

CPU on a Glass Substrate Using CG Silicon TFT

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Abstract

For the first time, an entire CPU has been successfully fabricated on a glass substrate suitable for LCD mass production. By using the advanced CG-Silicon Thin Film Transistor (TFT) process, with a maximum processing temperature 550°C, it was possible to use Corning 1737 glass as the substrate. The fabricated 8-bit CPU contains approximately 13,000 TFTs, and occupies an area of 169 mm². The CPU operates successfully in a system with a clock frequency of 3 MHz and a supply voltage of 5V.

Introduction

The use of liquid crystal displays (LCDs) has spread extremely rapidly in recent years, but price erosion in the face of increasingly intense competition is becoming a serious problem. To overcome such circumstances, we must not only work to lower costs, but also to heighten the level of added value imparted to LCDs. By doing so, we will shed the traditional model of "selling size" and transform the business into one of "selling function," thereby making it possible to maintain the health of the industry with continuing possibilities for future growth. Consequently, there are two potential paths to increasing the added value of LCDs. One is "high-resolution LCDs" featuring higher display resolutions and better image definition, and the other is "System LCDs" incorporating peripheral functions on the panel itself.

Sharp, in collaboration with Semiconductor Energy Laboratory Co., Ltd., developed CG (continuous grain) Silicon technology⁴⁾⁵⁾ and proposed System LCDs built around this process, with commercial production beginning in the autumn of 2002. These System LCDs are high value-added devices based on integrating various functions onto glass, and are well suited to our networked, mobile society. They hold out the promise for dramatically changing the nature of the display business in the future. This paper introduces a CPU-on-glass developed using CG Silicon technology, a world first. Providing proof for the concept of implementing a CPU on glass has made it possible to significantly broaden the possibilities for System LCD technology in the future¹⁾.

1. Background and Development Objective

Table 1 shows the roadmap Sharp has laid out for System LCDs, and the key technologies needed for each generation. In contrast to an a-Si LCD in which only the display section consisting of pixel switches and interconnects can be formed on the glass, we have now developed the first practical LCD with integrated LCD driver ICs. This is the first generation of System LCDs, and such an LCD with a function to switch between low and high resolutions is already in production²⁾.

We regard the second generation of System LCDs to be those equipped with a digital interface. We have already developed a prototype LCD with digital drivers fabricated on the glass with embedded DA

Table 1 Roadmap for System LCDs

Year	2002	2003	2005
Generation	1st Generation	2nd Generation	3rd Generation
TFT Characteristics	High Mobility	Small Distribution	Short-Channel TFTs
Mobility	200cm ² /Vs	300cm ² /Vs	400cm ² /Vs
Design Rule	3 μ m	1.5 μ m	0.8 μ m
Metalization	Al wiring	Multi-layer wiring	Low-resistance wiring
Integrated circuit(s)	Drivers	DACs, op-amps, timing generators	Controllers, low-end CPUs

converters, op-amps and other components³), and consider second-generation System LCDs to be on the near horizon. We intend to have commercial models available during fiscal 2003.

The next step will be to incorporate peripheral circuits other than drivers. We consider circuit operation in the 20- to 30-MHz range to be the minimum level necessary for incorporating peripheral systems. Being able to achieve operating frequencies in this range will make it possible to integrate LCD controller and signal processing circuitry, and it appears that revolutionary application products such as cards with embedded displays and ultra-thin computers will be achieved in a single stroke.

But what technologies will we need to achieve such System LCDs? As shown in **Table 1**, we consider improvement in TFT properties and innovations in interconnect technology to be the keys to developing such LCD-based systems. In improving TFT characteristics, continuous improvement in the properties of LCD materials (better mobility) and shrinking IC feature sizes will be the critical factors.

