GROWTH AND CHARACTERIZATION OF GARNET THIN FILMS FOR MAGNETOOPTICAL READOUT

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ABSTRACT

Magnetic tape offers potential capacities of 20 Mbits/cm², while conventional readout heads are limited, particularly by the impossibility of integrating a large number of heads in a stack. A magneto-optical high resolution transducer, using thin garnet films, allows the exploration of the whole track width. These films, grown by liquid phase epitaxy, have to satisfy to some properties as : magnetization about 300 Gauss, high Faraday rotation and low uniaxial anisotropy (K_u). Films of $\text{YIG Bi}_x\text{Ga}_{1-x}\text{Al}_y$, $\text{YIG Bi}_x(\text{Ga}, \text{Al})_y$ were grown from different melts composition.

As grown films present high Faraday rotation but also high uniaxial anisotropy. Annealings at several temperatures are necessary to decrease K_u .

For gadolinium garnet films doped with Bi and Pr, ($\text{Gd IG} : \text{Bi Pr Al}$), the required Faraday rotation and uniaxial anisotropy are obtained as grown, the presence of praseodymium decreasing the K_u .

1. INTRODUCTION

Magnetic tape has a potential storage density (20 Mbits/cm²) quite comparable to that of optical media. Furthermore it takes advantage of a long history of industrial development leading to low price high quality and availability. Tests on commercial VTR showed that the noise limitation to very high density lies in the head and playback amplifier noise rather than in the tape itself. Another strong limitation to high density recording on tape is the inability to integrate headstacks to a very high level. In order to record the full width of the tape in a single pass with a limited number of heads one has to scan the tape with a rotating drum. The most obvious method of scanning is transverse and was actually used in the 2 inches VTR. However the need to stabilize the tape when the head enters the track restricts the use of this scanning device to very wide tape. The most common method of scanning is oblique as are all modern VTR. The major drawback of helical scanning is the loss of azimuth when the tape dimension changes due to variation in humidity and temperature. Longitudinal readout offers many advantages but the number of tracks needed for a high capacity recorder ranges from 1000 to 2000 with 5 microns pitch. Whereas the most advanced project integrates 20 magnetic heads with 90 microns pitch for Static Digital Audio Tape (SDAT).

Optical readout offers a high signal to noise ratio especially at low head to tape speeds : magnetic signal power ranges between pico Watts and nano Watts, whereas optical source power ranges between micro Watts and milli Watts. The other advantage of optical readout is the possibility to image thousands of tracks on readily available integrated detectors. 5000 cells CCD are today available at a reasonable cost. The low longitudinal resolution of optic compared to magnetic heads is not a major drawback since the tape signal to noise ratio varies as the inverse of the longitudinal density squared and only the first power of track density. In other words, for the same area density a square bit form offers better depth magnetization of the tape and less spacing loss than a conventional elongated bit form.

A good compromise between track density and bit density is a typically 5 by 1 square microns bit cell. A dedicated optical system allows such resolution over the full width of a half inch tape.

A magneto-optical high resolution transducer [1,2] allows the exploration of the whole track width if its characteristics satisfy following specifications : magnetization : $4\pi M_s = 300$ Gauss (Experiments showed that the saturation magnetization should not exceed half the coercivity of the tape) ; Faraday rotation : $\Phi_F > 10000^\circ/\text{cm}$ ($\lambda = 6328 \text{ \AA}$) ; zero-field strip domain period $P_0 = 3 \mu\text{m}$, which implies optimal characteristic length and uniaxial anisotropy (K_u) of 0.13 and 3600 erg/cm³, respectively. The obtention of a high Φ_F requires the use of Bismuth which induces a high K_u due to the non-uniform distribution of this ion in the garnet dodecahedral site. This problem can be solved in two ways : either by proceeding to annealings which reduce K_u through migration of Bi ions, or by doping the films with ions that make magnetization planar.

2. EXPERIMENT

Epitaxy furnace is a three zones furnace controlled by computer. Substituted Yttrium and Gadolinium iron garnet layers were grown by LPE on one inch-diameter (III)₂ - oriented GGG or substituted GGG substrates with a lattice constant of 12,383 and 12,498 Å respectively. The substrate has a small tilting during the whole process to decrease the melt residual after dipping. At the end of growth process the substrate was rapidly removed from the melt and rotated with 900 rpm to spin off the melt.

