Infrared magnetoreflection in $CoFe_2O_4$ single crystals

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Abstract. Magnetoreflection of unpolarized infrared radiation for single crystals of magnetostrictive cobalt ferrite spinel was studied. The correlation between magnetoreflection and magnetoelastic properties of that type of spinel was observed. It is shown that the magnetoreflection is the most pronounced in the region of a middle-infrared impurity band and reflection minima near phonon bands.

1. Introduction

Currently, a new branch of spintronics – straintronics is intensively studied. Straintronics studies changes of the elastic properties of spintronic materials under deformation due to application of a magnetic or an electric field [1-2]. There are a huge number of magneto-optical effects related to magnetoelastic properties of magnetic materials, preferably in polarized light [3-5]. However, research of magneto-optical effects in unpolarized light can also be of high importance. For example, huge magnetoreflection and magnetotransmission of natural IR radiation up to few tens of percent for various magnetic semiconductors possessing the magnetoresistance effect were obtained [6]. The four different physical mechanisms except for a deformation one were defined to contribute to these effects depending on the spectral region of interest [6]. Meanwhile, mechanic deformations could strongly influence the absorption of ferromagnetic semiconductors of the spinel type [7]. However, no experimental studies have been performed in this field yet.

In this work, we report about the discovery of huge magnetoreflection of unpolarized light and its correlation with magnetoeleastic properties of ferrimagnetic spinel $CoFe_2O_4$ with a high magnetostriction effect.

2. Experimental setup and samples

The $CoFe_2O_4$ single crystals (a_0 = 8.38 Å) were grown by the floating zone method [8]. In the experiments the samples in the form of plates (surface (001)) with a geometrical size of 4x4 mm^2 and a thickness d = 290 μm were used. According to the XRD and EDXMA data, the samples under study are single-phase and correspond to nominal compositions. The samples were polished before optical measurements with an average roughness better than 1 μm. Reflectivity and magnetoreflection of samples have been explored in natural (unpolarized) light in the spectral range of 1 - 30 μm at room temperature with the help of a custom created cryomagnetic device based on a prism spectrometer. The magnetic field H up to 3.6 kOe was directed along [100] axis of the sample (in-plane geometry) and perpendicularly to the incident light (Voigt geometry). The reflection coefficient was defined as $R = I_s/I_{Al}$, where I_s and I_{Al} are, respectively, intensities of unpolarized light reflected from the sample and the aluminium mirror used as a reference. Magnetoreflection was calculated as a relative change in reflection in the presence (R_H) and absence (R_0) of a magnetic field: $\Delta R/R_0 = (R_H-R_0)/R_0 \cdot 100\%$.

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Magnetostriction measurements were performed by the standard tensometric method in the same geometry of experiment as the magnetoreflection ones. The relative accuracy of the experiments was about 0.2%.

3. Result and discussion

The spectral dependence of reflectivity $R(\lambda)$ and optical conductivity $\sigma(\lambda)$ of the $CoFe_2O_4$ single crystal (insert in figure 1 (a)) are typical for band-gap semiconductors. They are formed by the fundamental absorption at $\lambda < 1.5$ μm, a frequency-independent part up to $\lambda = 10$ μm (with $R \sim 15$ %) and phonon bands E_1 at $\lambda = 16.4$ μm and E_2 at $\lambda = 24.2$ μm [9]. The optical conductivity was calculated from the reflectivity data for the $CoFe_2O_4$ crystal via Kramers-Kronig calculations (figure 1 (a)). As one can see, the results are in good accordance with the reflection spectrum.

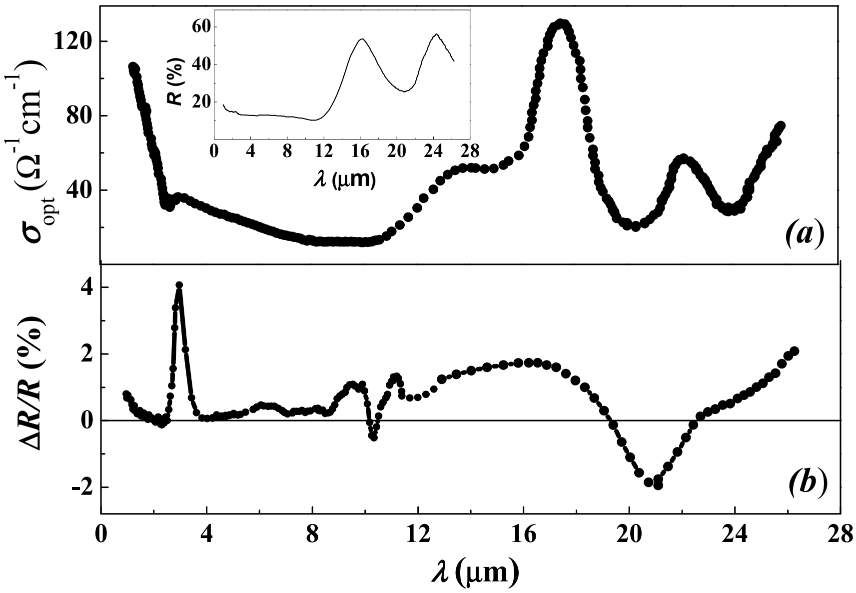

Figure 1. Spectral dependences of optical conductivity $\sigma(\lambda)$ (a) and magnetoreflection $\Delta R/R(\lambda)$ (b) for $CoFe_2O_4$ single crystals at $T = 295$ K in a magnetic field $H = 3.5$ kOe, $H \parallel [100]$. The insert shows the spectra of reflectivity $R(\lambda)$ of the sample.

