A Preparative Technique for Spiral Thin-Film Transformer at GHz Frequency Band

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***Abstract*—This paper present a preparative technique for spiral thin-film transformer with ferrite magnetic core. RF magnetron sputtering is used to prepare ferrite thin film on SiO_2 layer. Compatible problems of thin film with IC technology are observed by SEM. The problems are resolved through sputtering parameters modification and heating treatment addition. S-parameters are measured at 10MHz-20GHz. The result shows that The experience result shows, magnetic core thin-film transformer with 15:15 ratio-turn can obtain the maximal transmission efficiency 80.9% at 10MHz-20GHz, and the air core transformer can obtain the maximal transmission efficiency 55.4% at same frequency range. Ferrite thin film can improve the transmission efficiency evidently.**

I. INTRODUCTION

Thin-film transformer is an indispensable component because of its performance of signals insulation and transmission, signals synthesis and conversion. It is being found increasing use in radio frequency circuit such as oscillators, mixers, low-noise amplifiers (LNAs), baluns, matching networks and filters [1-3]. But it is not catch more attention until the 90's of last century.

Some technologies have been used to fabricate the thin-film transformer like multilayer printed technology, MEMS, superconducting thin film and so on[4-7]. However, there are still exist disadvantages, the areas of transformer fabricated by multilayer printed technology are too large (usually more than 1mm*1mm), transformers fabricated by MEMS technology are more expensive because of complicated technique, and the transmission efficiency of all these transformers must be further upgraded. In this paper, IC technology and Ni-Zn microwave ferrite is used to resolve these problems and improve the performance of transformer.

II. DESIGN OF THIN-FILM TRANSFORMER

2.1. Design principle

In the past, the microwave loss of common low-resistivity silicon substrate (LRS) is too high to use in RFIC. Compound semiconductor technology played a crucial role in RFIC. However, with the development of IC technology, using many new technologies appeared and improved the microwave performance of substrate, such as high-resistivity silicon substrate (HRS) technology and LRS with a thick silicon oxide interlayer technology. Now, IC technology exhibit excellent performance in radio frequency range. Adopting IC technology can not only decrease the area and cost of thin-film transformer, but also increase their consistency.

An air core spiral can't achieve big inductance in radio frequency range. Using magnetic core spiral is a way to resolve the problems above. Ni-Zn microwave ferrite is a suitable material to make thin film magnetic core. However, it is difficult to use fabricate and etching technology of magnetic material in standard IC technology. For improve the performance of transformer, it is necessary to use magnetic material, and the use of magnetic material brings the compatible problems of magnetic thin film technology with IC technology. The way to fabricate a transformer with magnetic core based on IC technology is presented below.

2.2. Structrue design

Fig1 show the schematic structure of thin-film transformer. We designed stacked spiral thin-film transformers included octagonal spiral and square spiral. The primary coil and secondary coil are overlapped completely. Overlapping coils has high magnetic coupling which can transmit energy more effective.

The whole structure consists of 10 layers besides the Silicon substrate.

1) Layer 1 is SiO_2. It supplies the whole device and isolates Si substrate. Thermal oxidation is used to fabricate

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SiO_2 .The thickness of SiO_2 layer is 1μm, thick oxide can reduce the parasitical capacitance[8].

2) Layer 2 is Si_3N_4. PECVD is used to fabricate. The thickness of Si_3N_4 layer is 120 nm. The electrical resistivity of Si_3N_4 is $10^{15}\Omega\bullet$cm, substrate with highly electrical resistivity can reduce substrate loss. Furthermore, Si_3N_4 has low-fluidity and difficult to corrupt, these characteristics can improve the compatibility of subsequent etching process[9,10].

3) Layer 3 is Metal1. Metal1 is lead wire using aluminum. DC magnetron sputtering is used to fabricate Al. Two lead terminals of primary spiral are prepared. The thickness of Al layer is 0.7 μm.

4) Layer 4 is SiO_2. SiO_2 with 1μm thickness isolate lead wire and primary spiral and fabricated by PECVD.

5) Layer 5 is primary spiral. DC magnetron sputtering is used to fabricate Al with 1μm thick.

6) Layer 6 is SiO_2 or ferrite thin film. Air core thin-film transformer use SiO_2 and magnetic core thin-film transformer use ferrite thin film. Ferrite is highly resistant material, so the thin film can be used as magnetic core and insulating layer. It brings the structure simpler. RF magnetron sputtering is used to prepare ferrite thin film or PECVD is used to prepare SiO_2. The thickness is 1μm.

