Analysis of magnetorefractive effect in $La_{0.7}Ca_{0.3}MnO_3$ thin films in the IR spectral range

A.N.Yurasov, T.N.Bakhvalova, A.V.Telegin[*], Yu.P.Sukhorukov[*]

Moscow State Institute of Radioengineering, Electronics and Automation (Technical University), 119454 Moscow, Russian Federation
[*]Institute of Metal Physics, Ural Division of Russian Academy of Sciences, 620990 Ekaterinburg, Russian Federation

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We have reported the results of investigation of a magnetorefractive effect on magnetoreflection and magnetotransmission modes in $La_{0.7}Ca_{0.3}MnO_3$ manganite thin films and crystals in the middle IR spectral range. The effects can reach several percents for single crystals and up to 20–40 % for thin films near Curie temperature. It was shown that the magnitude and spectra of the magnetorefractive effect strongly depend on magnetoresistance and optical properties of manganites. The overall qualitative agreement was obtained between the calculated in the framework of the effective medium approach data and experimental data.

Представлены результаты исследования магниторефрактивного эффекта на магнитоотражение и магнитопрохождение в тонких пленках и кристаллах манганитов состава $La_{0.7}Ca_{0.3}MnO_3$ в средней части ИК диапазона. Эффекты могут достигать несколько процентов для кристаллов и возрастать до 20–40 % для тонких пленок вблизи температуры Кюри. Показано, что величина и спектры магниторефрактивного эффекта сильно зависят от магнитосопротивления и оптических свойств манганитов. Достигнуто хорошее качественное согласие между экспериментальными данными и расчетами, выполненными в рамках теории эффективной среды.

1. Introduction

Magnetorefractive effect (MRE) is a high frequency response of magnetoconductance (MC) and consists in variations of the coefficients of reflection and transmission of electromagnetic waves of samples with GMR, TMR or CMR under magnetization (see [1], and references therein). Recently, it has been shown that magnetotransmission and magnetoreflection in manganites in the infrared spectral range near Curie temperature caused by MRE [2, 3]. The developed theories of MRE in metallic multilayers and granular alloys with GMR and TMR could not be appropriated for $La_{0.7}Ca_{0.3}MnO_3$ [2–4]. In this work, we present the results of calculations of MRE in $La_{0.7}Ca_{0.3}MnO_3$ bulk crystals and thin films in the framework of the effective medium approach (EMA) supposing that $La_{0.7}Ca_{0.3}MnO_3$ manganites consist of low and high resistivity phases with volume fractions depending on the magnitude of an applied magnetic field.

2. Model calculations and results

We considered semi-infinite $La_{0.7}Ca_{0.3}MnO_3$ crystals and thin films of the same compound with different thickness and some unpublished data of $La_{0.7}Ca_{0.3}MnO_3$ films were also used. We studied the temperature and spectral vari-

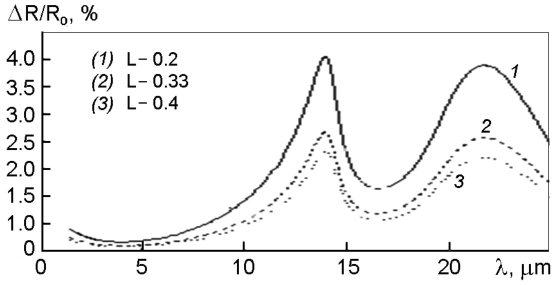

Fig. 1. The calculated MRE ($\Delta R/Ro$) for crystal $La_{0.7}Ca_{0.3}MnO_3$ ($y = 0.13$, $T = 250$ K, magnetic field $H = 3$ kOe) for different form-factor L.

ations of magnetoreflection and magnetotransmission effects (see experimental details in [3–6]). So supposing that $La_{0.67}Ca_{0.33}MnO_3$ manganites consist of low and high resistivity phases with volume fractions depending on the magnitude of an applied magnetic field, all our calculations were carried out in the framework of the effective medium approach theory (EMA) [7]. We calculated MRE ($\Delta R/Ro$) for crystal $La_{0.7}Ca_{0.3}MnO_3$ for different shape of the volume fraction like sphere ($L = 0.33$), and two ellipsoid ($L = 0.2$) and ($L = 0.4$) (Fig. 1). It was obtained that this form-factor could strong influence on the value of the MRE.