The application of an external static magnetic field significantly changes the reflectivity (not shown) of $CoFe_2O_4$ and leads to appearance of the magnetoreflection effect $\Delta R/R$. It is worth to notice that this is the first experimental observation of the strong influence of a relatively weak magnetic field on the reflection coefficient of a magnetic semiconductor in the infrared range. In our case, the value of magnetoreflection for $CoFe_2O_4$ single crystals reaches about 4% at $H = 3.5$ kOe (figure 1 (b)), which is close to the values of $\Delta R/R$ for non-magnetostrictive ferromagnetic Hg(Cd)Cr_2Se_4 single crystals with the spinel structure [6].

The growth of $\Delta R/R(\lambda)$ at $\lambda < 1.5$ μm is associated with influence of magnetic field on the absorption edge ($E_g = 1.18$ eV for $CoFe_2O_4$), well-known for magnetic dielectrics as a "blue shift" [11]. A so-called MIR absorption band appears in magnetoreflection at $\lambda = 3$ μm. According to [12], this MIR-band is associated with the elastic modes of the crystal. We suppose that the observed peculiarities and a peak of $\Delta R/R(\lambda)$ in the region $1.5 < \lambda < 4.5$ μm are due to a change of the intensity and position of the MIR-band on temperature and magnetic field. Moreover, a small contribution of the tails of the absorption edge has to be taken into account. At $\lambda > 8$ μm, spectrum of $\Delta R/R(\lambda)$ is formed by the shift of the reflection minima near the phonon bands in the same way as it occurs in ferromagnetic semiconductors with strong electron-phonon interaction [6].

Figure 2 presents field dependences of magnetostriction and magnetoreflection at $T = 295$ K.

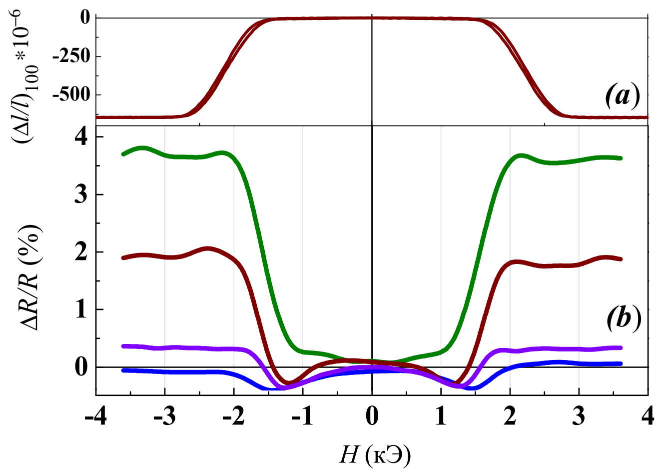

Figure 2. Field dependences of magnetostriction $(\Delta l/l)_{100}$ (a) and magnetoreflection $\Delta R/R$ (b) for $\lambda = 2.3$ μm (blue line), $\lambda = 2.9$ μm (green line), $\lambda = 3.2$ μm (red line) and $\lambda = 8$ μm (violet line) for $CoFe_2O_4$ single crystals at $T = 295$ K, $H \parallel [100]$.

Magnetoreflection is an even effect and is saturated at $H_s > 2.5$ kOe. The complex form of magnetoreflection between 1 kOe and 2 kOe can be explained by the different contributions of opposite sign associated with the fundamental absorption edge (positive $\Delta R/R$) and MIR-band (negative $\Delta R/R$). The behavior of $(\Delta l/l)_{100}$ is in good correlation with the published data for $CoFe_2O_4$ crystals [13]. One can notice a close correlation between magnetostriction and magnetoreflection field dependences. For example, magnetostriction appears at $H > 1.5$ kOe and shows a saturation at $H > 2.5$ kOe as well as magnetoreflection. The small changes of $(\Delta l/l)_{100}(H)$ and $\Delta R/R(H)$ at weak magnetic fields can be explained by the crystallographic anisotropy as well as by the crystal domain structure and the demagnetization factor. From the similarity of $\Delta R/R(H)$ and $(\Delta l/l)_{100}(H)$ dependences, we can conclude that the magnetoreflection in the region $1.5 < \lambda < 4.5$ μm may be connected with the occurrence of magnetoelastic strains in the $CoFe_2O_4$ crystals, so a new mechanism of magnetooptical effects in magnetostrictive semiconducting materials is observed.

4. Conclusion

In the wide infrared range, the giant magnetoreflection effect up to 4% was observed in the ferrimagnetic single crystal $CoFe_2O_4$ with a giant magnetostriction at room temperature. The effect was explained by the shift of the absorption edge at short wavelengths, by the change of the intensity and a position of the MIR-band and a shift of the reflection minima under the magnetic field applied. The close correlation of the magnetoreflection with magnetoelastic deformations in $CoFe_2O_4$ may pave the way for discovering a new mechanism of magnetoreflection of light in ferrimagnetic materials. The effect can be promising for creation of new magnetic-field-driven optical materials.

Asknowledgments

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