7) Layer 7 is second spiral. DC magnetron sputtering is used to fabricate Al with 1μm thick.

8) Layer 8 is insulation layer. PECVD is used to fabricate SiO2 layer with 1.2 μm thickness.

9) Layer 9 Metal4 is also lead wire using aluminum. DC magnetron sputtering is used to fabricate Al. Two lead terminals of primary spiral are prepared. The thickness of Al layer is 1.2 μm.

10) Layer 10 is passivation layer. PECVD is used to fabricate SiO2 layer with 1.2 μm thickness.

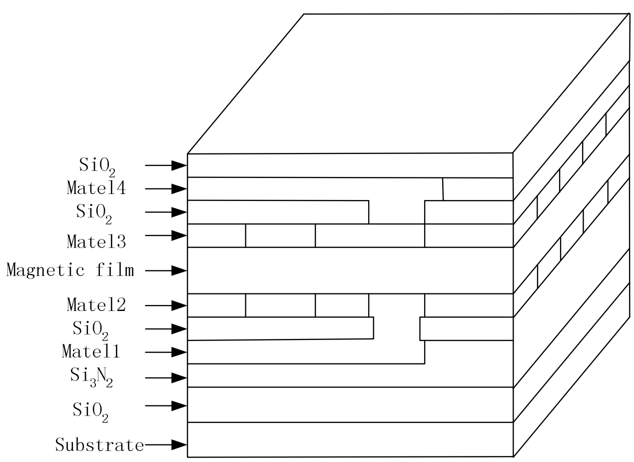


Figure 1. Structure of thin-film transformer

2.3. Technics design

As functional layer and insulating layer, the compatible problem of ferrite thin film with IC technology is a difficulty of thin-film transformer preparation. Ferrite is not a standard material in IC process technology. We met some problems in preparation progress.

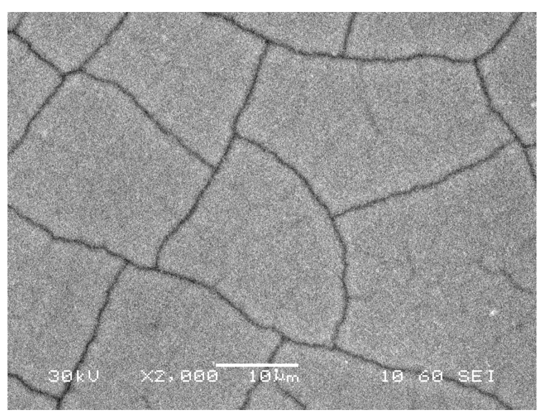
2.3.1 Preparation of ferrite thin film

There are some ways to fabricate ferrite thin film like PLD, sol-gel, but sputtering is in common usage on IC technology. So RF magnetic sputtering is used to prepare ferrite thin film.

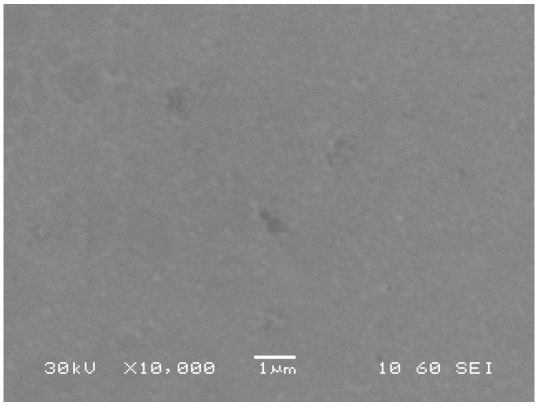
We adopted modified NiZn ferrite material to fabricate magnetic thin film through RF magnetron sputtering Alliance Concept DP650.

The sputtering gas is high-purity argon atmosphere 99.999%, sputtering pressure is 8μbar, background vacuum is $4.810*10^{-6}$mbar, space between target and substrate is 100 mm, RF forward power is 1262 W_{RF}, back forward is $4W_{RF}$, flow rate of Argon is 57 sccm, the deposition rate is 0.648μm/h.