The frequency-dependent conductivity for magnetized two-phases samples from EMA equations can be written as:

$$\sigma(\omega,H) = \left[\frac{(1-y)\sigma_2 + y\sigma_1 - L(\sigma_1+\sigma_2)}{2(1-L)}\right] \times \left[1 + \left(1 + \frac{4\sigma_1\sigma_2(1-L)}{(1-y)\sigma_2 + y\sigma_1 - L(\sigma_1+\sigma_2)}\right)^{1/2}\right], \quad (1)$$

where σ_2 and σ_1 are the conductivities of the low and high resistivity phases, correspondently, y is the volume fraction of the high conductivity phase for magnetized samples, L — form-factor. If to denote x as a fraction volume of the high conductivity phase in the case of zero magnetic field, then

$$\sigma_2 = \frac{\sigma(\omega,0)[L(\sigma_1 - \sigma(\omega,0) - \sigma_1 x + \sigma(\omega,0)]}{L(\sigma_1 - \sigma(\omega,0) + \sigma(\omega,0)[1-x]}.\text{v} \quad (2)$$

The values of optical constants were obtained from [4–6]. Then using (1) Frenel's formulas and the experimental data of $\sigma(\omega,0)$ and σ_1 from [4–6] we calculated the MRE spectra. These spectra for crystal are demonstrated in Fig. 1. The modeling calculations for crystal of $La_{0.7}Ca_{0.3}MnO_3$ with $y = 0.13$ demonstrate that the MRE is about several percent and has a main maximum near 14 μm. It's related with the existence of the local maximum for $\sigma(\omega,H)$ in $La_{0.7}Ca_{0.3}MnO_3$ manganites. These facts are in good agreement with experimental data [2].

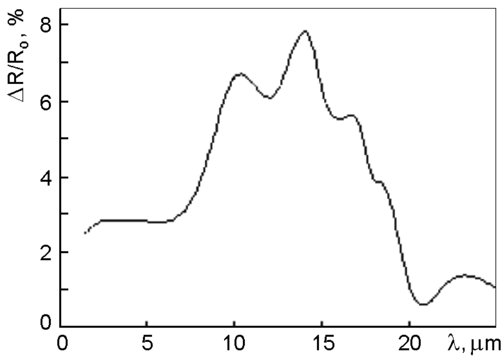

Fig. 2. The calculated MRE ($\Delta R/Ro$) for thin manganite film $La_{0.7}Ca_{0.3}MnO_3$ ($d = 180$ nm, $y = 0.1$, $T = 250$ K, $H = 3$ kOe).

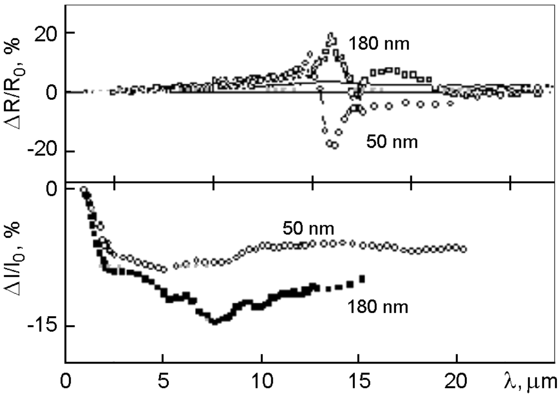

Fig. 3. The spectra of magnetoreflection ($\Delta R/Ro$) (upper) and magnetotransmission ($\Delta I/Io$) (bottom) for thin $La_{0.7}Ca_{0.3}MnO_3$ film with thickness 50 and 180 nm and $La_{0.7}Ca_{0.3}MnO_3$ crystal (solid line) at $T = 250$ K in the magnetic field of 3 kOe (upper) and 8 kOe (bottom), respectively.

In the case of thin films, the MRE ($\Delta R/Ro$) changes strongly (Fig. 2). We have demonstrated that sign, magnitude, frequency dependencies of MRE are very sensitive to the model parameters and a sample thickness from diagrams comparison in Fig. 1 (crystal $La_{0.7}Ca_{0.3}MnO_3$ — model of the semi-infinite space), Fig. 2 (the film $La_{0.7}Ca_{0.3}MnO_3$ ($d = 180$ nm)) and Fig. 4 (the film $La_{0.7}Ca_{0.3}MnO_3$ ($d = 300$ nm)).

