Performance Electronics Integration in Flexible Technology

Richard L. Chaney, Douglas R. Hackler
American Semiconductor, Inc.
3100 S. Vista Ave, Ste 230, Boise, ID 83705
richchaney@americansemi.com
208.336.2773 www.americansemi.com

Abstract: *FleX™ is a new, flexible, Silicon-on-Polymer (SOP) technology for low cost, high performance CMOS. FleX is useful in 3D circuit integration and solves problems facing flexible electronics where high-temperature processing and flexible requirements preclude the use of standard CMOS and performance requirements preclude the use of organic thin-film transistors or other exotic metal-oxide materials. FleX technology combined with Flexfet Advanced CMOS provides an Ultra Low Power (ULP) solution that further benefits portable and battery powered applications.*

Keywords: FleX; Silicon on Polymer; flexible CMOS; 3D IC; SOI; thin film transistor (TFT); roll-to-roll; substrate transfer technology (STT); Flexfet; Ultra Low Power (ULP); double-gate CMOS

Introduction

High performance logic and memory are required for flexible sensor and display technologies to meet market expectations and application requirements for flexible electronic products. Roll-to-roll (R2R) flexible manufacturing is intolerant of high processing temperatures and deforms during manufacturing and use by design. Conventional semiconductor materials and device structures frequently require high temperature processing and tend to fail or function poorly when flexed. Emerging flexible systems and state-of-the-art high performance complementary metal oxide semiconductors (CMOS) are generally incompatible. Existing flexible product prototypes use either organic thin-film transistors that have low mobilities or exotic metal-oxide materials that are hard to work with. These novel transistors can provide utility for flexible technology but neither approach provides high performance, high density logic and memory. FleX is a new, flexible, Silicon-on-Polymer technology for low cost, high performance CMOS for flexible logic and memory.

Current Approaches & Limitations

Flexible electronics are evolving at a rapid pace, but will not become a mainstream market without high performance logic and memory integrated into the flexible device. Industry R&D of Thin Film Transistors (TFT) has resulted in printable and flexible TFT for large formats and Roll-to-Roll (R2R) processing. TFT is limited by low mobility and large feature sizes. Low mobility results in poor performance compared to standard CMOS. Large feature sizes do not allow high levels of integration necessary for microprocessors, memory, mixed-signal sensing circuitry, or RF transmit/receive modules. These limitations make TFT unfeasible for high performance logic or memory.

Flexible CMOS based on thinning of crystalline CMOS wafers has been proposed based on Substrate Transfer Technology (STT). STT has been conceptualized, but until now, not realized in a viable CMOS process and certainly not for 200mm substrates.

FleX Enables Flexible

American Semiconductor has recently demonstrated a Substrate Transfer Technology for Silicon on Polymer called FleX. This process has produced flexible mechanical samples of CMOS with triple metal as shown in Figure 1 with total thickness of approximately 20 microns. This technology appears feasible to assemble using standard industry laminate manufacturing methods. This assembly capability can be used to install high performance multiple layer metal Silicon on Polymer CMOS on curved surfaces and flexible substrates.

Figure 1. FleX Silicon On Polymer Wafer.

FleX has been demonstrated on 200mm silicon using substrate transfer technology to create flexible silicon on polymer, showing a feasible path for integration of high performance CMOS for flexible electronics applications as depicted in Figure 2.

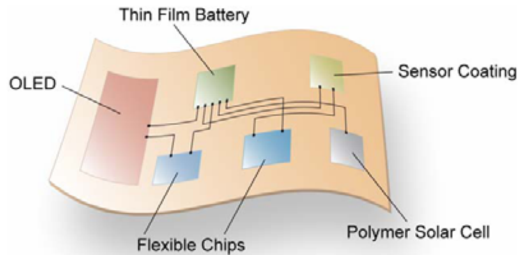

Figure 2. Burghartz "Ultra-Thin Chips and Related Applications, A New Paradigm in Silicon Technology," IEEE 2009

FleX Fabrication

American Semiconductor has developed a new process to enable the manufacture of flexible circuitry. FleX processing can be applied to any SOI wafer. Initial work has been done with Flexfet™ CMOS fabricated on standard SOI substrates. The lower portion of the SOI substrate, or handle silicon, is generally used for handling purposes and mechanical support. The FleX process uses Substrate Transfer Technology to replace the handle silicon with a flexible polymer to provide the necessary mechanical support with the desired flexibility.

Further handling and integration of the FleX SOP wafers has been conceptualized. For example, Flexible Surface Mount Technology (FSMT) can be used to transfer the FleX CMOS to roll-to-roll processing as shown in Figure 3.

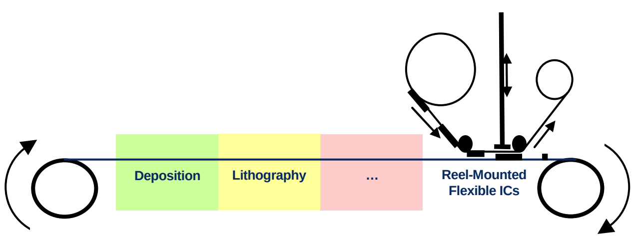

Figure 3. FleX "chips" added to Roll-to-Roll processing lines.

