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CONTROL OF ANISOTROPY FIELD IN HIGH FIGURE OF MERIT MAGNETIC GARNET FILMS FOR MAGNETO OPTIC APPLICATIONS

B. Perrand, M.F. Armand, H. Moriceau and J. Daval


Abstract - The aim of this paper is to describe the growth conditions and magneto-optical properties of iron garnet films with a high bismuth content having a high Faraday rotation (\( \Theta_F > 15000^\circ / \text{cm} \) at the 6328 Å wavelength), low absorption coefficients (\( \alpha < 1000 \text{ cm}^{-1} \) at 6328 Å) and controlled anisotropy field (200 < \( H_k \) < 3000 oe).

I - INTRODUCTION

For a few years, a new interest has been observed for magneto-optical applications using bismuth substituted magnetic garnet films. Devices applications such as printers, displays or optical components, based on the Faraday effect have been investigated /1,2/. These devices require high Faraday rotation constants, which are achieved by a large amount of bismuth in the compositions of the garnet films /3/.

For these applications the main films parameter is the figure of merit defined as \( 2 \frac{\Theta_F}{\alpha} \). In some devices such as printers or displays, the value of the anisotropy field, \( H_k \), is also an important parameter. Indeed, for these applications, cells of approximate dimensions 50 \( \mu \text{m} \) x 50 \( \mu \text{m} \) are defined in the magnetic garnet films, for example by a chemical etching. In each cell, the magnetization has any of the perpendicular directions, and a minimum field \( H_{SW} \) has to be applied to switch the magnetization (\( H_{SW} = H_k - 4 \pi M_s \) /4/.

The aim of this paper is to describe the growth conditions and the properties of such garnet films grown by liquid phase epitaxy and suitable for magneto-optical applications.

II - FILM GROWTH CONDITIONS

As the lattice constants of the garnet films, \( a_f \), are increased with bismuth content (\( \Delta a_f / \Delta x_{B_1} \approx 0.085 \text{ Å} \)), different substrates were needed such as Gd\(_3\)Ga\(_5\)O\(_{12}\) (\( a_s = 12.383 \text{ Å} \)), Sm\(_3\)Ga\(_5\)O\(_{12}\) (\( a_s = 12.44 \text{ Å} \)), (GdCa)\(_3\)(GaMgZr)\(_5\)O\(_{12}\) (\( a_s = 12.497 \text{ Å} \)).
Nd$_3$Ga$_5$O$_{12}$ ($a_s = 12.508$ Å). 2" diameter substrates used, were grown in our laboratory (SmGG, NdGG) or purchased from Crismatec (GGG, CaMgZr:GGG).

A large number of films with RE$_{3-x}$Bi$_x$Fe$_{5-y}$SyO$_{12}$ compositions were studied by varying bismuth content, $x_{Bi}$, and iron substitution, $y_s$, respectively in the (0,1.3) and (0,1.25) range.

Small lattice mismatches between films and substrates have been achieved by means of various cations of different sizes such as lutetium, thullium, yttrium, gadolinium or praesodymium in the dodecaedral sites and gallium or aluminium in the tetraedral and octaedral sites.

Up to 8 μm thickness films were grown by isothermal liquid phase epitaxy from PbO-Bi$_2$O$_3$-B$_2$O$_3$ fluxes in the 750-950°C temperature range using the horizontal dipping mode with alternate or uniform rotation. Films composition and properties were controlled by the choice of the melt and the supercooling. Melts used to grow these bismuth substituted iron garnet films were characterized by the following molar ratios:

$$12 < \frac{Fe_2O_3}{RE_2O_3} < 25 ; \quad 5 < \frac{Fe_2O_3}{S_2O_3} < \infty ; \quad 1 < \frac{PbO}{Bi_2O_3} < 7 ; \quad 5 < \frac{PbO}{B_2O_3} < \infty$$

III - FILMS CHARACTERIZATION

Films thicknesses were deduced with a good accuracy from an interference fringe count method in the (0.55 μm to 0.70 μm) wavelength range. Refractive index variations versus wavelengths, $n(\lambda)$, had been performed by the "m" dark lines method /5/.

Magnetic properties (Anisotropy constant, $K_u$, Magnetization, $4\pi M_s$, Curie temperature, $T_c$, and compensation temperature, $T_x$) were investigated by vibrating sample magnetometer, optical techniques based on Faraday effect and ferromagnetic resonance.

The Faraday rotation, $\theta_F$, was measured by rotation of the polarisation axis of a monochromatic light and the absorption, $\alpha$, deduced from spectrophotometry (at 6328 Å wavelength).

Lattice mismatch, $\Delta a = a_s - a_f$, was determined by X-ray diffraction. Films compositions were determined by micro-probe X-ray analysis at 20 keV.

IV - RESULTS

Depending on the substrate used, several compositions have been investigated. On GGG substrates, the maximum bismuth content in the films is about 0.7 by garnet.
formula and for the others substrates, the maximum amount of bismuth is about 1.3.

