FleX™ Silicon-on-Polymer™: Flexible (Pliable) ICs from Commercial Foundry Processes

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Abstract: *Flexible systems have been limited by the ability to integrate IC functionality. Traditional ICs are not flexible, and flexible transistors are large and slow. American Semiconductor's FleX process addresses these limitations by transforming full thickness silicon wafers into flexible wafers. American Semiconductor and Jazz have partnered to demonstrate commercial foundry processes in the FleX form factor.*

Keywords: FleX; flexible; CLAS; conformal; antenna; flexible hybrid system; semiconductor; FHS; Jazz; IC; foundry

Introduction

Flexible systems have been limited by the ability to incorporate integrated circuits (ICs) or IC-type functionality into a flexible form factor. Traditionally packaged ICs are thick, rigid, and require attachment and connection methods that are not directly compatible with flexible circuit boards. Without the ICs, flexible systems lack the functionality that high performance ICs offer. This gap has limited the usefulness and market adoption of flexible electronics.

American Semiconductor's FleX Silicon-on-Polymer process addresses these limitations by transforming full thickness silicon wafers into flexible wafers and subsequently singulated die. The IC becomes flexible and ultra-thin, enabling new attachment and connection methods that are compatible with flexible circuit manufacturing. FleX enables flexible hybrid systems (FHS) that combine flexible printed electronics and high performance flexible ICs into a single system that delivers the best of both technologies. The flexible printed electronics deliver large form factor elements such as wiring, interconnects, and sensors. FleX Silicon-on-Polymer delivers integrated circuit (IC) functions in a flexible form factor that is compatible with the printed electronics.

The FleX process can be applied to any SOI wafer. For optimal performance it is desirable to have a process design kit (PDK) specific to FleX ICs. American Semiconductor and Jazz Semiconductor have partnered to demonstrate the Jazz CS18 process in FleX. The result is a proven foundry process that customers can design in and immediately recognize their ICs in a flexible format.

Flexible Hybrid Systems

The benefits of flexible hybrid systems are clear. Combining printed electronics with FleX ICs creates very thin, very flexible circuits and systems in a form factor that is compatible with conformal and bendable requirements. The FHS overcomes limitations that prevent the independent technologies from fulfilling complete system requirements. Specifically, FleX ICs provide the ability for localized signal processing and control in sensor systems. Local signal processing greatly improves the sensor performance reducing signal loss from long transmission lines. In addition, local processing allows the use of data communication protocols between sensors and controllers.

Flexible Hybrid Systems are a combination of flexible printed materials and flexible silicon-based ICs that create a new class of flexible electronics, as illustrated in Figure 1. This fusion of technologies is desirable as it combines the most compelling features of the individual technologies while eliminating the limitations of each.

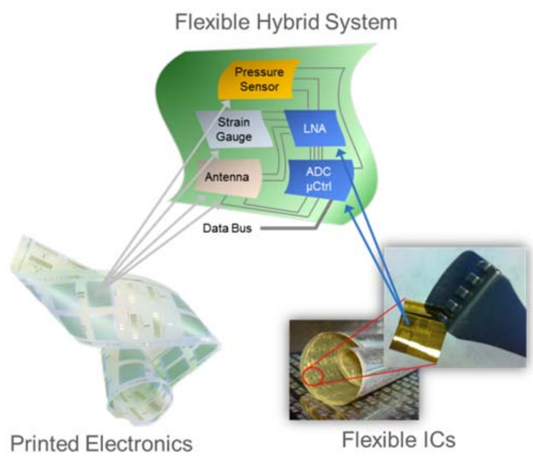

Figure 1: Flexible Hybrid System

Printed technologies are relatively mature in the flexible electronics area, and new advances continue to be made. Printed electronics have many desirable features. One of the most compelling features of printed electronics is the large format possible. Printing can be done on roll-to-roll production lines on material several feet wide by hundreds of feet long, producing large form factor sensors or sensor arrays potentially covering entire aircraft wing structures. Additionally, printed electronics are relatively low cost.

The limitation that must be overcome with printed electronics is that the electron mobilities of printed transistors are low and feature sizes are much larger than silicon ICs. Printed transistors are useful in large, low density applications such as displays, but cannot be used for high performance IC applications such as microprocessors or memory. This has traditionally been a limitation for printed electronics, but is overcome in Flexible Hybrid Systems using FleX Silicon-on-Polymer.

