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1-V Multigigahertz MOSFET Amplifier with an On-Chip Inductor Fabricated on a SIMOX Wafer

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Abstract—**This paper describes a technology that can be used to integrate multigigahertz microwave circuits into large-scale digital circuits. Spiral inductors and a MOSFET amplifier with an inductive load were fabricated on the SIMOX wafer in order to demonstrate the feasibility of the SOI technology. With a 1-V supply voltage, peaking of the amplifier gain was observed, as expected from circuit simulations, at 1-4 GHz. These results show that microwave circuits with inductors can be implemented on a SIMOX wafer by using the conventional digital CMOS LSI process.**

I. INTRODUCTION

Si-based technologies for RF front-end circuits have recently been developed in an attempt to apply an all-Si technology to L-band MMICs (Monolithic Microwave Integrated Circuits) and their integration with digital circuits [1]. The main objective of these efforts is to fabricate highly integrated portable personal digital RF communications terminals. The key issue in implementing such all-Si technology is that the Si-based microwave circuits should be able to be integrated into VLSIs. The microwave circuits need both passive and active devices that perform well even in the multigigahertz range. The f_{MAX} of active devices must be high and an inductor, which is one of the passive devices most commonly used in microwave circuits, needs to have a sufficiently high self-resonance frequency [2]. One possible solution to this application is to use a Silicon-on-Insulator (SOI) technology [3], because the microwave performance of SOI-MOSFETs is sufficiently good in the multigigahertz range [4]. However, an inductor on a SOI wafer—and thus a microwave circuit including such an inductor—has not yet been reported. This paper therefore reports the first MOSFET RF amplifiers with inductors made on a SIMOX wafer.

II. DEVICE FABRICATION AND MODELING

We used a low-dose SIMOX wafer that had a 100-nm-thick buried oxide layer. This wafer was suitable for this work not only because of the high quality of its top Si layer but also because of its good conduction of heat from active devices to the substrate [5]. We used 0.25-μm nMOSFETs/SIMOX. The on-chip spiral inductors had 5-μm metal width, 5-μm spacing, and four-turn. The active and passive devices were made using the same process as that used for making CMOS/SIMOX LSIs [6] so that we could easily embed the microwave components in LSIs. We made simple MOSFET amplifiers with these spiral inductors to evaluate the effects of the inductors operating in the multigigahertz range. We did this by designing common-source

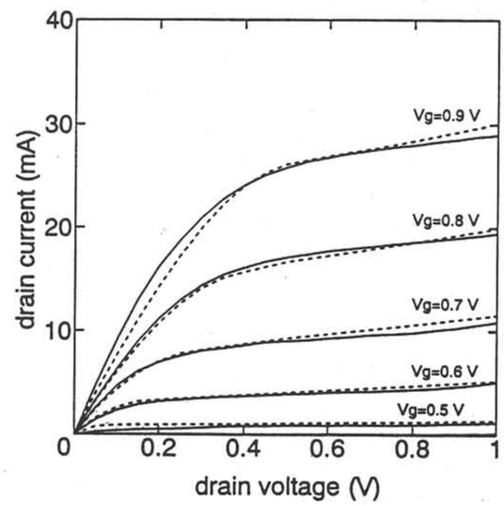

Fig. 1. Measured (dashed line) and simulated (solid line) DC characteristics. Lg= 0.25 μm, Wg= 600 μm.

amplifiers with their peak gain in that range. All of the small signal results presented were obtained in on-wafer S-parameter measurements using an HP8510B network analyzer and Cascade microwave probes.

The characteristics of nMOSFETs were modeled using the circuit simulator HSPICE. We first modeled the DC characteristics and then used the DC model to optimize capacitances such as C_{OV} and C_D (respectively the gate-overlap capacitance and drain-to-substrate capacitance of MOSFETs) so as to fit the measured S-parameter characteristics. S-parameters of each single spiral inductor were measured to obtain parasitics, which were derived assuming an equivalent circuit in HSPICE. The HSPICE model parameters obtained this way were used to perform circuit simulations of the fabricated amplifiers.

III. RESULTS

Figure 1 shows the good agreement between the measured and modeled DC characteristics of a typical 0.25-μm nMOSFET on SIMOX. The common-source current gain H21 and the unilateral power gain U are shown in Fig. 2. The values of f_T and f_{MAX} at a supply voltage of 1 V were respectively about 19 and 27 GHz. The capacitances C_{OV} and C_D were optimized with using measured S-parameters of the nMOSFET whose DC characteristics are shown in Fig. 1, and the measured and modeled S-parameters are shown in Fig. 3.

