Technology Trend and Requirement of Mobile Displays Using Low-Temperature Poly-Si (LTPS) Technologies

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Abstract

A lot of research for system-on-panel(SOP) have been done to integrate display systems including data driver, gate driver, timing controller, DC-DC converter, and smart functions such as embedded touch screen, ambient brightness sensing and luminance control, finger printing on the glass. Recently, the cost of an one-chip driver IC with various functions has decreased rapidly, and new mobile display interface technologies have been introduced. So it is necessary to examine the feasibility of SOP for practical mobile applications. In this paper, we will re-examine LTPS technologies for mobile displays in terms of various aspects and discuss the practical limitations on SOP technology and future technology trend of mobile displays.

1. Introduction

System-on-panel (SOP) is a system in which most of the display system is integrated on a panel. The goal of SOP is integrating display driver, control circuit, memory, and CPU besides the pixel array all together. Recently, SOP enables a display to play a role not o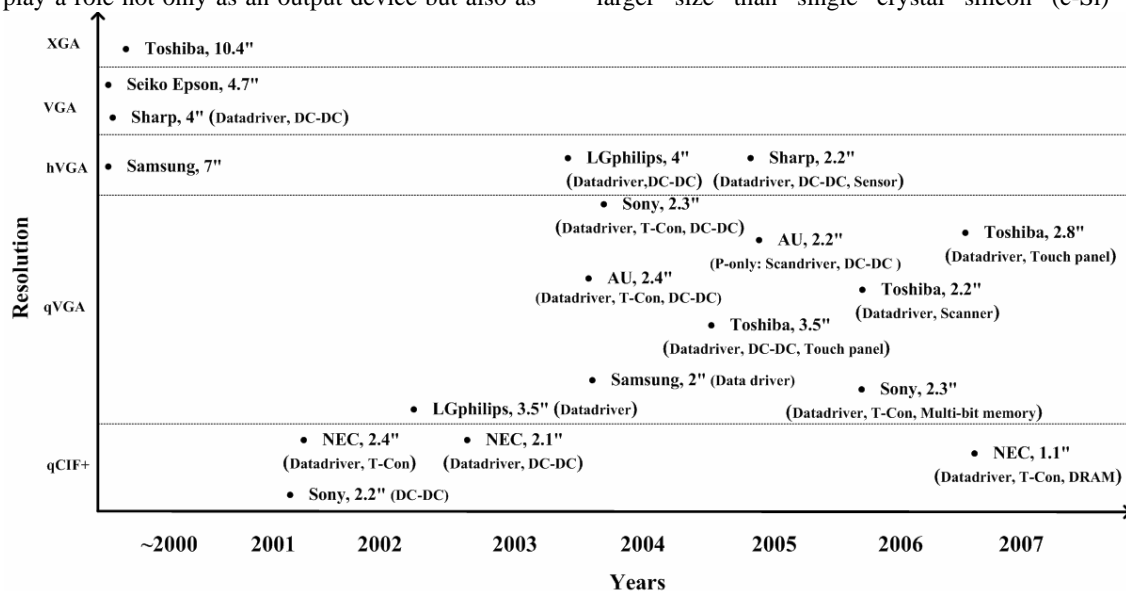nly as an output device but also as an input device by embedding various functions such as built-in scanner, touch panel, ambient sensors on the panel.

SOP integration level has been improved by the improvement of TFT characteristics. Nowadays, not only gate driver can be integrated on a panel as large as 23-inch WXGA using a-Si:H TFTs but also TFT sensors are used for controlling backlight[1,2]. However, the circuit integration level is still limited because of low mobility and threshold voltage shift of a-Si:H TFTs. On the other hand, poly-Si TFT having mobility of over dozens cm^2/Vsec may warrant more merit in the SOP field. Especially, low-temperature poly-silicon (LTPS) fabrication technology under 500°C makes poly-silicon crystal on the glass substrate possible. Figure 1 shows the development of SOP using LTPS referred to previous research and achievements. Starting with the integration of gate driver and 6-bit digital data driver in 1998, integration of system level components has been researched as well nowadays. Integration of timing controller and frame memory as well as driving circuit came in 2002 and in 2006. In 2005, pixel structure including scanner function was announced [3-10].

While LTPS TFTs show better performance than a-Si:H TFTs, they still have lower mobility, higher threshold voltage, and larger size than single crystal silicon (c-Si) transistors.

Fig. 1. Trend of the developed SOP technology.

Particularly, the electrical characteristic of poly-Si TFTs can change significantly according to how the grain boundary of poly-Si is formed. This makes the integration of analog circuits difficult. In this paper the guideline of electrical characteristics of TFTs for realizing SOP is discussed based on experimental result.