In a-Si, the fact that the carrier (electron) mobility only ranges from 0.5 to 1 cm²/Vs limited the speed of the switches that drive the display to several μ s to several tens of μ s. Mobility for low-temperature poly-silicon (LPS) is faster, in the range of several tens to 100-150 cm²/Vs, making it possible to integrate LCD drivers with operating frequencies of less than several MHz. By contrast, CG Silicon offers mobility in the range of 200 to 300 cm²/Vs. CG Silicon uses a catalyst as the technique to bring about crystallization, and compared to polycrystalline silicon (LPS) formed by laser annealing, CG Silicon is a semiconductor material exhibiting extremely high mobility thanks to large crystal grain size and the crystal orientation of adjacent grain boundaries being in alignment. Also, because laser annealing is not the primary means used to bring about crystallization, CG Silicon is not subject to the effects of variations in laser energy, and as a semiconductor, it offers superior uniformity and stability.

The prototype for the current 8-bit CPU represents a move toward the development of third-generation processes. We have been working to assess their possibilities and gauge the strengths of existing processes.

2. CPU Design

The CPU in the current design is a Z80[®] **1, a CISC processor with an 8-bit computational processing path. As shown in **Fig. 1**, it consists of ALU, register array, data bus

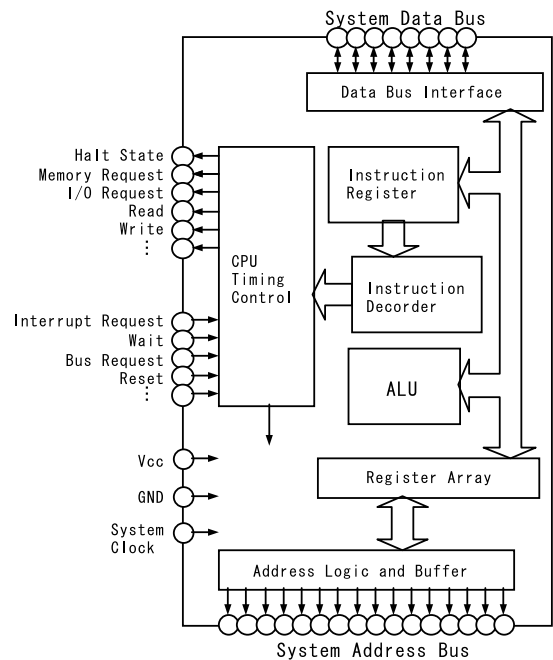


Fig. 1 Block diagram of Z80

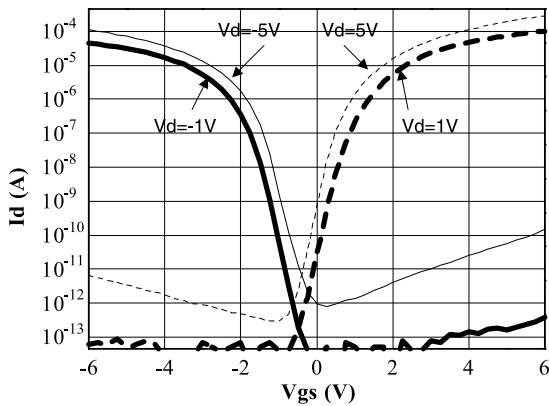


Fig. 2 Current characteristics of CG Silicon TFTs

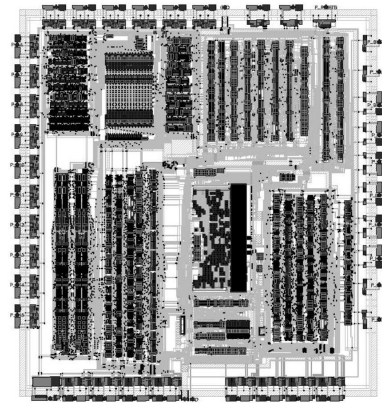


Fig. 3 CPU layout

interface, instruction decoder, CPU timing control, address logic and buffer blocks. **Fig. 2** shows the electrical current characteristics for the CG Silicon TFTs now being used. The graph in **Fig. 2** plots the current characteristics of n-channel and p-channel TFTs having a gate length of $L = 2 \mu\text{m}$ and gate width $W = 8 \mu\text{m}$, making the threshold voltage in the n-channel TFTs around $V_{\text{thn}} = 1 \text{ V}$ and in the p-channel TFTs around $V_{\text{thp}} = -1.5 \text{ V}$. In addition, at a gate voltage of $V_{\text{gs}} = 5 \text{ V}$ and a drain voltage of $V_{\text{ds}} = 1 \text{ V}$ in the n-channel TFTs, the ON current is approximately $I_d = 9.5 \mu\text{A}/\mu\text{m}$, and at a gate voltage of $V_{\text{gs}} = -5 \text{ V}$ and a drain voltage of $V_{\text{ds}} = -1 \text{ V}$ in the p-channel TFTs, approximately $I_d = 4.0 \mu\text{A}/\mu\text{m}$. The fact that we were able to achieve current characteristics with values this high means that it is conceivable that a CPU on glass with a supply voltage of 5 V can become a reality.

