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Production and Characterization of A Planar Inductor YIG A Variable Structures

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Abstract : In this paper, we study three methods of integrated inductors based on magnetic material. For the first one, the thin film of magnetic material is a deposited by RF magnetron sputtering on an alumina substrate. The thick layer of YIG of the second one is obtained by micromachining of a bulk wafer. The same technique is used for the sandwich inductor. The use of magnetic material improves the performances of the inductor and reduces its dimensions. The manufactured components are characterized in high frequency. The obtained results show a good correlation between simulations and measurements. The use of a single magnetic layer allows doubling the inductance value in a planar inductor. For the sandwich inductor (coil between top and bottom thick magnetic layers), it is possible to multiply the inductance by a factor high as the relative permeability μ_r of the magnetic material.

Keywords: Inductor, sputtering, micromachining, simple structure, sandwich structure, YIG, photolithography, network analyzer

I. INTRODUCTION

The integration and miniaturization of passive components such as the inductor is booming and requires new planar fabrication technology. This technology will allow mass production making it more competitive component. The inductor is used in electronic devices such as chargers, mobile phones and embedded electronics [1, 2, 3]. Two technologies are usually used to manufacture these planar inductors : Micro-Electro-Mechanical Systems (MEMS) and Monolithic Microwave Integrated Circuits (MMIC). MEMS technology uses a series of micromachining and microelectronics (photolithography and etching) [4, 5, 6]. As for the MMIC technology, the manufacturing process involves the deposition of a number of successive layers of metal and dielectrics. The shapes of the deposited layer can be obtained by two different lithography process : lift-off or etching [7, 8, 9]. The process of manufacturing is often accompanied by the characterization using the Vector Analyzer Networks [6, 7, 10] and the results are compared to those of the simulation. 3D simulators are most used such as HFSS or Momentum [4, 6, 11, 12]. In this article, we propose three manufacturing process of micro-inductors with magnetic material. The first magnetic thin layer of Yttrium Iron Garnet (YIG) is sputtered RF [10, 13, 14]. The second, the thick layer is obtained by micromachining massive commercial YIG [15]. Thick layers of the sandwich structure are obtained by micromachining. The vector network analyzer of Agilent N5230A associated with coplanar points was used to characterize the various inductors realized. The inductance value was simulated and measured for planar spiral inductors with or without magnetic material.

II. MATERIALS AND METHODS

2.1. Inductors structures

The prototyping phase has been reduced thanks to the 3D tool design assistance. The software HFSS (High Frequency Structure Simulator), version 10.0, was used to design the inductor structure to 7 turns and analyze the influence of parameters (geometry of the spiral and characteristics of magnetic material) on the value of inductance L. Figure 1 shows the three inductors structures studied : without magnetic material, with YIG and sandwich

a) without magnetic material **b) with YIG** **c) sandwich**

Figure 1 : Different structures of planar inductors

2.2 . Manufacturing process

The different steps of the manufacture of copper windings uses techniques "clean room". However, for the realization of the magnetic circuit, two techniques are used : the radio frequency sputtering and micromachining of YIG ($Y_3Fe_5O_{12}$).

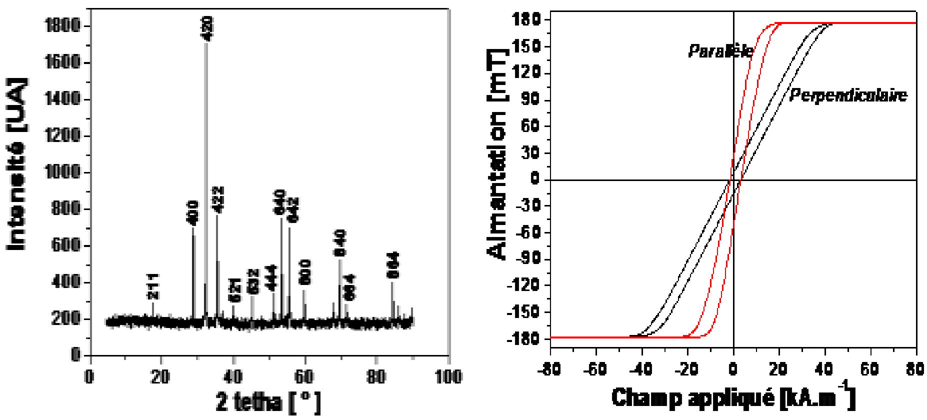
2.2.1. Fabrication of the integrated inductor with thin magnetic film

