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Magneto-Optical Properties in Transparent Region of Implanted Garnet Films

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***Abstract*—**We investigated magneto-optical Kerr effect in transparent region of implanted ferrite-garnet films for the (YBiCa)3(FeGe)5O12. The implantation process was carried out at room temperature by Ne+ ions with energy of 100 KeV and with various doses (0.5-2.5) 1014 ion/cm^2. We discovered that slight deviation of the plane of external alternating magnetic field from plane of sample leads to appearance intensive magneto-optical maximum in transparent region of garnet films ħω=0.5-2.0 eV. In the proceeding, we have also found that the deviation of polarization plane from P- component of incident light leads to the appearance of the similar magneto-optical effects in this region. The research of magnetization processes in transparent region of garnet films showed that the formation of magneto-optical effects in region ħω=0.5-2.3 eV has a rather complex character.

***Keywords*—**Ferrite-garnet films, ion implantation, magneto-optical, thin films.

I. Introduction

THE interaction of the light with the magnetized materials is characterized by some peculiarities on which the magneto-optical research method is based. Magnetized ferromagnetic, and dia- and paramagnetic materials placed in the external magnetic field reveal properties of double birefringence and dichroism, which cause different magneto-optical effects both on the reflected and transmitted light of the sample. In general magneto-optical effects can be divided into two groups: 1) Faraday and Cotton-Mutton Effects produced by the light which propagates through magnetic crystal, and 2) Magneto-Optical Kerr Effects, which are created by the light reflected from the magnetic crystal [1].

The methods of magneto-optical researches have lots of priorities, and their sensitivity towards spin is one of them. This enables us to define spin zone where different optical transfers are taking place [2]. The magneto-optical methods are also sensitive to the inhomogeneous properties of the magnetic, to a shape of a particle, to changes of the sizes, and to creation of a new magnetic phase [2]-[9]. Therefore, the detailed study of the magneto-optical properties of nano-heterostructures, thin films, implanted surfaces, magnetic fluids and other structures in relation to their structural content and technological production is necessary to explain the general laws of the formation of their physical properties. This would be a solution to many practical puzzles amongst which is to be mentioned the construction of modern materials according to the magnetic and magneto-optical parameters. The other prospects are to use them in modern elements with different memory capacities and integral optics, in magneto-optical devices, and in laser technology, etc.

Nowadays it has been a particular interest to study the magneto-optical properties of ultrafine magnetic structures. Magneto-optical investigation of these types of structures such as: magnetic fluids, thin discontinuous metal films, heterogenic glasses and etc. are the subject of overall interest conditioned by both theoretical and practical significance [3]-[9]. Besides, the ultrafine magnetic structures with structural heterogeneities, there are the media, heterogeneities of which carry magnetic character.

Heterogeneous magnetic structures could be formed in the surface layer of the solid by the different kind of outer impact, for instance, by the ion implantation. Implantation affects the physical-chemical properties, phase composition and surface structure of the solid. As a result, different radiation defects may cause the heterogeneity of the local magnetic properties [2], [9], [13].

There are considerable scientific and practical interests regarding investigation of the characteristic properties of magneto-optical behavior of the ion-implanted garnet films [10]. The coverage of their use could be conditionally divided into categories: visualization and mapping of spatial structures of magnetic fields; magneto-optical memory devices and storage of special use of information; magneto-optical sensors of super strong and super weak magnetic fields. In devices based on magneto-optical materials are used Faraday and Kerr magneto-optical effects. In this perspective, practical importance is given to ion implanted ferrite-garnet films as ion implantation weakens cylindrical magnetic domains, and it subsequently contributes to better use of their parameters [10]-[12].

In the present work, we give the results of magneto-optical investigations of the properties of the surfaces in transparent region of the ion-implanted $(YBiCa)_3(FeGe)_5 0_{12}$ garnet films.

