

# Characteristics of double planar thin film inductor with Ni-based magnetic film for DC/DC integration

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**Abstract.** This paper mainly describes the design, fabrication and test of double planar thin film inductor. The thin film inductor has a sandwich structure, which consists of a double-square spiral planar Cu coil between top and bottom Ni magnetic thin films on a glass substrate; it is fabricated by dry and wet processes. The inductor is  $2.7 \times 1.9 \text{ mm}^2$  in area, which is suitable for a MHz switching DC - DC converter integration. The finally measurement shows that inductance of 0.71uH constant up to 1.5MHz, and a quality factor of 1.09 at 1.5 MHz.

## Introduction

As the size and weight of portable electronic products constantly decrease, and its power management chip requirements for internal integration is becoming more and more important. Thin-film magnetic inductors are useful for integrated power delivery solutions for microprocessors and mobile devices[1][2]. In recent years, with the rapid development of MEMS fabrication technology, specially the Quasi LIGA processing technology based on the 3D non-silicon materials becomes one of the most advanced technologies to study on micro-inductive device. Combined the thin-film technology with MEMS technology, miniaturized inductor device is developed, which will have the advantages of having a low resistance, small size, low loss, low cost and mass production. Especially, for power electronics applications, such as switching converters and inverters, planar inductive devices operating in higher frequencies, have many advantages over their conventional counterparts; better thermal management and higher power densities[3][4].

In addition, for the devices with magnetic thin film, the magnetic thin film can be well concentrated magnetic field lines and effectively reducing the eddy current loss of substrate, so loss of the substrate can be ignored here[5]. At the same time, in order to reduce the area occupied by the planar film inductor and compatible with the process, this paper proposed a planar inductor with magnetic shielding film layer structure. What's more, in order to design more number of turns in smaller area, in the design adopted double planar spiral inductors for the structural are designed and optimized.

## Design of planar inductor

Professor S.S Mohaa, through research and analysis, combining with the predecessors' achievements, proposed a simple formula for the square, hexagonal and octagonal inductance calculation [6].

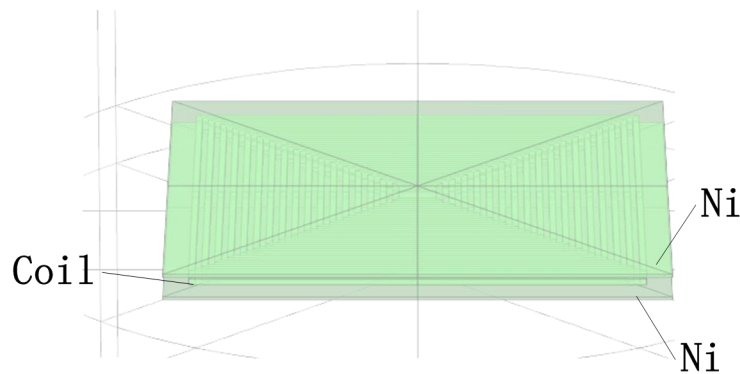
(1)

The inductance is found from where  $L$  is the inductance value of the inductor, the unit for nH,  $n$  represents the coil number of turns,  $\mu_0$  is the magnetic permeability,  $d_{avg}$  is the average of the inductance coil inside and outside diameters, both  $K_1$  and  $K_2$  are constant, which are determined by the shape of the inductance coil, and  $\rho$  represents the fill rates. From (1), it can be seen that in order to achieve large inductance,  $n$  should be much larger. Besides the inductance is also related to the size of the coil. At the same time, in order to reduce the area accounted for the planar inductor and compatible with the process, this paper designed a double planar spiral inductor with magnetic shielding layer, which is a sandwich structure. The novel spiral coil structure is shown in Fig. 1. On

the other hand, this paper also designed the inductor structures with different size to study the effect of inductor with different size on its properties. Sizes and shapes are shown in Table 1.

**Table.1** The sizes and shapes of the inductors

shape	square						circle		
Coil inner area (mm <sup>2</sup> )	0.11*0.08			0.15*0.1			$\pi \cdot 0.1^2$		
spacing (um)	20			20			20		
Line width (um)	20	30	40	20	30	40	20	30	40
Number of turns (single layer)	17	14	12	18	14	12	17	13	11
type	A	B	C	D	E	F	G	H	I



**Fig.1** The structure of magnetic thin film inductor

## Fabrication

There exist some of the key steps for fabricating the thin film inductor, such as sputtering, photolithography and electroplating. During the MEMS fabrication, it addressed the following key manufacturing technology. 1) Through rational design and double-sided mask overlay alignment mark and multilayer depth lithography technology to solve the question in the multi-layer mask overlay process and get plating resist mold, to obtain good aspect ratio resist mold. 2) By exerting additive in the plating solution, to achieve a high aspect ratio micro-sized plating issues. 3) Polyimide resolved the insulation issue between the Micro inductor layers and the micro interturn. After coating polyimide and the drying and curing process, then precision mechanical polishing, the substrate can be guaranteed to have a flat surface. Through the above processes, the structure of the proposed thin film inductor with two same spirals, which have 17 turns. In order to improve the inductance of the thin film inductor, the connection between two coils is in series by a through-hole. The 10 um thickness Ni magnetic thin films for the top and bottom magnetic layers were electroplated by Ni. A 20 um thickness of Cu film for the thin film coil was also prepared by electroplating technology. The single coil structure is shown in fig.2. Fig. 3 is a SEM image of an example of the fabricated magnetic thin film inductors. Dimensions of the thin film inductors fabricated in this work are listed in Table I.

