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DIELECTRICS

Magnetostriction of $(YSmLuCa)_3(FeGa)_5O_{12}$ Garnet Films by the Low-Frequency Magnetic Susceptibility Method

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Abstract—Certification of new magnetic materials requires high-precision nondestructive methods. The method of measuring the magnetostriction constant of films by studying low-frequency magnetic susceptibility at elastic deformation of the films is proposed. The method allows a tenfold improvement of the accuracy of measurements of the magnetostriction constant as compared with the methods applied earlier.

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1. INTRODUCTION

There are several methods of measuring the magnetostriction constant [1]. The method of two-crystal X-ray diffraction provides a sufficiently good accuracy of measuring λ (about 15%) [2]. It is based on measuring the shift of diffraction X-ray peak from the film in an external magnetic field. However, the registration of this effect requires a high-precision adjustment of the examined film, which hinders the application of this technique for metrological control of films in conditions of mass production.

There are lower-precision methods of measuring film magnetostriction constants that are based on measuring the strains emerging in samples in an external magnetic field under the action of mechanical stresses [3] and on measuring the electric capacities of a capacitor with the studied magnetic medium between its plates [4]. The practical use of the first method [3] is limited by the necessity to apply considerable mechanical stresses to the film. The second method has another disadvantage: the requirement of independent measurement of the sample electric inductivity [4].

The ferromagnetic resonance (FMR) method based on the shift of a resonance line under the action of mechanical stresses applied to the film is widely used for the nondestructive measuring of magnetostriction constants [5]. This method also has disadvantages. Its low resolution power, low sensitivity to the magnetoelastic effect, and high error of measurements (more than 20%) are stipulated by the larger resonance line width as compared to the resonance line shift caused by the pressure applied to the film. The FMR line width in films is determined by the rapidly relaxing rare-earth ions contained in the films, and is usually about 1–2 kOe [6]. At the same time, the line shift at the bend of the film–support system up to a half of its thickness does not exceed a few dozen oersteds [5].

2. RESULTS

The proposed method of measuring magnetostriction constants is based on measuring the field dependence of a low-frequency magnetic susceptibility at the film remagnetization. The method consists in a simultaneous action of a radiofrequency magnetic field, mechanical stresses, and a constant magnetic field on a magnetic film. Special features in the curve of field dependence of differential low-frequency magnetic susceptibility $\chi H_{\|}$ are observed at certain values of the magnetic field intensity (Fig. 1). Here $H_{\|}$ is the constant magnetic field between the electromagnet rods, which is directed in parallel to the film plane.

The value of $H_{\|}$ varies with variations of the film deflection as a result of the mechanical effect on the film. Field $H_{\|}$ corresponds to the film transition either from the multidomain state to the single-domain state or from the state with one domain structure to the state with the structure of another type. The value of $H_{\|}$ corresponding to each of *1*–*7* curves (Fig. 1) changes as a result of the mechanical effect on the film. The magnitude of these changes indicates constant λ. The mechanisms determining the width of $\chi(H)$ features do not depend on the relaxation rate of rare-earth ions, but are mainly caused by the demagnetizing fields and by redistribution of volumes of domains of different magnetic phases [7]. Typical widths of these features of $\chi(H)$ are about 100 Oe [8], which is an order of magnitude less than the FMR line width.

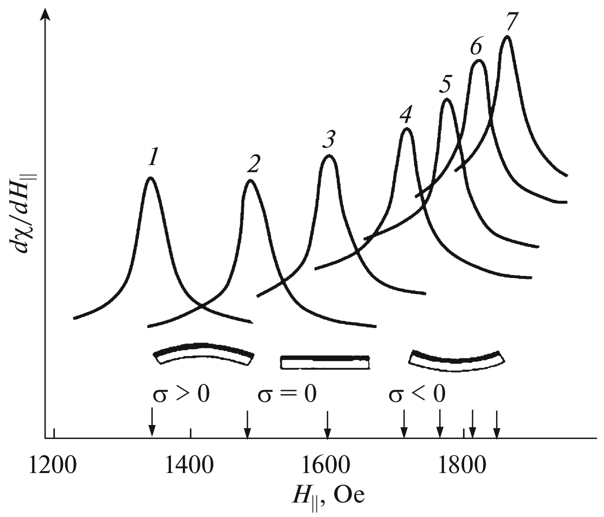

Fig. 1. Susceptibility $d\chi/dH_\parallel$ in the function of planar magnetic field $H_\parallel$ for different pressures p: (*1*) 1, (*2*) 0.5, (*3*) 0, (*4*) –0.5, (*5*) –0.7, (*6*) –0.9, and (*7*) –1 atm.

The measurements have been carried out at the inductive-frequency facility with a modernized measuring sensor (Fig. 2).

The facility provides an opportunity of a uniform mechanical loading of an examined film, which is attained by fixing the support as a diaphragm and evacuating the space on one of its sides. In this case, the uniform mechanical loading is applied to the film–support system made in the form of a disk with radius R that is much larger than its thickness h to produce the deflection of the disk center to a distance not exceeding its half-thickness (Fig. 2). The standard film of garnet $(YSmLuCa)_3(FeGa)_5O_{12}$ with an easy magnetization axis $\langle 111 \rangle$ that is perpendicular to the film plane is used to measure λ. The saturation magnetization of the film is $4\pi M_s = 190$ Oe. The film was applied to the gallium gadolinium support (the Poisson ratio $\nu = 0.29$) with thickness $h = 0.527$ mm, which was freely supported by a ring with radius $R =$ 14 mm. A multilayer inductance coil 5 mm in diameter was fastened to the film–support system. Pressure difference p up to 1 atmosphere was created on both sides of the film–support system (Fig. 2). The differential magnetic susceptibility was measured on a frequency of 1 MHz in a planar magnetic field up to 2 kOe.

