Mixed-Signal Micro-Systems in Emerging SOI Technologies

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***Abstract*— Silicon-On-Insulator (SOI) technologies have recently attracted interest in the development of next-generation high-performance micro-systems. The absence of latch-up, the reduced parasitic capacitance, the circuit isolation and multi-threshold devices are just a few of the advantages of this technology. This article introduces a flavor of SOI called Silicon-On-Sapphire (SOS), describing the fabrication process, the advantages for innovative low-power, low-voltage, high-speed micro-system design. We present the design and development of several advanced SOS micro-systems, such as: analog-to-digital converters, monolithic digital isolation buffers, image sensor arrays, low-voltage and low-current detectors, and communication systems.**

I. Introduction

Silicon-on-insulator technology is a key player in the manufacturing of the next generation of high-speed, high-performance microprocessors and radio frequency communication circuits. The SOI technology allows for higher-speed circuits and microprocessors while, at the same time, lowering the power demands of these high-performance components. IBM was one of the first companies to use SOI to fabricate microprocessors [1]. Laboratory testing shows that SOI-based processors feature a 20-25% speed advantage and an average saving of 40-50% in power consumption when compared to their bulk CMOS counterparts [2]. The application of SOI technologies in radio frequency (RF) circuits has also increased, due to higher circuit speeds, lower power consumption, enhanced circuits insulation, and increased performance of passive components [3].

This paper introduces the use of SOI technology for high-performance mixed-signal micro-systems. The examples reported show that SOI analog and mixed-signal circuits can benefit from the insulating substrate and provide higher performance at lower power draw than similar feature-size bulk-CMOS processes. The advantages of SOI extend to the combination of high-performance digital, RF and analog circuits, and thus are the preferential substrate for the design of the next generation of mobile-targeted circuits and systems.

II. The SOI process

Silicon-on-insulator is a VLSI fabrication process in which a thin layer of silicon is deposited on the top of an insulating material ([4]). Silicon-on-sapphire, in which the insulating material is synthetic sapphire, was one of the first SOI processes available. In an SOI process, active metal-oxide-semiconductor (MOS) devices and other passive devices are fabricated in and on the thin layer of silicon.

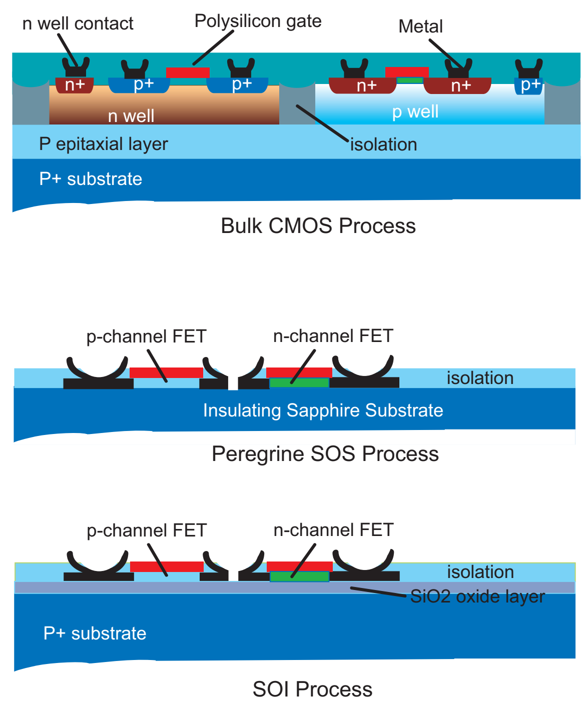

Fig. 1. Comparison of the CMOS wafer cross-section (top), an SOS CMOS wafer (middle) and an SOI CMOS wafer (bottom). The circuit in each of these cross-sections is a CMOS inverter ([3]).

In SOS, a thin layer of silicon is grown on top of a sapphire substrate, as can be seen in Figure 1. In this Figure, the main difference between bulk CMOS, SOS and SOI are clearly visible. At the top of Figure 1 we report the cross-section of a typical deep-submicron CMOS process. In this cross-section the example circuit is a CMOS inverter. The SOS process cross-section shows a clear advantage in simplicity and reduction of fabrication masks needed to design the same CMOS inverter circuit. SOS MOSFETs are obtained on a ultra-thin (100nm) film of silicon grown on top of a sapphire substrate. The bottom cross-section of Figure 1 shows the same CMOS inverter implemented in an SOI process. SOI uses a buried silicon dioxide layer to separate the top thin film of silicon and obtain similar benefits and reductions in manufacturing steps that SOS provides. SOS offer the additional advantage of a transparent substrate and higher quality passive components [5].

III. SOS Mixed-Signal Micro-Systems

SOI technologies require a reevaluation of traditional design of both digital to analog and analog to digital converters. SOI technologies can be used to simplify the design of the ADC, to increase the performance and lower power consumption. The design presented in [6], [7] is a 8-bit SAR ADC manufactured in a 0.5μm SOS process. The SAR ADC was the first of its kind to be designed, fabricated and tested on the SOS process. It was designed to both take advantage and serve as an example design of SOS mixed-mode circuits. The FOM value for this SOS ADC is 20fJ/conversion, which was a record performance at the time. We also report the design of an ultra-low power SAR ADC in SOS by taking advantage of the C-2C ladder DAC structure [8]. The FOM value for this SOS ADC is 8fJ/conversion, which was only recently paralleled in 0.13μm processes.

The SOS process is also an established technology for hybrid optoelectronic micro-systems. The transparency of the substrate to wavelengths from infra-red to ultra-violet, opens opportunities for applications in high-speed free-space interconnects and 3D integration. SOS has opened up new and innovative application of silicon-based micro-systems, such as: imaging [9], three-dimensional optical interconnections [10], and ultra-violet imaging [11].

SOS-based micro-system also innovate and advance biomedical low-noise micro-systems. A current measurement systems [12] employs an integrating headstage with a pulse frequency modulated output. This device offered the largest current-recording dynamic range: from pico- to tens of micro-amperes of current. Application of SOS current measurement system are in patch-clamp biosensor interfaces [13], [14].

Using the silicon-on-sapphire fabrication process, it is possible to design innovative isolation circuits and three-dimentional circuits. Single-chip isolation circuits can be obtained in SOS by taking advantage of the insulation of the sapphire substrate [15]. These devices can be used in a wide variety of applications that require passing signals across an isolation barrier: power supplies, remote sensing, medical and industrial applications. We also report multi-chip modules that use bondless capacitive coupling to provide both bidirectional communication and also exchange power supply between two separate dies [16].

Finally, SOS can also be used to develop innovative RF micro-systems, as pulse radios and ultra-wide band (UWB) communication systems [17]. These system provide multi-megabit communication rates at power consumptions of less than one milli-watt.

IV. Summary

SOI technologies provide advantages for the design of analog and mixed-signal micro-systems that are only available in deep sub-micron bulk CMOS processes. For this reason they can reduce the cost of mixed-signal micro-systems, while at the same time increasing performance and improving passive and active components. The insulating and transparent substrate provides advantages for creative system design.

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