Ultra-High Speed CMOS Circuits in Thin SIMOX Films


AT&T Bell Laboratories, Murray Hill, NJ 07974

J. C. Sturm

Dept. of Electrical Engineering, Princeton University, Princeton, NJ 08544

ABSTRACT

CMOS dual-modulus prescaler circuits were built in very thin SIMOX films. They operate at 6.2 GHz, the highest speed ever reported for a digital CMOS circuit and 50% faster than the control circuits built in bulk Si. The high speed is obtained by taking advantage of the intrinsic properties of the SOI structure combined with the symmetric CMOS technology that simultaneously optimizes the characteristics of both the p and n-channel transistors.

EXPERIMENT

The SOI structure was formed by implanting 4-inch n-type (100) wafers with 1.7x10**18 oxygen ions at 200 keV while holding the substrate temperature at 615 °C. The wafers were then coated with 0.5μm of LPCVD oxide and annealed for 30 min. in a lamp furnace. Wafers were heated from the back side up to their melting temperature so that the optical properties of Si would provide an intrinsic feedback necessary to keep the device side precisely at 1405°C [6]. After annealing, the structure consisted of 2400Å of crystalline Si with some dislocations but no oxide precipitates, on 3500Å of synthesized SiO₂, with atomically abrupt interfaces. Subsequently, the Si overlayer was thinned by oxidation to about 1200Å to obtain films that are fully depleted in the transistor channel regions.

Device fabrication processes were optimized for bulk Si and not for SOI structures. Lateral isolation was achieved by local oxidation through the Si film thickness. Gate oxide thickness was 125 Å, and CoSi₂ was used in the source, drain, and gate areas [7]. No additional implant aimed at the Si/buried oxide interface was used. The final device structure is shown in Fig. 1.

Fig. 1 Schematic structures of n- and p-channel transistors on SOI.

34.4.1
The prescalers, designed as dual modulus divide-by-128 or 129 counters, consisted of a high speed divide-by-4 or 5 counter, and a lower speed divide-by-32 counter [8]. The block diagram of the prescaler is shown in Fig. 2. The speed of this prescaler is determined by the divide-by-4/5 counter, which uses two NAND gates and three edge-triggered D-type flip-flops clocked synchronously by the high-frequency input signal. To reduce the capacitive loading, 0.75μm wide aluminum lines and 0.5μm metal salicide runners were used.

![Block Diagram of Prescaler](image)

**Fig. 2** CMOS prescaler functional block diagram.

### RESULTS AND DISCUSSIONS

Current-voltage characteristics of both n- and p-channel transistors for design gate length of 0.62μm, and effective channel length 0.42μm, are shown in Fig. 3. The kink effect, typical of SOS and SOI devices, is absent because the thin Si film is fully depleted. These traces were obtained using a back-gate bias, V_{bg}, of -6V. We found that -4 to -6V back-gate bias was needed to turn off the finite leakage at low gate voltages. The application of V_{bg}, in addition, helped make the V_{th} of n- and p-channel devices nearly symmetric. The threshold voltages for n- and p-channel devices with several different L_{eff}, as a function of backgate bias are shown in Figs. 4 and 5.

![Drain Current vs. Voltage Characteristics](image)

**Fig. 3** Drain current vs. voltage characteristics of 0.62 μm (L_{eff}=0.42μm) n- and p-channel transistors with -6V back-gate bias.

![Threshold Voltage vs. Back-Gate Bias](image)

**Fig. 4** Threshold voltage of n-channel devices as a function of back-gate bias.
The threshold voltages for -6V bias on the substrate were 0.24V and -0.30V, and the mobilities were 420 cm²/V·s. and 100 cm²/V·s in n- and p-channel transistors respectively. Figure 6 illustrates the subthreshold characteristics of 0.62, 1 and 2μm n-channel transistors with the subthreshold swings indicated on the figure.

The ring oscillator delays per stage measured in 49 stage ring oscillators for the SOI and the bulk monitors are shown in Fig. 7. The delays in the circuits on SOI are ~40% lower for all channel lengths.

34.4.3
The best SOI prescaler was found to be functional at 6.2 GHz (Fig. 9) consuming 210 mW of power at Vdd of 3.5V. The effective gate length of the transistors is approximately 0.4\mu m. Back-gate bias between -4 and -6.5V with respect to the Vss was applied so that a threshold voltage of about 0.2V was obtained for both p and n channel transistors.

![Oscilloscope traces for the input and output signals for the SOI prescaler: (a) divide-by-128, and (b) divide-by-129.](image)

Maximum operation frequency was dependent upon the supply voltage (Vdd), and varied by about 1.6 GHz per volt of Vdd (see fig. 10). One partially operational prescaler (+ 64) had a toggle frequency of 7 GHz. It is noteworthy that the prescaler is still functional at 2 GHz with the supply voltage as low as 1.4V dissipating only 11 mW of power. The speed of this SOI prescaler at 6.2 GHz is substantially higher than those of similar prescalers that have been published to date (generally ranging from 2.5 GHz to 4.6 GHz, see Ref. 8). This speed, in addition, is 2.5 times higher than the fastest reported Ga-As and Bipolar + 128/129 counters.

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REFERENCES