FleX Silicon-on-Polymer

FleX is a proprietary process to transform standard silicon wafers into flexible wafers. American Semiconductor has demonstrated its revolutionary FleX process by creating flexible, ultra-thin, single-crystalline CMOS with multi-layer metal interconnect.[1] CMOS is first fabricated using a standard SOI process on 200mm wafers and then the silicon substrate is removed. The FleX process completely removes the handle silicon and adds a polymer mechanical substrate to create ultra-thin flexible wafers as shown in Figure 2. The FleX wafers may be used at the wafer-scale or singulated into individual FleX ICs. FleX provides IC functionality that is orders of magnitude faster than printed transistors.[2] FleX is a post-fab process that can be applied to any SOI CMOS wafer and has been demonstrated on three different CMOS processes from two different CMOS wafer foundries. FleX delivers fully functional, flexible wafers with a final silicon thickness of less than 200nm. FleX has been demonstrated with functional CMOS ICs successful launched into space in June 2012 under the NASA RockSat program.

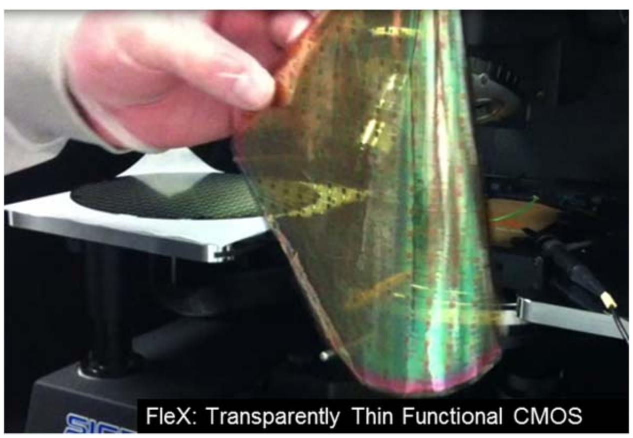

Figure 2: FleX Wafer – 130nm CMOS

Jazz CS18 in FleX

The FleX process can be applied to any SOI wafer. However, the replacement of silicon with polymer in the final wafer can change some parameters. For example, completely removing the handle silicon will typically improve the RF performance by eliminating the parasitics of the handle silicon. This is also a beneficial shift for increasing the digital frequency performance and lower power consumption of a CMOS process by reducing parasitic capacitance. The transistor performance improvements demand optimized electrical models in the PDK. For designers to get the optimal results in a FleX IC, they use a PDK based on the final electrical performance. American Semiconductor and Jazz Semiconductor have partnered to demonstrate the Jazz CS18 process in FleX and subsequently deliver a FleX-PDK for designers to use when creating flexible ICs.

Jazz CS18-FleX is the industry's first commercially available flexible foundry process. CS18-FleX testing to date has shown excellent results. The Jazz CS18 wafers show the extraordinary physical results after the FleX process is complete, as shown in Figure 3.

Figure 3: Jazz CS18 Wafer After FleX Processing

DC test data taken pre- and post-FleX shows no shift in transistor performance, which is the desired result. Data is presented from the same wafer in full thickness and FleX forms for both NMOS and PMOS transistors in Figures 4 and 5, respectively, where the full thickness wafer data is shown in red and the FleX wafer data is shown in blue.

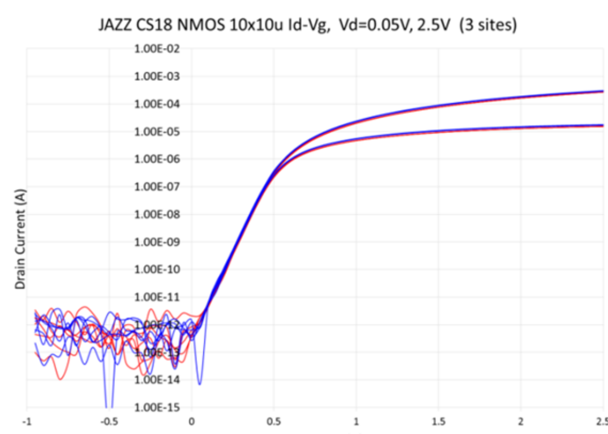

Figure 4: Jazz CS18 NMOS Transistor pre-FleX (red) and post-FleX (blue)

