Circuit Integration Technology of Low-Temperature Poly-Si TFT LCDs

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Abstract

By the SOG (System-on-Glass) technology with excimer laser anneal process, the number of IC chips and the area of the mounted IC chips on the printed circuit board are reduced. In new circuit integrations on the glass substrate, we have developed D/A converter including the new capacitor array, amplifier comprising the original comparators and new display device with capturing images by integrated sensor into a pixel. This paper discusses the application of circuit integration of low-temperature poly-Si.

1. Introduction

Poly-Si TFT-LCD is the most promising display for mobile information equipment, because higher resolution, lower power consumption, smaller module size and higher module durability. Those performances are achieved by integrating peripheral driver circuits and memory in each pixel on the glass substrate.

Since mass production of 10.4-inch XGA in 1998[1], we realized high-resolution (202ppi) 4-inch VGA display [2] and 2.15-inch static memory embedded display for personal digital assistant or cellular phone [3]. These issues are essentially on the basis of the initial stage technology of integrating the C-MOS digital circuits on the glass substrate [4].

The technology of integration in the next generation is the SOG (System on Glass) achieving optimized integration of the display module system, and the accumulating functional circuit integration into a pixel.

As one of the evidences achieving the SOG, we have demonstrated the data drivers and their controller.

The data driver has D/A converter including the new capacitor array and the original amplifier comprising the serially connected comparators. The comparators containing the simple inverter circuits and capacitors are serially connected for canceling variation of TFT's threshold voltage.

Conventional low temperature poly silicon (LTPS) TFT-LCDs, even for digital drivers, need driving voltage more than 10V [1] [2] [3]. The power consumption of integrated data driver on the high driving voltage is serious problem.

We have solved this problem for the first time reducing driving voltage to 5V [5] with new circuit configuration and advanced process technology, which include three-micron design rule and improved poly-Si TFT characteristics.

Moreover, the memory for low power consumption was integrated into the each pixel and is effective when still picture is displayed [3].

This advanced integration has been achieved for using low temperature poly-Si TFT technologies and provided an advanced display system with lower power consumption, smaller module size, and higher durability.

2. Progress of Display System

Figure 1 shows the block diagram of display system by the recent SOG technology. We integrated the data driver on the glass substrate of the developed display system. Impact of the data driver integration meaning analog circuit integration is not only the reduction of the number of ICs on the printed circuit board (PCB) but also wide application of other functional device.

The future display system will integrate full circuits of the display system on the glass substrate by the SOG technology. In this display, it is important that the system interface is connected to the glass substrate directly without buffering system and the circuit architectures reducing layout area of peripheral drivers [12][13].