The magneto-optical method of investigation of the surface of the solid [1], in which use is made of the fact that the light reflected from a magnetized medium penetrates into a sample to a small depth and the magneto-optical reflection effects are proportional to the magnetization of the surface layer, has already been widespread.

II. Experimental Details

In our experiments we used $(YBiCa)_3(FeGe)_5 0_{12}$ garnet films of 1.0 μm thickness prepared by means of liquid phase epitaxy on $Gd_3Ga_5O_{12}$ substrates with the (111) crystallographic orientation. The thickness of the substrates

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was 450 μm.

The implantation process was carried out at room temperature by Ne^+ ions with energy of 100 KeV and with various doses (0.5-2.5) $\cdot 10^{14}$ ion/cm^2. During this process, permeation depth of the implanted ions covered 0.1 μm, maximum quantity of the implanted ions went to the depth 0.07 μm.

For the magneto-optical investigation of a garnet surface we have chosen the odd-magnetization equatorial Kerr effect. The equatorial Kerr effect consists in a change in the intensity of linearly polarized light reflected from the sample in the case of reversal of magnetization of the sample. It can be written as:

$$\delta = \frac{I_H - I_{H=0}}{I_{H=0}} \quad (1)$$

where I_H and $I_{H=0}$ are, respectively, the intensities of light reflected from the magnetized and demagnetized sample.

The tensor of dielectric permittivity for bulk ferromagnetic materials can be represented as:

$$\varepsilon = \begin{pmatrix} \varepsilon & i\varepsilon' & 0 \\ -i\varepsilon' & \varepsilon & 0 \\ 0 & 0 & \varepsilon_0 \end{pmatrix} \quad (2)$$

where $\varepsilon = \varepsilon_1 - i\varepsilon_2$; $\varepsilon_0 = \varepsilon_{01} - i\varepsilon_{02}$ and $\varepsilon' = \varepsilon_1' - i\varepsilon_2'$.

The equatorial Kerr effect is related to the tensor components of the dielectric permittivity as follows:

$$\delta = \frac{2Sin2\varphi(A\varepsilon_1' + B\varepsilon_2')}{A^2 + B^2} \quad (3)$$

where $A = \varepsilon_2(2\varepsilon_1' Cos^2\phi - 1)$, $B = (\varepsilon_2^2 - \varepsilon_1^2)Cos^2\varphi + \varepsilon_1 - Sin^2\varphi$ and φ is the angle of light incidence on the sample.

The magneto-optical properties were measured at room temperature in the energy range 0.5-4.0 eV, the light incident angle being $\varphi = 70^0$.

The complex study of magneto-optical properties implies the calculation of each component of dielectric permittivity of the sample material.

To define the components of tensor dielectric permittivity of magneto-active medium besides the knowing of the meaning of magneto-optical effect it is necessary to define with the help of any optical method the optical coefficients reflection n and absorption k. The most widely used optical methods are the ellipsometry and the methods which study the intensity of the light reflected from the sample (Every method).

In the current work the optical constants were determined using the every method [14].

III. Results and Discussion

The research of the spectral dependences of the equatorial Kerr effect in transparent region for unimplanted and ion-implanted with various dose $(YBiCa)_3(FeGe)_5O_{12}$ ferrite-garnet films has shown that the deviation of polarization plane from P- component of incident light leads to the appearance of intensive magneto-optical maximum in the region $\hbar\omega$ =0,5-2,0 eV. For examples, Fig. 1 presents the dependences of the equatorial Kerr effect δ_e on the quantum energy of incident light $\hbar\omega$ for the $(YBiCa)_3(FeGe)_5O_{12}$ films before (1) and after (2) the implantation process with dose $2.0\cdot 10^{14}$ ion/cm^2, measured at $\varphi = 70^0$ and $\theta = 5^0$, where θ is the angle of deviation of the polarization plane from P- component of incident light.