2-1. YIG : Bi_x Ga_y (x = 0.26 - 0.32 ; y = 1.06 - 1.01)

The films grown from these compositions have not large Faraday rotation ($\phi_F \approx 2000^\circ/\text{cm}$), but due to their high crystallographic quality they have been used to analyze the behaviour of the physical parameters after heat treatment. A set of as-grown films have been obtained at 1133 °K and from Fig. 1, it is observed that whatever their thickness, the stripe period condition $P_0 = 3$ microns is not obtained. On the other hand, after quenching at different temperatures ($T = 1305 - 1473$ °K) the value of P_0 can be decreased. An increase of the saturation magnetization $4\pi M_s$ (from 243 to 350 Gauss) is associated with the gallium migration from tetrahedral to octohedral sites during the heat treatment [3]. Such an increase explains a part of the shift of P_0 with T as observed in Fig. 1. The other part is due to the decrease of the uniaxial anisotropy when T_q increases since P_0 is an increasing function of the characteristic length $l = (AK_u)^{1/2} / \pi M_s^2$. That is the reason why in table 1 two samples of same $4\pi M_s$ (319 and 324 Gauss) but different K_u (4200 and 12660 erg.cm⁻³) present strong difference for their characteristic length and therefore for P_0 .

Fig. 1. Stripe Domain period dependence (P_0) with film thickness (h) for Grown and quenched films. Solid lines are calculated from "Shaw table".

	As grown T_G	Quenched at T_q				As grown T_G
T_G and T_q (°K)	1133	1305	1397	1473	1150	
K_u (erg/cm ³)	8500	7000	4200	2200	12660	
$4\pi M_s$ (Gauss)	243	283	319	350	324	
l (μm)	0,238	0,179	0,115	0,103	0,156	
Q	3,6	2,3	1,05	0,50	3,03	
$\mu_w \times 10^{-3}$ (cm.s ⁻¹ Oe ⁻¹)	65	80	95	130	50	

Table 1 - Magnetic properties of YIG : Bi Ga films before and after heat treatment. Uniaxial anisotropy (K_u). Magnetization ($4\pi M_s$). Characteristic length (l). Quality factor (Q). Domain mobility (μ_w).

2-2. YIG : Bi_x (Al Ga)_y (x = 0.4 - 0.6 ; y = 1.02 - 1.1)

Fig. 2 shows that whatever the growth temperature (T_G) may be, no film prepared from this composition verifies the condition : $P_0 = 3 \mu\text{m}$ ($4\pi M_s = 217$ to 350 G). The characteristic length l is too large due to the high K_u . To avoid this, quenching at various temperatures T_q has been performed. Only the results obtained with films of the series Nr. 1581 ($4\pi M_s = 217$ G) at $T_q = 1471^\circ\text{K}$ are plotted in Fig. 2. It is well known that the uniaxial anisotropy K_u is defined from two contributions : K_u^G which is growth induced and K_u^S which is stress-induced anisotropy. It is observed from Fig. 3 that high K_u values are mainly associated with growth-induced anisotropy. Annealing in an oxygen atmosphere can reduce significantly K_u^G without change on K_u^S (Fig. 4). Some films exhibit a planar magnetization ($K_u \approx 0$) after

Fig. 2. Dependence of the stripe domain period P_0 with the film thickness h for different growth (T_G) and quenching (T_q) temperatures. Solid lines are calculated from "Shaw table".

quenching at too high temperature ($T_q = 1473^\circ\text{K}$). Quenching at a lower temperature gives a very precise control of K_u and therefore an approach of the selected characteristic length ($l = 0.13 \mu\text{m}$). However, one of the specifications is not met. The Faraday rotation cannot exceed $4000^\circ/\text{cm}$ and, in spite of many attempts an increase of the magneto-optical effect is associated with a bad surface morphology of the films. When the bismuth oxide content is too large in the melt, the viscosity

becomes too high and the quality of the film surface decreases. However, in the optical devices the defect concentration must be lower than 1 defect/cm², which cannot be reached with such solutions.

Fig. 3a 3b. Variation in K_u as a function of growth temperature T_g before and after quenching. K_u^S = stress contribution, K_u^G = growth contribution.

2-3. Gd IG : Bi Pr Al

Substituted - gadolinium garnet has been selected since higher Bi contents can be introduced in such a host [4]. Praseodymium ions has a high contribution to the Faraday rotation but its main effect is to reduce K_u [5]. Similar result can be obtained with Nd^{3+} ions. The saturation magnetization is reduced to the selected value from the substitution of Fe^{3+} by non magnetic ions. The best choice is obtained with Al^{3+} ions with a smaller content compared to Ga^{3+} in order to match the lattice parameters of the films and substrates.

