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Characterization of integrated inductors with one and two YIG layers for low-power converters (1 W)

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Abstract. These last years, the miniaturization of electronic components allows to increase the number of equipment. Consequently, the realization of integrated inductors with high inductance and low-cost manufacturing is highly desirable. The objective of our work is the characterization of inductors with one or two magnetic layers in order to integrate these components in low-power converters (1W). Extracted parameters show a strong increase of the inductance either by simulation or by measurement according to the magnetic thickness layer. For inductance with two magnetic layers, inductance value is higher when the bottom YIG layer thickness is higher than the top YIG layer thickness.

1 Introduction

These last years, the miniaturization of electronic components allows to increase the number of equipment [1-2]. Consequently, the realization of integrated inductors with high inductance and low-cost manufacturing is highly desirable. In order to reduce components size and to increase their performance, a solution can be the use of magnetic material.

The objective of our work is the characterization of inductors with one or two magnetic layers in order to integrate these components in low-power converters (1W).

This paper is decomposed into four parts. First of one concerns the inductor process, where fabrication of one and two YIG layers inductors are presented. Then the studied model is described in order to extract the inductance according to simulation and measurement values. The third part concerns simulation and measurement process. Inductors are simulated using HFSS software (High Frequency Structure Simulation) and measured using an impedance meter and a LCR meter with a probing system. The last part concerns results obtained by measurement which were compared with the simulation results according to the frequency and the YIG layer thickness.

2 Fabrication of integrated inductors

Inductors are constituted by a magnetic substrate and a thin metallization layer. Inductors are realized using magnetic substrate of yttrium iron garnet (YIG). The YIG thicknesses varied between 100 µm to 500 µm.

The metallization have been realized in copper by using an RF sputtering deposition. The thickness of the copper layer is equal to 5 µm. In order to obtain the design of inductor (figure 1 and Table I), a photolithography process has been used.

To finish the inductor with one YIG layer realization, a bonding is necessary to connect the central pad to the outside pad (figure 2).

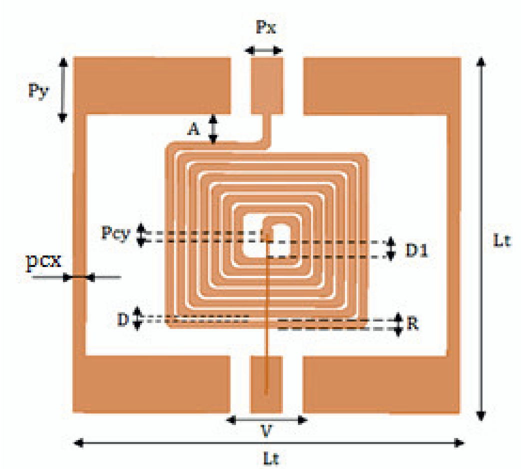

Fig. 1. Design of the magnetic inductor

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Table I. Inductors parameters

R	Conductor width	125 µm
D	Distance between turns	60 µm
D1	Distance between the central pad and the first turn	400 µm
Px **Py**	Outside Pad width Ground plane width	500 µm 1000 µm
Pcy = Pcx	Inside pad width.	200 µm
V	Distance between the ground planes.	1200 µm
Lt	Device side	6270 µm
A	Distance between the last turn and the ground plane	500 µm
N	Number of winding turns	7
S	Device area	3mm x 3mm

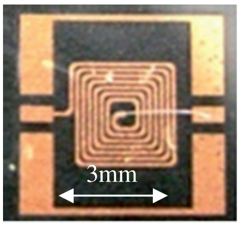

Fig. 2. Inductors realized with one magnetic layer

For inductors with two magnetic layers, a second magnetic layer is glued on the copper layer. A hole in the second layer is planned for the bonding. The magnetic layer thickness ranges from 100 to 500 µm. Figure 3 shows realized device with this configuration.

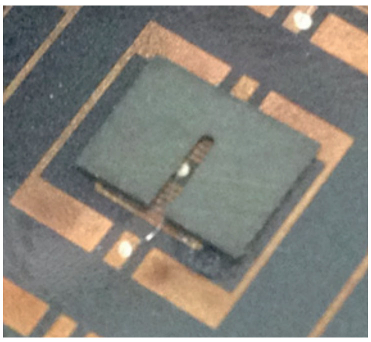

Fig. 3. Inductors with two magnetic layers

3 Inductors modeling

In order to extract the device properties, it will be need to define an electrical model. The chosen model is an RLC model (figure 4) in order to take into account losses in the winding, the capacitive coupling and the effect of the substrate [3-7].