2. Technical requirement for SOP

Figure 2 shows the block diagram of 8-bit VGA TFT-LCD panel for the convenience to describe and understand the design issues and TFT requirement for SOP. The integration of frame memory, image processing system, and microprocessor has no benefit with current fabrication stardards because too much area is required for integrating these circuits altogether by large fabrication rule of TFTs. Figure 2 shows the requirements of each system level which can benefit through SOP integration in the current fabrication standards. Integrated blocks are data driver, gate driver, timing controller, and DC-DC converter as depicted in figure 2. The components are divided into digital circuits composed of shift register, sampling/ holding latch in data driver, and timing controller, and analog circuits composed of analog buffer of data driver and DC-DC converter. Development direction of each circuit and the requiring TFT characteristics classified by resolutions will be covered in detail.

2. 1 Digital Circuit

Digital circuits which should be integrated into SOP can be largely divided into display driving circuits and system digital circuits. In the display driving circuits, there are data driver and gate driver. The key circuit block is shift register in data driver block since its operation frequency is the highest among display driving circuits.

In order to find out the LTPS TFT's requirements, such as threshold voltage and mobility, and to design the shift register by increase the resolution of SOP, we have simulated the shift register and sampling latch by sweeping the threshold voltage and mobility of TFT. Figure 3 shows the requirement of the threshold voltage and mobility of TFTs to design the shift register and sampling latch in the data driver assuming that the gate length of TFT is either 2 µm or 4µm and VDD is either 5V or 3.3V.. .

The system digital circuit is represented by microprocessor. However, it is difficult to make the microprocessor operate in tens of MHz using LTPS and its size is too big so that we optimized integration level of system digital circuit. By considering the current status of LTPS TFT technology, integration of timing controller is possible and necessary. The block diagram of the timing controller is shown in figure 4. There are many blocks in timing controller and we classify the integration steps into three by considering the operation frequency, the degree of difficulty to circuit design and design rule of current LTPS TFT.
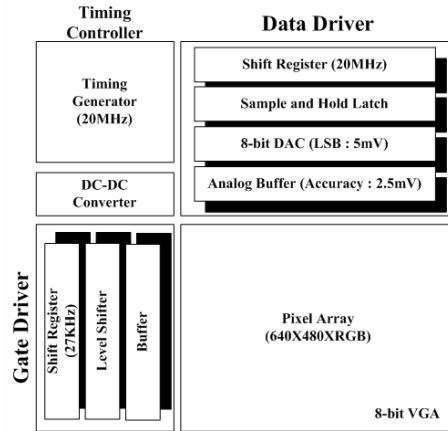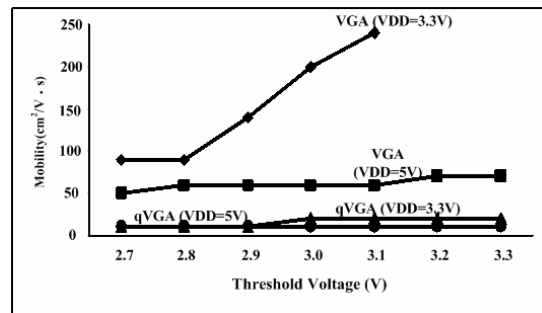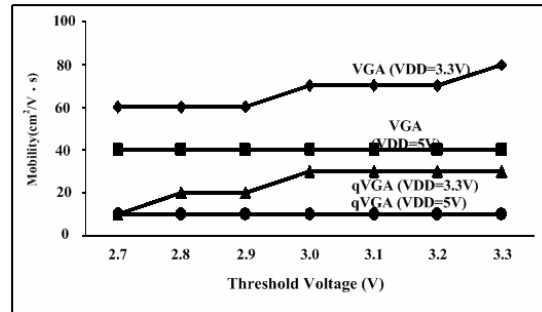

Fig. 2. The block diagram of SOP.

