Monolithic Silicon-Glass Double Balanced Mixers for Wireless Communications

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Abstract

This paper describes the design, fabrication, and performance of monolithic double balanced mixers designed for cellular applications at 900 and 1800 Mhz. The mixers have been fabricated using a process which combines silicon and glass to form a heterolithic microwave integrated circuit (HMIC[1,2]). The glass provides a low loss substrate for RF or microwave passive structures, while the silicon pedestals embedded in the glass allow the formation of Schottky barrier diodes and vias. The resulting circuits have levels of performance similar to those of hybrid double balanced mixers, but are small, low cost, monolithic die suitable for assembly in a low cost plastic package.

Introduction

At low microwave and RF frequencies mixers are usually hybrid circuits. These components, constructed from wirewound ferrite baluns and discrete silicon Schottky barrier diodes, offer several performance advantages over competing technologies. Silicon Schottky diodes have much better 1/f performance than GaAs diodes or GaAs FETs, and much better dynamic range than silicon bipolar transistors, commonly used in Gilbert cell mixers. Mixers constructed from diodes do not require DC bias, unlike mixers based on three terminal devices. Silicon Schottky barrier diodes also offer an additional degree of flexibility, since the barrier height can be adjusted by changing the anode metallization, allowing LO drive levels and intermodulation characteristics to be tailored to a specific application.

Hybrid mixers have several disadvantages, especially in cost and size. Ferrite based baluns have hand wound coils and are relatively large; packages for hybrid circuits are too large for today's cellular systems. The performance of the ferrite baluns degrades at higher frequencies. At 1800 and 2400 Mhz, where many new systems are under development, the repeatability of the electrical characteristics of the ferrite baluns is poor, resulting in poor uniformity of mixer characteristics.

In this paper a new approach to mixers is described. Silicon and glass are combined to realize a circuit which has the advantages of a silicon Schottky diode double balanced mixer, but which is fully monolithic and includes passive elements on a low loss glass substrate. This approach should be useable through microwave and low millimeter wave frequencies. We describe circuits designed for 900 and 1800 Mhz.

HMIC Process

Figure 1 is a cross sectional view of an HMIC circuit. The process for producing these circuits starts with a 100 mm diameter N+ silicon wafer on which N+ buffer and N epitaxial layers have been grown. Anisotropic etching is used to remove silicon from the wafer, leaving pedestals where diodes and vias will be located. N-type phosphorus diffusion on the sidewalls of the pedestals improves the N+ silicon conductivity and facilitates formation of cathode contacts on the Schottky diodes. Areas where the silicon has been removed are filled with a borosilicate glass with a low dielectric constant (4.1) and a low loss tangent (0.002) This glass forms the low loss substrate on which passive microstrip elements are realized. After deposition of the glass, the top of the substrate is ground and polished to within a few microns of the tops of the silicon pedestals, and holes are etched in the glass to the pedestal tops, allowing metal contacts to be made to the diodes and vias.

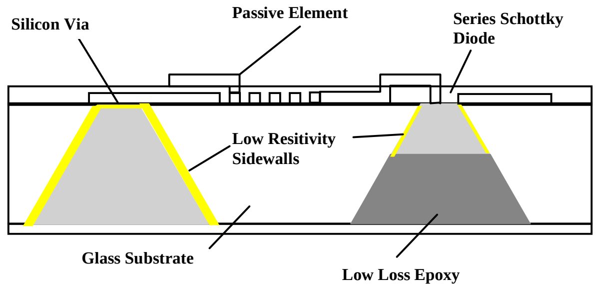

Figure 1: HMIC Circuit Cross Section

The diodes in Figure 1 are in a series configuration with anode and cathode contacts on the top of the wafer. The diodes are isolated from the microstrip ground plane by etching the base of the silicon pedestals from the backside of the wafer and backfilling with an electrically insulating epoxy compound. Metal contacts and passive elements are formed on the top of the wafers with two layers of Ti-Pt-Au metallization. Airbridges and crossovers are formed with the second metal layer. A 0.3 micron thick layer of silicon nitride is used as passivation and also forms MIM capacitors. A layer of polyimide is used to provide scratch protection for the metal structures on top of the circuit.