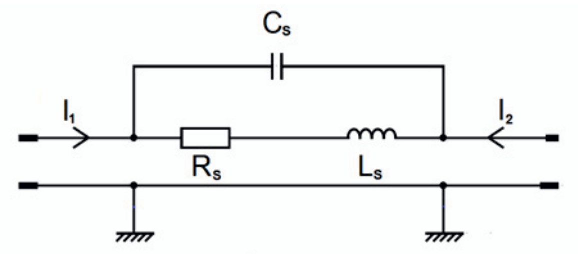

Fig. 4. Studied model

The admittance of the studied model can spell as follows:

$$Y = \frac{1}{R_S + jL_S\omega} + jC_S\omega \qquad (1)$$

So, R_S and L_S parameters can be obtained by:

$$R_S = \frac{-\mathrm{Re}(Y)}{\mathrm{Re}(Y)^2 + (\mathrm{Im}(Y) + C_S\omega)^2} \qquad (2)$$

$$L_S\,\omega = \frac{\mathrm{Im}(Y) + C_S\omega}{\mathrm{Re}(Y)^2 + (\mathrm{Im}(Y) + C_S\omega)^2} \qquad (3)$$

The determination of the capacitance value (C_S) is obtained at the frequency resonance.

4 Description of inductors simulations and measurements

Simulations are realized by using the HFSS software based on the finite element method (FEM). This tool provides 3D electromagnetic field simulation and is well suitable to study high frequency components. This software generates a mesh for simulation according to geometry, material properties and some parameters that have been specified by the user. The simulation results are expressed as S_{ij} parameters. To analyze the simulation results, intermediate relations are used to obtain admittance parameters [8].

Measurements are realized by using an impedance meter (Agilent 4294A) and a LRC meter (HP 4284A). These equipments allow to obtain an inductance extraction on a broad band frequency (20 Hz to 110 MHz). In order to minimize measurement error, inductors are measured with a probing system and an OSL (Open Short Load) calibration.

5 Results

5.1 Inductor with one magnetic layer

5.1.1 Inductance value according the frequency

Inductances values are extracted by impedance meter and LRC meter for measurement and by simulation up to 100 MHz.

According to figure 5, results are obtained for inductors with 500 µm magnetic layer thicknesses. A good correlation is observed on the broad band frequency.

The inductance value is constant and equals to 220 nH up to 10 MHz. After this frequency, the inductance value decreases and it is due to the magnetic permeability which is not constant and decreases with the frequency.

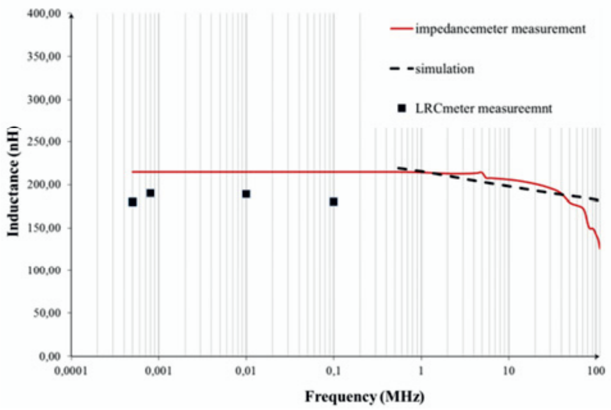

Fig. 5. Inductance value according to the frequency for a 500 µm YIG layer thickness

5.1.2 Inductance value according to the magnetic thickness layer

This part consists in highlighting the influence of magnetic material on the inductance value. For this, measurements and simulations are made by varying the magnetic material thickness between 0 and 500 µm. The inductance value without ferrite (L_0, reference value) equals 100 nH at 100 MHz.

According to the figure 6, the introduction of the magnetic material increases the inductance value. Results show that the inductance value increases significantly with the magnetic material when thicknesses are lower than 100 µm. Beyond this thickness, the inductance value tends toward 200 nH which corresponds to the twice of the inductance reference. So these results show that it is not necessary to have a magnetic layer of high thickness in the inductor in order to increase its inductance because the magnetic field is well canalized when the thickness is higher than 200 µm.

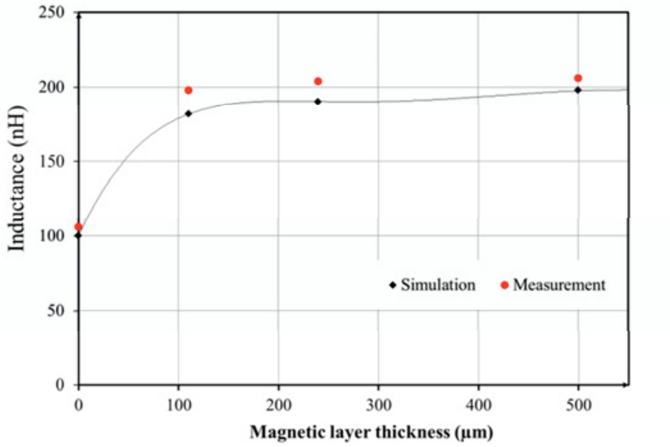

Fig. 6. Inductance value at 10 MHz according to the YIG thickness

5.2 Inductor with two magnetic layers

5.2.1 Inductance value according the frequency

Bottom and top YIG layers establishing the inductor presents the same thickness and is equal to 100 µm.