It is found that the surface of ferrite film appears crack due to high stress accumulated when the thickness of film has rise to 1μm. The crack of film surface can be found in SEM image magnified 2000 times, as showed in Fig.2 (a). This question is solved through sputtering parameters modification and deposition rate decrease. The sputtering pressure is increased to 11μbar; flow rate of Argon is increased to 60 sccm, then the deposition rate is decreased to 0.436μm/h. The SEM image magnified 10000 times is showed in Fig.2 (b). The surface of thin film is smooth and has better quality.



(a)

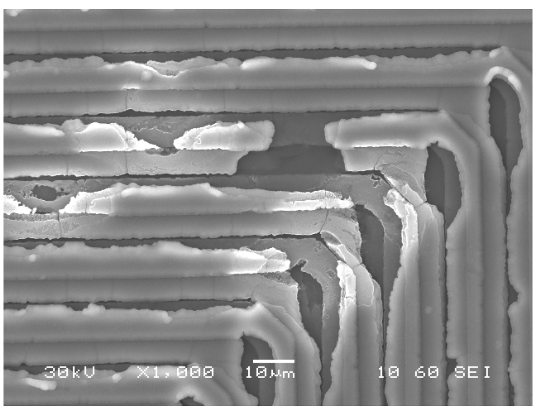


(b)

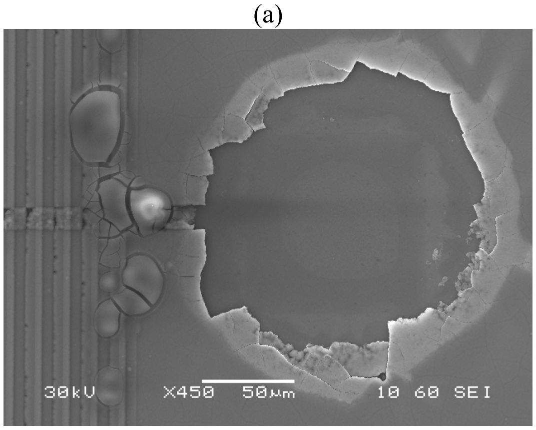
Figure 2. SEM image of ferrite thin-film (a) SEM image of ferrite thin-film with cracks magnified 2500 times. (b) SEM image of ferrites thin-film with higher quality magnified 10000 times.

2.3.2 Cohesiveness problem

The ferrite film contact SiO_2 and Al according to the structure of thin-film transformer. Ferrite thin film has poor cohesiveness to SiO_2 layer or Al film. In subsequent processing, ferrite film will crack and desquamate after etching and cleaning, as showed in Fig.3.



(a)



(b)

Figure 3. SEM image of sample (a) coil (b) Pad

Heating treatment is used to improve the cohesiveness of ferrite film. The experiment results shows that the stress of ferrite film can be decreased and the cohesiveness can be increased after the film having been heated for 30 minutes at 300℃ and cooled to room temperature for 25 hours. The SEM image of a sample with heat treatment is showed in Fig.4.

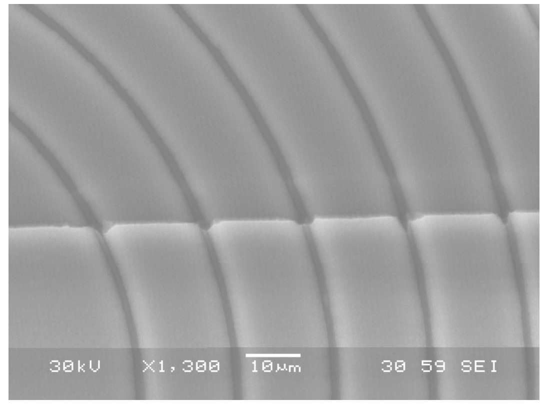


Figure 4. SEM image of sample with heat treatment

2.4. Fabrication sequences

The modified fabrication process is showed in fig.5. After modified the fabrication process, we can get a transformer sample with better quality.

