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INFLUENCE OF COBALT SUBSTITUTIONS ON THE DOMAIN STRUCTURE OF (100) AND (111) YIG FILMS[1]

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Films of $Y_3Fe_{5-x-y}Co_xGe_yO_{12}$ ($x = 0 \div 0.1$, $y = 0 \div 0.14$) prepared by the LPE method possess a strong dependence of the magnetocrystalline anisotropy constant K_1 on the Co^{2+} content. Due to the fact that the total anisotropy field perpendicular to the film plane $H_A = 2K_u/M_s$, determined by FMR, is small for these materials ($q = H_A/4\pi M_s < < 1$) both the influence of magnetocrystalline anisotropy and the stress induced anisotropy will play a significant role in the domain structure. In particular bubble domains were observed on (100) films with $K_1 > 0$ and with the tensile stress ($\sigma > 0$), while for the (111) plane this was the case if $K_1 < 0$ only.

ВЛИЯНИЕ ДОБАВОК КОБАЛТА НА ДОМЕННУЮ СТРУКТУРУ (100) И (111) ПЛЕНОК ИЖГ

На пленках типа $Y_3Fe_{5-x-y}Co_xGe_yO_{12}$ ($x = 0 \div 0,1$; $y = 0 \div 0,14$),полученных методом ЭЖФ, обнаружена выразительная зависимость константы магнитной кристаллической анизотропии от концентрации ионов Co^{2+}. С учетом факта, что определенное методом ФМР анизотропное поле, перпендикулярное к плоскости пленки, очень мало, на доменную структуру влияет, кроме наведенной анизотропии, связанной с напряжением, также магнитная кристаллографическая анизотропиа. Цилиндрические домены наблюдались на пленках (100) при $K_1 > 0$ и растягивающем напряжении $\sigma > 0$, тогда как на пленках (111) только при $K_1 < 0$.

I. INDTRODUCTION

In the previous paper [1] the influence of the stress induced anisotropy and the magnetocrystalline anisotropy on a domain structure was studied for two Co^{2+} concentrations. It was shown that a special type of domains called rectangular bubbles may exist in the remanent magnetic state if a tensile stress is present. The aim of this paper is to continue the study of the films with $\sigma > 0$ by extending the

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composition range of the (100) films as far as the Co^{2+} content is concerned and also by investigating the influence of Co^{2+} on the domain structure for the (111) films.

II. MEASUREMENTS

The way in which the composition of the films, the lattice mismatch and the magnetic parameters such as $2K_1/M_s$, $2K_2/M_s$, $4\pi M_{sef}$ were determined by using EMA, the double crystal X-ray method and FMR, respectively, are described in more details in [1] and [2]. The results of our measurements including the previous ones are summarized in Table 1.

For the (100) films $2K_1/M_s$ changes its sign with increasing Co^{2+} content; becoming positive it increases the value of the total anisotropy field perpendicular to the film plane $H_A^{(100)}$ [4]:

$$H_A^{(100)} = \frac{2K_1}{M_s} - \frac{3\lambda_{100}\sigma}{M_s} + \frac{2K_u^g}{M_s}. \qquad (1)$$

Table 1

Co^{2+} content	(100) plane				(111) plane				
		$\frac{2K_1}{M_s}$ [79.6 Am^{-1}]	$H_A^{(100)}$ [79.6 Am^{-1}]	Remanent domain structure		$\frac{2K_1}{M_s}$ [79.6 Am^{-1}]	$\frac{2K_2}{M_s}$ [79.6 Am^{-1}]	$H_A^{(111)}$ [79.6 Am^{-1}]	Remanent domain
traces	1	-70 ± 10	<0	irregular stripes	1′	-75 ± 15	$\approx0\pm20$	120 ± 20	stripes, bubbles Fig. 3
0.01^5	2	145 ± 10	180 ± 10	stripes, r. bubbles (Fig. 2a–d)	/				
0.02	3*)	220 ± 10	245 ± 10	stripes, r. bubbles	3′	235 ± 15	-150 ± 20	95 ± 20	stripes
0.05^5	4*)	510 ± 10	555 ± 10	stripes, r. bubbles	4′	580 ± 20	-270 ± 15	-154 ± 20	worse quality of stripes
0.11	5	970 ± 10	1090 ± 10	stripes, r. bubbles	5′	1060 ± 20	-520 ± 20	-500 ± 20	hardly any stripes

*) see [1]

As λ_{100} was found to be large and negative for bulk samples of corresponding compositions (see Fig. 1), the second term in (1) is positive and should substantially increase the positive $H_A^{(100)}$ values (Table 1). These values were calculated using FMR data and the values of lattice mismatch supposing that the growth induced anisotropy field $2K_u^g/M_s$ may be neglected for the (100) films with $\sigma>0$ (see [1]).

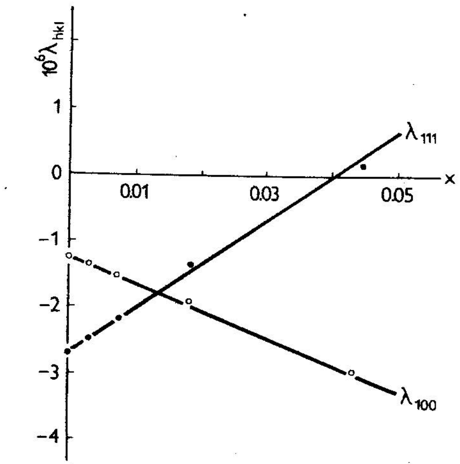

Fig. 1. Concentration dependence of the magnetostriction constants for $Y_3Fe_{5-x-y}Co_xGe_yO_{12}$ single crystals at $T=295$ K according to [3].