According to the figure 7, results show an inductance value equals to 750 nH at lower frequency, which corresponds to an increasing factor equal to 7.5 compared with air inductor. These results show that the magnetic field are canalized between the bottom and upper YIG layers.

On the other hand, the inductance value remains constant up to 1 MHz. After this frequency the inductance value decreases. It is due to the increasing losses in the magnetic films and the eddy current which are not taken into account in our model.

5.1.2 Inductance value according the magnetic thickness layer

In this part, two studies are realized. The first one concerns inductors which present the same bottom and top YIG layers thicknesses and the second one concerns inductors where bottom YIG layers thickness are different of the top YIG layers thickness.

According to figure 8, inductance values present a good concordance between simulation and measurement. One can observed a significantly increasing of the inductance value with the increasing of the magnetic material thickness. This increase is important for lowest thicknesses (less than 250 µm). The inductance value increases respectively from 7 times L_0 for 100 µm to 15 times L_0 for 500 µm thicknesses.

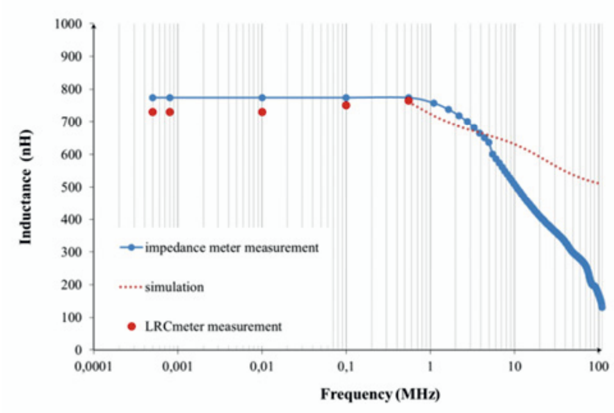

Fig. 7. Inductance value according to the frequency for a 100 µm YIG layers thicknesses

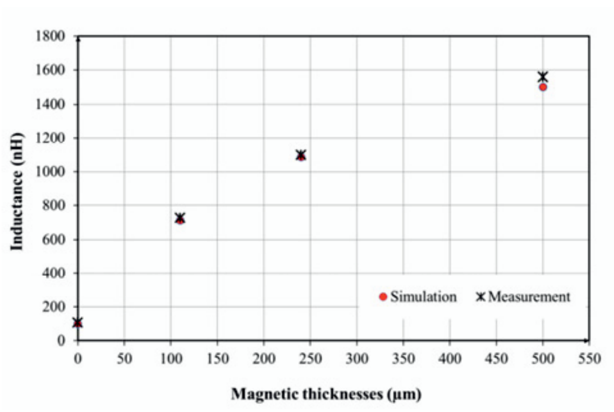

Fig. 8. Inductance value at 1 MHz according to the YIG bottom and top layers identical thicknesses

In the case where bottom and top layers present different thicknesses, the increasing inductance value presents some difference. According to table II and figure 9, inductance value presents better results when the thickness of the bottom layer is higher than the thickness of the top layer. This difference can reached to a factor equal to 20% for inductor constituted by a 500 µm bottom layer and a 110 µm top layer compared with inductor constituted by a 110 µm bottom layer and a 500 µm top layer.

Table II. Summarize inductance value for some condition

Inductance value (nH)		Inferior YIG thickness (µm)		
		110	240	500
Superior YIG thickness (µm)	110	730	900	830
	240	1018	1100	1440
	500	1094	1490	1560

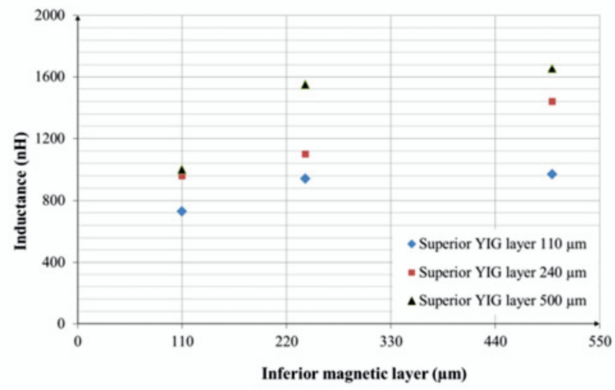

Fig. 9. Inductance value at 1 MHz according to the YIG thicknesses where bottom and top layer are different

6 Conclusion

In this article, the use of magnetic material allows to increase the inductance value with the aim of miniaturizing this component.

Measurements realized with an impedance meter and a LRC meter and simulations realized with the HFSS software allow to determine the inductance value on a broad band frequency and according to the YIG layer thicknesses.

Results show that inductors realized with two magnetic layers allow to canalize the magnetic field in the component. On the other hand, inductance value is higher when the bottom YIG layer thickness is higher than the top YIG layer thickness.

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