Circuit Design

Figure 2 is a schematic for a double balanced mixer. The mixer comprises an RF balun, LO balun, and Schottky ring quad. Each balun is realized by a pair of spiral transformers connected in parallel at the unbalanced input and in series at the balanced outputs. MIM capacitors are used to resonate the self inductance of the transformers at both the input and the outputs, providing a match over a 30% bandwidth. The baluns operate as 4:1 step up transformers, transforming a 50 ohm input impedance to 200 ohms between the balanced outputs[3]. The balun outputs are connected to a silicon Schottky barrier diode ring quad. The IF output is connected to the center tap of the RF balun.

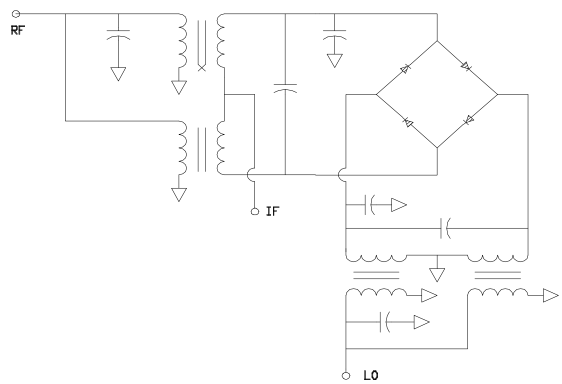

Figure 2: HMIC Double Balanced Mixer Schematic

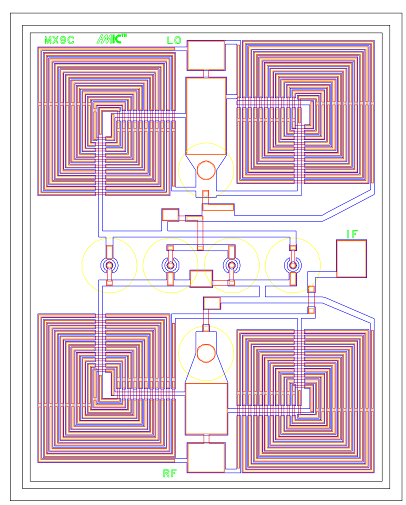

Figure 3: 900 Mhz Mixer Layout

Figure 3 is a layout for a 900 Mhz circuit realized with the HMIC process, while Figure 4 is a layout

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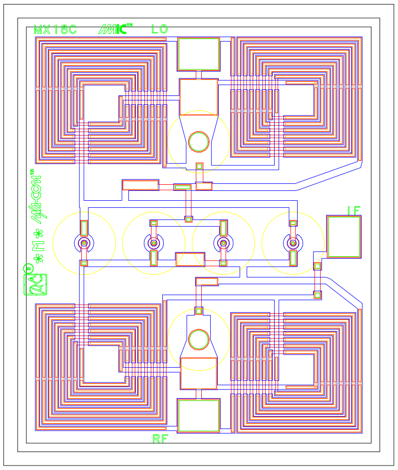

Figure 4: 1800 Mhz Mixer Layout

for an 1800 Mhz circuit. The 900 Mhz circuit is 1.52 by 1.20 mm while the 1800 Mhz circuit is 1.25 by 1.04 mm; both die are 0.125 mm thick. A photograph of the 900 Mhz mixer appears in Figure 5.

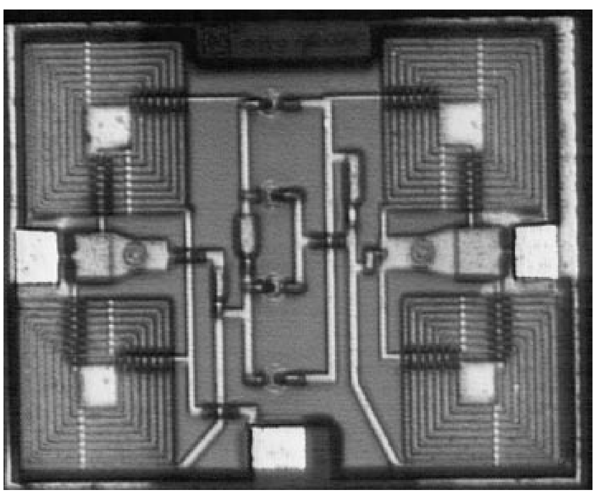

Figure 5: 900 Mhz Mixer Photograph

The spiral transformers in both mixers are realized by coupled transmission lines with a line width of 15 microns, spacing of 5 microns, and metal thickness of 2.5 microns. The transformers were modeled using an electromagnetic simulator[4]. The silicon Schottky diode in the 900 Mhz mixer is a low barrier device with a zero-bias junction capacitance of 0.32 pF and a Vf of 0.24 volts at 1 mA forward bias. The diode in the 1800 Mhz circuit is similar, but with a zero-bias junction capacitance of 0.20 pF.