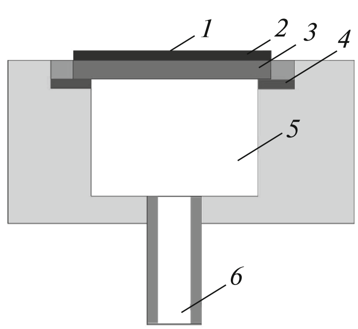

Fig. 2. Inductive-frequency facility: (*1*) film deflection, (*2*) and (*3*) garnet film and garnet support, (*4*) rubber ring, (*5*) base, (*6*) coupling to the vacuum pump.

In Fig. 3, the shift of the field of effective magnetic anisotropy $\delta H_\parallel$ is shown as a function of pressure p. The magnetostriction constant $\lambda = -2.55 \times 10^{-6}$ is determined by the shift of the field of effective magnetic anisotropy with accuracy of ±1.5%.

The deflection is controlled by measuring pressure difference p on both sides of the disk. The film strain σ is expressed through p according to formula [9]

$$\sigma = \frac{3}{8}(3+\nu)p\left(\frac{R}{h}\right)^2. \quad (1)$$

Mechanical stress σ applied to the film induces the magnetostriction effect, which results in the shift of the field of effective magnetic anisotropy $H_\parallel$ [5] by

$$\delta H_\parallel = \frac{3}{2}\frac{\lambda_{111}}{M_s}\sigma, \quad (2)$$

where M_s is the saturation magnetization and σ is assumed positive in the case of the film extension.

The calculation formula for determining the magnetostriction constant λ_{111} taking into consideration relations (1) and (2) is

$$\lambda_{111} = \frac{\delta H_\parallel M_s}{p}\left(\frac{h}{R}\right)^2 \frac{16}{(3+\nu)}. \quad (3)$$

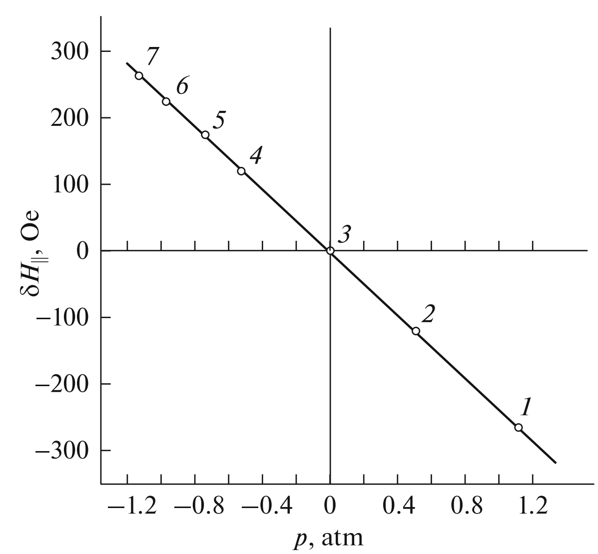

Fig. 3. Dependence of the magnetic anisotropy field $\delta H_\parallel$ on pressure p applied to the film: (*1*) 1 atm, (*2*) 0.5 atm, (*3*) 0 atm, (*4*) –0.5 atm, (*5*) –0.7 atm, (*6*) –0.9 atm, (*7*) –1 atm.

3. DISCUSSION OF THE RESULTS

The improvement of accuracy of constant λ measurement within the method of a low-frequency susceptibility (LFS) is attained by narrowing the band of apparent variations of $\chi(H)$ in comparison with the FMR line width. Other things being equal, the error in determining the resonant magnetic field (for the FMR method) or in the maximum of $d\chi/dH_{\|}$ (for the LFS-method) is proportional to the line widths. Since the band of apparent variations of $\chi(H)$ measurements is an order of magnitude narrower than the FMR line width, the error of constant λ measurement caused by the error generated at measurements of magnetic field $\delta H_{\|}$ by the LFS method is an order of magnitude less than in the FMR method.

4. CONCLUSIONS

The low-frequency susceptibility method has been used for the first time for the case of elastic deformation of a sample to improve the measurement accuracy of magnetostriction constant λ. The method of nondestructive control. In comparison with methods applied earlier, the accuracy of measurement of magnetostriction constant λ is an order of magnitude better.

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REFERENCES

1. E. V. Kharin, Cand. Sci. Dissertation (Baikov Inst. Metallurgy and Mater. Sci., Moscow, 2016).
2. J. Mada and K. I. Yamaquhi, J. Appl. Phys. **53**, 596 (1982).
3. I. J. Jida, Phys. Soc. Jpn. **22**, 1201 (1967).
4. E. R. Callen, A. E. Clerk, and B. Desavage, Phys. Rev. **130**, 1735 (1963).
5. G. P. Vella-Coleiro, Rev. Sci. Instrum. **50**, 1130 (1979).
6. R. V. Telesnin, A. M. Zyuzin, A. F. Martynov, and V. V. Randoshkin, *Physics of Magnetic Materials* (Irkutsk, 1981) [in Russian].
7. K. P. Belov, A. K. Zvezdin, A. M. Kadomtseva, and R. Z. Levitin, *Orientation Transitions in Rare-Earth Magnetics* (Nauka, Moscow, 1979) [in Russian].
8. S. P. Timoshenko, *Course of the Theory of Elasticity* (Nauk. Dumka, Kiev, 1972) [in Russian].

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