Air-Gap Stacked Spiral Inductor

Seung Won Paek and Kwang Seok Seo

Abstract—**In this letter, we propose an air-gap stacked spiral inductor using air-bridge technology. By stacking metal lines, inductor area can be reduced by 25%–45% compared with conventional spiral inductors. The air-gap structure yields low parasitic capacitance, so that the resonance frequency is higher than that of conventional inductor in spite of the reduced inter-wire distance.**

***Index Terms*—Inductor, MMIC, semiconductor process.**

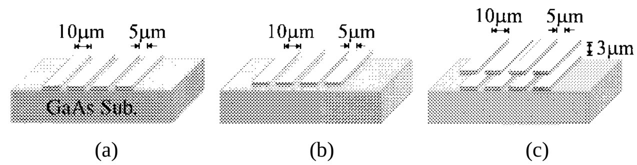

Fig. 1. Cross section of various types of inductors. (a) Conventional inductor. (b) Floated inductor. (c) Stacked inductor.

I. Introduction

THE SPIRAL inductor is one of the main components in monolithic microwave integrated circuits (MMIC's). The goals of inductor design for MMIC's are: 1) large inductance at small area; 2) high resonance frequency (f_R); and 3) high Q factor [1]. Since spiral inductor occupies a large area in MMIC's, reducing its size is crucial for reducing chip size. Air-bridge technology is commonly used at the cross-over part of the inductor track and center feed line. The main idea of this letter is that if we use both metal layers of the air-bridge as the inductor track, the area can be much reduced.

Recently, a stacked spiral inductor was fabricated using multilevel interconnection technology [2]. But its resonance frequency is lower than that of the nonstacked inductor because of larger inter-wire capacitance due to the high dielectric constant inter-metal materials. For the air-gap stacked inductor, parasitic capacitance can be reduced since the air has a much lower dielectric constant than any other dielectric materials; the resonance frequency can therefore be enhanced.

II. Design and Fabrication

We designed three types of inductors of the same line/space geometry. Fig. 1(a) is the cross section of the conventional spiral inductor Fig. 1(b) is the floating spiral inductor where the metal lines are floated in the air by air-bridge technology so that parasitic capacitance can be reduced. Fig. 1(c) is the stacked spiral inductor, which is the combined form of (a) and (b). Since metal lines are overlapped, area can be reduced.

Fig. 2 is the photograph of a 7.5-turn stacked inductor. The inductors are laid out as an octagon type since it is known to have better property than the square type [3]. The posts of air-bridge are located at the short side corner of octagonal track. The ground plane was placed 50 μm apart from both side edges of inductor, as a coplanar waveguide structure, for on-wafer radio frequency (RF) characterization. The distance between inductor edge and the ground metal plane was 50 μm and the thickness of the semi-insulating GaAs substrate was about 400 μm. The fabrication process of air-gap stacked inductor is identical to the air-bridge process of conventional inductor. The metal thickness was 2 μm and the height of air-gap was 3 μm.

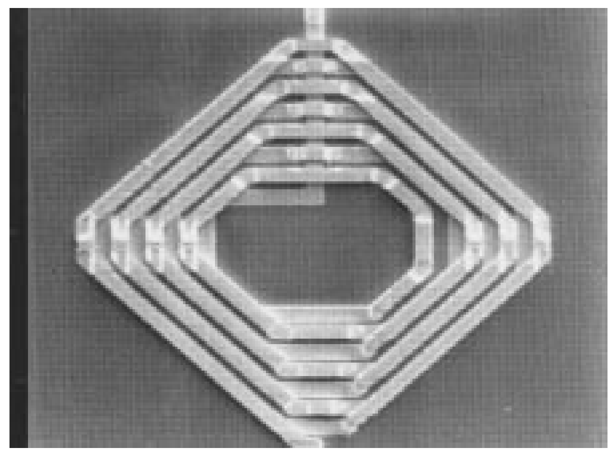

Fig. 2. Photograph of 7.5-turn fully stacked inductor. At the long side of octagonal track, two metal layers are overlapped with air-gap. The posts of air-bridges are located at the short side corner.

III. Result and Discussion

S-parameters of inductors were measured by a HP8510C network analyzer. Modeling was performed in the frequency range from 500 MHz to about 130% of resonance frequency (f_R) using the equivalent circuit shown in the inset of Fig. 3. The error in modeling is less than 2.0%. Fr is determined by inductance L and parasitic capacitance. Fig. 3 shows the measured f_R of various inductor structures. F_R of stacked

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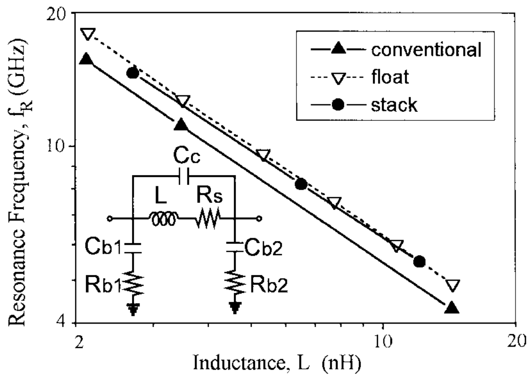

Fig. 3. Resonance frequency of various inductors. The inset is the equivalent circuit used for modeling.

