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RF Integrated Spiral Inductor with Double-Sided Ferromagnetic Layers

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1. Introduction

There is a strong demand for high-quality integrated passives for RF circuitry. This work demonstrates a new RF integrated spiral inductor with double-sided ferromagnetic layers for 2GHz application, as an extended work of our first trial that demonstrated L=7.6 nH, R= 6.8 Ω and Q=7.1 at 1 GHz by an on-top type ferromagnetic inductor[1].

2. Structure and Dimension

Fig. 1 shows the outlook of the fabricated a 200 x 400 μm size spiral inductor. Two ferromagnetic $Co_{85}Nb_{12}Zr_3$ amorphous films sandwich the spiral with SiO_2 insulator in between. The hard axis of magnetization is in the vertical direction of the figure. Magnetic field from the coil current is applied to the hard axis direction at the top and bottom legs of the spiral, which contributes to enhance the number of magnetic flux. On the other hand, the magnetic field at the left and right legs of the spiral is applied along easy axis direction. Here, the number of magnetic flux remains unchanged.

In detail, the magnetic films are applied narrow slits along the length direction of the spiral as shown in Fig. 2(a). These slits or the magnetic wire array structure increase the demagnetizing field along the flux path and therefore effective anisotropy field, Hk, increases. This greatly helps to enhance the ferromagnetic resonance (FMR) frequency of the magnetic film and to make a broad bandwidth inductor [3].

As compared with the on-top type inductor shown in Fig. 2(b), the proposed inductor is advantageous as; (a) number of magnetic flux linkage across the coil current is larger. Therefore inductance and quality factor are enhanced. (b)Leakage magnetic flux is smaller. Therefore electromagnetic interference (EMI) to the integrated circuits and devices should be insignificant. (c)Eddy current losses in substrate should be smaller because of low level leakage flux.

In Fig. 3, the coil thickness, t_c is 3μm, the coil width, w_c, is 8μm, the coil spacing, d_c, is 3μm, the magnetic film thickness, t_m, is 0.1μm, the slitted magnetic wire width, w_m, is 7-9 μm, and the magnetic film wire spacing, d_m, is 2-4μm.

3. Results

Fig. 4 shows measured high frequency characteristics of the proposed inductors. A wafer probe (GGB Industries, Picoprobe Model-10) and a network analyzer (HP 8720D) were used to extract the impedance parameters. The reference air core exhibited L=6.8 nH and Q=10.3 at 2 GHz.

In Fig. 4(a), the inductance of each ferromagnetic inductor was higher than the air core inductance. In the low frequency range, the inductor with no-slit ferromagnetic film showed the highest inductance, achieving L=9.1 nH at 1 GHz. The value obtained was higher than the air core's by 47 %. This is because of high permeability of the no-slit ferromagnetic film.

With raising the drive frequency, however, the inductance degraded because of the low FMR frequency of the no-slit ferromagnetic film. The influence of the FMR is also seen as the increase of resistance in Fig. 4(b) and the degradation of the quality factor in Fig. 4(c).

The ferromagnetic inductors with micro wire array film structure exhibited as high quality factor as the air core up to 2 GHz. The best performance was L=7.9 nH and Q=12.7 at 2 GHz obtained for the ferromagnetic wire width of 7 μm and its spacing of 4 μm. The inductance was higher by 19 % and the quality factor was better by 23 % as the air core.

4. Conclusions

The two ferromagnetic CoNbZr films sandwich the spiral to enhance the number of magnetic flux linkage across the coil current. The performance obtained was L=7.9 nH and Q=12.7 at 2 GHz for a 200 x 400 μm size 4-turn rectangular spiral.

References

[1] M. Yamaguchi, K. Suezawa, K.I. Arai, Y. Takahashi, S. Kikuchi, W. D. Li, Y. Shimada, S. Tanabe, K. Ito, *J. Appl. Phys*. **85**, 7919 (1999).

[2] M. Yamaguchi, K. Suezazwa, M. Baba, K. I. Arai, Y. Shimada, S. Tanabe and K. Itoh, *IEEE Trans. Magn.*, **36**, 3514 (2000).

