Novel Materials and Integration Schemes for CMOS-Based Circuits for Flexible Electronics

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Abstract

The development of low temperature, thin film transistor processes that has enabled flexible displays also presents opportunities for flexible electronics and flexible integrated systems. Of particular interest are possible applications in flexible, low metal content, sensor systems for unattended ground sensors, smart medical bandages, electronic ID tags for geo-location, conformal antennas, neutron/gamma-ray/x-ray detectors, etc. In this talk, we review the state-of-the-art in flexible electronics materials and devices and present recent results in our efforts to fully integrate complementary metal oxide semiconductors. We conclude with a discussion of the constraints of thin film transistors and the remaining challenges.

Introduction

In the last few years, there have been substantial development efforts in reducing the amorphous silicon thin film transistor processing temperatures to be compatible with a plastic substrate (heat stabilized polyethylene naphthalate or PEN) and for handling flexible substrates in standard processing equipment. The development of low temperature, thin film transistor also presents opportunities for flexible electronics and flexible integrated sensor systems.

One limitation of amorphous silicon transistors is that only N-channel devices are possible - that is only devices that are activated with positive voltages are available. P-channel devices – devices that are activated with negative voltages – are also needed to build low power CMOS circuits, the technology of choice for the silicon integrated circuit industry. The development of flexible CMOS is, therefore, essential to reduce the power consumption of portable, flexible integrated sensor systems. We have recently combined an N-channel amorphous silicon thin film transistor process with a P-channel organic thin film transistor process to form CMOS circuits on a flexible plastic substrate (Fig. 1).2

Results and Discussion

Our flexible CMOS process was achieved by fabricating the nMOS a-Si:H and the pMOS device on a flexible plastic substrate. The formation of vias enables the arbitrary connection of nMOS and pMOS devices to form any conventional CMOS circuit.3

A cross section of the integrated process is shown in Fig. 1. Typical characteristics for these integrated devices for nMOS are for a-Si:H TFT a saturation mobility of 0.8 cm²/Vs with on/off ratio greater than 10⁶. The subthreshold slope is approximately 0.6 V/decade with a threshold voltage slightly greater than 1 V. The hysteresis between forward and reverse sweeps of the drain-source voltage is also approximately 1V. Typical characteristics for a pMOS pentacene TFT are: saturation mobility is 0.08 cm²/Vs with an on/off ratio greater than 10⁴.4 The threshold voltage is approximately -1.4 V after fabrication.

Figure 2 shows optical images and input-output characteristics for 2-input NAND and NOR gates, respectively. In both cases, for input A a square wave with a 20ms period and 50% duty cycle is used. For input B, a square wave with a 40ms period and 50% duty cycle is used. As expected for a NAND gate, the output stays high except when both A and B are logic high. On the other hand, for NOR gates the output stays low except when both A and B are logic low, as expected. These results demonstrate that with our integration approach we can achieve working CMOS devices on flexible substrates.

There are still two limitations of flexible electronics: speed and stability. The switching speed of transistors is determined by their minimum feature size or gate length and by the mobility of the charge carriers. The result is a switching speed of a transistor with a mobility of 1cm²/Vs is roughly 100,000 times slower than single crystal silicon. Therefore, single crystal silicon operates at GHz frequencies whereas amorphous silicon operates at a few 10s of kHz frequencies. Generally, organic thin film transistors are even slower than amorphous silicon; however ZnO and other mixed oxide thin film transistors are faster than amorphous silicon. These fabrication and material limitations pose a difficult challenge for transmit and receive circuitry.

Conclusions

We have shown a novel integration approach for pentacene pMOS and a-Si:H nMOS. These TFTs were integrated on a flexible PEN substrate to fabricate CMOS circuits including inverters, NAND and NOR gates. The principal remaining challenges for flexible electronics are sufficient switching speed and stability. Emerging thin film transistor technologies, such as ZnO and mixed oxide, promise improvement in these areas.

References