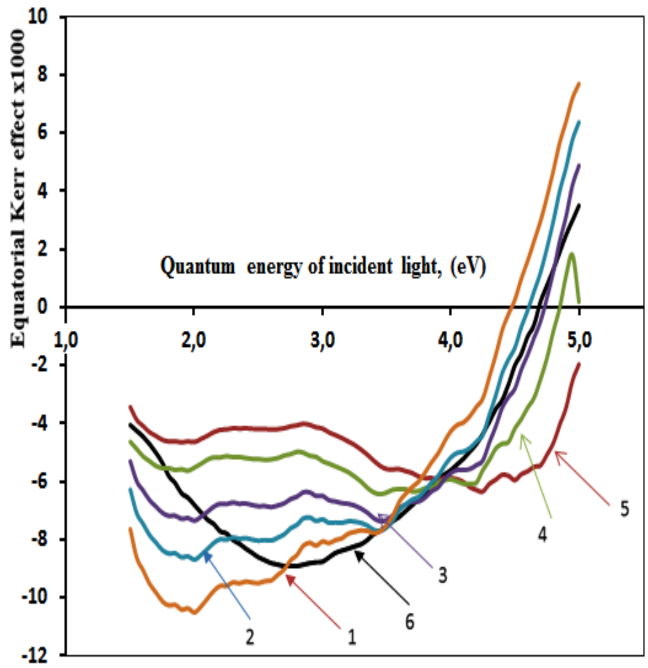

Figure 2. The calculated equatorial Kerr effect spectra of the nano-dispersive cobalt for q=0.2, f=1/3 and for different e_0=2.0 (Curve 1), 1.8 (Curve 2), 1.6 (Curve 3), 1.3 (Curve 4), 1.0 (Curve 5) and experimental dependences for Co films with 1.2 nm (Curve 6).

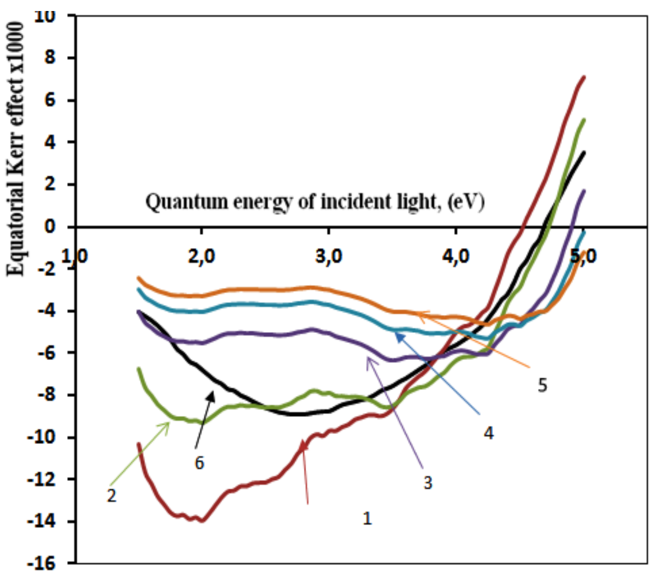

Figure 3. The calculated equatorial Kerr effect spectra of the nano-dispersive cobalt for q=0.2, ε_0=1.3 and for different f=0.2 (Curve 1), 0.25 (Curve 2), 1/3 (Curve 3), 0.4 (Curve 4), 0.45 (Curve 5) and experimental dependences for Co films with 1.2 nm (Curve 6).

The experimental results were compared with calculations in the framework of the effective medium approximation Eqn. (5) that allows to make some conclusions about dielectric permittivity of the medium and shape of magnetic particles. Fig. 2 gives the dependences of equatorial Kerr effect on the quantum energy of incident light, $\hbar\omega$, calculated by Eqns. (5) and (6) for namo-dispersive cobalt for different ε_0, and q=0.2, f=1/3. In this and following calculations the dielectric permittivity tensor components for bulk cobalt were used.

In Fig. 3 the frequency dependences of equatorial Kerr effect are presented for nano-dispersive cobalt with different values of the shape factor f, calculated in the framework of the effective medium approximation Eqn. (5) for q=0.2. In our case ε_0=1.3.

It is evident from the Figure 3 that the shape of magnetic particles influence significantly the magneto-optical properties of nano-dispersive cobalt.

Conclusion

The influence of the shape of magnetic particles and dielectric permittivity of the medium on the magneto-optical properties of the ultrafine metal films is investigated using the nano-dispersive cobalt as examples. The results have confirmed the significant change of the components of the tensor of effective dielectric permittivity and subsequently of the magneto-optical and optical properties which was brought about by the change of the shape of magnetic particles.

These calculations proved that if we take into account the shape of the particles, we will achieve a good agreement of the experimental results and the theoretical calculations.

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