The main manufacturing steps of an integrated inductor in thin layer are :

- Deposition of the magnetic layer on the alumina substrate ;
- Deposition of the copper film on the magnetic layer ;
- Photolithography and wet etching necessary to obtain the pattern of the spiral inductor ;
- And finally, the wire bonding for the terminal connections.

a. Thin layer of ferrite (YIG)

The conditions for depositing thin films of YIG ferrite on the RF sputtering alumina substrate described by [14] are used to obtain different thicknesses of 5 to 17 microns. These thicknesses are a function of the deposition time. The layers obtained are amorphous and are treated at 740 ° C for 2 hours to obtain a crystal structure. The Analysis of the sample by X-ray diffraction of Figure 2a shows that the YIG crystallized.



a) X-ray pattern of YIG **b)** YIG hysteresis curve

Figure 2 : X-ray pattern and hysteresis curve of YIG film having a thickness of 12,4µm

The hysteresis curve of Figure 2b obtained by VSM (Vibrating Sample Magnetomer) indicates that the saturation magnetization of about 177 mT and the coercive force of 2.3 kA / m are near the solid ($\mu_0 M_s$ = 110 to 180 mT and H_c = 1.5 and 2.5 KA / m).

b. Formatting driver

The copper layer is deposited on the YIG by sputtering. The drivers shaping is done by photolithography in the "clean room" using the positive and wet etching resin as described by [15]. The bonding connects between the pads