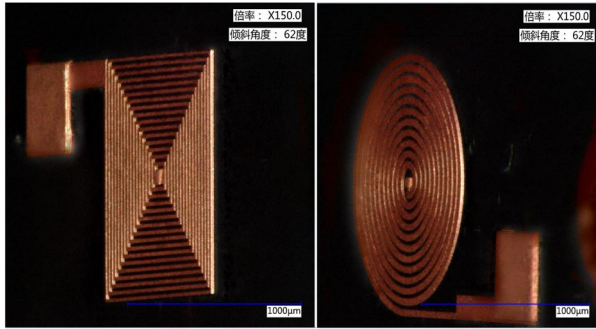


Fig.2 3D structure of the single coil

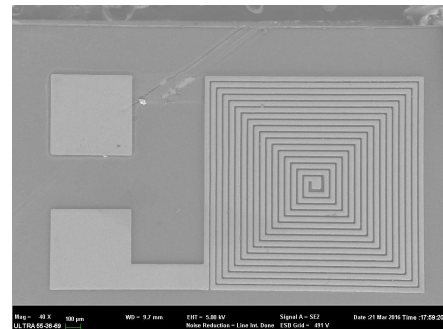


Fig.3 Example of SEM image of fabricated magnetic thin

## Results and conclusion

The frequency characteristics of the thin film inductors were measured by Agilent E4991A Rf impedance material analyzer, at 0.5V. Fig. 4(a) –(c) indicate the inductance  $L$  of several kinds of magnetic thin film inductors (type A to I in the figure). With an increase of the line width, the total inductance of the fabricated inductor decreases due to the self and mutual inductance decrease.

The inductance  $L$  was nearly proportional to the number of turns of the inductor. The smallest width of device line with square (type D; 20µm of the line width and  $0.15 \times 0.1 \text{ mm}^2$  of Coil inner area) had a 1 uH constant inductance up to 128.8 kHz. However, Fig. 5(a) –(c) indicates the frequency characteristics of quality factor of several kinds of magnetic thin film inductors (type A to I in the figure). The quality factor was not definite to the number of turns of the inductor. The quality factor reflects the performance of the inductor. However, the high inductance and high quality factor can't be achieved at the same time. the inductor must compromise between them.

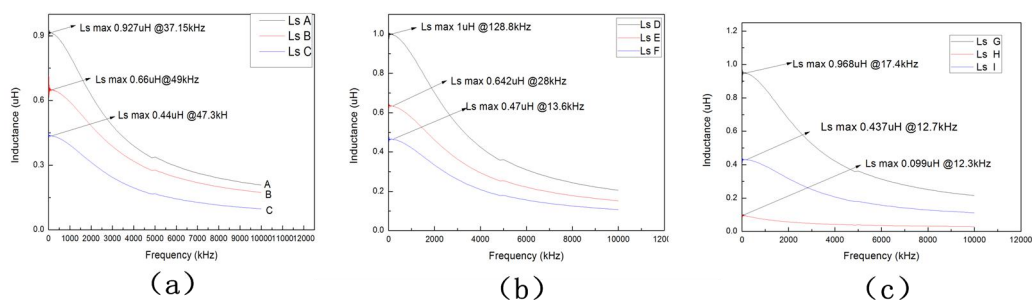
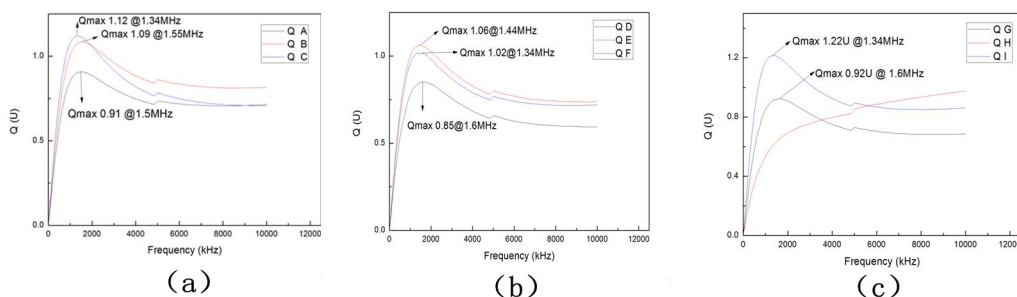
Fig. 4. the inductance  $L$  of several kinds of magnetic thin film inductors

Fig. 5. the quality factor of several kinds of magnetic thin film inductors

The twin spiral type thin film inductor with Ni magnetic thin films is fabricated and its characteristics are investigated. This paper represents a suitable for the miniaturization of DC – DC converter integrated micro thin film inductor in a  $2.7 \times 1.9 \text{ mm}^2$  size. The inductance was about 0.77uH at 1.5MHz and the quality factor was about 1(type B; the line width with 30µm and coil inner area with  $0.11 \times 0.1 \text{ mm}^2$ ). The magnetic flux inductance offsets with each other is the main limiting factor to the quality of the on-chip spiral inductors.

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