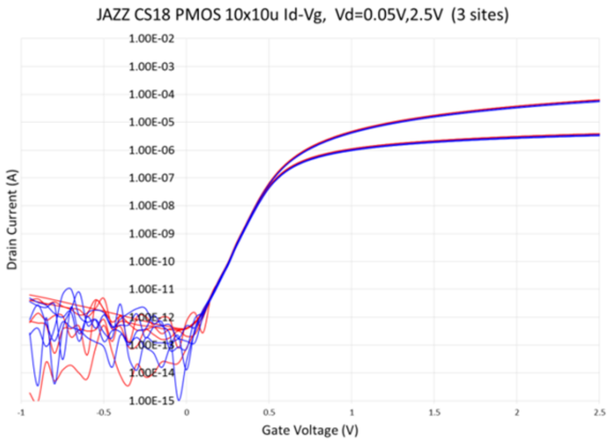

Figure 5: Jazz CS18 PMOS Transistor pre-FleX (red) and post-FleX (blue)

FleX IC and Flexible Hybrid Applications

Flexible ICs and Flexible Hybrid Systems open the door to innovation in a variety of different markets and applications. FleX ICs and FHS are desirable in multifunctional aircraft structures such as conformal load-bearing antenna structures, fly-by-feel control, and structural health monitoring. Flexible Hybrid Systems will be transformative for ground based military applications including soldier-borne electronics. FleX ICs and FHS hold the promise of revolutionary advances for medical technologies, including wearable, surgical, and implantable devices. FleX enables new developments in consumer devices such as tablets, phones, and the emerging segment of worn electronics.

One area of significant interest for Flexible Hybrid Systems is multifunctional aircraft structures (MAS). MAS hold the potential to drastically alter and improve the capability of air vehicles by integrating functional systems as a part of the airframe structure. MAS takes a large step toward allowing aircraft to be designed around mission requirements rather than by platform limitations.[5]

Conformal load-bearing antenna structures (CLAS) are one implementation of multifunctional aircraft structures. American Semiconductor recently delivered proof-of-feasibility CLAS prototypes to the Air Force Research Laboratory demonstrating Flexible Hybrid System integration. These Phase I prototypes showed clear benefits of using FleX ICs and printed electronics in cutting edge UAV and aviation applications.

The technology developed by American Semiconductor to create its CLAS prototypes is directly compatible with manufacturing advanced MAS sensors and localized processing capability required for structural health monitoring and fly-by-feel applications, as illustrated in Figure 6.

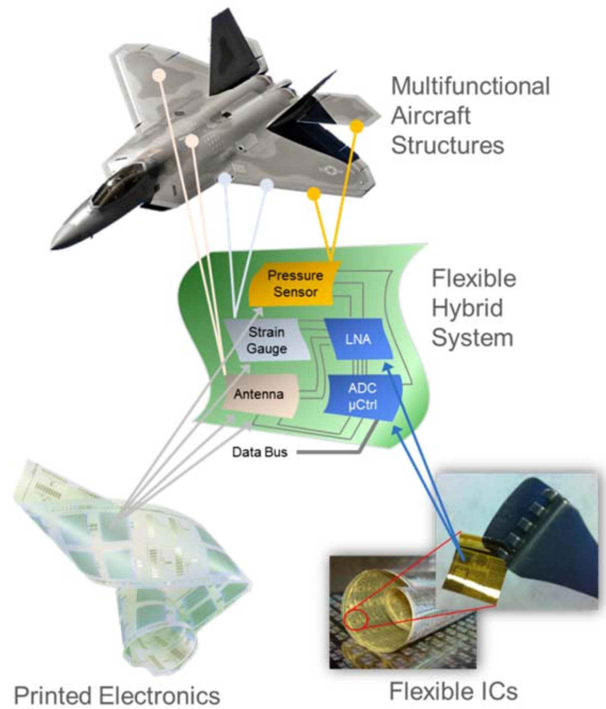

Figure 6: Flexible Hybrid Systems Integrated into Multifunctional Aircraft Structures

Structural Health Monitoring (SHM) embeds strain gauges, temperature sensors, pressure sensors, and other sensors into the structural components of aircraft. SHM would enable aircraft maintenance based on need rather than by schedule, potentially saving millions of dollars each year across military or commercial aviation fleets. Additionally, SHM improves safety by monitoring the aircraft dynamically, in flight and on the ground, providing valuable lifetime information which can be critical as both military and civilian assets are often operated beyond their designed lifetimes.

Fly-by-Feel (FBF) embeds sensors and control into flight surface structures. This provides information that cannot be obtained today, such as the stagnation point of the wing in real time. This information can be used to improve flight performance and efficiency and paves the way to smart, reconfigurable flight surfaces, much like birds use their feathers to optimize flight.