We next designed a CPU based on the CG Silicon TFT characteristics given above. The design enables the reuse of IC process design resources such as circuit structure and layout, and illustrates the ease of circuit design on glass. The process used was a 3.0- μm CG Silicon process, and the gate length L of the TFTs was 2 μm . **Fig. 3** shows the results of laying out the CPU. Terminal pin-out used a flexible printed circuit (FPC), identical to those on standard LCDs. The size of the CPU core is approximately 13 mm square, and including the FPC, is approximately 20 mm square.

**1 Z80[®] is a registered trademark of Zilog, Inc.

3. Prototype

We used Corning 1737 glass (transition temperature: 640°C), a typical material used for LCD substrates, and created a prototype CPU using a process with a maximum temperature of 550°C. We also formed a prototype LCD on the same glass substrate at the same time, confirming the fact that a display incorporating complex circuit logic elements could be created. The TFTs used for the CPU had a single-drain structure, while the TFTs for the LCD has an LDD (lightly doped drain) structure. The interconnects utilized the same composition as conventional LCD processes, and consisted of a gate electrode layer and a single metal wiring layer.

An outline of the CPU prototyping process is given below. Using Corning 1737 glass for the substrate, a P-CVD process was used for continuous film forming of the base layer and the a-Si. A metal catalyst was then added, resulting in crystallization at 550°C, forming the CG Silicon. The 550°C of this crystallization process is the maximum temperature used in the current CPU prototyping process. Channel doping was then followed by, in order, forming the gate insulator film, gate electrodes, and source/drain regions. A self-aligning ion injection process was used to form the source/drain regions, which is advantageous in shrinking

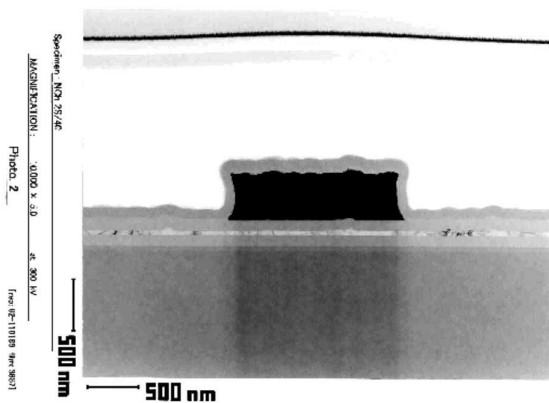


Fig. 4 Cross-sectional TEM photograph of the CG Silicon TFT (Photo provided by Semiconductor Energy Laboratory Co., Ltd.)