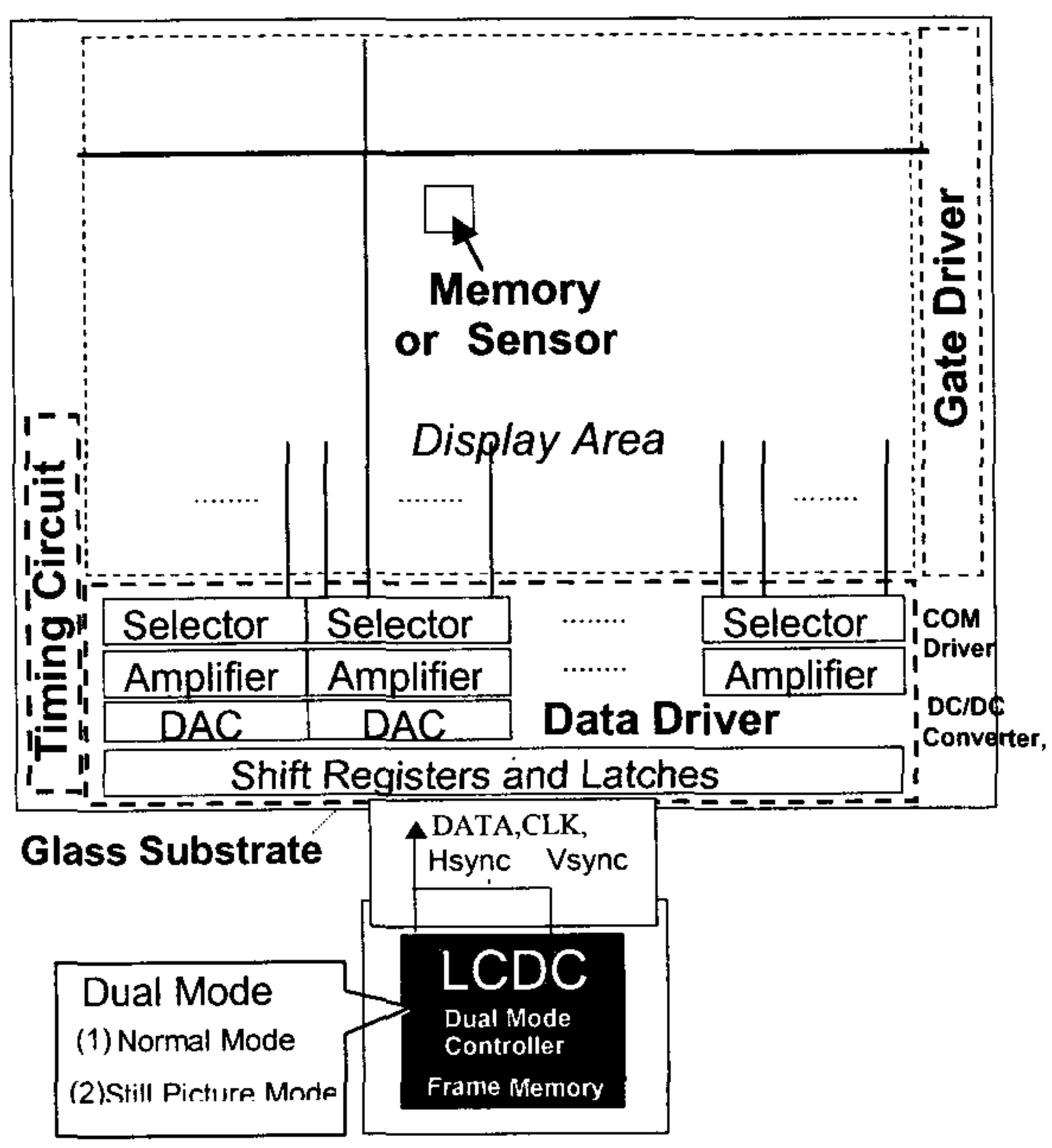

Figure 1 Block diagram of LTPS TFT-LCD

3. Integrated Analog Circuits

3.1 Circuit Structure

The Block diagram of LTPS TFT-LCD is shown in Fig.1. The display has 6-bit digital data driver which supports display of 262,144 colors and 1-bit memory in pixel supported 8 colors [6]. The data driver was integrated on the glass substrate and the digital image signal is applied from an external controller (LCDC), the data driver. The data driver is equipped with the circuit (shift registers and latches) holding a digital image signal, the D/A converter (DAC), the amplifier which outputs analog signal, and the selector which distributes output analog signal to the predicted signal line from the amplifier.

The DAC and amplifier circuits need many control signals. In making all control signals output to the external controller (LCDC), the number of LCDC output pins increases. Therefore, IC package become large, the line pattern area of the PCB increases, and the failures of LCDC connections increase.

In this problem, we have integrated the controller of the DAC and amplifier. The controller using a few source signals such as 'H/V sync' from the LCDC generates timing signals for integrated circuits on the glass substrate and allows simple digital interface between the glass substrate and the LCDC.

3.2 DAC circuit

The DAC circuit consists of the multiplexer for generating reference voltage with gamma correction and capacitor array using four capacitors with an equal capacitance in Fig. 2.