The original labyrinth domain structure of our films viewed by the Faraday effect is showh for sample 2 in Fig. 2a. The rectangular bubble domain as shown in Fig. 2d were observed for all (100) films with $K_1>0$ as a remanent structure if the sample was subjected before firstly to an in-plane field (Fig. 2b) and, secondly, to a strong enough perpendicular magnetic field. When increasing the perpendicular field gradually, characteristic changes of the domain structure were observed (Fig. 2c) before reaching the state with rectangular bubbles. A similar type of transient domain structure was reported for Mn^{3+} containing films [5] and interpreted in terms of a transition between the Neel and the Bloch walls due to a strong magnetostriction effect.

For (111) films the growth rates were chosen in such a way as to prepare also the samples with $\sigma\geqslant0$. In this case the total anisotropy field perpendicular to the film plane is [4]

$$H_A^{(111)} = -\frac{4}{3}\frac{K_1}{M_s} - \frac{4}{9}\frac{K_2}{M_s} - \frac{3\lambda_{111}\delta}{M_s} + \frac{2K_u^g}{M_s}. \qquad (2)$$

The values for our films were calculated from FMR data [6] according to the relation:

$$\frac{\omega}{\gamma} - H_\perp = H_A^{(111)} - 4\pi M_s. \qquad (3)$$

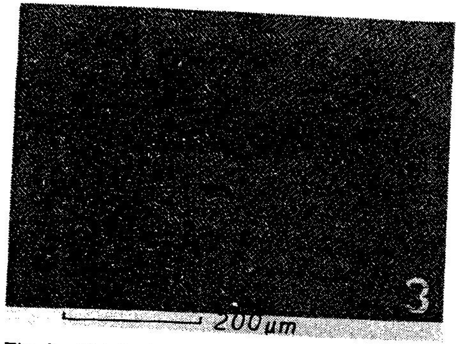

Fig. 2a. Origin domain structure of sample No 2 [$K_1>0$, (100) plane].

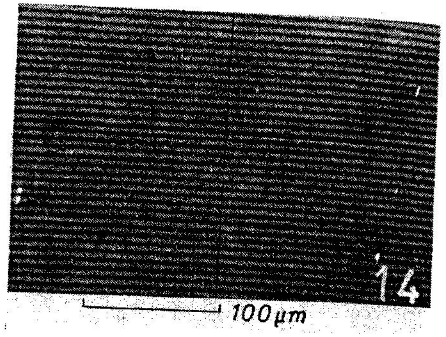

Fig. 2b. Remanent domain structure of the same sample after the influence of the inplane field. Stripes parallel with the [110] direction.

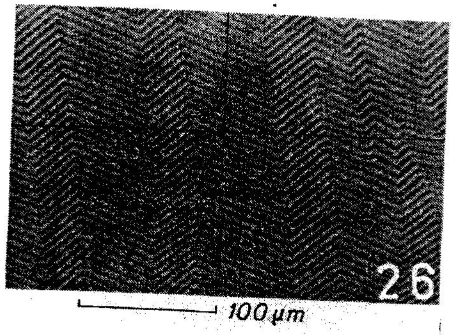

Fig. 2c. Domain structure in the applied perpendicular field 49000 Am^{-1} (sample No 2).

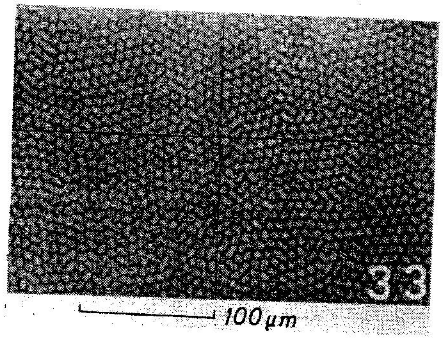

Fig. 2d. Rectangular bubble domains after subjecting sample No 2 to a perpendicular field 78800 Am^{-1}. Bubble domain walls are mostly parallel with the [100] and the [010] directions.

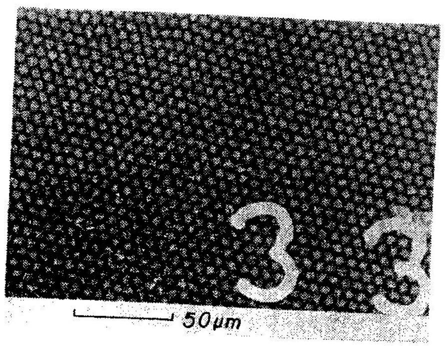

Fig. 3. Bubble domains in sample No 1′[$K_1<0$, (111) plane] after being subjected to a perpendicular field 59700 Am^{-1}.

Taking into account the dependence of λ_{111} on the Co^{2+} content (see Fig. 1) the contribution to $H_A^{(111)}$ of the stress induced anisotropy for a higher Co^{2+} content is expected to be negative and also the contribution of the magnetocrystalline anisotropy for all samples with $K_1>0$ will oppose the growth induced anisotropy field $2K_u^g/M_s$. Thus the resulting $H_A^{(111)}$ will decrease with an increasing Co^{2+} content in agreement with data in Table 1 including the domain observations, where only for the sample No 1′ a bubble domain structure was detected (Fig. 3).

III. CONCLUSIONS

Rectangular bubble domains were observed for all (100) films with $K_1>0$ in agreement with the values of $H_A^{(100)}$. Due to the fact that the values of this field are very small for all samples ($q = H_A^{(100)}/4\pi M_s<1$), the direction of magnetization in stripes and bubbles is not perpendicular to the film plane but makes an angle of about 60 degrees from the normal to the film [7]. As far as (111) film are concerned we can only conclude here that the compositions with $K_1>0$ are not appropriate for bubble domains.

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