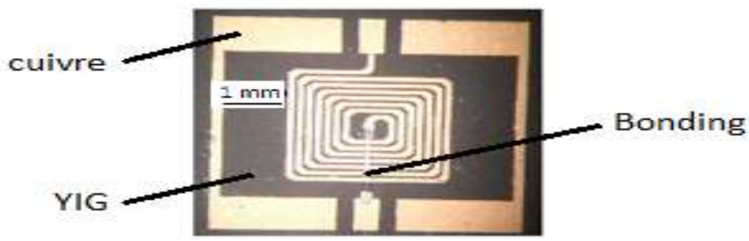


Figure 3 : Image final sample thin film

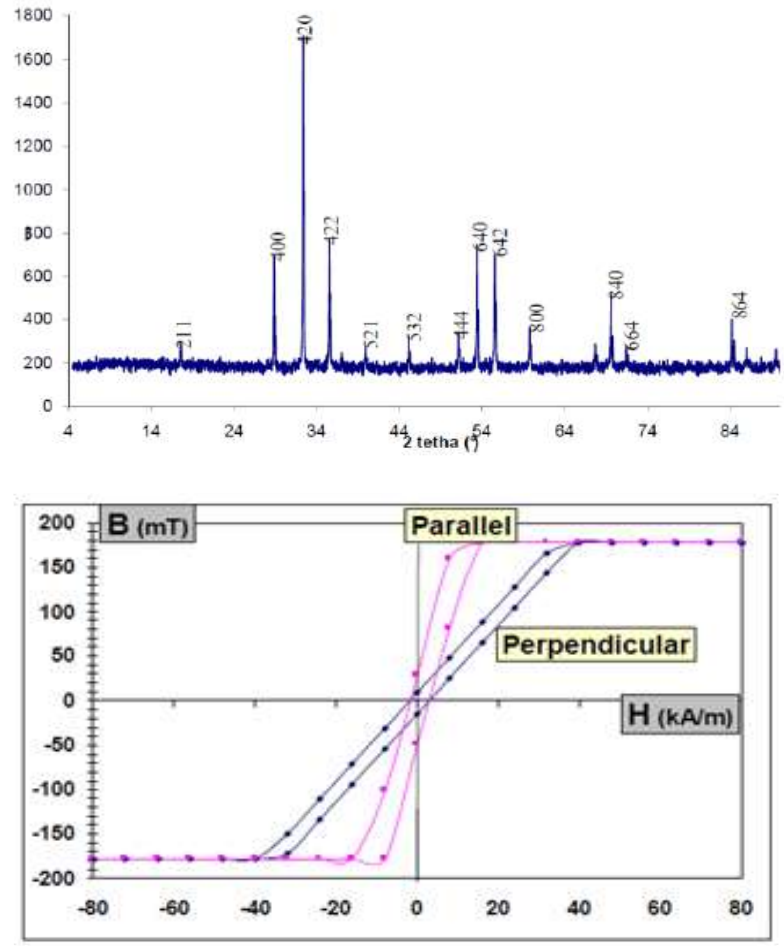
2.2.2. Fabrication of the integrated inductor with thick magnetic film

The sputter deposition of the art does not provide a significant layer. Indeed, for high thicknesses, YIG is little adherent to the substrate so that the layers take off partially or completely during annealing. So you have to use another method such as micromachining for these layers. The manufacturing process includes the following main steps:

- Lapping and Polishing YIG substrate micro fabricated ;
- Deposit of copper on the YIG by sputtering.

a. Machining of the YIG substrate

The YIG is a massive square of 50.8 mm square and a thickness of 1 mm. The different thicknesses (50 to 500 µm) of the YIG are obtained by lapping. As the YIG is very breakable during machining, it is bonded to a glass substrate. The ferrite of the surface state after the running has a roughness between 200 and 500 nm. Polishing provides a better surface for easy forms planar lithography. An average roughness of about 80 nm is a good between the accession of the copper layer and the engraving quality. [15]



a) X-ray pattern of YIG **b)** YIG hysteresis curve

Figure 4 : Characterization of YIG substrate

The characterization results are identical to those of the thin layer, unless the coercive force (0.5 KA / m) which is slightly below the solid.

b. Conductive material

The procedure is the same as that of the section 2.2.1.b. 5 illustrates the final sample of microinductor thick film.

Figure 5 : Picture of a chip inductor thick YIG layer

2.2.3. Fabricating integrated sandwich inductor

This fabrication is to glue a top layer of YIG on the inductance performed in Section 2.2.2. The collage of two ferrite strips with and without notch is parallel to the bonding using glue "synthetic resin Repositionnable75-3M".

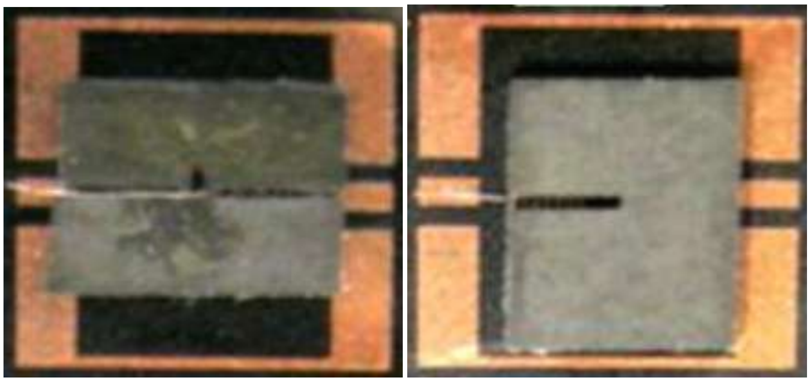
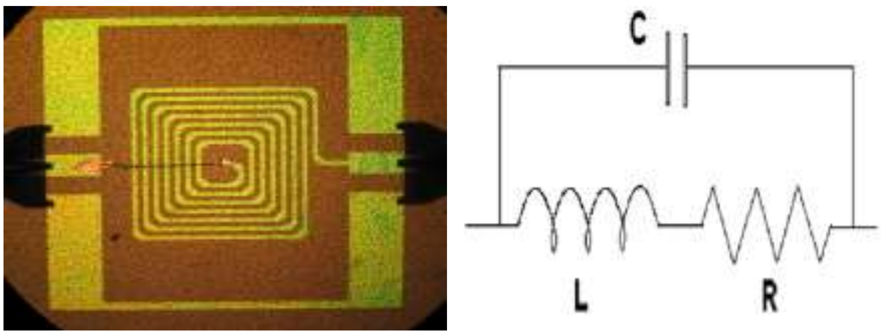


