SUSPENDED MEMBRANE INDUCTORS AND CAPACITORS FOR APPLICATION IN SILICON MMIC'S

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ABSTRACT

This paper considers the fabrication and modelling of suspended membrane inductors and capacitors on ordinary Silicon substrates. A single post-processing etching step was added to an otherwise standard process. For both components, parasitic capacitances to ground are drastically reduced, enabling high frequency operation. Furthermore, the measured quality factor Q is demonstrably improved with respect to normally fabricated thin film components.

INTRODUCTION

The emergence of viable high frequency silicon and SiGe BJT technology has stimulated the search for methods of realizing high performance passive components in integrated MMIC form [2,3,5]. The selective etching of silicon is one of the more attractive methods reported to date [1,2,5]. Spiral inductors with Q's of 20 at 4.3 GHz and others with self-resonant frequencies up to 70 GHz have been described. These results have in general been achieved on very high resistivity silicon substrates [4], which are not applicable to most standard bipolar processes. The reported geometries are relatively large. Suspended membrane metal-insulator-metal (MIM) capacitors based on the same etching technique have not, as far as we know, been presented. Only one result has been reported to date describing an interdigitated capacitor fabricated on a dielectric membrane; no published results of measured Q are available [2].

PROCESSING

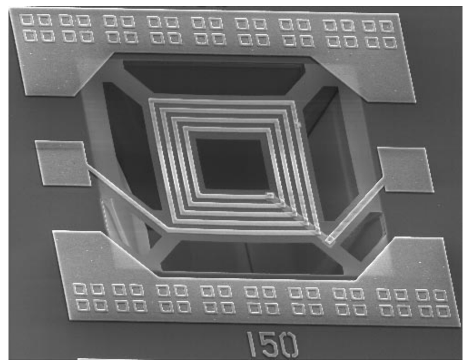

Figure 1: Photo of suspended spiral inductor

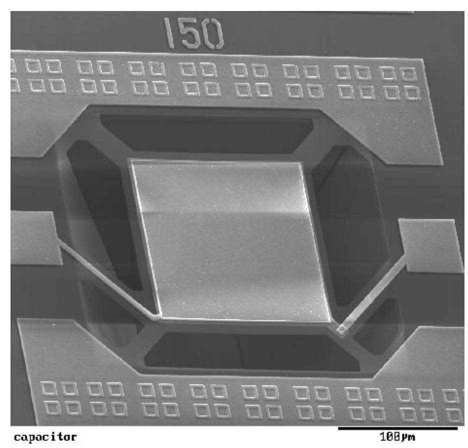

Figure 2: Photo of suspended MIM capacitor

This paper presents recently realized passive components based on silicon micro-machining applied to a standard 15 GHz bipolar process (DIMES-03). This process uses low stress silicon nitride (Si_xN_y) for surface isolation [6]. A film of Si_xN_y facilitates the formation of thin membranes without buckling or cracks by selective etching the underlying silicon. Spiral inductors, MIM capacitors, shown in Figure 1, 2 and microstrip lines on standard 3.5Ωcm silicon <100> substrates suitable for integration with active components have been fabricated. The thickness of first and second metal are 0.6 μm and 1.4 μm, respectively. A layer of Al_2O_3 is used between the two metal layers to obtain high value, small area MIM capacitors. Only one single post-processing etching step is needed to remove a portion of the substrate to form the suspended membrane. After integration of the components the wafer is selectively protected by a mask of Si_3N_4. The silicon is etched from the top side of the wafer using KOH, which has proven preferable to backside etching in realizing miniaturized components for MMIC applications. The etch automatically stops and forms grooves under the passive components bounded by silicon <111> planes, as shown in Figure 3 and 7.