Figure 1 shows the variation of the Faraday rotation measured at 6328 Å wavelength with the bismuth content for two films compositions:

(I): (YLuBi)$_3$(FeGa)$_5$O$_{12}$/Gd$_3$Ga$_5$O$_{12}$ (111)
(II): (GdTmBi)$_3$(FeGa)$_5$O$_{12}$/Gd(Ga)$_3$(MgZrGa)$_5$O$_{12}$ (111)

Table 1 gives the magneto-optical properties of two films with composition respectively:

A: $Y_{2.11}Lu_{0.43}Bi_{0.48}Pb_{0.02}Fe_{3.67}Ga_{1.25}Pt_{0.022}O_{12}$
B: $Gd_{1.69}Tm_{0.29}Bi_{1.02}Pb_{0.07}Fe_{4.5}Ga_{0.4}Pt_{0.03}O_{12}$

<table>
<thead>
<tr>
<th>Film composition</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate</td>
<td>Gd$_2$Ga$<em>5$O$</em>{12}$</td>
<td>Gd$<em>{2.7}$Ca$</em>{0.3}$Mg$<em>{0.35}$Zr$</em>{0.65}$Ga$<em>4$O$</em>{12}$</td>
</tr>
<tr>
<td>Thickness : $h$ ($\mu$m)</td>
<td>3.2</td>
<td>2.8</td>
</tr>
<tr>
<td>Index : $n$ ($\lambda = 6328$ Å)</td>
<td>2.28</td>
<td>2.44</td>
</tr>
<tr>
<td>Magnetization : $4\pi M_S$ (G)</td>
<td>160</td>
<td>290</td>
</tr>
<tr>
<td>Anisotropy field : $H_k$ ($\alpha$)</td>
<td>1200</td>
<td>3200</td>
</tr>
<tr>
<td>Anisotropy constant : $K_u$ (erg/cm$^3$)</td>
<td>$7.6 \times 10^3$</td>
<td>$37.2 \times 10^3$</td>
</tr>
<tr>
<td>Faraday rotation : $\theta_F$ ($\lambda = 6328$ Å)</td>
<td>-3600</td>
<td>-17000</td>
</tr>
<tr>
<td>Absorption : $\alpha$ ($\lambda = 6328$ Å)</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>Factor of merit : $Q$ (°/dB) ($\lambda = 6328$ Å)</td>
<td>1.7</td>
<td>3.9</td>
</tr>
<tr>
<td>Curie temperature : $T_c$ (°C)</td>
<td>150</td>
<td>254</td>
</tr>
<tr>
<td>Compensation temperature : $T_x$ (°C)</td>
<td>no</td>
<td>-50</td>
</tr>
<tr>
<td>Lattice mismatch $\Delta a = a_s - a_f$ (Å)</td>
<td>+0.0002</td>
<td>-0.0065</td>
</tr>
</tbody>
</table>

In the B composition, the figure of merit, $2\theta_F/\alpha$ is increased, but the anisotropy field is too high. So to decrease this value, we have studied some substitutions by praseodymium in the dodecaedral sites. The influence of praseodymium content on the film anisotropy has been already shown in the (YbPrBi)$_3$(FeGa)$_5$O$_{12}$/Gd$_3$Ga$_5$O$_{12}$ system /6/. Praseodymium in the (GdTmBi)$_3$(FeGa)$_5$O$_{12}$ composition leads to decreasing anisotropy field as shown in the figure 2. At the same time, the other main parameters ($4\pi M_S$, $\theta_F$, $\alpha$, $\Delta a$) are not varied.

To minimize the absorption coefficient, $\alpha$, it is necessary to adjust the melt composition and the growth conditions. It can be easily observed that, on films grown from a some melt, if the growth temperature is changed, $\theta_F$ and $\alpha$ decrease or increase at the same time. Indeed, the absorption, for a constant amount of bismuth in the films, is very sensitive to the concentration of lead and platinum in the film. Furthermore a lot of films with low absorption coefficients are obtained from melts with lower molar ratio PbO/B$_2$O$_3$ /7/.
V - CONCLUSION

We have grown by isothermal liquid phase epitaxy, high concentration bismuth substituted iron garnet films with good and controlled properties required for several magneto-optical applications. On large lattice parameter gallate substrate, we obtained films with a very high figure of merit (2 ΘF/α measured at 6328 Å - 4 °/dB).

To control the films properties \(4\pi M_S, \Theta_F, \alpha, \Delta a\), it is necessary to adjust the melts composition. The value of the anisotropy field, \(H_k\), in the system (GdTmBi₃)(FeGa)₅O₁₂ is fitting with an incorporation of praesodymium in the films.

Fig. 1 - Rotation Faraday (at 6328 Å wavelength) versus the bismuth content, \(x\), for two compositions: \(\text{(I)(YLu)}_3-x\text{Bi}_x\text{(FeGa)}_5\text{O}_{12}/\text{Gd}_{3}\text{Ga}_5\text{O}_{12}\), (II) (GdTm)₃-x\text{Bi}_x\text{(FeGa)}_5\text{O}_{12} (open circles correspond to films A and B given in Table 1).
Fig. 2 - Anisotropy field versus the prasodymium content for the composition

$$\text{Bi}_{1.15}(\text{GdTm})_{1.85-x}\text{Pr}_x\text{Te}_{4.6}\text{Ga}_{0.4}0_{12}$$

$$\Theta_F = 2.10^4 \text{o/cm}$$

$$4\pi M_s \sim 300 \text{ G}$$

$$\alpha \sim 1250 \text{ cm}^{-1}$$

REFERENCES


