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FERROMAGNETIC RESONANCE IN THIN FILMS YIG : Co[1]

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The ferromagnetic resonance was studied on LPE (111) films of the composition $Y_3Fe_{5-x-y}Co_xGe_yO_{12}$, $x = 0 \div 0{,}11$; $y = 0 \div 0.14$. The measurements of the resonance field and linewidth were made at room temperature in the X and K wavebands, for the in-plane as well as the perpendicular orientation. Resonance relations were derived for the in-plane geometry. From the measured resonance fields, the g-factor, the effective magnetization and the fields of cubic anisotropy $2K_1/M$, $2K_2/M$ were determined.

ФЕРРОМАГНИТНЫЙ РЕЗОНАНС НА ТОНКИХ ПЛЕНКАЦХ ИЖГ : Co

Исследован феромагнитный резонанс на тонких пленках (111) типа $Y_3Fe_{5-x-y}Co_xGe_yO_{12}$ ($x = 0 \div 0{,}11$; $y = 0 \div 0{,}14$), /которые были получены методом ЭЖФ. Произведены измерения резонансного поля и ширины спектральной линии при комнатной температуре в диапазоне X и K при параллельной и перпендикулярной ориентациях. Получены расчетные формулы для анализа зависимости ориентации резонансного поля в плоскости пленки. На основе измерений резонансных полей определены: g — фактор, эффективная намагниченность и поля кубической анизотропии $2K_1/M$, $2K_2/M$.

I. INTRODUCTION

Recently the magnetic properties of Co-substituted (001) YIG films have been investigated, especially with respect to their interesting domain structure [1—3]. The anisotropy fields and the g-factor have been measured by the ferromagnetic resonance (FMR) method. The purpose of this article is to extend the FMR study to the (111) films with the composition $Y_3Fe_{5-x-y}Co_xGe_yO_{12}$, where $x = 0 \div 0.11$; $y = 0 \div 0.14$. For these films the anisotropy fields will be determined taking into account the second order cubic anisotropy contribution. An attention will be also given to the FMR linewidth.

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II. METHOD AND RESULTS

The films were grown by the LPE method on (111) $Gd_3Ga_5O_{12}$ substrates [2]. Their thickness was between 3 and 8 μm. The samples employed in the FMR measurement were of an approximately square form with the dimensions from 2.5 to 5 mm. The FMR experiments were carried out at the X and the K bands in the cylindrical cavities oscillating in the modes TE_{101} and TE_{102}, respectively. The FMR spectrum was detected as the first derivative of the absorption signal by means of a 100 kHz modulation field (spectrometer JES-3BQ).

First, we shall write the resonance relations corresponding to the in-plane and the perpendicular configuration used in our experiments:

a) In-plane geometry

The angular dependence of the resonance field is assumed to be in the form [4]

$$B_r(\varphi) = B_0 + \cos(6\varphi - \Delta) + \text{other terms}, \qquad (1)$$

where φ is the angle measured from the arbitrary reference direction in the (111) plane. The coefficients B_0, B_6 and Δ can be obtained by the harmonical analyses of the measured angular dependence. Theoretically they may be expressed as

$$B_0 = P - 2\pi M_{eff} + \frac{1}{2P}\left(2\pi M_{eff}\alpha_0 - \beta_0 + \frac{\alpha_0^2}{4} + \frac{\alpha_6^2}{8}\right) - \frac{\alpha_0}{2} \qquad (2)$$

$$\pm B_6 = \frac{1}{2P}\left(2\pi M_{eff}\alpha_6 - \beta_6 + \frac{\alpha_0\alpha_6}{2}\right) - \frac{\alpha_6}{2}, \qquad (3)$$

where $P = \sqrt{\left(\frac{\omega}{\gamma}\right)^2 + (2\pi M_{eff})^2}$; $\alpha_0 = -\frac{B_{A1}}{2} + \frac{B_{A2}}{18}$; $\alpha_6 =$

$= \left(\frac{6+\beta}{36\beta}\right) B_{A2}$; $\beta_0 = \frac{10\beta}{36} B_{A1}^2 + \left(\frac{10\beta+3}{648} + \frac{1}{72\beta}\right) B_{A2}^2 + \frac{5\beta}{36} B_{A1}B_{A2}$;

$\beta_2 = -\left(\frac{18+10\beta}{36}\right) B_{A1}^2 - \left(\frac{10\beta+3}{648}\right) B_{A2}^2 - \left(\frac{9+5\beta}{36}\right) B_{A1}B_{A2}.$

The parameter β depends on the resonance field B_r and the effective magnetization $4\pi M_{eff}$ as $\beta = \frac{B_r}{B_r + 4\pi M_{eff}}$. The relations (2), (3) are derived using the binomial expansion, so that they are valid under the condition $P^2 \gg$ (the term in the parenthesis of the corresponding equation).

