OPTIMIZATION OF HIGH Q CMOS-COMPATIBLE MICROWAVE INDUCTORS USING SILICON CMOS TECHNOLOGY

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ABSTRACT

We present the extensive experimental results showing the important dependences of layout parameters on RF performance of rectangular spiral inductors, in order to determine the optimized layout parameters for designing the high Q inductors used in RF ICs at 2 GHz. The detailed comparative analysis is also carried out to investigate substrate effects by varying the substrate resistivity.

INTRODUCTION

With the rapid growth of wireless communication markets, Si is recognized as a fascinating material to meet the demands of low-cost, high integration, and mature technologies. For the fabrication of inductors on silicon substrate, it is difficult to obtain high quality factor (Q) on Si wafers because of the substrate loss [1]. To overcome this difficulty, the various kinds of approaches have been tried, but a few results with high peak Q have been recently reported using thick gold and high resistivity Si wafer (150 ~ 200 Ω·cm) [2], and using the multilevel interconnection metals [3]. However, it is very difficult and expensive to apply these complicated technologies. Thus, we have previously demonstrated the experimental possibilities to obtain high Q only by increasing the resistivity of the Si substrate, without any modifications from the standard CMOS technology [4]. However, the dependences of geometric parameters on Q has not been analyzed in detail. For designing optimal structure layout, this dependence will be valuable information.

In this paper, the dependences of geometric parameters on the Q of rectangular spiral inductors have been extensively analyzed in order to find the optimum layout parameters and investigate the substrate effect on the Q.

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INDUCTOR FABRICATION PROCESS

A standard CMOS technology with the double-metal interconnects was used to fabricate various structures for rectangular spiral inductors. The metal layer for inductors was formed by the second metal layer with the total thickness of 1.1 μm consisting of TiW (75 nm)/Al-1%Si (800 nm)/TiW (220 nm) [5]. The isolating oxide thickness between the first metal and the silicon substrate was about 1.2 μm as the same thickness of the conventional CMOS process. The substrate was grounded to make the same bias condition of inductors operating in CMOS RF ICs. To reduce high metal resistance of our process, the other inductors with the metal thickness of 2 μm were fabricated by repeating the second metal process twice.

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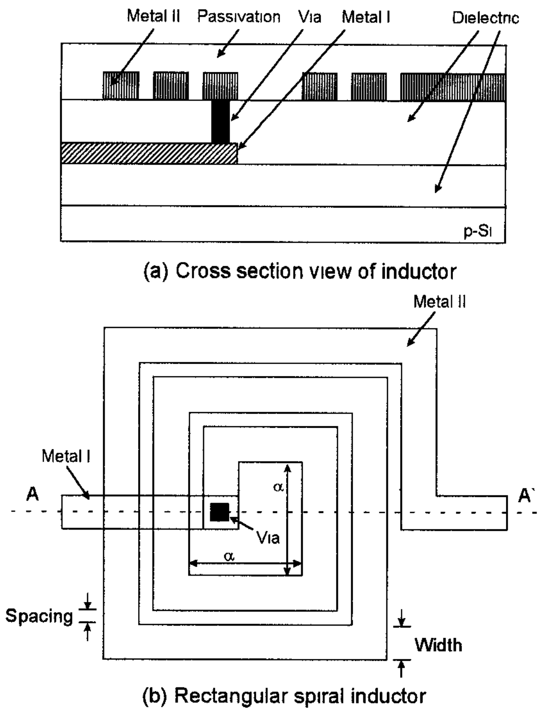

Fig. 1. Cross sectional view and layout of rectangular spiral inductor. The α represents the inner diameter of inductor.

RESULTS AND DISCUSSION

The cross sectional view and layout of rectangular spiral inductor are shown in Fig. 1. Fig. 2 shows a small-signal equivalent circuit used for modeling inductors in this work. The "open" pad patterns were also measured and used to remove the pad parasitics from measured S-parameters [6]. The Q of the inductor was determined as the ratio of the imaginary part to the real part of the one-port input impedance transformed from the measured two-port S-parameters. The circuit parameters for Fig. 2 omitting C_f are determined directly from the Y-parameters converted from the measured S-parameters : R = Real $(-1/Y_{12})$ and L = $(1/\omega)$ Imag $(-1/Y_{12})$.