(a)

(b)

Fig. 3. Requirement mobility and threshold voltage of LTPS TFT for shift register : (a) 4µm of gate length and (b) 2µm of gate length.
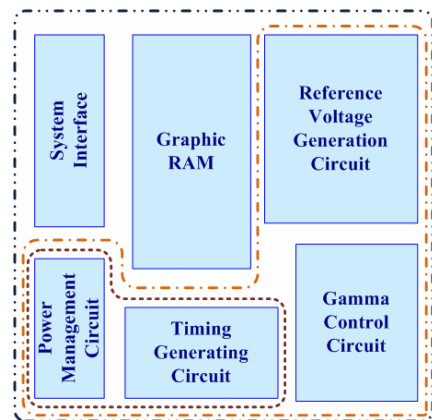

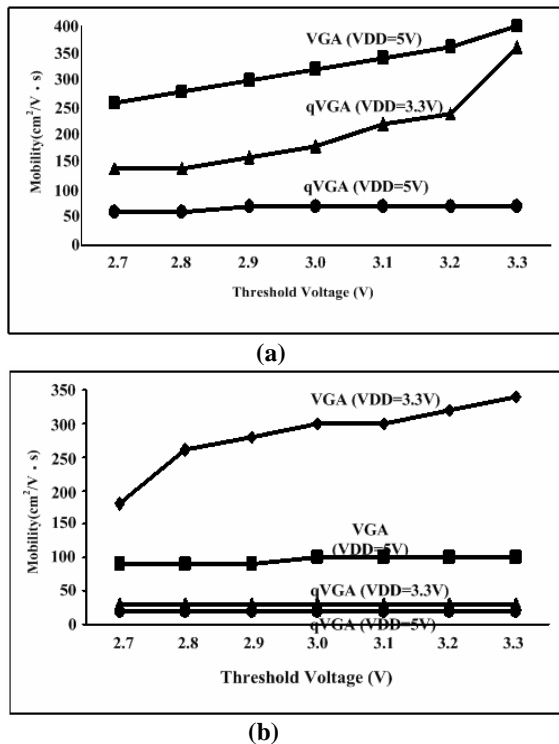Fig. 4. The block diagram of timing controller.

(a)

(b)

Fig. 5. Requirement mobility and threshold voltage of LTPS TFT for timing generator : (a) 4μm of gate length and (b) 2μm of gate length.

The circuits blocks in short term are the timing generator and power supply unit. SOP integration of timing generator block is effective in reducing the number of the external interfaces between LTPS panel and external display system. And its operation count and circuit complexity is lowest in the timing controller. Integrating the power supply unit, which generates the necessary high voltage supply for TFT-LCD panel, allows the use of low voltage timing controller ICs and this can effectively reduce the system cost.. Thus, we select the timing generator and power supply unit as the first step of timing controller integration.

Figure 5 shows the mobility of TFT and the operation requirement of threshold voltage according to VDD and resolution in the timing controller. When we design VGA panel at low VDD(3.3V), the gate length need 2μm and the mobility need 300cm²/Vs at 1V of threshold voltage.

2.2 Analog Circuit

Non-uniform electrical characteristics of LTPS TFT have been significant obstacles in the integration of analog circuit. The key analog circuit is analog buffer, but much effort has been put into designing the data driver circuit without using analog buffer as shown in figure 6 [11]. This panel contains a 6-bit data driver without buffer, gate driver, DC-DC converter and timing generator. However, the structure without buffer is limited to the size of driving panel and resolution. This architecture is available in 6-bit or 8-bit qVGA display but it is difficult to drive data line load at hVGA, VGA or higher resolution, due to the amount of capacitance and resistance load of data line and line time of each resolution.
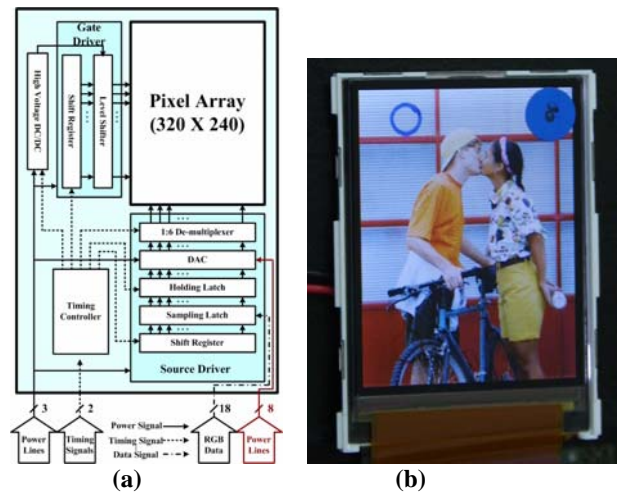

(a)   **(b)**

Fig. 6. Proposed 2.2-inch qVGA LTPS TFT-LCD panel: (a)Block diagram and (b) The photograph of display image.