Conventional array consists of any different size capacitor weighted by the bit data. It is very sensitive for the variation of capacitance on process shifts that the error voltage of the DAC using the conventional capacitor array. But our capacitor array using same size capacitor is tough for the process shifts. The capacitor formation process is same as gate insulator formation process of the TFT. The homogeneity of the range of 5V is good enough for D/A conversion [5].

In the Figure 2, the multiplexer selects and outputs two voltages Vrl and Vr2 from several reference voltages. Then the capacitor array divides between Vrl and Vr2 by lower significant bits (LSBs) and generates final voltage by following principle scheme. First, input-side capacitors are charged up Vrl or Vr2 depending on the LSBs through switches of D1, /D1, D2, /D2, D3, /D3. Then, every input-side capacitor is connected to output-side capacitor one after another using the switches of S0, S1, S2, S3 and final voltage is completed at the output-side capacitor.

3.3 Analog amplifier

Generally, the amplifier is used the differential circuit in the design of the crystal silicon process. However the amplifier constituted by LTPS needs to fulfill the following three conditions.

(1) It can constitute from a few circuit elements.

(2) The dynamic range of output voltage is wide.

(3) The variation of TFT characteristics on a glass substrate can be compensated enough.

The developed original amplifier consists of three-step in-series connection of the magnification stage constructing a