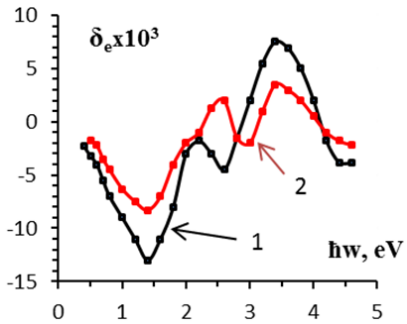

Fig. 1 Dependences of the equatorial Kerr effect δ_e on the quantum energy of incident light $\hbar\omega$ for the $(YBiCa)_3(FeGe)_5O_{12}$ films before (curve 1) and after the process of implantation $2.0\cdot 10^{14}$ ion/cm^2 (curve 2), measured at $\varphi = 70^0$ and $\theta = 5^0$

According to Fig. 1, the magneto-optical spectrum in transparent region $\hbar\omega$=0.5-2.3 eV of unimplanted and implanted garnet surfaces have the magneto-optical maximum in the region of light quantum energies $\hbar\omega$ =1.4 eV; The magneto-optical properties of the ion-implanted garnet films of these samples were reported previously [15], [16]. These researches of equatorial Kerr effect for garnet films showed that garnet films are not characterized by the similar peaks. It follows that in the specific experimental conditions these peaks are observed.

Fig. 2 presents the dependences of the detected equatorial Kerr effect on the angle θ of deviation of the polarization plane from P- component of incident light in the transparent region of garnet films at slight deviation of the plane of external alternating magnetic field from the plane of the sample.

According to Fig. 2, the dependences of the equatorial Kerr effect on the angle of orientation of the polarization plane from P- component of incident light θ are symmetrical with respect L. L is shifted on 2-3 degree from P- component of incident light.

The research of this effect showed that the orientation of the external magnetic field significantly influences on both the

effect itself and sign of effect.

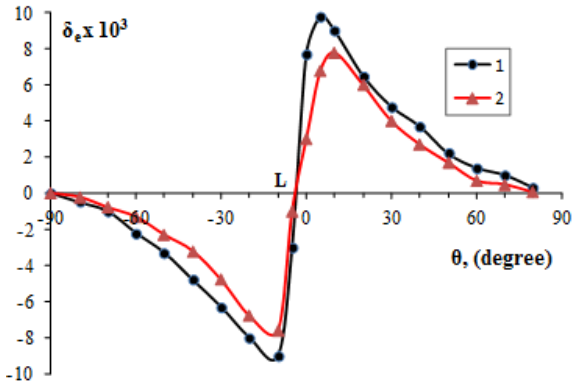

Fig. 2 Dependences of the equatorial Kerr effect δ_e on the θ for the $(YBiCa)_3(FeGe)_5O_{12}$ films ($\varphi = 70^0$) before (curve 1) and after the process of implantation $2.0 \cdot 10^{14}$ ion/cm^2 (curve 2)

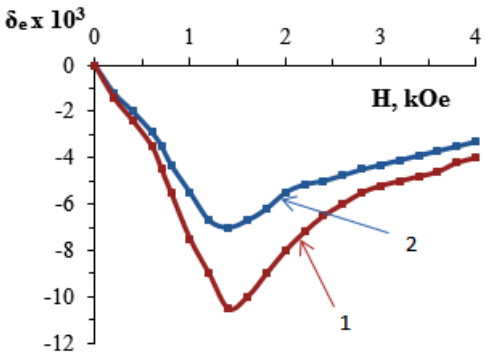

Fig. 3 Dependences of the equatorial Kerr effect δ_e on the magnitude of the external alternating magnetic field $H_\sim$ for the $(YBiCa)_3(FeGe)_5O_{12}$ films before (curve 1) and after the process of implantation $2.0 \cdot 10^{14}$ ion/cm^2 (curve 2)

We discovered that if the orientation of the external magnetic field strictly parallel to plane of sample the effect is not observed on the P-component of incident light. But slight deviation of the plane of external alternating magnetic field from plan of sample leads to appearance intensive magneto-optical maximum in transparent region ($\hbar\omega$ =1.4-1.6 eV) of garnet films.

