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Magnetostriction Constants of Epitaxial La, Ga: YIG Films Measured by Microwave Resonance

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Abstract. The magnetostriction constants of $Y_{2.85}La_{0.15}Fe_{3.75}Ga_{1.25}O_{12}$ epilayers have been measured by observing the shift of the resonance line of a thin film which is stressed by three-point bending. The result is $\lambda_{111} = -(0.75 \pm 0.15) \times 10^{-6}$ and $\lambda_{100} = -(0.4 \pm 0.1) \times 10^{-6}$ which is in agreement with the measurements on bulk single crystals. This result indicates that there is no growth induced contribution to the magnetostriction in thin films of this garnet grown by liquid phase epitaxy.

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The magnetostriction constants λ_{111} and λ_{100} of garnets have been measured by a variety of methods on bulk crystals [1]. Knowledge of these constants is necessary since part of the uniaxial anisotropy of epitaxial garnet films for bubble devices is due to magnetostriction and the stress introduced by the mismatch between the lattices of the film and the substrate [2]. It is worth while to measure the magnetostriction constants of epitaxial films directly as it is possible that there is an additional magnetoelastic energy induced by the growth process [3, 4]. It is the purpose of this paper to demonstrate a method that can be used for measuring the magnetostriction constants of epitaxial films and to present results for bubble films of approximate composition $Y_{2.85}La_{0.15}Fe_{3.75}Ga_{1.25}O_{12}$.

Our method of measurement is based on the possibility of exciting the microwave resonance of a large thin plate on a spot of about 1 mm^2. The experiments are performed on a conventional microwave spectrometer containing a special cavity: the "microwave milliscope", similar to Soohoo's microscope [5]. The milliscope is simply a rectangular TE_{102} cavity (10 GHz frequency) with one thin wall (0.25 mm). At the spot where samples are usually placed, e.g. at $\frac{1}{4}$ of the cavity height, we have made a circular hole in the thin wall (diameter 2 mm). A large sample is fixed to the outside of the thin wall and the resonance is excited only on the spot facing the hole in the wall. Since the sample is kept outside the cavity, simple methods can be used to strain the sample in order to measure the magnetostriction. In our method we use a three-point loading of a rectangular plate ($X \times Y \times Z = 0.5 \times 2 \times 10$ [mm]) (see Fig. 1). The deformation is a bending along the Y-axis. Half-way along the length of the plate, where the screw (Fig. 1)

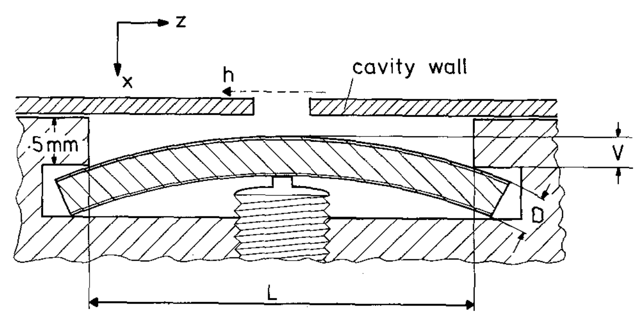

Fig. 1. Schematic drawing of the sample mount. The screw displaces the middle of the $0.5 \times 2 \times 10$ [mm] sample plate. The resonance is excited in the middle of the plate only by the microwave field leaking out of the hole in the cavity wall ($L = 9$ mm)

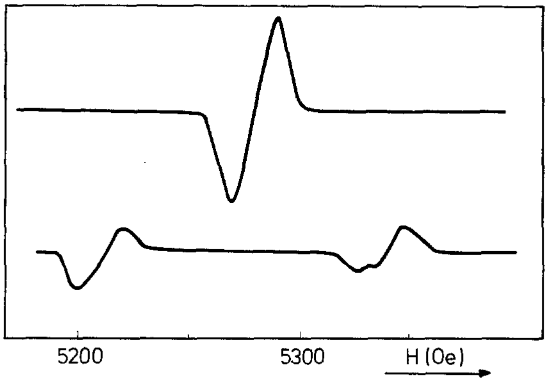

Fig. 2. Derivative absorption line of a YIG film measured before (*a*) and after (*b*) applying the strain. Lines from the films on both sides of the substrate shift in opposite directions

displaces the sample, the deformation is circular with radius [6]

$$R = L^2/12V .$$

The meaning of the symbols can be read from Fig. 1.

The displacement V is calculated from the rotation angle and the pitch of the screw. Although the strain is essentially non-uniform within the thickness of the 500 μm thick plate, varying from compression (bottom surface) to tension (top surface), the strain is practically uniform in the thin magnetic films on both surfaces which are typically less than 5 μm thick. The elongation of these films along the z-direction is

$$\frac{\Delta l}{l} = \pm \frac{6VD}{L^2}, \tag{2}$$

where the + and − sign refer to the top and bottom films, and the stress is

$$\sigma = Y \frac{\Delta l}{l}, \tag{3}$$

where Y is Young's modulus ($Y = 20.8 \times 10^{11}$ dyne/cm^2).

