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Ferromagnetic RF Integrated Spiral Inductor with Closed Magnetic Circuit

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1. Introduction

Miniaturized and high-Q on-chip spiral inductor is an integrated passive required for high performance RF silicon devices and circuits. While most efforts are done to reduce ohmic/eddy-current losses and stray capacitance, this paper tries to enhance the inductance by means of introducing permeable materials to the spiral structure. This work is on the series of our study to use ferromagnetic thin film to spiral inductor as the on-top type [1] and the sandwich type [2] inductors. Actually this paper demonstrates the first experimental results on the closed magnetic circuit type GHz-drive integrated spiral inductors.

2. Structure, Micro-Fabrication and Measurements

Fig. 1 shows the structure of the closed magnetic circuit type inductor discussed in this paper. The inductor consists of a stack of the 0.2-μm-thick RF-sputter deposited CoNbZr, the RF-sputter deposited SiO2, the 3-μm-thick electrodeposited Cu coil, the SiO_2 with surface planarization, and the 0.2-μm-thick RF-sputter deposited CoNbZr. Lead line was also processed to complete the four turn and 380x380 μm^2 two-port type inductor with ground guards.

The top-side SiO_2 layer was applied special taper etching process to make sure the closed magnetic circuit structure, Fig. 2 shows the test pattern of the taper etching process, showing the cross section of .the tapered lines with different trench widths. The SiO_2 thickness was set to either of 1 μm or 4 μm. The line/space [μm] of the coil was either of 10/3, 10/5, 20/3, or 20/5. The CoNbZr film was applied slit to shift the ferromagnetic resonance (FMR) frequency. Its line/space was identical to those of the Cu. Fig. 3 shows the completed inductor. The pad line was drawn from the center of the spiral to the left.

Two GSG type RF wafer probes (Cascade Microtech, Inc., ACP40-A-GSG) were used to measure scattering parameters of s_{11}, s_{21} and s_{22}, respectively, by using a network analyzer (HP 8720D). A equivalent circuit analysis we propsed [3] was applied to extract the lumped element constants. The definition of the quality factor, Q, of the inductor in this work is the ratio of the impedance of the series inductance to the series resistance ($Q=\omega L/R$.)

3. Results and Discussion

The patterned Cu and CoNbZr were aligned as face to face. The 10/3 and 10/5 designs with 1-μm-thick SiO_2 layers exhibited the quality factor Q=12, being highest among the published data at 1 GHz[2]. This was achieved through: (a)The narrower Cu coil design and the thinner SiO_2 design yielded higher magnetic field at the magnetic film area. (b)The magnetic slit design of 10/3 and 10/5 well shifted the FMR frequency beyond 1 GHz. (c)Stray capacitance between the coil legs, and between the coil and magnetic film was negligible at 1GHz.

4. Conclusions

The closed magnetic circuit type ferromagnetic RF integrated inductor exhibited the quality factor Q=12, being highest among the published data at 1 GHz

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References

[1]M. Yamaguchi et al., J. Appl. Phys., **85**, 7919-7922 (1999).
[2]M. Yamaguchi et al., IEEE Trans. Microwave Theory and Techniques, **49**, 2331-2335 (2001).
[3]M. Yamaguchi et al, Jpn. J. Appl. Phys., **42**, 2210 – 2213 (2003).

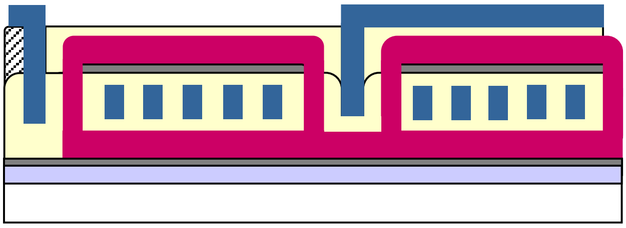

Fig. 1 Closed magnetic circuit type RF integrated inductor.

