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Enhancement of Inductance and Q-Factor of RF IC Inductor Using Magnetic Material

S.RAJENDRA KUMAR[1], D.V.S.RAMANJANEYULU[2], B.SRINIVASA RAO[3]
ACE Engineering college, Hyderabad,Telangana[1,2,3]
Email: sraja070707@gmail.com[1]

Abstract- In the design of RFIC's, one of the major constraints is inductors. Because they occupy large area and quality factor is less. Because of low quality factor the parasitic losses will occur at high very frequencies. Substrate eddy current losses is one among the contributing parasitic losses. This paper presents an importance of magnetic material in the improving the inductance and Q-factor of RF IC inductor. By integrating the magnetic nano-material to the on-chip inductors, the measurement performances show noticeable improvement even at very high frequency range. In this paper we examine the four different magnetic materials Ni-AAO nano composite Core, Ni-Zn-Cu , Co_2Z and Permalloy(80% Ni and 20% Fe)in the fabrication of spiral inductors. In all these cases a significant improvement in the inductance and quality factor of RF IC inductor is observed.

Index Terms- Quality factor, spiral inductor,permalloy, Ni–anodic alumina oxide (Ni–AAO) nano composite core

1. INTRODUCTION

Inductors are used in IC's in RF circuits like Low Noise Amplifiers ,VCO, Passive and active filters and Impedance matching circuits. The main problem about on chip inductors is the large area and the low quality factor. Because of low quality factor, parasitic losses occurred at the higher frequencies. To improve the inductance density and quality factor of on-chip spiral inductors in RFICs employment of magnetic materials is one of the popular approaches. The air-core integrated spiral inductors occupy large chip area and having less Q-factor. The main reason of these both the problems are that the nonmagnetic media (e.g. air or silicon dioxide) surrounding the metal lines in these structures are rather poor when it comes to storing magnetic energy. As the energy stored in a medium increases with its permeability, the adding of a magnetic material with high permeability into these devices would thus allow one to make them smaller and to increase their quality at the same time. The enhancement of inductance will reduce chip area occupied by the inductor for less manufacturing cost and increasing the inductor's Q-performance for RF IC applications.[1].Air-core inductors on silicon are commonly configured as spirals. This geometry is easy to fabricate and allows for reasonably high (compared to other integrated structures) inductance per unit area values. At the same time, however, it allows for significant field penetration into the silicon substrate, leading to high loss and crosstalk. While approaches such as the use of high-resistivity silicon or partial removal of the substrate beneath the RF passives have been proposed, showing an increase of the quality factor of the devices, they come at the expense of increased cost and higher process complexity.

2. SPIRAL INDUCTOR USING Ni-AAO NANO COMPOSITE CORE

The spiral inductor of 3.5 and 4.5 turns, which are made of 5-µm thick electroplated Cu and designed with 100µm in inner diameter,15µm in line width , and 5µm in line spacing, are used in the inductance enhancement using the Ni-AAO nano composite core[2],as shown in Fig.1.

In this, the two port scattering parameters of the inductors are measured with an on-wafer probe station using the high – frequency probes and network analyzer. The parasitic parallel capacitance between the contact pads of inductor is de-embedded using the measured result of designed dummy pattern. The de-embedded S-parameters are then transformed in to Y-parameter [3],[4], and the equivalent series inductance(L) and quality factor (Q) of inductor are extracted from the Y-parameters based on the following equation.

$$L = Im(1/Y_{11}) / 2\pi f$$
$$Q = Im(1/Y_{11})/Re(1/Y_{11})$$

Where f is a signal frequency. The frequency dependent inductance and quality factor of the fabricated inductor are depicted in the fig.2(a) & 2(b)

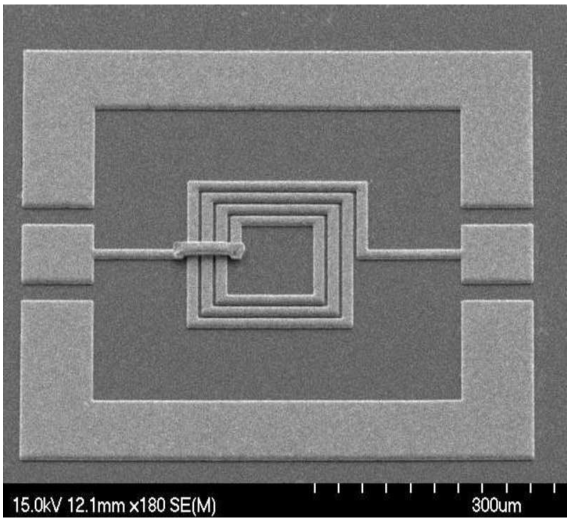

Fig.1 SEM photogaph of as-fabricated on chip spiral inductors with Ni–AAO nano composite

It is observed that Q-factor is having peak value 14 at 1GHz. And inductance having the peak value 3.7 at 7GHz.If frequency increases further both factors are showing better values compared to air-core type.