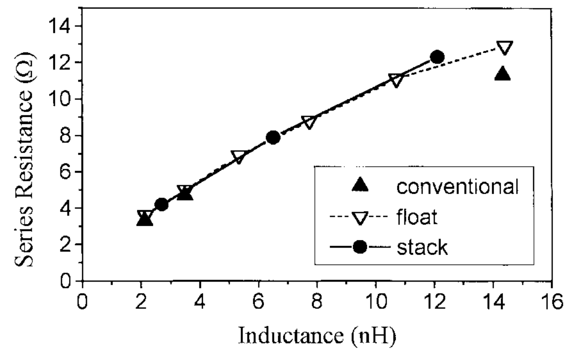

Fig. 5. Relation between inductance and series resistance of inductors.

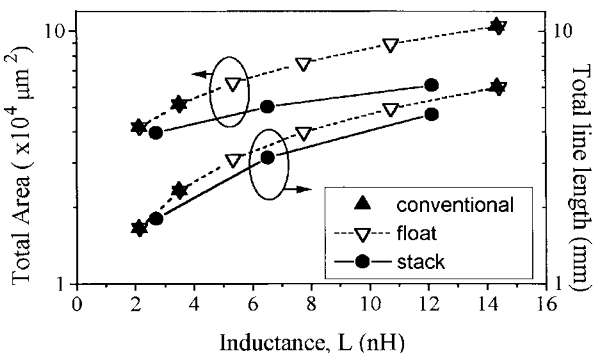

Fig. 4. Total line length and total area of inductors. Stacked structures need shorter line length and smaller area than nonstacked structures.

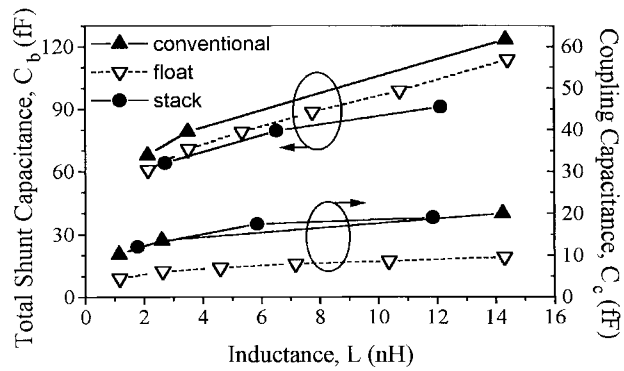

Fig. 6. Relation between parasitic capacitances and inductance. C_b is the sum of shunt capacitance C_{b1} and C_{b2}, shown in the inset of Fig. 3.

inductor is similar to floated inductor which is about 10%–15% higher than the conventional inductor of the same inductance. This improvement can be explained by reduction of parasitic capacitance.

Fig. 4 shows the relation between the inductance and the area/length of various types of inductors. As can be expected, the stacked inductor needs much less area than the conventional or floated type to realize the same inductance. The area reduction ratio is about 25%–45%. Higher area reduction ratio can be obtained for larger inductance. Also from Fig. 4, stacked structures needs about 10% shorter total line length than nonstacked structure. This is the consequence of increased mutual inductance by smaller line-to-line distances in the stacked inductor [4], which is determined by bottom photoresist thickness in the air-bridge process. In addition, the distance between second and third nearest neighboring lines can be reduced much more by stacking the metal lines to two levels. Fig. 5 shows the series resistance of various inductors. Though total line length of the stacked inductor is a little shorter than nonstacked inductor, and its series resistance is a little larger. This is due to contact resistance between first metal and second metal layer, which may be reduced by appropriate surface treatment.

Reducing the line-to-line distance may result in the increase of inter-wire coupling capacitance C_c. However, as shown in Fig. 6, C_c of stacked inductors are similar to that of conventional inductor of the same inductance. In a floated inductor, metal lines are surrounded by air except for the posts of air-bridges, which bring out smaller C_c than other structures. But in the conventional inductor, metal lines are laid on high dielectric constant material (GaAs), and thus C_c is much larger. In stacked inductors, which is the combined form of conventional and floated inductors, the effective dielectric constant of the surroundings would be smaller than that of the conventional inductor. Thus, the two effects—reduced line-to-line distance and reduced effective dielectric constant—are canceled by each other, and thus C_c of the stacked inductor is similar to that of the conventional inductor. Fig. 6 also shows that the stacked inductor has much smaller value of total shunt capacitance C_b than the nonstacked inductor. From this result, it can be understood that the reduced area of the stacked inductor gives smaller C_b for the same inductance. For microstrip geometry, where substrates are usually thinned, C_b increases and becomes dominant factor of f_R, which makes air-gap stacked structure more effective for enhancing f_R.

IV. Conclusion

By using air-gap stacked structure, about 25%–45% of inductor area can be reduced and resonance frequency can be enhanced about 10%–15% without additional process complexities. So, air-gap stacked inductors can be easily employed in MMIC fabrication processes.

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