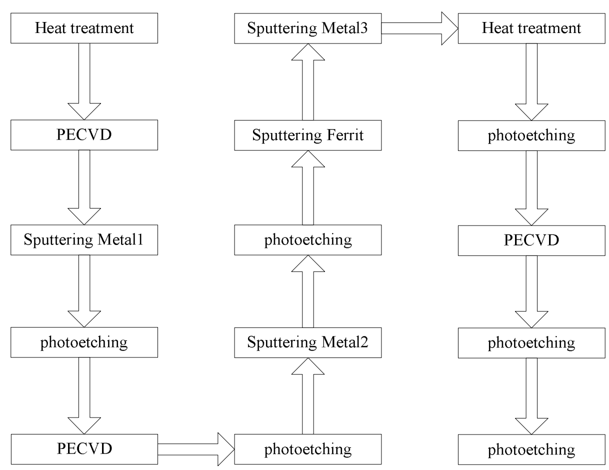


Figure 5. Fabrication sequences of the thin-film transformer

III. MEASUREMENT RESULTS AND DISCUSSIONS

Two kinds of thin-film transformers are measured: air core thin-film transformer and magnetic core thin-film transformer. The turn numbers of two spirals are all 15, the spiral width line is 12μm, the spiral distance line is 3μm, the thickness of Al layer is 1μm, and the spiral area are $1*1mm^2$, Fig.6 showed the surface topography of the transformer. The transmission characteristics are measured at 10MHz-20GHz by vector network analyser Agilent PNA E8363B and probe Cascade Microtech ACP GSG. The measured results are showed in Fig.7.

As shows in Fig.7, the transmission efficiency of air core thin-film transformer more than 50% at 4.3GHz-14.2GHz, and the maximum is 55.4% at 11.2GHz; the transmission efficiency of magnetic core thin-film transformer more than 50% at 0.5GHz-20GHz, and the maximum reached 80.9% at 9.25GHz. It means that the whole transmission efficiency of thin-film transformer gets largely improved by ferrite thin film, and it results in that the bandwidth of magnetic core thin-film transformer is larger than air core thin-film transformer.

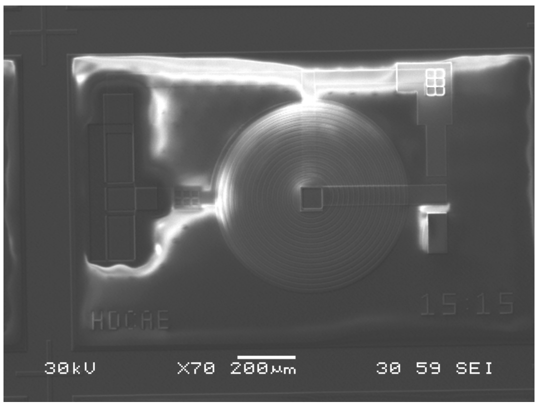
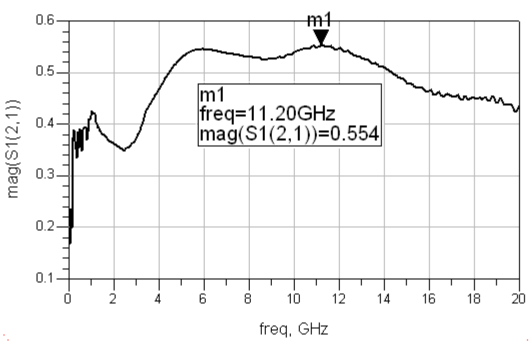
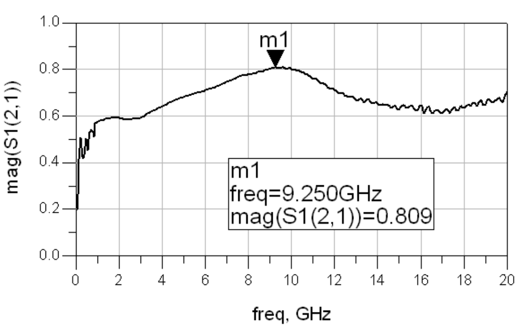


Figure 6. SEM image of transformer with 15:15 turn ratio



(a)



(b)

Figure 7. 15:15 transformer's S(2,1) curve (a)air core thin-film transformer (b)magnetic core thin-film transformer

IV. CONCLUSIONS

A thin-film transformer using ferrite film based on Si IC technology was presented. The compatible problems of thin film with IC technology are resolved, the structure and technological design of thin-film transformers are proposed, and performance of the transformers are tested. The experience result shows, magnetic core thin-film transformer with 15:15 ratio-turn can obtain the maximal transmission efficiency 80.9% at 10MHz-20GHz, and the air core transformer can obtain the maximal transmission efficiency 55.4% at same frequency range. Ferrite thin film can improve the transmission efficiency evidently. The thin-film transformer has advantages like small in size, operating at high frequency, suitable for mass production, and so on. The preparative technique can be used to fabricate miniature ferrite device and the transformer is expected to apply on RF circuit.

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