MAGNETOIMPEDANCE AND MAGNETOINDUCTANCE EFFECT IN (BiY)$_3$(FeGa)$_5$O$_{12}$ THIN FILM

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The giant magnetoimpedance (GMI) effect due to the magnetoinductance of a coil with an insulating layer of (BiY)$_3$(FeGa)$_5$O$_{12}$ (Bi:YIG) as core is studied at different frequencies. The layer is grown by LPE (Liquid Phase Epitaxy) method on GGG (GaGd Garnet) substrate and has a thickness of 8 μm. Experimental results concerning the magnetoinductance of Bi:YIG layer at 1 kHz are also presented. The impedance of the coil changes by varying the applied magnetic field. The increase of the magnetic field decreases the magnetoinductance of the coil. The magnetoimpedance ratio can reach values of 81 % and 43 % at frequencies of 120 kHz and 250 kHz, respectively, for H = 60 Oe. Such ratio can approach to 46% at a frequency of 1 kHz for H = 50 Oe. The variation of the magnetoinductance recommends this material for applications as magneto-inductive switches.

1. Introduction

Magnetoimpedance (MI) effect has recently attracted great interest because of its application in micro-magnetic sensors and magnetic recording heads. The dependence of the electrical impedance in a ferromagnetic wire on the applied field was firstly observed many years ago [1]. But the first experiments, on the so called giant magnetoimpedance (GMI) effect, were performed in 1994 [2-3] and resulted into the development of practical devices and applications. The GMI effect has been observed in thin films, multilayers, sandwiches [4-5], but also in YIG films as inductors [6].

Garnet based materials have suitable GMI response, because of their specific domain structure due to the magnetocrystalline anisotropy. Bi:YIG thin films could be used in technology, at low and high frequencies [7].

In this paper, the magnetoimpedance (MI) and magnetoinductance of Bi:YIG thin films are studied to develop new applications in magnetic sensors. Magnetic excitation due to the domain walls movements has been studied by applying an AC magnetic field to the magnetic sample as a core of the solenoid. Magnetoimpedance response of Bi:YIG thin films vs. applied magnetic field at different frequencies and magnetoinductance at 1 kHz, are also presented.

2. Experimental procedure

The film is grown by LPE (Liquid Phase Epitaxy) method on GGG (Gallium Gadolinium Garnet) substrate with (111) orientation, which has quasi in-plane magnetization with saturation magnetization equal to $4\pi M_s$=300 Oe. The film has thickness of 8 μm and is grown on both sides of

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the substrate. Such films contain wedges like domain structure. The edges of the domains are not perpendicular to the crystal growth direction, but they may be saturated under small in-plane magnetic fields.

MI measurement has been performed using a R-L series circuit. A DSP Lock-In Amplifier (Model 7265 from Perkin Elmer) was used to measure the output voltage, at room temperature. The AC and DC magnetic fields were applied in the plane of the sample, but perpendicular to each other. A Helmholtz coil system was used to generate the magnetic fields. DC magnetic field was calibrated vs. current using a Leybold 516-60 magnetometer and a TTi 1906 computing multimeter.

3. Results and discussion

Fig. 1 shows the dependence of the impedance, Z, on the applied magnetic field, when the field varies between -60 and 60 Oe, at frequencies of 10, 120, and 250 kHz, respectively. It shows that the impedance increases by increasing the applied field up to a value where it compensates the magnetic coercivity field and then starts to decrease. Slight asymmetry that exists may be related to the little deviation of the applied magnetic field direction relative to the projection of the (111) axis on the film plane.
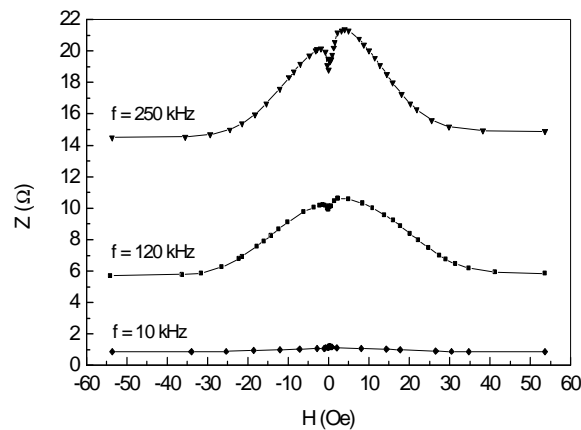

Fig. 1. Variation of the impedance, Z, vs. magnetic field measured at different frequencies.

Table 1 presents the variation of Z when the magnetic field varies from -60 Oe to 60 Oe.

Table 1.