The characteristics of the inductor were investigated by using the S-parameters measured with the network shown

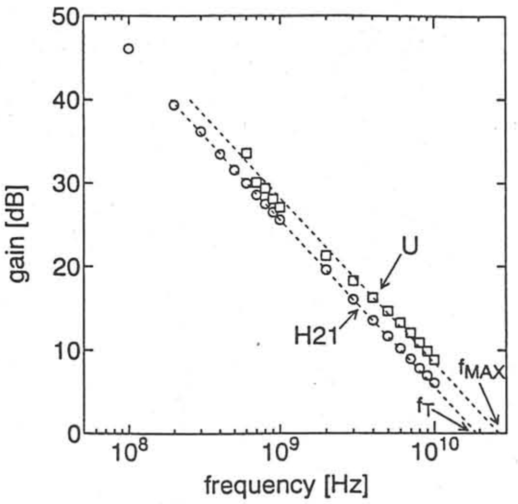

Fig. 2. Frequency dependence of typical nMOSFET current gain H21 and unilateral power gain U computed from measured S-parameters. Lg= 0.25 μm, Wg= 600 μm. Drain voltage V_{DS} was 1 V and gate voltage V_G was 1 V.

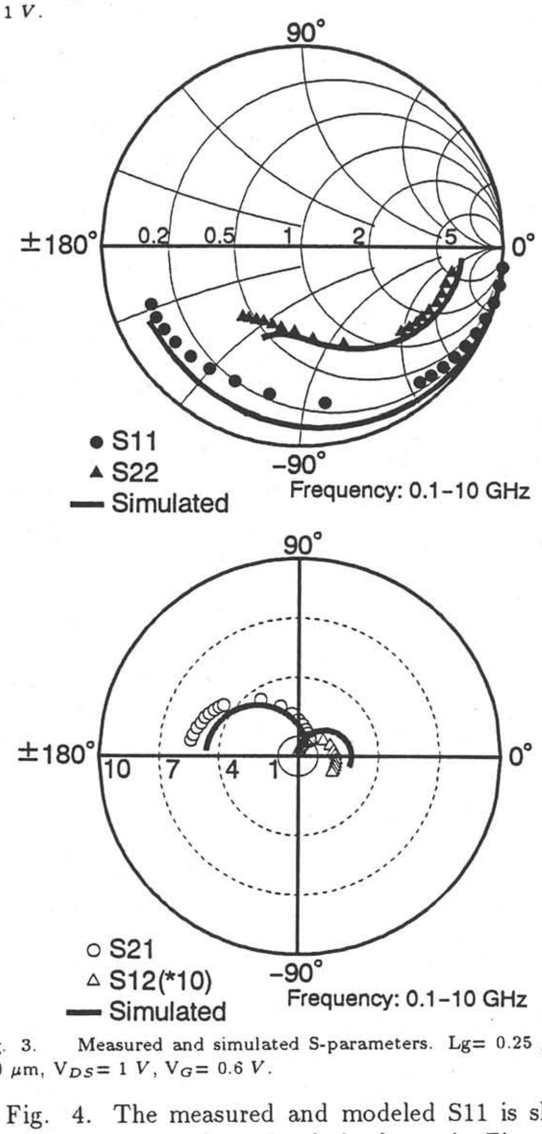

Fig. 3. Measured and simulated S-parameters. Lg= 0.25 μm, Wg= 600 μm, V_{DS}= 1 V, V_G= 0.6 V.

in Fig. 4. The measured and modeled S11 is shown in Fig. 5. The equivalent circuit is shown in Fig. 6. The self-resonance frequency was 17 GHz which was sufficiently high. We made two types of common-source amplifiers as

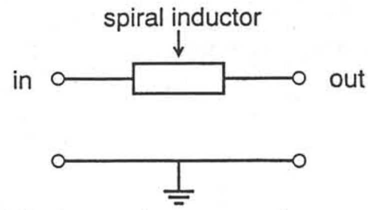

Fig. 4. Network for S-parameter measurement.

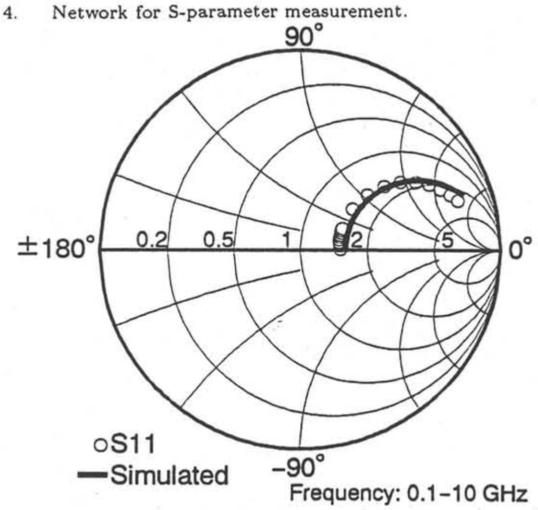

Fig. 5. Measured and simulated S11 of the inductor shown in Fig. 4.

shown in Fig. 7. One had the inductor as a peaking coil, and the other had a poly-Si resistor instead. The resistance of the poly-Si resistor was designed to be the same as the parasitic resistance of the inductor. Figure 8 shows the measured gain for the two types of amplifiers, and it is evident that peaking of the gain is obvious only for the inductor type: gain was boosted by 2–4 dB at 1–4 GHz. The peaking evident in a similar plot of the simulated gain (Fig. 9) agrees with the experimental results, thus showing that the model is appropriate. The two-tone intermodulation distortion characteristics of the amplifier with the inductor were measured (Fig. 10). Input signals were 2.00 GHz and 2.01 GHz. The output third-order intercept-point of 9.2 dBm was obtained, which is acceptable for the RF front-end application. The amplifiers presented in this paper are simple, but their performance demonstrates the feasibility of using an SOI device and inductor in microwave circuits operating in the multigigahertz range.

