Thick Epitaxial YIG Films with Narrow FMR Linewidth

I.I. Syvorotka[1,*], I.M. Syvorotka[1] and S.B. Ubizskii[2]

Abstract. *The La-doped yttrium iron garnet (YIG) films with thickness up to 130 μm were grown by liquid phase epitaxy (LPE) method. All grown thick films demonstrate "mirror" and "striation" types of surface morphology that depend from film growth temperature and thickness. Addition of B_2O_3 is favourable to a change the surface morphology into a "mirror" one. The mechanisms of the morphological changes are discussed. It was found that the ferromagnetic resonance (FMR) linewidth appreciably depends from surface morphology of grown films. For thick films with "mirror" surface the FMR linewidth is less than 0.8 Oe and more than ten times less in comparison with films with "striation" surface.*

Key words: liquid phase epitaxy, yttrium iron garnet films, surface morphology, ferromagnetic resonance linewidth.

I. Introduction

The yttrium iron garnet $Y_3Fe_5O_{12}$ (YIG) is one of the most important garnets for microwave applications because of its narrow ferromagnetic resonance (FMR) linewidth that reaches values about 0.6 Oe [1] and corresponds to very low microwave loss. Due to the very slow magnetic relaxation process in these materials, magneto-static surface and volume waves can propagate in the garnet film allowing an analogue signal processing directly in the microwave range. Devices like filters, delay lines, oscillators and circulators have been designed using such garnet films. At this many devices need films with thickness more than few micrometers that cannot be obtained with pure YIG grown on gadolinium gallium garnet (GGG) substrate without mechanical stresses and cracks induced by a lattice parameter mismatch of about 0.007 Å [2].

This work is devoted to growth conditions investigation for the thick epitaxial La-doped YIG films and influence of their surface morphology on the FMR linewidth.

II. Experimental

The garnet films with nominal composition $Y_{2.93}La_{0.07}Fe_5O_{12}$ were grown by standard liquid phase epitaxy (LPE) method on (111)-oriented GGG substrate with 2 and 3 inch diameters from a supersaturated melt based on the PbO-B_2O_3 flux. All technological experiments were carried out on air using the five-heating-zone LPE furnace "Garnet-3" (LPAI, France). The growth temperature was varied in the range 900…1000 °C.

The surface morphology of grown films was observed using the phase interference contrast mode of polarizing microscope ECLIPSE LV100 POL (Nikon, Japan).

FMR linewidth was measurement at frequency 3 GHz by non-destructive FMR spectrometer based on the local excitation of magneto-static wave (MSW) resonance in a small area of the film under a bias magnetic field with hole-like profile. Such magnetic profile is created by a small hole in a one of electromagnet pole located close to the film surface. The MSWs are excited by the electromagnetic waves emanating from short-cut waveguide positioned in a magnet pole hole.

III. Results and Discussion

One of the main parameters determining the LPE film growth technological conditions is a concentration of the crystal-forming oxides into the melt. An extraction of the garnet-forming oxides from the melt occurs during the film growth process. It results in the change of crystal-forming oxide concentration in the flux and in such a way changes the solution saturation temperature in time. If the film growth temperature within the LPE process is kept up constant then it leads to continuous decreasing of the supercooling degree and growth rate as well as to changes of the film composition and its properties over the growing layer thickness. Using series of some simple additional experiments the main growth-strategy parameters for growth of thick YIG:La films with different diameters were found. The growth rate change with temperature $\partial f/\partial T$ and growth temperature change with extracted mass of garnet $\partial T/\partial m$ found for charge of the total mass 5 kg are presented in the Table 1.

Table 1. Main growth-strategy parameters for grown YIG:La films

Diameter, inch	$\partial f/\partial T$, μm/min/°C	$\partial T/\partial m$, °C/g
2	-0.034	-2.2
3	-0.040	-3.2

To keep a constant growth rate the film growth temperature is decreased as a rule for each subsequent film in series, or it is fluently going down during growth run for thick films. The value ΔT_g of temperature lowering for growing film with needed thickness was calculated by

$$\Delta T_g = \rho h \pi D\left[\frac{D}{2} + l\right] \cdot \frac{\partial T}{\partial m}, \qquad (1)$$

where ρ is garnet density, h is film thickness, D is substrate diameter and l is substrate thickness.

Using found growth-strategy parameters and (1) the YIG:La films with thickness up to 130 μm at growth rate 0.1…0.8 μm/min was successfully grown.

The grown films demonstrated two type of surface morphology. The first type was a "mirror" film surface, and the second was classified as a "striation" one [3] and presented in Fig.1.

[1] SRC "Carat", R&D Institute of Materials, Lviv, Ukraine
[2] Lviv Polytechnic National University, Lviv, Ukraine
[*] syvorotka.jr@gmail.com

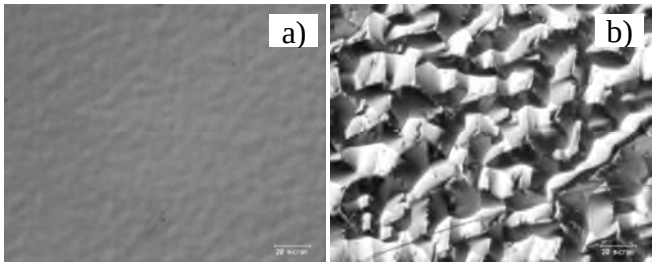

Fig. 1. Surface morphology of thick YIG:La films, classified as "mirror" (*a*) and "striation" (*b*). Magnification is ×400 on both photos.