Circuit Performance

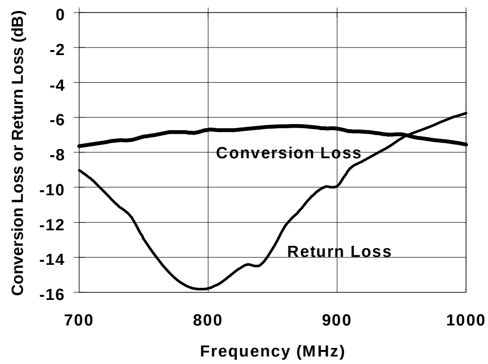

Figure 6: Conversion Loss and RF Input Return Loss For 900 Mhz Mixer

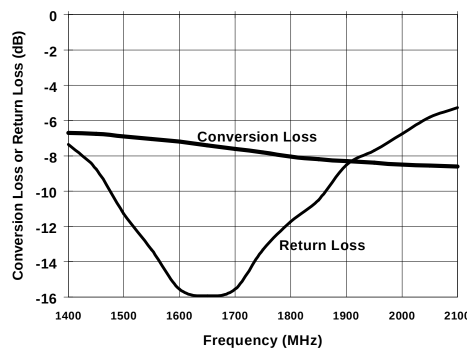

Figure 7: Conversion Loss and RF Input Return Loss For 1800 Mhz Mixer

Figure 6 contains plots of conversion loss and input return loss versus frequency for the 900 Mhz mixer, while Figure 7 is a similar plot for the 1800 Mhz mixer. The 900 Mhz mixer operates from 700 to 1000 Mhz while the 1800 Mhz mixer covers the 1400 to 2100 Mhz band. Table 1 contains a summary of typical measured characteristics for these two circuits at the center of their operating bands, compared to a 900 Mhz hydrid circuit realized with wire wound ferrite baluns and discrete silicon Schottky diodes. The hybrid mixer is a M/A-COM Eurotec ESMD-C1X8.

Specification:	900 Mhz Monolithic Die	1800 Mhz Monolithic Die	900 Mhz Hydrid Circuit (ESMDC1X8)
RF Bandwidth	0.7-1.0 GHz	1.4-2.0 GHz	0.8 - 1.0 GHz
IF Bandwidth	DC-300 Mhz	DC -300 Mhz	DC - 200 Mhz
Conversion Loss	7.0 dB	8.0 dB	7.0 dB
RF Input RL	10 dB	12 dB	Not Specified
LO-RF Isolation	32 dB	28 dB	30 dB
LO-IF Isolation	27 dB	26 dB	25 dB
Input IP3	+12 dBm	+12 dBm	Not Specified
Input 1 dB Compression	+2 dBm	+2 dBm	+ 0 dBm

Table 1: Comparison of Monolithic and Hydrid Mixer Typical Characteristics

Conclusion

We have described the design, fabrication process and measured performance of two monolithic silicon-glass double balanced mixers for 900 Mhz and 1800 Mhz. These fully monolithic circuits were fabricated using a heterolithic microwave integrated circuit (HMIC) process, which allows the advantages of silicon Schottky barrier diodes, a low loss glass substrate and IC processing to be realized in small, low cost die. The performance characteristics of the die compare favorably to those of currently available hybrid mixers. The die can be assembled into a small, low profile, low cost surface mount plastic package, such as the SOIC-8 or SOT25.

Acknowledgments

The authors are indebted to Joe DeMoura and Steve Massa, who designed and developed early versions of these two circuits. We also would like to acknowledge the contributions of Chris Souchuns, who provided models for the Schottky barrier diodes, and Jim Drohan, who completed layouts of both circuits.

References

1. United States Patent 5,268,310
2. “HMIC: A Silicon Microwave Integrated Circuit Process”, Microwave Journal, Vol. 37, No. 1, January 1994, pp. 136-138.
3. DeMoura, J., and Massa, S., “HMIC Double Balanced Mixer for Cellular Communications”, M/A-COM Seventh Annual Engineering Conference, October 1993, pp. 279-283.
4. Hewlett-Packard Momentum, Ver. A.01.00.