Surface mount technology using flexible, conductive adhesive has been proposed for mounting a flexible laminate onto another flexible laminate.

FleX SOP with Flexfet™ Advanced CMOS

Ultra Low Power is a sought after goal for many applications. ULP can make cell phones and other battery powered devices operate longer between recharges. ULP is an enabling technology for low cost cube satellites, micro UAVs, and other emerging applications. Approaches to ultra low power generally trade performance for power. Some approaches, such as subthreshold ULP, trade so much performance that performance is not acceptable for most applications. Flexfet Advanced CMOS solves this problem with a technology that can be dynamically adjusted for speed and power, or targeted for Ultra Low Power.

Flexfet is an advanced SOI CMOS process characterized by an Independently Double Gated transistor. The novel design of the Flexfet transistor brings many benefits not realized in standard CMOS processes.

Designers can use Flexfet as a MIGFET (Multiple Independent Gate Field Effect Transistor) with each gate independently controlled. This enables Dynamic Threshold Control (DTC), allowing threshold voltage (Vt) to be controlled on-the-fly. DTC allows the same circuit to be optimized for speed or power, depending on the desired operation at the moment. Figure 4 shows a simple inverter designed in Flexfet using Independent Double Gates (as a MIGFET) where both the NMOS and PMOS bottom gates utilize Dynamic Threshold Control. Figure 5 shows how DTC is used to vary the inverter switching point by up to 430mV. Figure 6 shows a 101-stage inverter ring oscillator where Dynamic Threshold Control is used to tune the frequency. NMOS DTC varies the frequency from -11% to +9%. PMOS DTC varies the frequency from -34% to +19%. Dynamic Threshold Control of both NMOS and PMOS varies the frequency from -43% to +29%.

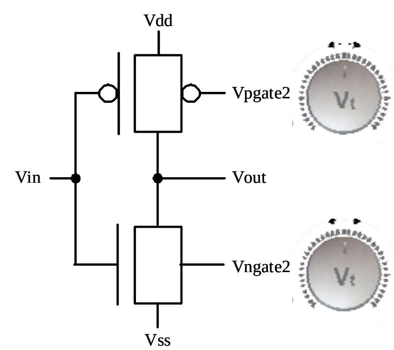

Figure 4. Flexfet MIGFET inverter showing Dynamic Threshold Control

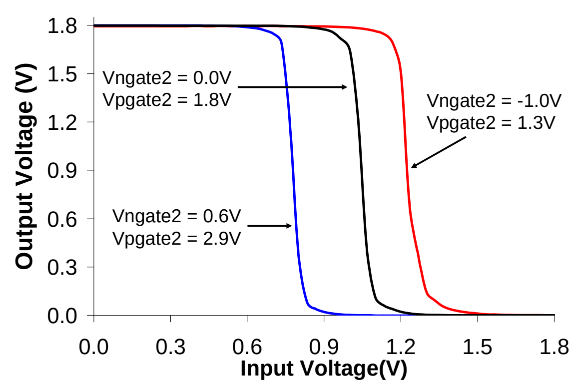

Figure 5. Flexfet 180nm MIGFET Dynamic Threshold Control - experimental data at 1.8V showing bottom gate voltage control of an inverter

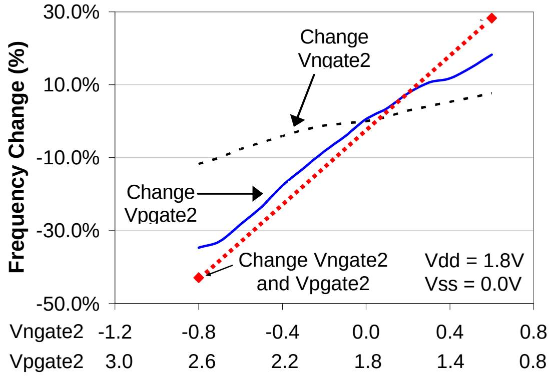

Figure 6. Flexfet 180nm MIGFET Dynamic Threshold Control - experimental data at 1.8V showing frequency tuning of a ring oscillator

In addition to frequency tuning, Dynamic Threshold Control can be used to compensate for variation in supply voltage. Figure 7 shows DTC supply compensation of a 101-stage ring oscillator. Before compensation the frequency shifted from -27% to +64%. After compensation the shift was -1.8% to 0.6%, yielding a 38X improvement. DTC supply compensation may be very useful for flexible electronics and other applications that run on batteries.