Frequency, kHz	Z_{min}, Ohm	Z_{max}, Ohm
10	0.866	1.195
120	5.715	10.636
250	14.494	21.372

The magneto-impedance ratio is defined as:

$$\Delta Z/Z\ (\%) = \{Z\ (H)/Z\ (Hmax)-1\},$$

where the maximum field, is chosen to be equal to $H_{max} = \pm53.67$ Oe (Fig. 1). The variation of MI ratio as a function of the magnetic field at frequencies of 120 and 250 kHz is shown in Fig. 2. By increasing the frequency the MI ratio decreases. The maximum values of MI ratio are 81% and 43% at frequencies of 120 and 250 kHz, respectively.
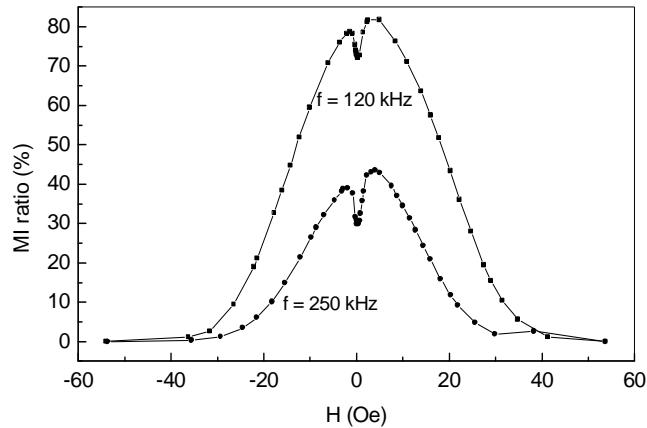
Fig. 2. MI ratio vs. magnetic field for different frequencies.

Magnetoinductance has been measured at a frequency of 1 kHz by using an L-C meter, which uses a bridge circuit. Fig. 3 shows the variation of the magnetoinductance as the magnitude of the DC magnetic field changes. The magnetoinductance, L, decreases from 19 µH to 13 µH as the magnetic field changes from 0 to 50 Oe. One can calculate the permeability using the following relation:

$$\mu = L/L_0,$$

where L_0 is the inductance of the coil with air core. The above equation shows that the permeability has similar dependence on magnetic field as the magnetoinductance.

The inductance ratio, defined as $\Delta L/L\ (\%) = L\ (H)/L\ (Hmax) - 1$ can change up to 46% in the above presented situation.
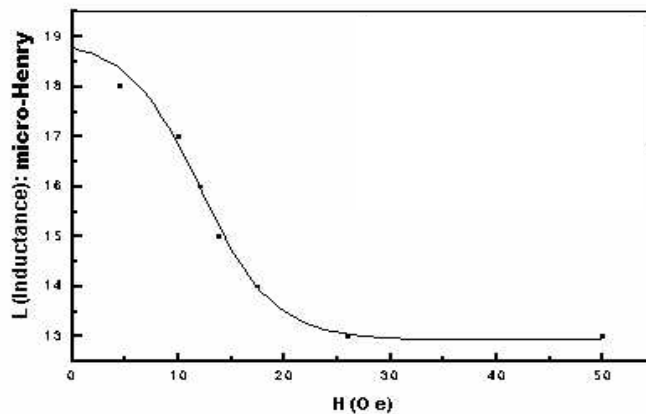

Fig. 3. Variation of the magnetoinductance vs. DC magnetic field.

Figs. 1 and Fig. 2 show that the MI signal exhibits double peak behaviour. Below 2 Oe the magnetic domain walls direction is perpendicular to DC applied magnetic field and parallel to AC magnetic field, so domain walls excitation contributes to the increase of the MI response. By increasing DC applied magnetic field over 2 Oe, the excited domain walls are going to damp and the MI response decreases. MI ratio decreases on frequency increase to 250 kHz, as shown in Fig. 2.

Fig. 3. indicates that domain walls motions at a frequency of 1 kHz are damped when applying a DC magnetic field. This typical behaviour of the magnetoinductance, fast dropping of the inductance for small variations of the magnetic field (5 < H < 20 Oe), suggests that such a material may be used successfully as a magneto-inductive switch.

4. Conclusion

MI effect at different frequencies (10, 120, 250 kHz) in Bi:YIG thin film as a core material has been studied. The response of the magnetic excitation due to the domain walls movements when applying an AC magnetic field parallel to the domains direction and a DC magnetic field perpendicular to the domains direction has been investigated by MI measurements. Magnetoinductance and permeability of Bi:YIG thin film at 1 kHz was studied, too. Such results may suggest the possibility of using Bi:YIG thin films in magnetic sensors and such work is in progress now.

Acknowledgment

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