Flexible Hybrid sensor systems can also be integrated into existing medical technology to improve performance. FHS has the potential to revolutionize medical technology by embedding sensors and control where it has not been possible before. Figure 7 illustrates potential medical applications such as futuristic implantable and surgical devices. Wearable medical devices exist but have limitations due to their size, weight, and overall form factor. The improvements enabled by FHS extend the utility of wearable medical devices on the battlefield, in the hospital, and in the home.

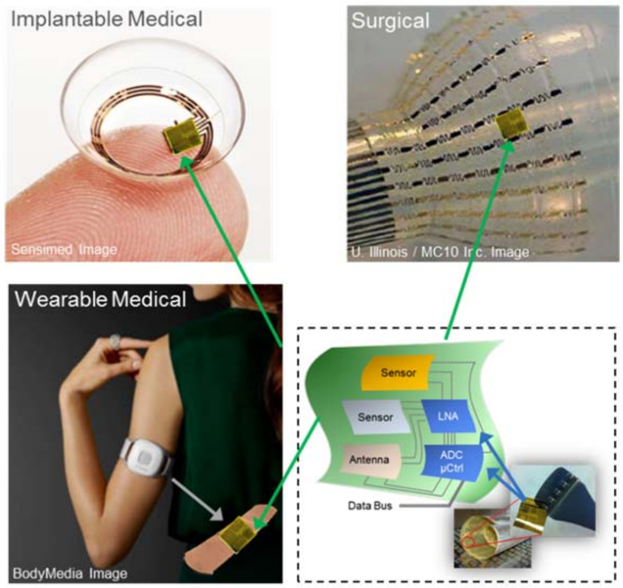

Figure 6: Flexible Hybrid Systems in Medical Applications

Flexible Hybrid Manufacturing

Flexible Hybrid Systems have been created as prototypes and conceptualized for high volume manufacturing. Prototyping can be rapidly accomplished using a variety of low-cost printing techniques combined with FleX ICs, as illustrated in Figure 7.

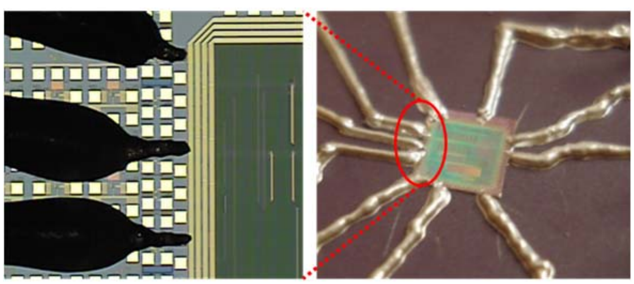

Figure 7: Conformally Attached FleX IC Prototype with Direct Write Flexible Interconnects

High volume manufacturing for Flexible Hybrid Systems has been conceptualized where a FleX IC integration station is added in a roll-to-roll printed electronics line, as shown in Figure 8. The example shows the FleX die integration at the end of the process, although it could feasibly be added at any point in the line as the product requires. With this methodology, Flexible Hybrid Systems can be produced in high volume at low cost.

Conclusions

The ability to provide FleX ICs from commercial foundry processes is a revolutionary shift for flexible electronics, enabling new functions across a wide spectrum of applications.

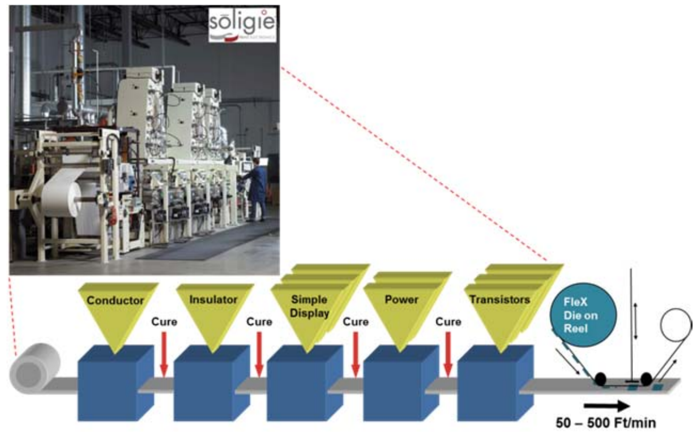

Figure 8: Flexible Hybrid Manufacturing Line

Acknowledgements

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