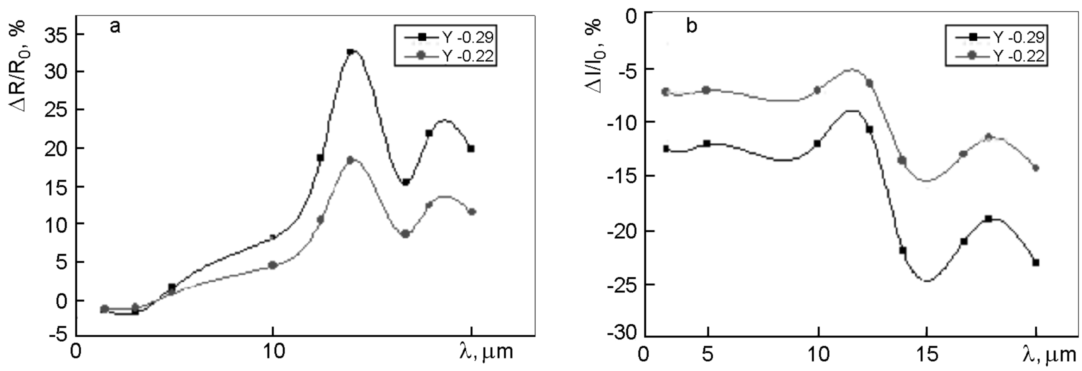

Fig. 4. The calculated spectra of magnetoreflection (a) and magnetotransmission (b) of $La_{0.7}Ca_{0.3}MnO_3$ film (d = 300 nm) for different volume fraction of the high conductivity phase y.

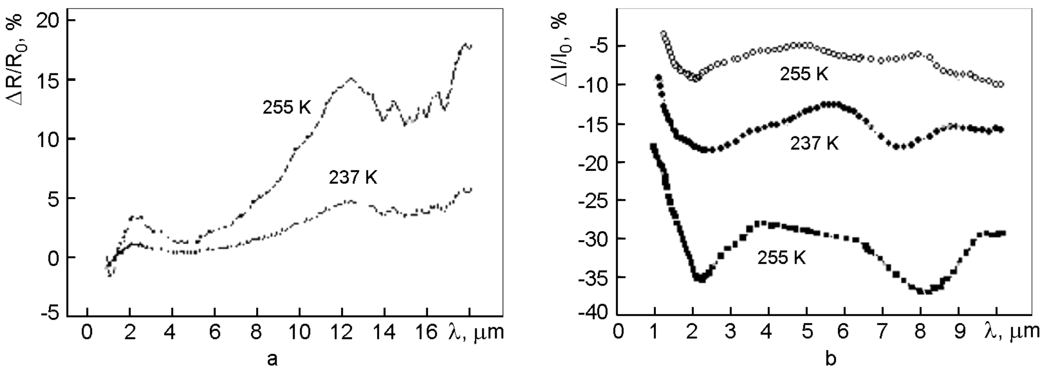

Fig. 5. The experimental spectra for manganite films $La_{0.7}Ca_{0.3}MnO_3$: magnetoreflection — a) (in-plane magnetic field is 4 kOe) and magnetotransmission — b) (out of-plane magnetic field is 8 kOe) for different temperature.

The experimental spectra for the thin films and crystal are demonstrated in Fig. 3 (T = 250 K). Values of the magnetoreflection can achieve the several percent for the crystal and to 20 % for the thin films in magnetic field. The main maximum of the MRE is near 14 μm as well as for crystal. We have demonstrated that the magnitude and the spectral shape of the obtained MRE spectra on reflection mode differ greatly from the one for crystals. The effect has in common positive sign that is opposite to the negative sign of magnetoresistance and magnetotransmission (Fig. 1, 2).

We calculated magnetoreflection (Fig. 4a) and magnetotransmission (Fig. 4b) for 300 nm thickness film with different values of y. In fact, different values of y correspond to different temperatures. We have shown that increase of y is corresponding to increase of the temperature to the point of Curie temperature. It was observed that the value of magnetotransmission increases up to 30–40 % and have negative sign of effect as well as magnetoresistance. We have rated that MRE (both $\Delta R/Ro$ and $\Delta I/Io$) for the thin films rapidly decreases approximately to zero if the $T < 225$ K in the 1–10 μm range. These calculated spectra are correspond to the experimental spectra (Fig. 5a,b) for different temperatures. Therefore, the change of the volume fraction of the high conductivity phases for magnetized samples y can strong change the MRE spectra.

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Аналіз магніторефрактивного ефекту в тонких плівках $La_{0.7}Ca_{0.3}MnO_3$ в ІЧ діапазоні спектра

А.Н.Юрасов, Т.Н.Бахвалова, А.В.Телєгін, Ю.П.Сухоруков

Представлено результати дослідження магніторефрактивного ефекту на магнитовідбиття і магнітопроходження в тонких плівках і кристалах манганітів сполуки $La_{0.7}Ca_{0.3}MnO_3$ у середній частині ІЧ діапазону. Ефекти можуть досягати кілька відсотків для кристалів і зростати до 20–40 % для тонких плівок поблизу температури Кюрі. Показано, що величина і спектри магніторефрактивного ефекту сильно залежать від магнітоопору і оптичних властивостей манганітів. Досягнуто гарну якісну згоду між експериментальними даними і розрахунками, виконаними в рамках теорії ефективного середовища.