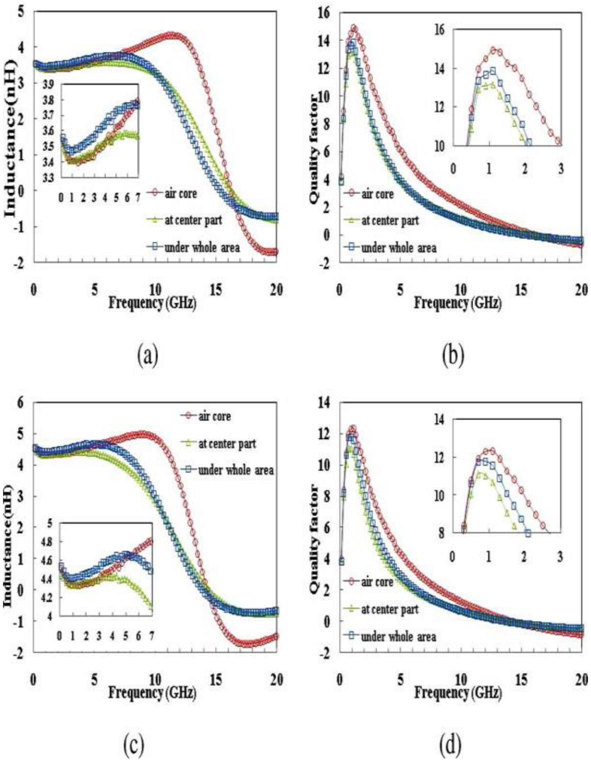

Fig.2 Measured high frequency characteristics of spiral inductors with Ni–AAO nano composite core. (a) Inductance of spiral inductor with N =3.5, din = 100 μm. (b) Q-factor of spiral inductor with N = 3.5, din =100 μm. (c) Inductance of the spiral inductor with N = 4.5, din = 70μm. (d) Q-factor of the spiral inductor with N = 4.5, din = 70μm.

3. SPIRAL INDUCTOR USING Ni-Zn-Cu and CO_2Z

Nanomaterials of Ni-Zn-Cu spinel and Co_2Z magnetoplumbite ferrite are used in this case. Fig.3 shows the fabricated single layer of magnetic inductor with ferrite nano-material coated on top. The single layer inductor is fabricated by MEMS process, then the area that will be filled with magnetic nanomaterial is etched to form a cavity. Through spin-coating method, the ferrite nanomaterial mixed in photoresist fill the cavity up, followed by photolithography and etching processes that define the patterning of the magnetic film[5].

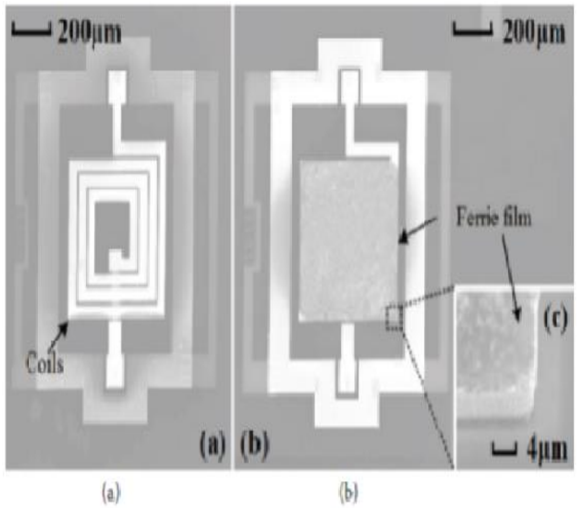

Fig.3 Single layer on-chip inductor (a) without ferrite (b) with ferrite.

Figure.4 shows the measured values of L and Q of single layer inductor with ferrite nano material. The single layer on-chip inductor shows better improvement when integrated with ferrite nano material. The maximum inductance gains are 35% and 21% with Ni-Zn-Cu and Co_2Z respectively, and the improvements are still effective even in high frequency (10GHz) range. The Q's improvement can also reach to over 3GHz, and the maximum gains are more than 160%and 100%with Ni-Zn-Cu and Co_2Z, respectively. It is observed that Q factor is having the maximum value 8 at 5GHz for Co_2Z and 4 at 4GHz for Ni-Zn-Cu. And Inductance having the peak value at 2.3nH at 0.1 GHz for Ni-Zn-Cu and 2.07nH at 0.1GHz. At 10GHz it is showing better results for inductance compared to air core type.