Figure 6 : Photography microinductor two layers of YIG without or with notch

2.3. Characterizations of components

The ccharacterization by high frequency of these micro-inductors is obtained using the vector network analyzer (VNA) Agilent N5230A associated with two coplanar points. The VNA calibrated OSL (Open-Short-Load) measures the S-parameters in both ports. The model of the inductor is holding RLC parasitic capacitance.



A) Inductor in coplanar tips **B)** RLC model of an inductor

Figure 7 : Inductor in coplanar tips and RLC model

III. RESULTS AND DISCUSSION

3.1. Inductor air

The figure below shows the inductance values measured for different copper thicknesses respectively 4, 10 and 15 microns and that of a simulation of 15 microns of copper.

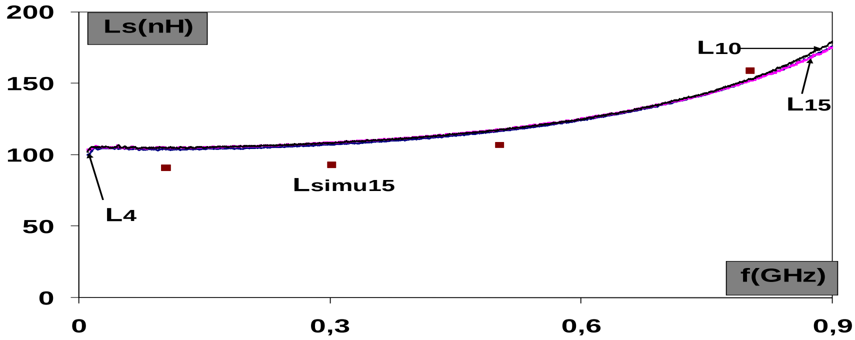


Figure 8 : Inductance value Ls as a function of frequency for various thicknesses

The values of the inductance Ls measured do not depend on the thickness of the copper. They are slightly greater than those of simulation. However, these values are very close, constant and about L_0 = 100 nH up to 500MHz. Beyond the apparent increase in the value of the inductor is due to capacitive effects that make it unsuitable RL series model.

3.2 Inductor to a YIG layer

For a thin film structure YIG 17 .mu.m, the measured inductance value of 114 uH, representing a contribution of 14% [15]. This shows that the field lines are not sufficiently concentrated in the thin layer of YIG. By cons, Figure 9 shows that the value of the integrated inductance thick film increases with the thickness of the ferrite to achieve twice L0. This means that the field lines are almost entirely channeled in the magnetic material to a thickness of 200 microns. In addition, the contribution of magnetic material is insignificant.