Fig. 3 shows the Q as a function of frequency for inductors with various number of turns (N) of inductors. In Fig. 3, the frequency at the maximum value of Q (f_{Qmax}) decreases with

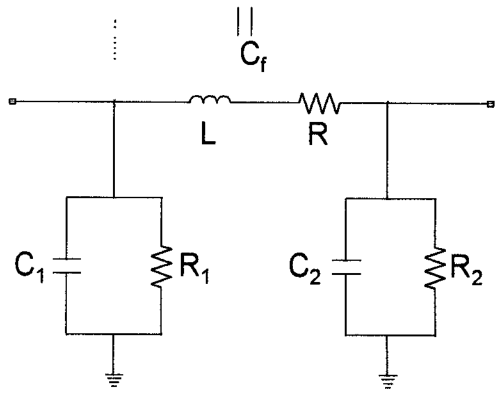

Fig. 2. A small-signal equivalent circuit used for modeling. The dotted line including C_f represents the fringing capacitance used for curve-fitting.

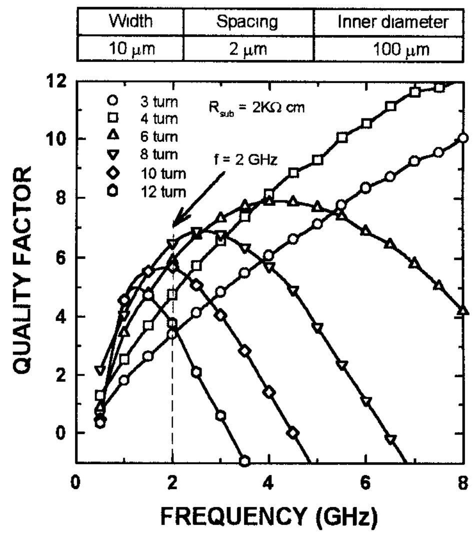

Fig. 3. The quality factor (Q) of rectangular spiral inductors with various kinds of the number of turns as a function of frequency.

the increase of N. At first, the Q at 2 GHz increases with the increase of N, but the Q at 2 GHz decreases above 8 turns due to the decrease of Q_{max} and f_{Qmax} attributed to the increase of fringing capacitance (C_f). Fig. 4 shows the Q and L with various kinds of the substrate resistivity as a function of N at 2 GHz. To inspect the influence of the metal thickness, the Q and L value of the rectangular spiral inductor with the metal thickness of 2 μm was also compared with these results. The 2 μm metal inductor shows the highest Q with the peak value of the 10.3 at 8 turns, which is nearly comparable with the reported result using gold process [3]. In Fig. 4, the Q increases with N, and drops at higher N at 2 GHz. The peaks value of Q increases at higher substrate resistivity. This effect is reasonable because R_1 and R_2 parameters in Fig. 2 become larger with increasing the substrate resistivity, indicating the reduction of substrate conducting loss [4].

Width	Spacing	Inner diameter
10 μm	2 μm	100 μm

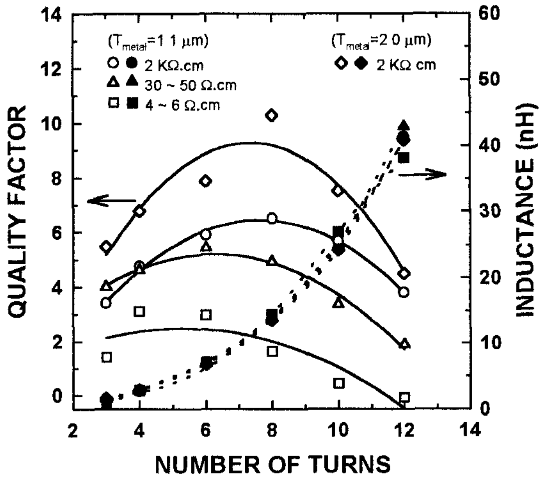

Fig. 4. The quality factor (Q) and inductance (L) of rectangular spiral inductors with various kinds of the substrate resistivity as a function of the number of turns. (f = 2 GHz)

In order to explain the above behavior, model parameters for inductors with different N were extracted by fitting the lumped model including C_f in Fig. 2 to the measured S-parameters using HP-EEsof LIBRA. These fitted results show the increase of C_f with larger N, which explains directly the decrease of Q_{max} and f_{Qmax} shown in Fig. 3. This effect can be caused by the increase of the fringing area with larger N [4].