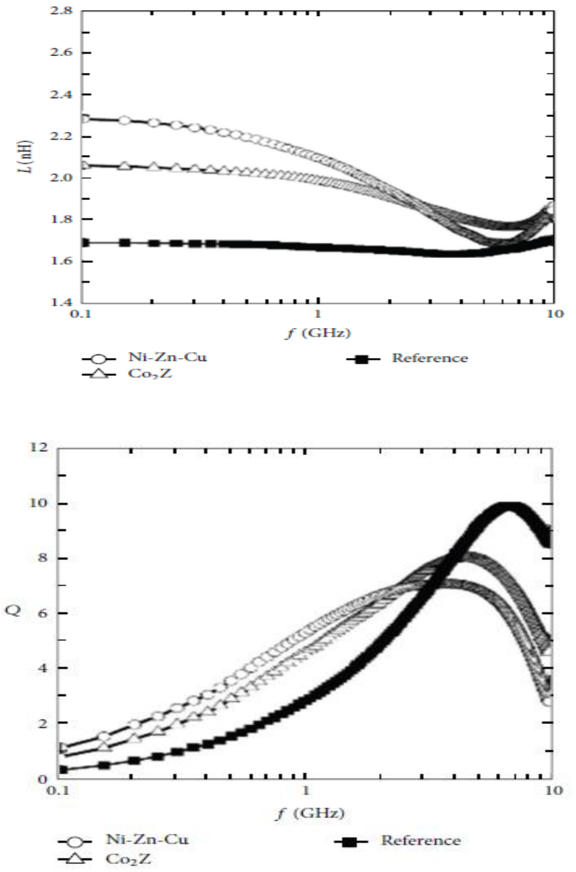

Fig. 4 Measured L and Q of single layer inductor with Ni-Zn-Cu and CO_2 Z nano material