In the above expressions γ is the spectroscopic spitting ratio, $B_{A1} = 2K_1/M$ the first order cubic anisotropy field, and $B_{A2} = 2K_2/M$ the second order cubic anisotropy field.

Table 1

Cobalt content x	$B_{r\perp}$ [mT] $f = 9.433$ GHz	B_0 [mT] $f = 9.433$ GHz	$\lvert B_6\rvert$ [mT]	$B_{r\perp}$ [mT]	g-factor ± 0.002
traces	503.2	258.7	0	995.4 $f = 23.483$ GHz	2.009
0.025	501.9	273.3	2.2	995.8 $f = 23.292$ GHz	2.004
0.05	511.4	285.3	5.7	1004.8 $f = 23.291$ GHz	2.000
0.11	519.6	306.4	14.95	1018.8 $f = 23.294$ GHz	1.984

For the angle Δ we have

$$\Delta = 6\varphi_0 + k\pi, \qquad (4)$$

where φ_0 is the polar angle of the reference direction with respect to the axis [110], $k = 0 \pm 1$. For the determination of the sign of B_6 it is necessary to know the angle φ_0. The positive sign corresponds to $k=0$ in the relation (4), the negative sign to $k = \pm 1$. In many cases, however, the sign of B_6 may be easily determined from the expected value of B_{A2} without specification of the angle φ_0.

b) Perpendicular geometry

The resonance field is given by the simple formula

$$B_{r\perp} = \frac{\omega}{\gamma} + 4\pi M_{eff} + \frac{2}{3} B_{A1} + \frac{2}{9} B_{A2}. \qquad (5)$$

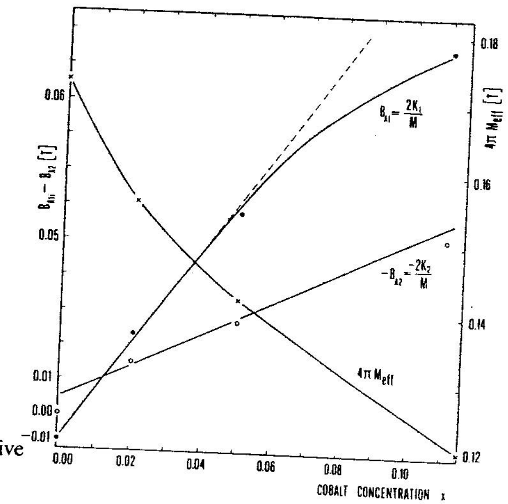

Fig. 1. The cubic anisotropy fields and effective magnetization vs cobalt concentration.

The results of the experiment are the values B_0, B_6, $B_{r\perp}$ at the X band and $B_{r\perp}$ at the K band. They are listed in Table 1. Here we give also the values of the g-factor calculated from the perpendicular fiels $B_{r\perp}$ at the X and the K bands. The anisotropy fields B_{A1}, B_{A2} and the magnetization $4\pi M_{eff}$ have been obtained by numerical computation using the relations (2), (3), (5). The resulting values are plotted in Fig. 1 as a function of the concentration x. We have also measured the minimum linewidth $(\Delta B_{pp})_{min}$, corresponding to a certain angle ϑ_{min} between the magnetic field and the film normal. The results are shown in Fig. 2.

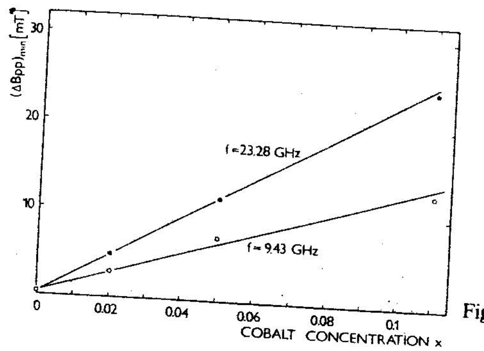

Fig. 2. The minimum linewidth vs cobalt concentration.

III. DISCUSSION

The second order anisotropy field B_{A2} depends approximately linearly on the Co concentration x, while the field B_{A1} is for a larger x, less than that expected from the linear variation (Fig. 1). For $x < 0.05$ both fields agree reasonably with those obtained on bulk single crystals [5]. As to the g-factor, its decrease with an increasing Co content (Tab. 1) cannot be satisfactorily explained at present (this decrease could be also connected with an inhomogeneity in the film). The measured minimum linewidth $\Delta B = \sqrt{3}(\Delta B_{pp})_{min}$ is in a good agreement with the results for the bulk single crystal at the X band [5]. In both these cases the relaxation mechanism seems to be connected with the presence of the Co^{2+} ions.

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