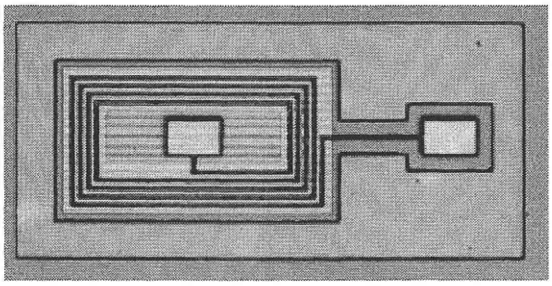
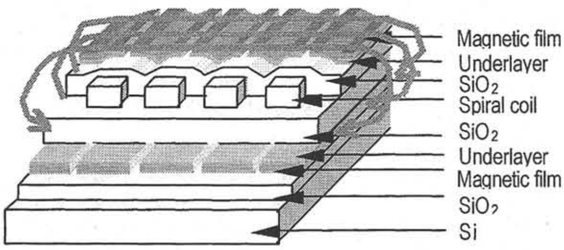
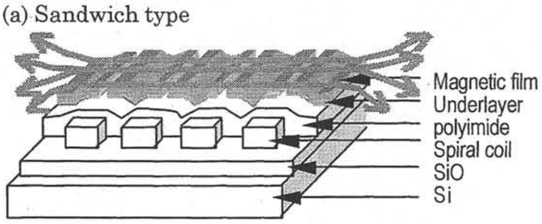


Fig. 1 Outlook of the fabricated sandwich-type ferromagnetic RF integrated inductor (200 x 400 μm²).



(a) Sandwich type



(b) On-top type

Fig. 2 Two types of ferromagnetic RF integrated

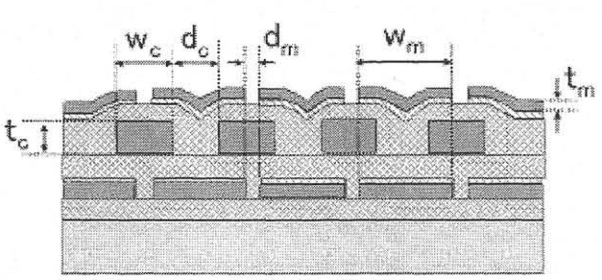
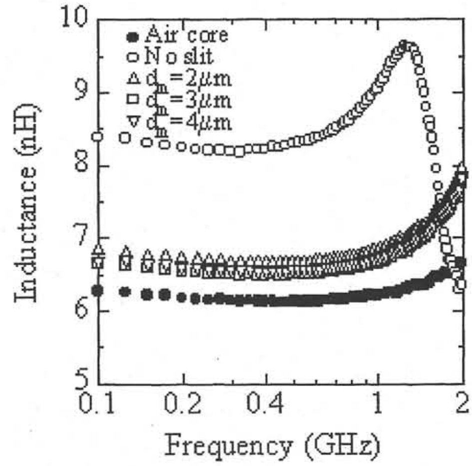
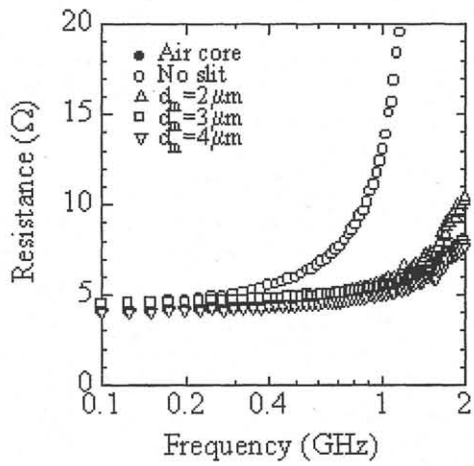


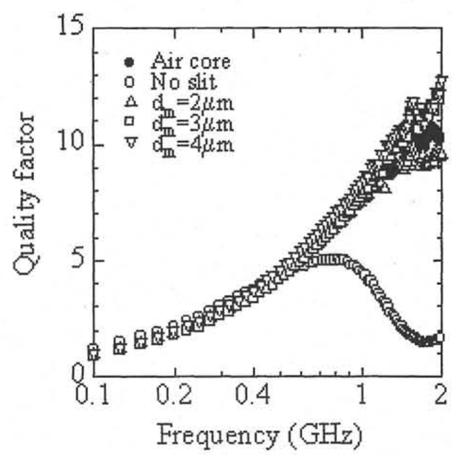
Fig. 3 Cross sectional view of the sandwich type



(a) Inductance



(b) Resistance



(c) Quality factor

Fig. 4 Measured electric characcteristics