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Fabrication and characterization of thin film spiral inductors toward a realization of variable impedance devices

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1. Introduction

An on-chip spiral inductor is one of the critical components for implementing radio frequency integrated circuits (RFIC's) [1,2] such as low-noise amplifier, a voltage-controlled oscillator, and an impedance matching network for wireless communications and sensors. On the other hand, there is requirement of tuning elements like variable impedance tuner[3] for adjusting the impedance deviation which is often introduced in fabrication process. The variable impedance devices can also be useful for tuning device such as voltage controlled oscillators in RFIC's. In this paper, aiming at realization of variable impedance devices by using an on-tip thin film inductor, we have proposed and fabricated a spiral inductor with an external electrode towards tuning impedances, and measured a variation of S-parameter before-and-after applying DC voltage to the electrode.

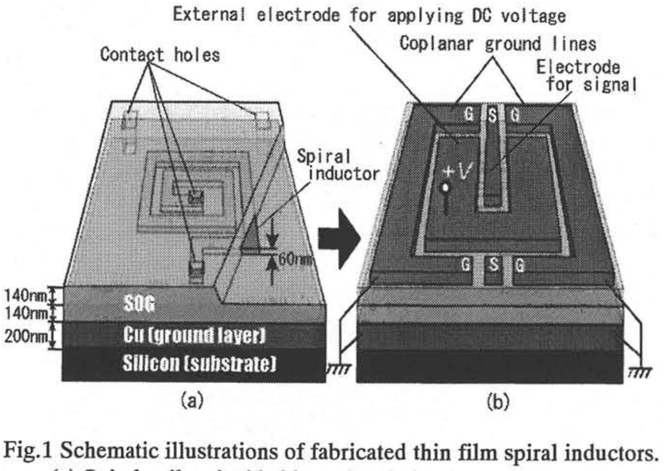

Fig.1 Schematic illustrations of fabricated thin film spiral inductors.
(a) Spiral coil embedded in an insulating layer.
(b) Fabrication of an external electrode for applying DC voltage V.

2. Device structure and Fabrication

We describe the typical device structure and fabrication process for the thin film spiral inductors with external electrodes for applying voltage to vary the impedance, and the structure is schematically shown in Fig.1. A ground metal layer was deposited on n-type silicon substrate. A thin film spiral coil was patterned and embedded in insulating layers whose thickness was 280 nm. Both the line width and the spacing of the spiral line were employed as 20 μm. The number of turns was five and the internal diameter of the spiral was 140 μm. An external electrode was fabricated on the top layer so as to cover the spiral coil whose area was 500 μm square. The external electrode was set for applying DC voltage to vary the impedance. Coplanar ground lines were fabricated beside the external electrode. Copper was employed for materials of the spiral coil, the ground layer, and the external electrode. All Copper film patterns were deposited by vacuum evaporation and lift-off process. Insulating layers were fabricated by using spin-on-glass (SOG). Hard cure time and cure temperature for SOG were 30 minutes and 250 °C, respectively. After the cure process, contact holes were formed by etching in 0.5 % HF. Figure 2 shows a top view of the fabricated inductors.

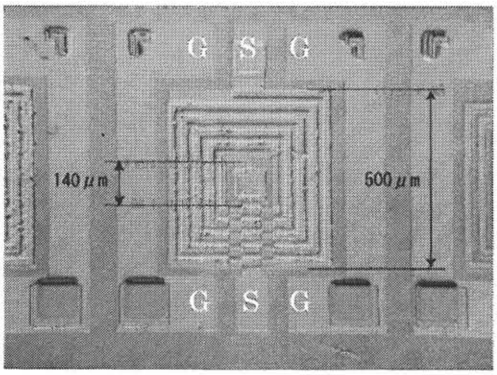

Fig.2 Top view of the fabricated inductors.

3. Measurements and Results

Two-port S-parameters in fabricated devices were measured for frequency f = 30 kHz to 6 GHz using ground-signal-ground (GSG) on-wafer probes and a network analyzer. Impedance calibration of system for measurement was performed by using the impedance standard substrate. Power of input signal for the measurement network was 10 dBm. Figure 3 shows frequency dependence of magnitude $|S_{12}|$ and angle $\angle S_{12}$ of the S-parameters from f = 30 kHz to 2 GHz. Dotted lines and solid lines indicate the values for the applied DC voltage to the external electrode V= 0 [V] and V= +5 [V], respectively. Measured amplitude and angle for S_{21} were coincidental with those of S_{12}. The $|S_{12}|$ was changed up to 21 % at 400 MHz due to V= +5 [V], and the $\angle S_{12}$ was changed up to 30 % at 500 MHz. Deviation for both S_{11} and S_{22} due to the V were observed enormously less than that for S_{12}.