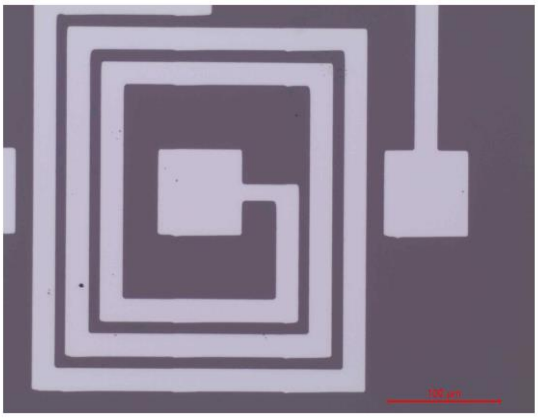

Fig.5 Fabricated inductor without permalloy

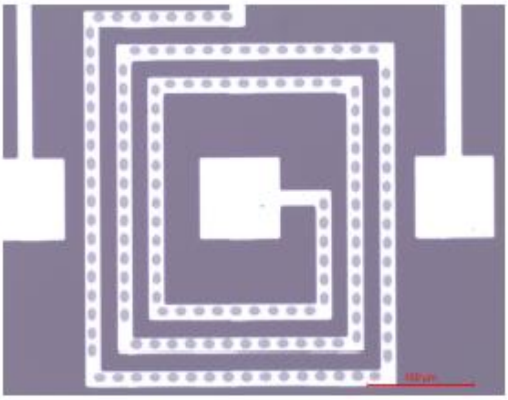

Fig. 6 Fabricated inductor with Permalloy patterns of size 8 µm X 11µmX 96nm

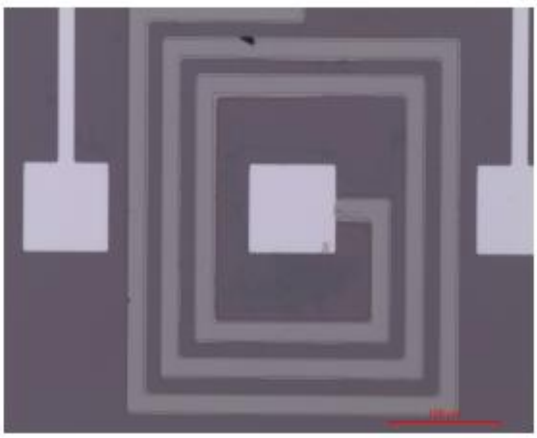

Fig.7 Fabricated inductor with bulk 96 nm thick Permalloy on top of aluminum

4. SPIRAL INDUCTOR USING PERMALLOY

The Permalloy (80% Ni and 20% Fe) is used as magnetic material in this case. A 200nm thick aluminium is sputter deposited on top of silicon dioxide on two wafers. To pattern the aluminium blanket deposition, standard lithography and etching techniques are employed. Inductor shown in fig.5 is obtained. Aluminium spiral inductors with 20µm wide lines and a metal to metal spacing of 10µm,and 15µm wide lines and a spacing of 15µm have been fabricated on all the two wafers. Permalloy patterns of thicknesses of 60nm and 96nm are directly sputter deposited on wafer1 and wafer 2 respectively using DC magnetron Sputtering on aluminium as shown in Fig.6 and Fig.7. Permalloy patterns of various shapes are formed using standard lithography and liftoff processes.[6]

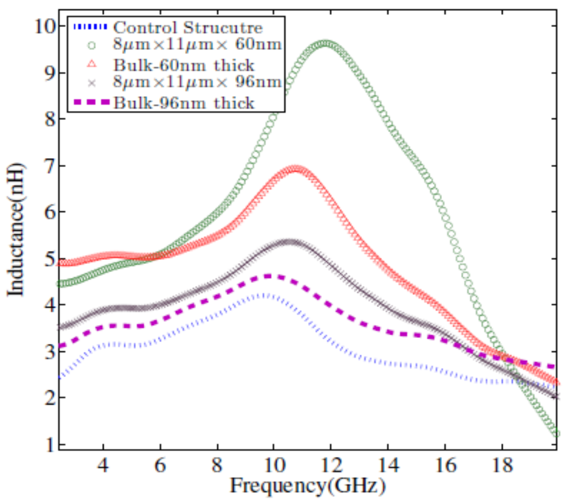

Fig.8 Inductance of the spiral inductors with patterned Permalloy, Bulk Permalloy(60 nm and 96nm thick) and without Permalloy

From the graph is is observed that Inductance is having the peak value of 9.5nH at 12GHz ,7nH at 11GHz,5nH at 10GHz and 4.5nH at 10GHz for 8µm X11µmX60nm pattern, bulk 60nm thick, 8µm x11µm X96nm and bulk 96nm thick respectively. In all these cases an improvement in inductance with magnetic material permalloy

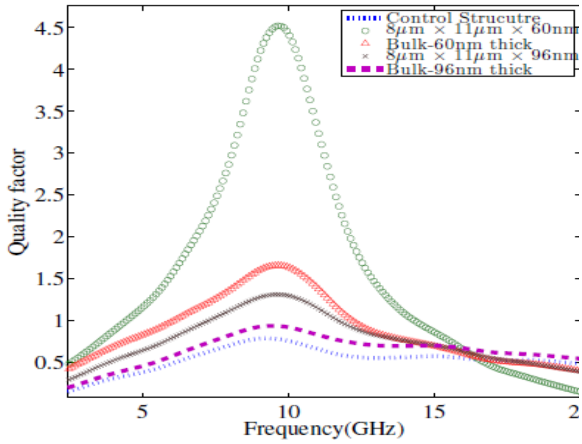

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Fig.9 Quality factor of the spiral inductors with patterned Permalloy, bulk Permalloy (60 nm and96 nm thick) and without Permalloy

5. CONCLUSION

Magnetic material	Q - factor	Frequency (GHz)	Inductance (nH)	Frequency (GHz)
Ni-AAO Nano composite	14	1	3.7	7
CO_2Z	8	5	2.3	0.1
Ni-Zn-Cu	4	4	2.3	0.1
Permalloy(8 µmX11µmX 60nm – pattern)	4.5	9.5	9.5	12
Permalloy(Bulk 60nm)	1.6	9.5	7	11
Permalloy(8 µmX11µmX 60nm – pattern)	1.3	9.5	5	10
Permalloy(Bulk 96nm)	1	9.5	4.5	10

Table: Peak values of Q-factor and inductance for different magnetic materials

Table shows the peak values of Q-factor and inductance for different magnetic materials at different frequencies. As seen from the Fig.2 at higher frequencies inductance and Q-factor will show better values for spiral inductor using magnetic material compared to air core. From Fig.4 ,it is observed that inductance will have better value at higher frequencies. And from Fig.8 very good improvement in the inductance and quality factor for permalloy patterned spiral inductor compared to air core.

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