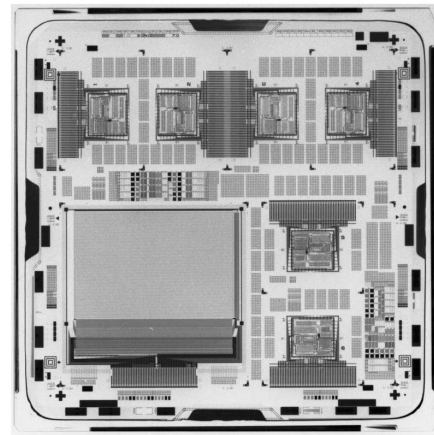


Fig. 5 Photo of the glass substrate on which the CPU is formed (Photo provided by Semiconductor Energy Laboratory Co., Ltd.)

the feature size. By forming the interlayer film, contact holes, and metal interconnects in sequence, the prototype TFT that has CG Silicon as the active layer was fabricated. **Fig. 4** shows a cross-sectional TEM photograph of the prototype TFT having a gate length $L = 2 \mu\text{m}$.

Using this process, we created a prototype CPU using CG Silicon TFTs on a transparent glass substrate. **Fig. 5** shows a photograph of the prototype glass substrate. This substrate is a glass sheet, five inches square with a thickness of 0.7 mm, and with six CPU chips and a single 2.2-inch LCD panel formed on a single substrate.

4. Evaluation

We used an IC tester to evaluate the prototype CPU. **Fig. 6** shows the shmoo plot of the prototyped chip. From the shmoo plot, we were able to confirm operation at 3 MHz with a supply voltage of 5 V. In addition, **Table 2** shows a comparison with a Z80[®] IC chip, a typical 8-bit microprocessor. As shown in the table, operating performance is in no way inferior to the Z80[®] IC chip, and we were able to reduce current consumption by approximately 40%. Because the TFTs have a SOI structure, the capacitance of the TFTs is small, and we think this contributes to faster operating speeds and lower power consumption.

We were also able to get the CPU to work as a replacement for an MZ-80C PC microprocessor once

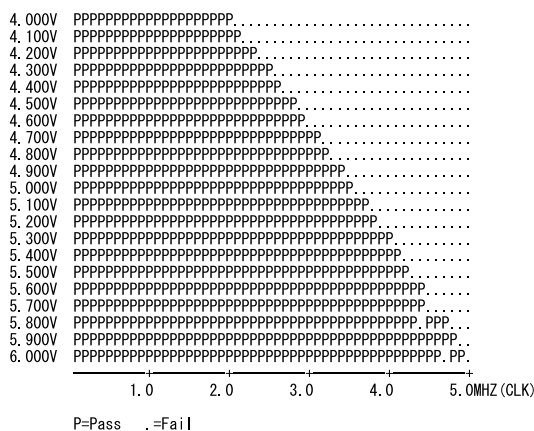


Fig. 6 Shmoo plot of the prototype chip

Table 2 Comparison of IC chip to CPU on glass

	IC chip	CG-Silicon
Era	1980s	2002
Process	2.5 μm	3.0 μm ($L=2.0\mu\text{m}$)
Supply voltage	5V	5V
Threshold voltage	0.5V/-0.5V	1.0V/-1.5V
Max. frequency	2.5MHz	3.2MHz
Active current	10mA(@2.5MHz)	3.0mA(@1.25MHz)
Leakage current	10 μA	10.8 μA

manufactured by Sharp. Specifically, we connected the flexible substrate used for the LCD panel to the prototype CPU on glass, and made connections to the 40-pin terminals where the MZ-80C microprocessor was mounted (Fig. 7). We were able to confirm that the second-source design prototype, in fact, operated with full compatibility with the regular microprocessor by actually running, for example, game software written for a PC of the time.

Conclusion

The current success of forming a CPU on a glass substrate using CG Silicon is a major milestone in the development of systems-on-glass. This development demonstrates the ability to form transistors on glass having a performance equivalent to the discrete IC chips of roughly 20 years ago. Further shrinking the line geometry will likely enable us to develop TFTs on glass offering even higher levels of performance. Based on the current results, we can look forward to the step-by-step development of peripheral devices on a display substrate, lowering costs and increasing the value added to system panels.

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Fig. 7 Verifying compatibility with the MZ-80C

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