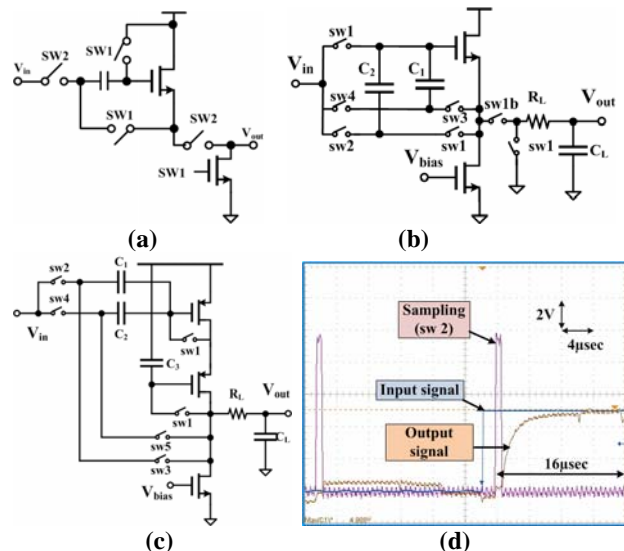**(a)**   **(b)**

(c)   **(d)**

Fig. 7. 1-stage analog buffer: (a) source follower type buffer [12], (b) common source type buffer [13], (c) Proposed common source type buffer [14] and (d) Measured waveform of Fig. 6. (c).

To design the larger size and higher resolution SOP, analog buffer is necessary. A lot of research has been done to make analog buffer using LTPS. Figure 7 (a) and (b) show the 1-stage analog buffers with source follower and (c) shows 1-stage analog buffer of common source type[12-14]. The buffers of figure 7 (a) and (b) sample threshold voltage of driving TFT and boost data voltage to compensate the threshold voltage. These buffers have sampling and boosting error and slow operation characteristic. To cancel the sampling and boosting error, common source analog buffer is proposed with feedback loop using capacitor [14]. Figure 7 (d) shows the output waveforms of figure 7 (c). It has maximum 8 mV offset. But 1-stage analog buffer is not appropriate to the 8-bit gray scale requires under 5 mV offset error. Therefore, the data driver for 8-bit or higher resolution needs 2-stage analog buffer like driver IC made by c-Si.

TABLE 1. Variation limit for 2-stage analog buffer

Resolution	Not using offset cancellation method		Using offset cancellation method	
	Mobility variation	Threshold voltage variation	Mobility variation	Threshold voltage variation
6-bit	±30 %	±20 mV	±60 %	±650mV
8-bit	±30 %	±5 mV	±15 %	±300mV
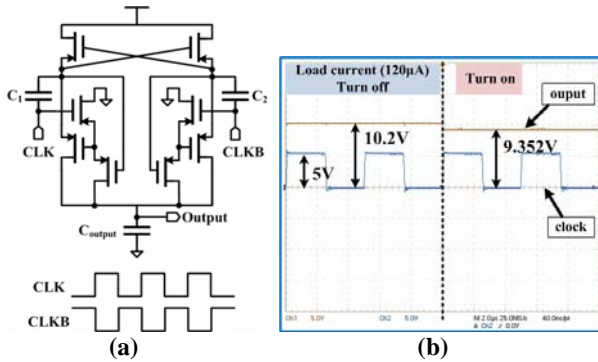
Fig. 8. Proposed DC-DC converter: (a) Schematic diagram and (b) Measured waveform.

The offset voltage becomes the key design issue in data driver using c-Si process. In LTPS, threshold voltage and mobility variation is larger than that of c-Si, so that the offset voltage of 2-stage analog buffer is much larger. To overcome this problem, we have to use offset cancellation methods. But offset cancellation methods can not compensate the process variation perfectly. Therefore we design and simulate the 2-stage analog buffer using LTPS TFT to find out the limitation of process variation for implementing the 6-bit and 8-bit gray scale.

The simulated limitation of process variation is summarized in table 1. Even though we use the offset cancellation method, mobility and threshold voltage variations should be under ±15 %, ±300 mV for 8-bit gray scale TFT-LCDs, respectively.

Other key analog circuits are power supply units such as DC-DC converter and regulator. Several research groups have attempted to integrate the power supply unit in SOP. The charge pump DC-DC converter has been developed and the voltage-doubler and cross-coupled DC-DC converter have been developed for increasing the efficiency [15, 16]. Figure 8 shows proposed cross coupled type DC-DC converter to reduce the on-resistance of driving TFT and enhance the power conversion efficiency up to 90% [17].

3. Conclusions

We briefly reviewed the developing trend of SOP during the past decade. And we described the design issues and TFT requirements of integrating the digital and analog circuits for data and gate driver, power supply unit, timing controller with LTPS TFT. To increase the integration level of digital circuit block, we examine the device characteristics such as threshold voltage and mobility of TFT and we present the practical limitation of process variation for analog circuit and SOP. Much more research is warranted until we can develop a competitive SOP.

4. References

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