Fig. 5 shows the Q and L with various kinds of the substrate resistivity as a function of the

Width	Spacing	Number of turns
10 μm	2 μm	8 turns

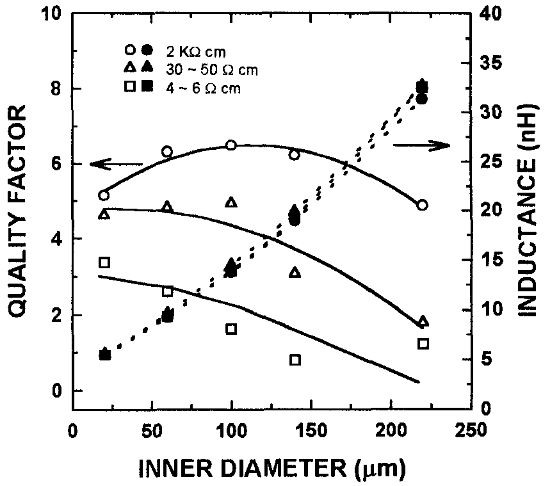

Fig. 5. The Q and L values of rectangular spiral inductors with various kinds of the substrate resistivity as a function of the inner diameters. (f=2 GHz)

Inner diameter	Spacing	Number of turns
100 μm	2 μm	4 turns

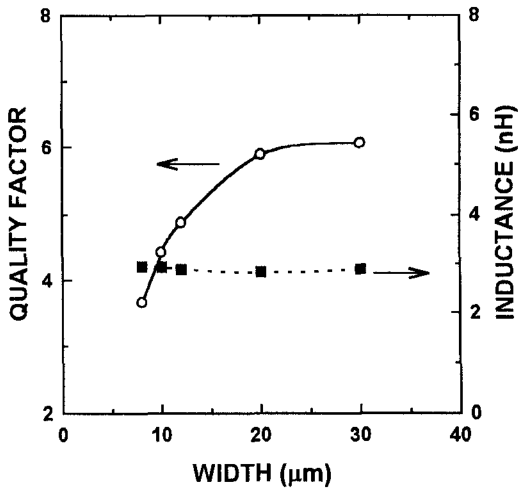

Fig. 6. The Q and L values of rectangular spiral inductors as a function of metal width fabricated on Si substrate of 2 KΩ.cm resistivity. (f=2 GHz)

inner diameter (α) at 2 GHz. At first, with the increase of α, the Q with the substrate resistivity

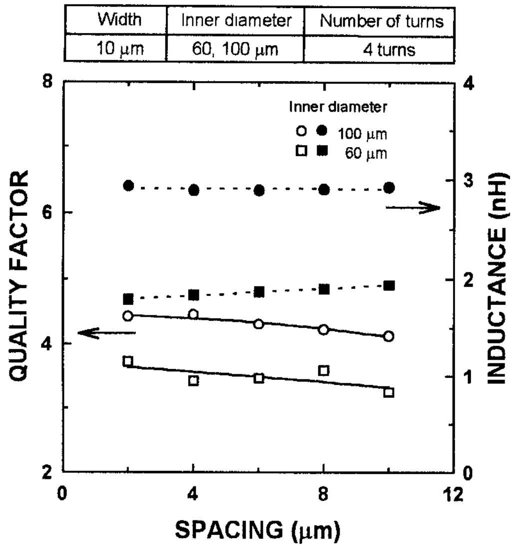

Fig. 7. The Q and L values of rectangular spiral inductors as a function of metal spacing fabricated on Si substrate of 2 KΩ.cm resistivity. (f=2 GHz)

of 2 KΩ.cm increases and then decreases beyond inner diameter of 100 μm. This trend is the same phenomena in the case of the number of turns in Figs. 3 and 4. For the case of lower substrate resistivity, any rising trend is not found as shown in Fig. 5.

Fig. 6 shows no variation of inductance with the increase of metal width, but the Q increases with increasing metal width. This is easily understood by the fact that the resistance of inductor decreases due to the increase of metal width. In Fig. 7, the Q slightly decreases with increasing metal spacing due to the rise of resistance of inductor.

CONCLUSIONS

We studied the geometric layout dependences on the performance of microwave inductors fabricated on the various kinds of Si substrate using standard CMOS double-metal interconnection technology. Based on these studies, we can determine the optimized range of layout parameters to obtain a maximum value of Q, which become valuable information for designing the optimal structure for RF IC applications operating at 2 GHz (PCS band range).

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