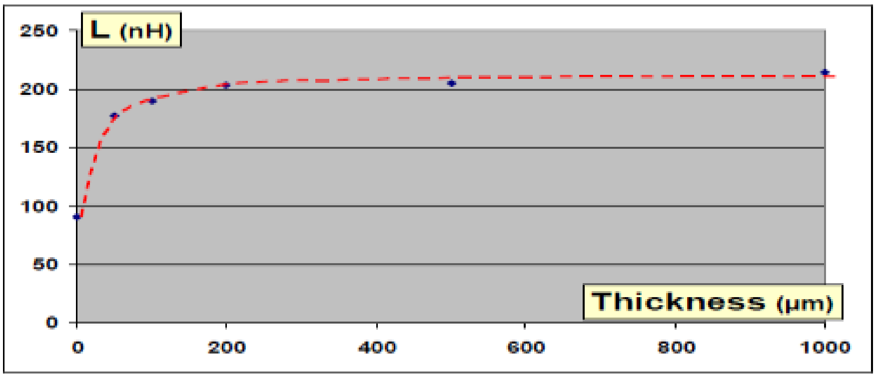


Figure 9 : Inductance L at 1 MHz depending on the thickness of the YIG

3.3 Inductor sandwich

The results of measurements and simulations of a sandwich inductance are shown in the figure below :

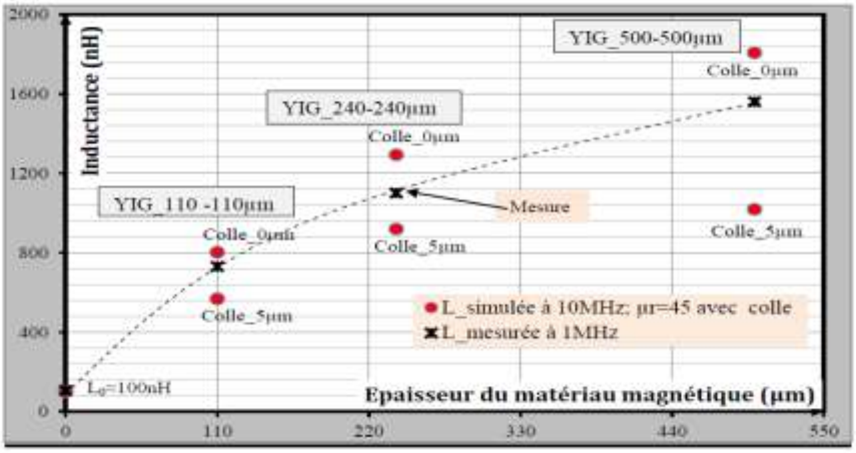


Figure 10 : Inductance L to 1 MHz according to the identical thickness of the lower and upper YIG

We observe a good correlation between simulation results and measurements.

However it is difficult to accurately obtain the inductance value due to the difficulty of measuring the thickness of the adhesive. As for the structure to a layer, the value of the inductance increases with the ferrite thickness. For example, the table below illustrates the L0 multipliers according to the thickness of YIG.

Table I : Multiplier value L0

Thickness YIG	L measured	Factor
110 µm	730 nH	7,3
240 µm	1100 nH	11
500 µm	1560 nH	15,6

To a limit thickness of YIG, the multiplier factor tends towards the relative permeability of the ferrite. Beyond this thickness, the magnetic material does not contribute, which results in stagnation of the value of the inductance. According to [10], the ÁR value of the low frequency YIG is of the order of 30.

III. CONCLUSION

The development of integrated micro-inductors discussed in this paper requires a variety of skills from design characterization of components through the various stages of manufacture of microelectronics. The study of the thickness of the conductor that shows its variation has no effect on the inductance value. However, to minimize the effects of high frequency skin, it is wise to optimize the thickness of the conductor. Two manufacturing techniques have been demonstrated: thin layer sputter deposition and micromachining of solid YIG. The results of the inductor show a good correlation between measurements and simulations. These values are increasing functions of the ferrite thickness and admit limits from a certain thickness. For a single magnetic layer structure, the limit value of the inductor can only be doubled. As against the structure having two magnetic layers allows to increase the inductance value by the relative permeability of the ferrite.

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