UNDER-ETCHED INDUCTORS

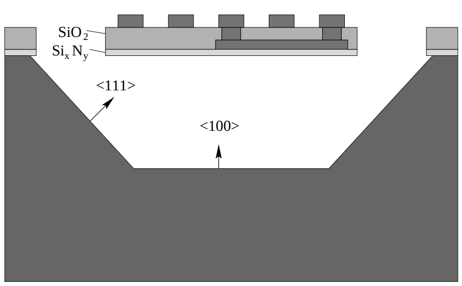

Figure 3: Cross-section of under-etched inductor

The spiral inductors have 5μm line width and line spacing with various number of turns, outer dimensions, orientations, and underetching to various depths. An equivalent circuit has been developed, as given in Figure 4, in which additional capacitors are introduced to account for the parasitic capacitance of the air bridge between the spiral metallization and the substrate. A simple polynomial has been found very helpful in modeling the high frequency behavior of the series resistance. The model fits very well with all the measurements. The results indicate that inductors with larger dimension and deeper etching yield higher Q, and that the ratio of the outer dimension to the etching depth is a useful figure of merit in describing the Q. Measured Q's range from 6 to 28 at frequencies from 6 to 18 GHz. The extrapolated resonant frequency for an 1.1 nH inductor is 84 GHz (Figure 5). The Q can be even higher with wider lines.

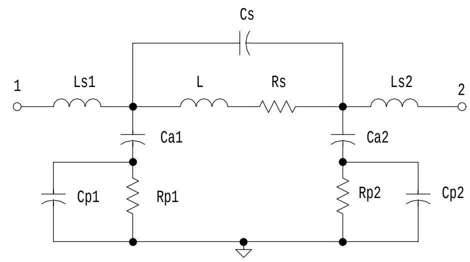

Figure 4: Lumped model of suspended spiral inductor

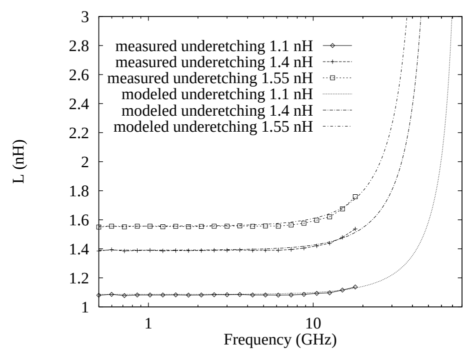

Figure 5: Measured and modeled inductance of spiral inductors

UNDER-ETCHED CAPACITORS

The suspended MIM capacitor described here is a new MMIC component with respect to those previously reported [1,2]. MIM capacitors of vari-