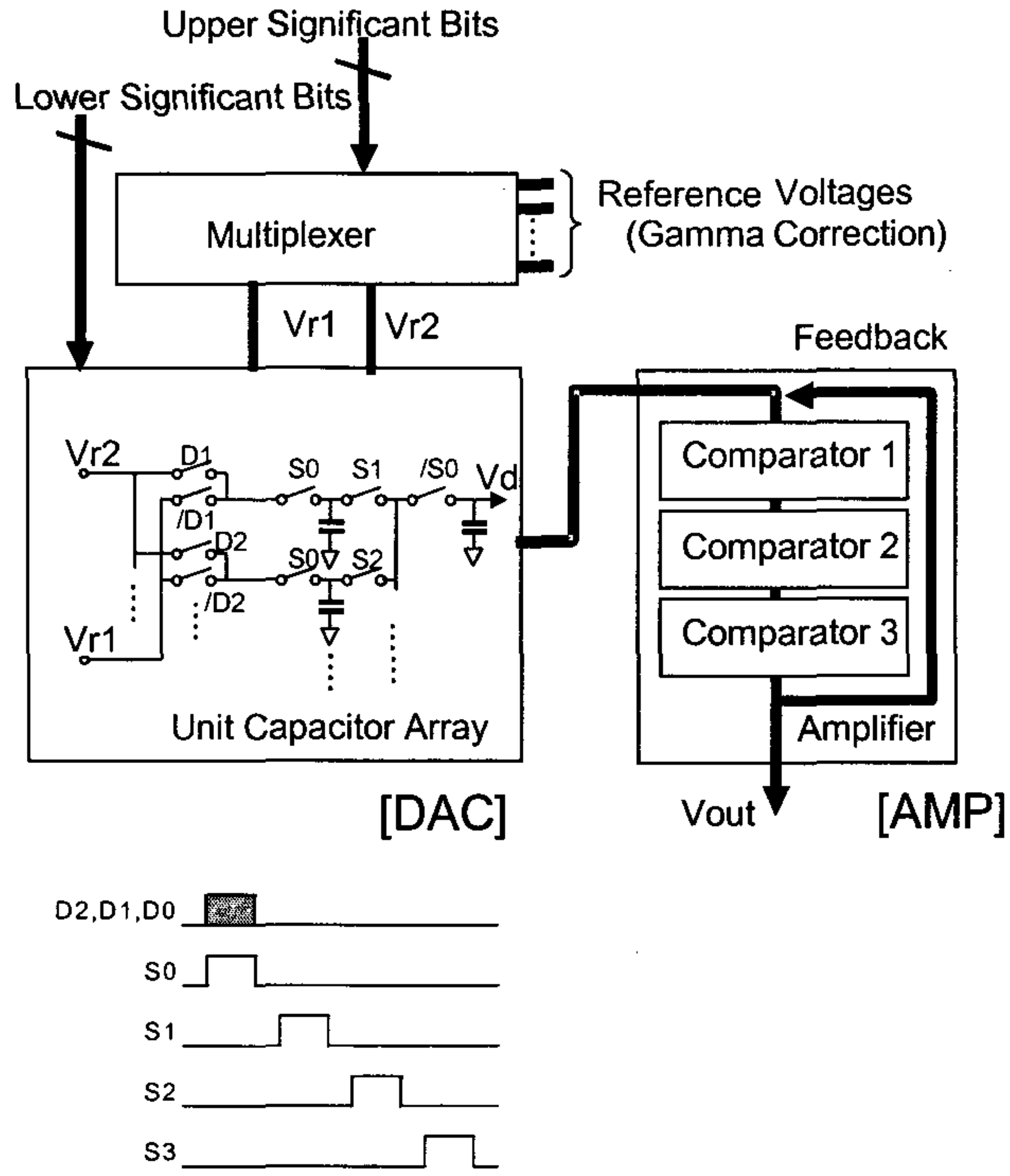

Figure 2 6-bit DAC and amplifier circuit and timing sequence of unit capacitor array

compensation capacitor and an inverter.

The dynamic range of output voltage is as wide as a supply voltage, and does not almost have being spoiled by the TFT characteristics.

First, the threshold voltage of the inverters is made to hold at the capacitor of comparator3, and the analog output voltage of the DAC circuit is made to hold at the capacitor of comparatorl by initializing of each comparators. Next, the Vout (a signal line voltage) is feedback to the capacitor of comparatorl.

Then, comparator3 starts charging or discharging of the signal line and it surely converges on the state where signal line voltage becomes equal to the output voltage of the DAC circuit. The magnification stage of the amplifier is established in three-step series, and it is sufficient gain for driving the signal line.

The output performance of analog amplifier is explained by Fig. 3. When an inverter is reset, the output voltage of the inverter is equal to input voltage that is the inverter threshold voltage (Vth) in Fig.3. The output characteristic of analog amplifier depends on the unit gain of the connecting each inverter, which is slop of input voltage and output voltage.
Since the amplifier gain is increased by the multiplied invert gain, good response amplifier can be made by increasing the number of the inverter to connect. Moreover, the output offset voltage depends on the input voltage and the output gain to amplifier, feed back output becomes like the following formulas.

$$\mathbf{Vout} = \mathbf{Vin} - \frac{\mathbf{Vin} - \mathbf{Vth}}{1 - \mathbf{A1A2} \ldots \mathbf{An}}$$

The number of the comparator consisting of the amplifier is decided by the design value of offset voltage. Here, when the marginal voltage of the voltage applied to the liquid crystal in the limit of visual sensitive is assumed to be 2mV and the gain of one comparator is assumed to be 10, the number of needed comparators becomes three comparators from the relation of Fig. 4.
We have designed and the TFT-LCD having QCIF-class display format to evaluate performance of the integrated analog circuit.
Figure 5 shows the example of output waveform and the display image with a gray scale pattern by operating of the proposal DAC and analog amplifier. Since H-line inversion driving method is adopted, the output signal turns the signal of the positive field, and the signal of the negative field. This figure shows display performance corresponding to 64-gray scale level. It is clearly confirmed that the gamma correction is performed successfully.
It is necessary that DAC circuitry perform gamma correction, to compensate for the non-linear electro-optical characteristics of LC pixel. Figure 6 shows measured offset voltage of a circuitry unit of 6-bit DAC and amplifier. It can be seen that the highest accuracy is achieved around Vout=2.5V. Vout means output voltage of the amplifier.