Fig. 3 presents the dependences of the equatorial Kerr effect δ_e on the magnitude of the external alternating magnetic field $H_\sim$ for the unimplanted garnet films $(YBiCa)_3(FeGe)_5O_{12}$. The angle of deviation of the polarization plane from P-component of incident light being $\theta = 5^0$.

Fig. 3 demonstrates that the dependences of δ_e on $H_\sim$ have a peculiar form. Specifically, at the beginning an increase of the magnitude of the magnetic field causes an increase of the effect. But the magnetic field with magnitude more than 1.3 kOe makes a decrease of the effect. To explain this complex behavior, we assumed that in the region of small magnetic fields at the equatorial magnetization of garnet films with the perpendicular anisotropy the presence of the small perpendicular component of magnetic field causes demagnetization of a sample along axis of easy magnetization which perpendicular of surface of sample. A further increase of the field may be connected by turning of direction of magnetization in plane of the film, which leads to a decrease in the magnitude of the δ_e.

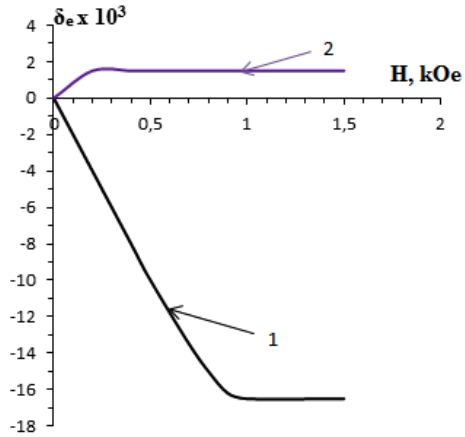

Fig. 4 Dependences of the equatorial Kerr effect δ_e on the magnitude of the external alternating magnetic field $H_\sim$ ($\hbar\omega$ = 2.6 eV) for the $(YBiCa)_3(FeGe)_5O_{12}$ films before (curve 1) and after the process of implantation $2.0 \cdot 10^{14}$ ion/cm^2 (curve 2)

Fig. 4 gives the dependences of the equatorial Kerr effect on the magnitude of the external alternating magnetic field $H_\sim$ for the $(YBiCa)_3(FeGe)_5O_{12}$ garnet films before and after the process of implantation in the region $\hbar\omega$ =2.6 eV. The research of magnetization processes of implanted films showed that implantation leads to a significant inhibition of the growth of anisotropy [15]. The latter is expressed in the decrease of the amount of saturation fields in-plane films. It could be seen from Fig. 4 that the unimplanted garnet films are magnetized by the magnetic field $H_\sim$=1.0 kOe, the implanted films are magnetized by $H_\sim$=0,2 kOe, whereas Fig. 3 demonstrates that the garnet films in the region $\hbar\omega$ =1.6 eV are not magnetized in fields 1.0-4.0 kOe. Therefore we can conclude that the formation of magneto-optical effects in the transparent region of garnet films has a rather complex character.

The experimental conditions were chosen to be optimum for the intensities of the effect to be studied.

IV. Conclusion

The conditions of the equatorial Kerr effect have been defined for the magneto-optical investigations of the properties of the surfaces in transparent region of the ion-implanted (YBiCa)3(FeGe)5O12 garnet films. We have detected that slight deviation of the plane of external alternating magnetic field from the plane of sample or the deviation of polarization plane from P- component of incident

light leads to appearance intensive magneto-optical maximum in transparent region of garnet films. The experimental conditions were chosen to be optimum for the intensities of the effect to be studied. The research of magnetization processes in the transparent region of garnet films showed that the formation of magneto-optical effects in the transparent region of garnet films has a rather complex character. It would be of considerable interest to observe the behavior of magneto-optical spectra by different magneto-optical effects both on the reflected and transmitted light of the sample, which will be a topic of future investigations.

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