IV. CONCLUSION

We made, for the first time, a multigigahertz MOSFET amplifier with an inductive load fabricated on a SIMOX wafer using the conventional digital CMOS LSI process. Peaking of the gain was clearly observed at 1–4 GHz, as expected from simulations. The output third-order intercept-point of 9.2 dBm was obtained at 2 GHz, with a 1-V supply voltage. These results show that multigigahertz microwave circuits with inductors can be implemented on SOI wafers.

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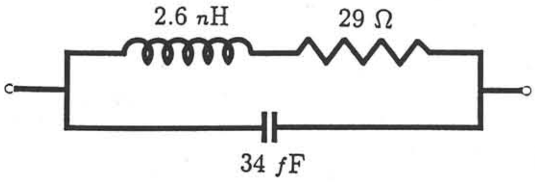

Fig. 6. Equivalent circuit of a four-turn spiral inductor.

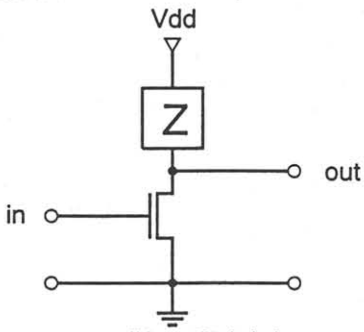

Fig. 7. Common-source amplifier. "Z" is inductor or poly-Si resistor as load.

technical support in fabricating devices. And we thank Noboru Ishihara, Tsuneo Tsukahara, and Masayuki Ishikawa in the High-Speed Integrated Circuits Laboratory for their support in AC measurements and for their useful discussions.

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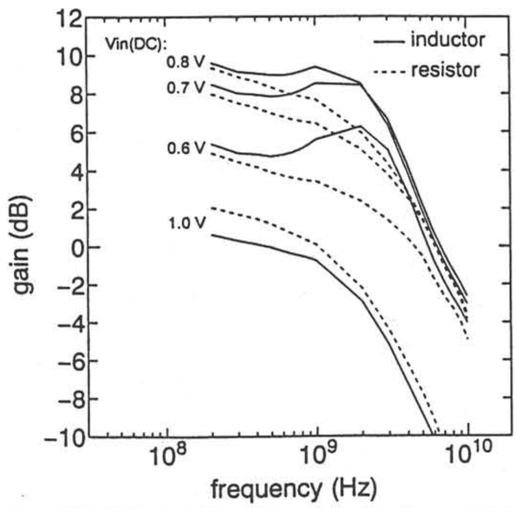

Fig. 8. Measured gain of both types of amplifiers. Supply voltage V_{dd} was 1 V and Wg was 600 μm.

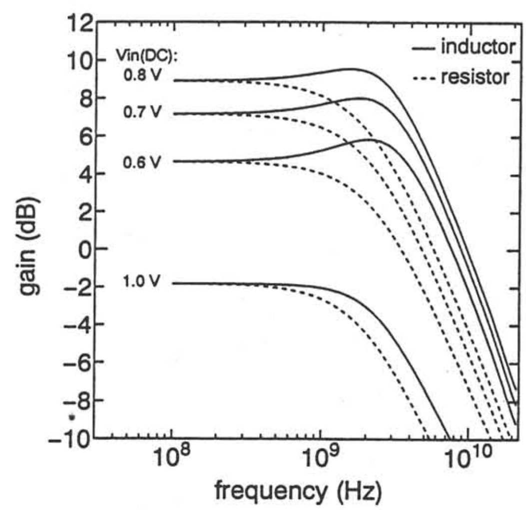

Fig. 9. Simulated gain of amplifiers whose measured gain is shown in Fig. 8.

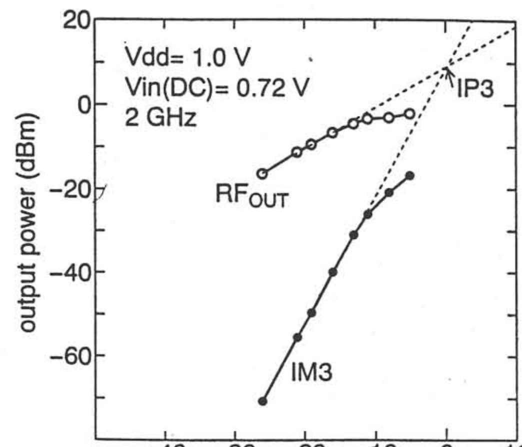

Fig. 10. Output power versus input power for the amplifier with the inductor: O fundamental frequency; ● third-order intermodulation product. Input signals were 2.00 GHz and 2.01 GHz.