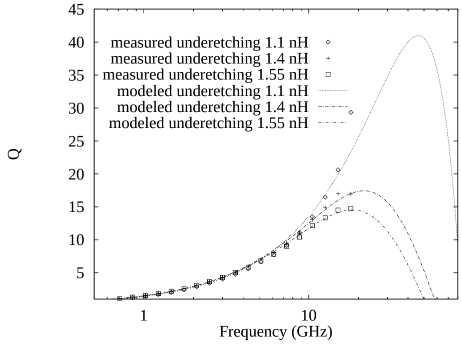

Figure 6: Measured and modeled quality factor of spiral inductors

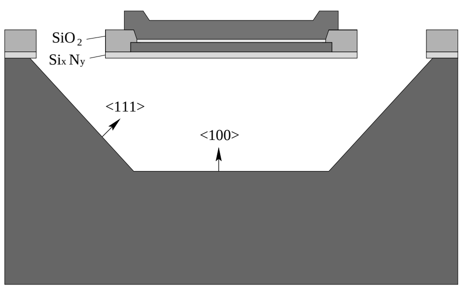

Figure 7: Cross-section of under-ecthed MIM capacitor

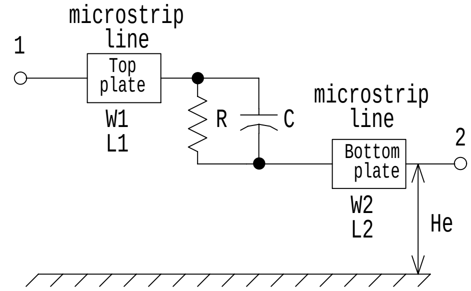

Figure 8: Hybrid model of suspended MIM capacitor

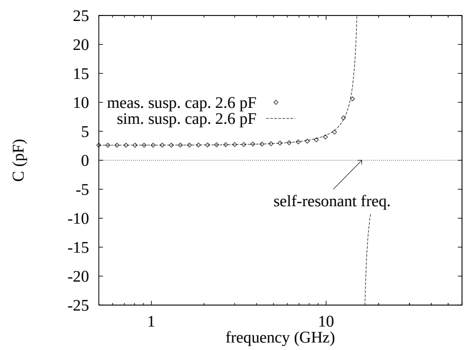

Figure 9: Measured and modeled capacitance of MIM capacitor

ous dimensions and etching depths were realized. Measurements on suspended capacitors and microstrip lines have been used to de-embed the capacitor characteristics. Although the self-resonant frequency is not improved, the Q of MIM capacitors realized on suspended membrane is significantly increased. This is very important for MIM capacitors in MMIC's with both plates floating. A lumped-distributed hybrid model has been developed (see Figure 8), in which a resistor in parallel with the capacitor models the dielectric loss between the plates. An equivalent ground and etching depth (He) have been introduced for the distributed elements, which are quite important for modeling the resonant frequency. The Q of a 2.6pF capacitor exceeds 100 at 2GHz with a resonant frequency of 15.9 GHz, while the same capacitor directly fabricated on silicon has a Q less than 10 (Figure 9).

APPLICATIONS

We have compared the small-signal performance of a simple LC high pass filter with suspended capacitors and conventional capacitors. The schematic of a simple third order high-pass filter is shown in Figure 11. The simulated results for the filter are shown in Figure 12, where we wish to stress that *measured* results were used for the suspended membrane and the conventional capacitors and inductors.

CONCLUSION

Suspended membrane inductors and capacitors on ordinary Silicon substrates have been presented. It was shown that, with the addition of one simple process step, inductors and capacitors are re-

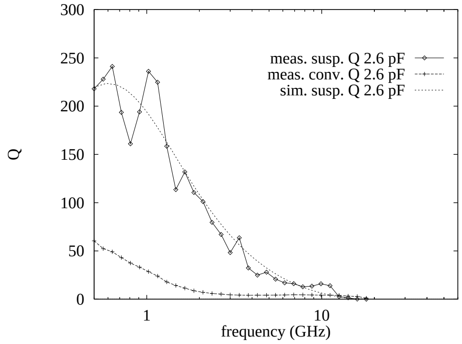

Figure 10: Measured and modeled quality factor of MIM capacitor

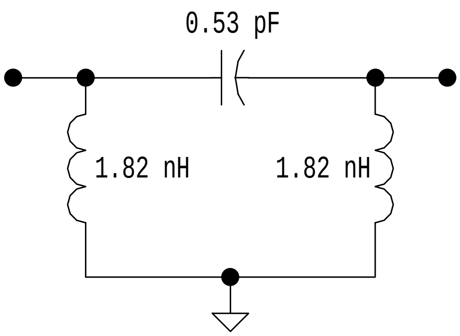

Figure 11: A simple high pass filter

alizable with drastically reduced parasitic capacitances to ground and higher component Q's. Both components were measured and modelled. It is clear from the data shown that suspended membrane structures have superior RF performance and are, therefore, a valuable contribution to silicon MMIC design.

REFERENCES

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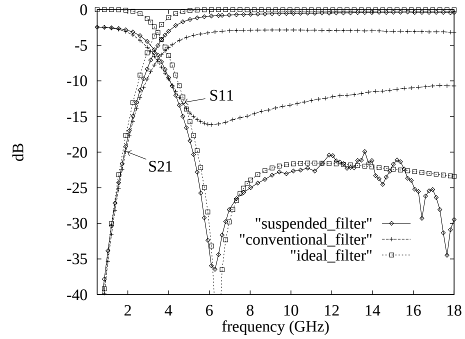

Figure 12: Comparison of three filters: filters with, without suspended MIM capacitor and filter with ideal elements

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