Because of the uniaxial stress in the plane of the film the position of the resonance line with the external field applied perpendicular to the film will shift. For [111] and [100] films this shift is [7]

$$\delta H_{111} = \frac{3}{2} \frac{\lambda_{111}}{M} \sigma, \quad \delta H_{100} = \frac{3}{2} \frac{\lambda_{100}}{M} \sigma. \tag{4}$$

In Fig. 2 we show the perpendicular resonance spectrum of a La, Ga:YIG film recorded before (*a*) and after (*b*) deforming the plate. Since the strains

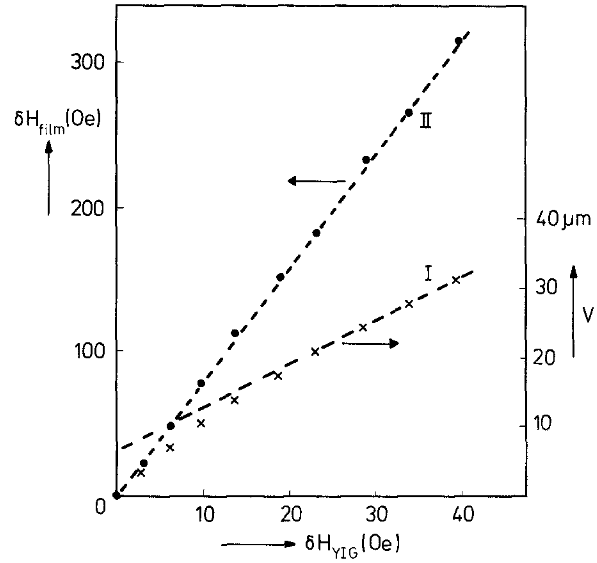

Fig. 3. Double plot of the shift of the resonance lines of an $Y_{2.85}La_{0.15}Fe_{3.75}Ga_{1.25}O_{12}$ layer on top of an $Y_3Fe_5O_{12}$ layer on a $Gd_3Ga_5O_{12}$ substrate. I. δH_{YIG} versus the displacement V of the screw. II. δH_{film} of the La, Ga:YIG layer versus δH_{YIG}

in the films on both sides have opposite sign, the resonance line splits into two lines which shift symmetrically. The small broadening of the lines compared to the shift shows that the strain is reasonably uniform. In Fig. 3 we show a plot of the line positions of a YIG film used for calibration of the equipment versus the displacement of the screw. Unfortunately there is a deviation from linearity for small displacements. From the slope the graph for large displacements we calculate, using (1–4), that $\lambda_{111} = -2.2 \times 10^{-6}$. From the literature λ_{111} is known to be -2.8×10^{-6} [8]. On repeating the experiment we find values of λ_{111} between 50% and 80% of this literature value. This is consistent with measurements of the strain, using strain gauges, which yield strains between 50% and 80% of the calculated strain and also yield non-linearity for small displacements.

We chose to increase the accuracy by combining measurement and calibration in one experiment. To this end we grew an epitaxial La, Ga:YIG film on top of pure YIG film. This ensures that the strain in the layers is equal, so that the magnetostriction can be measured by comparing the shift δH_{film} of the La, Ga:YIG film and the shift δH_{YIG} of the YIG film. From (4) it appears that these are related by

$$\delta H_{film} = \frac{M_{YIG}}{M_{film}} \times \frac{(\lambda_{111})_{film}}{(\lambda_{111})_{YIG}} \times \delta H_{YIG}. \tag{5}$$

In Fig. 3 we have plotted δH_{film} versus δH_{YIG} of the same sample for which we plotted δH_{YIG} versus v. The data now fit a straight line, the slope of which gives us $(\lambda_{111})_{\text{film}}/(\lambda_{111})_{\text{YIG}}$. We repeated this experiment several times and always found a straight line. Averaging these data and inserting $M_{\text{film}} = 5.5$ Gauss, obtained from measurements on similar La, Ga:YIG films on a vibrating sample magnetometer, yields $(\lambda_{111})_{\text{film}} = (-0.75 \pm 0.15) \times 10^{-6}$. We would like to point out that another way to combine measurement and calibration is simply to mount the epitaxial film plus substrate on top of a YIG film to ensure equal radii of curvature. One must then correct relation 5 for the different thicknesses of the substrates.

Experiments on a La, Ga:YIG film grown on a thinner than usual substrate, requiring smaller forces, did not exhibit the above mentioned nonlinearities. Apparently these are due to insufficient rigidity of the sample mount. This thinner substrate was 250 µm thick and [100] oriented. λ_{100} of the La, Ga:YIG film was found to be $\lambda_{100} = -(0.4 \pm 0.1) \times 10^{-6}$.

Our results can be compared with the data obtained for bulk crystals of Ga:YIG for the same Ga concentration [9]: $\lambda_{111} = -0.6 \times 10^{-6}$ and $\lambda_{100} = -0.7 \times 10^{-6}$. The data for λ_{111} are equal within experimental error but our result for λ_{100} is smaller than that of bulk Ga:YIG. However, it appears from [9] that λ_{100} is very sensitive to the Ga concentration so that this difference is not necessarily significant. This result indicates that there is no growth induced contribution to the magnetostriction in thin films grown by liquid phase epitaxy.

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