Surface morphology dependence from the film growth temperature and thickness for YIG:La films grown from flux with different B_2O_3 content is shown in Fig.2.

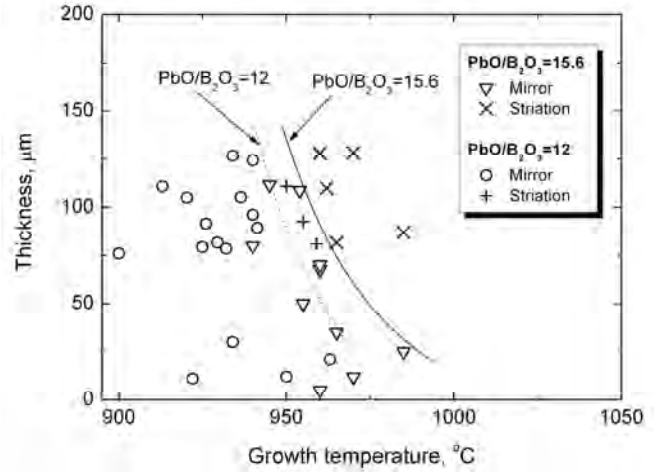

Fig. 2. Surface morphology dependence from the film growth temperature and thickness.

The morphological change for the thick YIG:La films with increase in film thickness and growth temperature is essentially attributed to the fact that the (111) face for garnets is an atomically rough "K-face" (kinked plane) and that the (110) and (211) faces are atomically smooth and stable "F-face" (flat planes) [4]. For "mirror" surface, the growth mechanism is normal (kinetic), since the (111) is a "kinked" plane for garnets. Solutes are easily incorporated into crystals on the "K-face". The surface irregularity observed on "mirror" surfaces results from the substrate surface irregularity.

When the morphology changes from "mirror" to "striation", the growth mechanism probably changes from the kinetic growth to the growth on the side faces of the surface irregularities, which are atomically smooth and progressed by tangential (diffusion) mechanism of growth.

The effect of growth temperature on the morphological changes could be explained by the temperature dependence of the diffusion process including a viscosity change with temperature.

Addition of B_2O_3 essentially shifts the morphological boundaries and changed the surface morphology of films into a "mirror". The effect of B_2O_3 on surface morphology for thick YIG:La films seems to be similar to that for thick $Y_{2.8}Gd_{0.2}Fe_5O_{12}$ films [5].

Fig. 3 shows the typical FMR spectrum measured at 3 GHz of the YIG:La films with different thickness. With increase of the film thickness a number of resonance lines decreases. The FMR measurements on the thin films with thickness a few micrometers showed very narrow linewidth of less than 0.4 Oe (Fig. 3*a*). The linewidth of main resonance peak for thick films with "mirror" surface was ≤ 0.8 Oe. The best result of FMR linewidth is 0.47 Oe showed film with thickness about 80 μm (Fig. 3*b*). This is significantly lower then for films with "striation" surface morphology. Such films showed the linewidth in range 8…10 Oe.

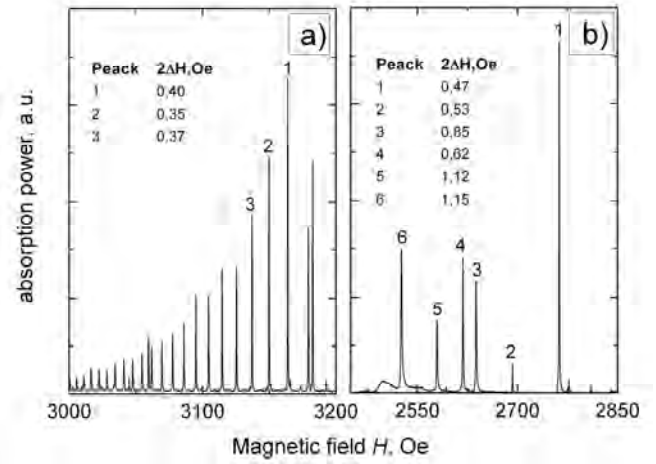

Fig. 3. The typical FMR spectrum at 3 GHz for YIG:La films with thickness 6 μm (*a*) and 80 μm (*b*).

IV. Conclusions

Thick $Y_{2.93}La_{0.07}Fe_5O_{12}$ epitaxial films demonstrate the "mirror" and "striation" type of surface morphology that depend from film thickness and growth temperature and could be explained by change of growth mechanism from kinetic to diffusion one. The flux compositions can also affect the mechanism for the growth process. It was established that the FMR linewidth strongly depend from surface morphology and is in about ten times less for "mirror" films than in films with "striation" surface.

Acknowledgment

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References

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