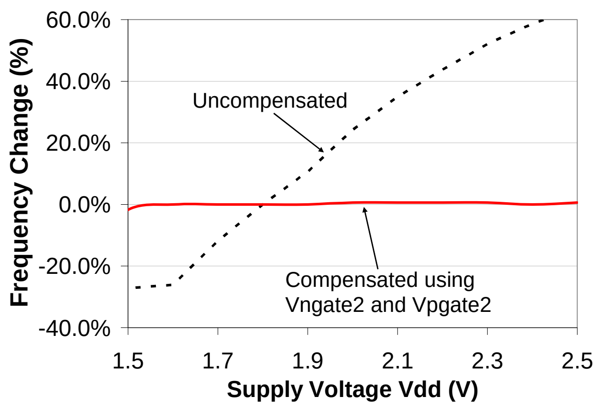

Figure 7. Flexfet 180nm MIGFET Dynamic Threshold Control - experimental data at 1.8V showing supply voltage compensation of a ring oscillator

Designers can also use Flexfet as a MUGFET, with the top and bottom gates tied together. This enables Ultra Low Power (ULP) operation, with Flexfet ULP running at or below 0.5V, fully depleted, as shown in Figure 8. Flexfet transistors operating at 0.5 V in double gate mode (as a MUGFET) have demonstrated a near ideal subthreshold slope of 64 mV/dec as shown in Figure 9.

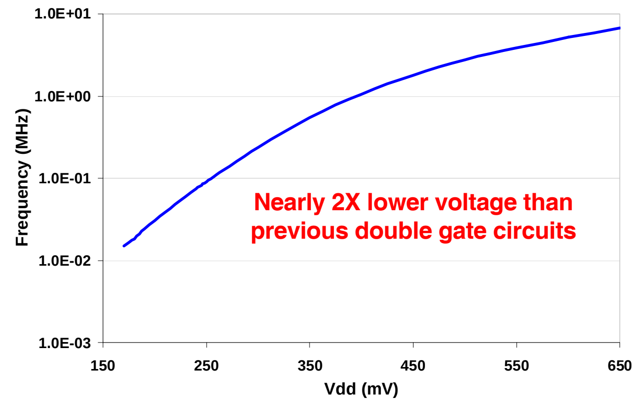

Figure 8. Flexfet 130nm MUGFET ring oscillators operating down to 170mV

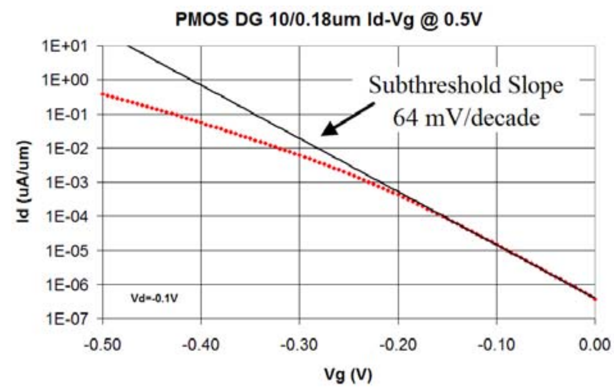

Figure 9. Double Gate (MUGFET) Flexfet PMOS FET with near-ideal subthreshold slope

Flexfet is a gate-last process, which enables integration of novel materials with low thermal budgets. The unique IDG design and SOI processing of Flexfet create an inherent radiation tolerance, which is extremely useful in avionics and space systems.

The Flexfet process is created using fully isolated thin mesa technology. This is well suited to accommodate the stresses resulting from the deformations associated with flexible electronics. Unlike bulk or continuous silicon processes, the isolated mesas mechanically float during flex deformations. Compressive and tensile stresses are not transferred to the transistors. Metal interconnects have been demonstrated as capable of meeting flexible requirements.

Combining FleX Silicon on Polymer and Flexfet Advanced CMOS provides significant reductions in size, weight, and power for flexible electronics. Flexible, ultra low-power, high-performance CMOS is a major enabler for flexible displays, micro-UAVs, autonomous micro-sensors, and other future applications. Design, manufacture, and characterization of mixed-signal circuits on these ultra thin flexible substrates will create a platform for production of a new class of flexible electronics that function beyond current capabilities

FleX Technology Status

FleX has been demonstrated on 200mm silicon using substrate transfer technology to create flexible silicon on polymer, showing a feasible path for integration of high performance CMOS for flexible electronics applications. Multiple lots of Flexfet CMOS have run through the FleX process, demonstrating a reproducible process suitable for volume manufacturing. Opportunities exist for future work to further demonstrate FleX CMOS performance and tune the CMOS process for FleX operation.

Conclusions

FleX demonstrates a new, flexible, Silicon-on-Polymer technology for low cost, high performance CMOS that meets market expectations for flexible electronics. Combined with Flexfet, FleX technology provides an ultra low-power solution that further benefits portable and battery powered applications. Additionally, FleX is useful in 3D circuit integration and solves problems facing flexible electronics where high-temperature processing and flexible requirements preclude the use of standard CMOS and performance requirements preclude the use of organic thin-film transistors or other exotic metal-oxide materials.

Acknowledgements

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