As a first-order attempt to study origin of the S-parameters varied with the V, an equivalent circuit consist of three impedances is employed as shown in Fig.4. Values of Z_1, Z_2, and Z_3 are evaluated independently by calculating with the measured S-parameters. Figure 5 shows a variation of the Z_2 with f = 30 kHz to 6 GHz plotted in the Smith Chart. It is found that the variation of the S-parameter due to the V caused by the variation of Z_2, since Z_1 and Z_3 after applying V= +5 [V] are consisting with those before applying DC voltage. Previously several equivalent circuits for the part of Z_2 including inductance, series resistances and capacitances have been proposed[4,5]. Further analysis must be needed to discuss a mechanism of the variation of the parameters due to the V in detail.

4. Summary

In summary, toward a realization of variable impedance devices, a thin film spiral inductor with external electrode for applying DC voltage V was proposed and fabricated. Two-port S-parameters of the inductors were measured up to 6 GHz and it is found that magnitude of both S_{12} and S_{21} was changed up to 21 %, and angle of those was changed up to 30 % by V= +5 [V]. With an equivalent circuit of the inductor, an impedance component involving the spiral inductor mainly contributes the variation of the S_{12} and S_{21}.

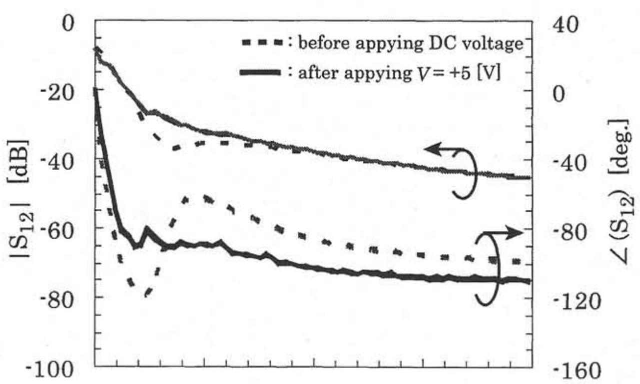

Fig.3. Measured frequency dependence of S_{12} parameters.
Dotted line: Before applying DC voltage.
Solid line: After applying V=+5 [V].

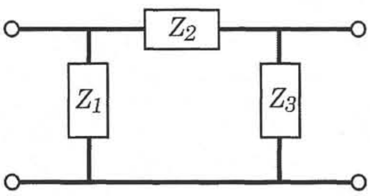

Fig.4 An equivalent circuit model for the fabricated device.

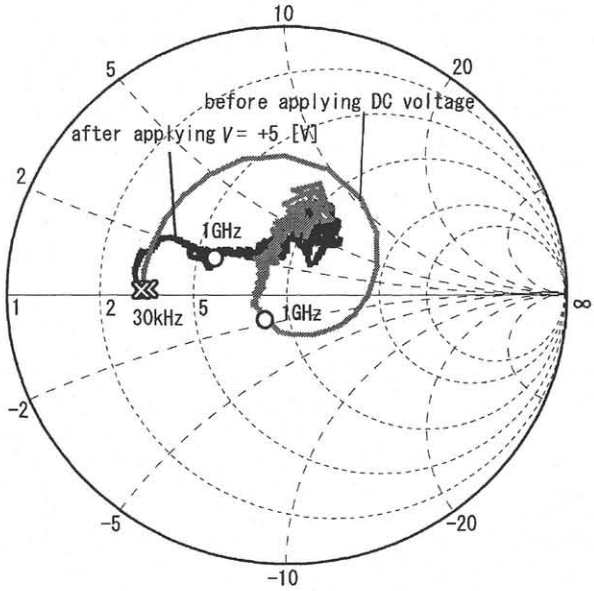

Fig.5 Effect of applying DC voltage for the impedance Z_2 normalized to 50 Ω plotted in the Smith Chart.

Acknowledgments

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