MELT	Melt ratio				T_g (°K)	Film Composition					$T_{comp.}$ (°K)
	Fe + Al Gd + Pr	Fe Al	Pb Bi + B	$\frac{\text{Garnet}}{\text{Total}}$		Gd	Pr	Bi	Fe	Al	
A	20	8	1.5	0.10	1038	1.70	0.34	0.96	4.34	0.66	200
B	18.1	8	1.5	0.11	1023	1.50	0.46	1.04	4.32	0.68	145

Table 2 - GdIG : Bi Pr Al. Melt ratio (Mole %) and film composition.

$T_{comp.}$ = compensation temperature.

Two melt compositions have been investigated as reported in Table 2 as a function of mole % ratios. The precise film compositions are obtained from electron microprobe analysis and the magnetic compensation temperature $T_{comp.}$ is deduced from Faraday rotation measurements at 6328 Å wavelength. As shown in Fig. 4, the uniaxial anisotropy presents smaller values compared to the previous compositions due to Pr^{3+} ions which contribute to an in-plane magnetization. Substituted GdIG garnets have high Faraday rotation ($\phi_F = 14000^\circ/\text{cm}$ at $\lambda = 6328 \text{ Å}$) and since heat treatment is not necessary to adjust the magnetic parameters, these compounds are very interesting from manufacturing process point of view. The uniaxial anisotropy can be controlled either from the growth temperature (K_u decreases with T_g) or

Fig. 4. Variation in K_u as a function of growth temperature T_g . Melt A

MELT	T_G (°K)	K_u (erg/cm ³)	$4\pi M_s$ (Gauss)	l (μ m)	Q	$\mu_w \times 10^{-3}$ (cm.s Oe ⁻¹)
A	1038	21300	206	0,48	12,6	0,723
	1030	19600	240	0,36	8,6	0,695
	1023	18300	300	0,26	5,2	0,690
B	1023	6400	340	0,13	1,4	1,400

Table 3 - Magnetic properties of GdIG : Bi Pr Al films.

from a higher praseodymium content in the melt (melt B). Compare to the previous compositions (Table 3) the domain wall mobility μ_w is lower due to the rare earth ions which increases the magnetic relaxation effects but the values of μ_w are high enough for devices applications.

2-4. The feasibility of the magneto-optical transducer was performed on a one channel mock-up [6]. The tape was recorded either conventionally or by Curie point writing of Chromium dioxide pigments in order to record very narrow tracks. The readout pick-up comprises :

- An HE-NE Laser
- A partially polarized beam splitter
- A .25 NA objective
- The magneto-optical transducer
- A polarizing beam splitter for rotation measurement
- Two optical detectors feeding a differential amplifier.

The partially polarizing beam splitter transmits about 90 % of the light to the objective. It reflects only 10 % of the returning beam towards the cells but 90 % of the information amplitude (perpendicular to the source polarization) is reflected. The polarization detector compares the amplitude of both projections 45° apart from the source polarization axis.

A second optical configuration has been tested : a conventional polarizing beam splitter and quarter wavelength plate were used to reflect nearly 100 % of the light toward the cells. Instead of detecting the polarization rotation (which in this configuration does not exist), two cells detect the far field shift due to the index difference between spin up and down domains. The highest recorded frequency to date corresponds to 16 kFCI on a 3 microns track i.e. 20 Mbits per square centimeter. The measured S/N ratio at 8 kFCI is 16 dB (RMS/RMS) over 16 kFCI Band width. This is slightly above the decoding threshold. Compared to a conventional head with a 1 mm track width, the S/N ratio is 7 dB lower. By introducing a 25 dB correction to account for the track width ratio, a 18 dB advantage to the optical head is obtained.

3. CONCLUSION

The feasibility of an optical readout of magnetic has been shown using thin garnet film transducers. Two solutions have been investigated : either from heat treatment which reduces K_u or by doping the films with ions which induce in-plane magnetization. Materials with optimum physical parameters and good surface quality as required in device application can be monitored from Bi Pr Al - substituted GdIG. Such a device enables the realization of a high data rate fixed head recorder. As an example : one Gigabit per second can be obtained by parallel reading of 2000 tracks on a half inch tape running at 20 ips. Of course such a recorder also needs a recording headstack. Work is going on integrating some 2000 record-only heads using thermally induced effects.

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