Table I Micro-Fabrication Process

Outline	Details
Cleaning	Sample dicing, cleaning
Bottom CoNbZr layer	Ti/CoNbZr/Ti sputtering
	Photo lithography, ion milling, P.R. removing
insulator	SiO_2 sputtering
Coil	Ti/Cu seed sputtering, align mark opening
	Photo lithography, Cu electroplating, Ti
	P.R. removing, Ion milling
insulator	SiO_2 sputtering
	Photo lithography, Taper etching, P.R.
Top CoNbZr layer	Ti/CoNbZr/Ti sputtering, align mark opening
	Photo lithography, ion milling, P.R. removing
insulator	SiO_2 sputtering
Pad open	Photo lithography, RIE, P.R. removing
Pad line connection	Photo lithography, Ti/Cu sputtering
	Lift off
Annealin	Magnetic field annealing

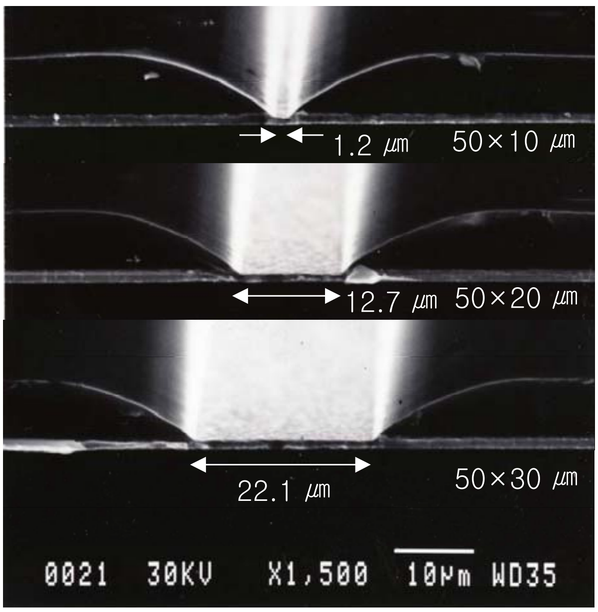

Fig. 2 Tapered SiO_2 layers with different window width.

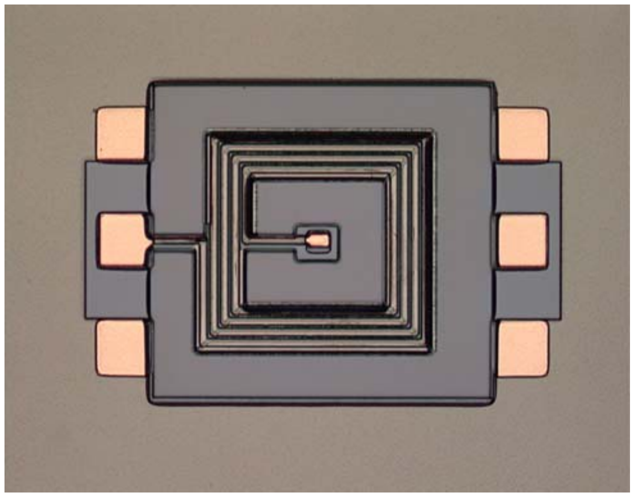

Fig. 3 Outlook of the completed inductor.

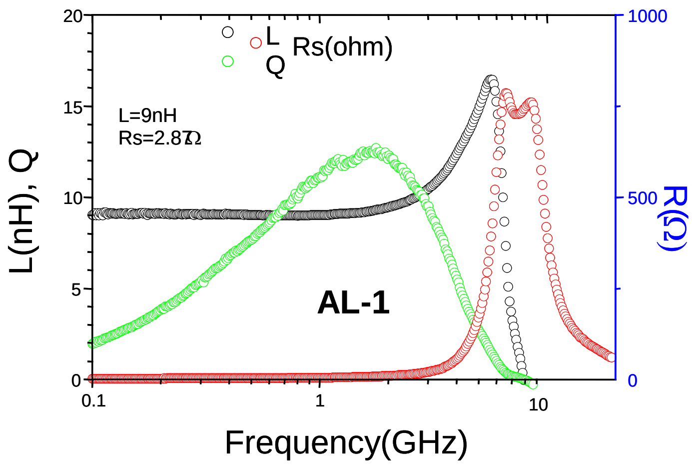

Fig. 4 Measured RF characteristics.