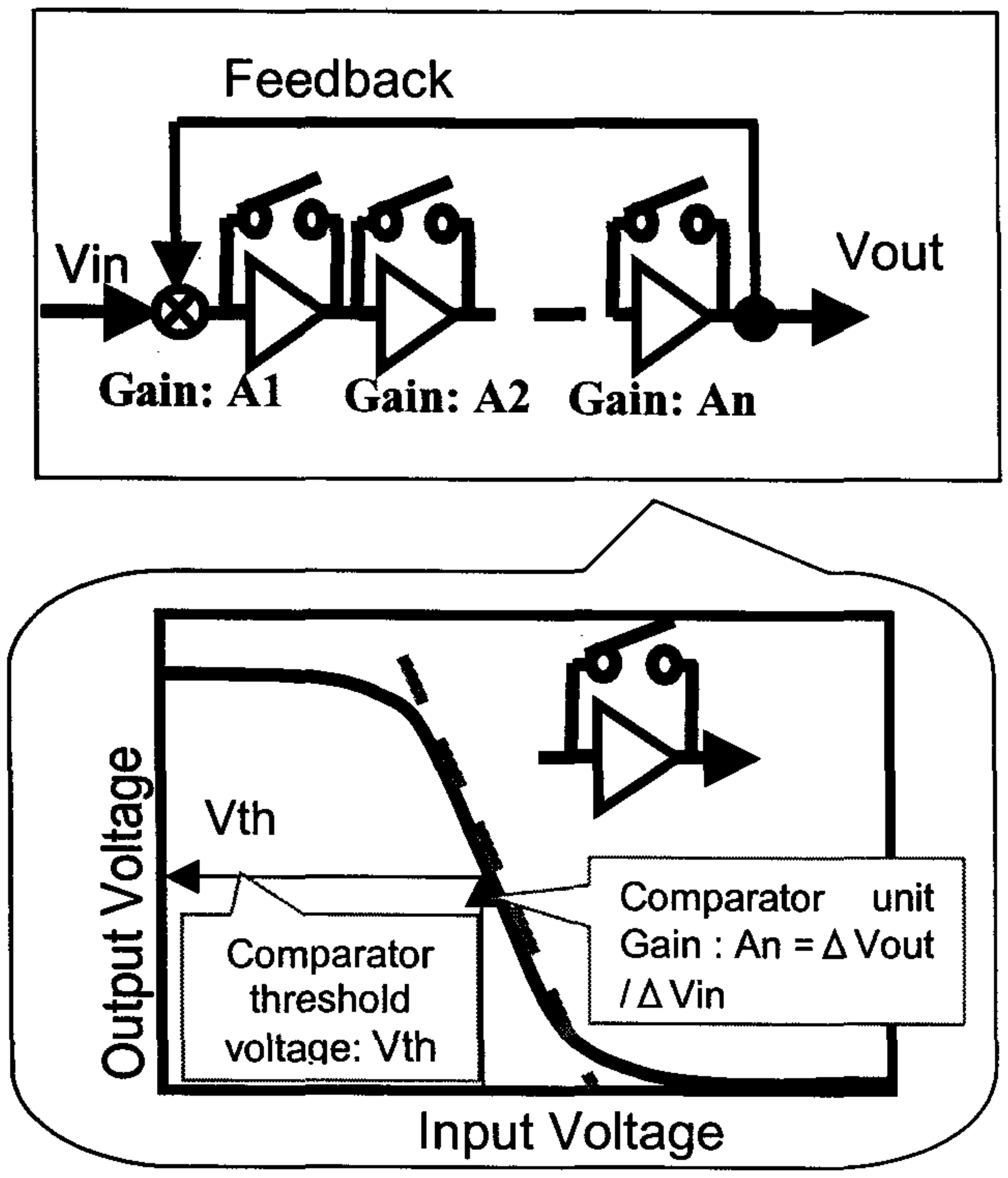

Figure 3 Analog amplifier circuit and comparator unit gain

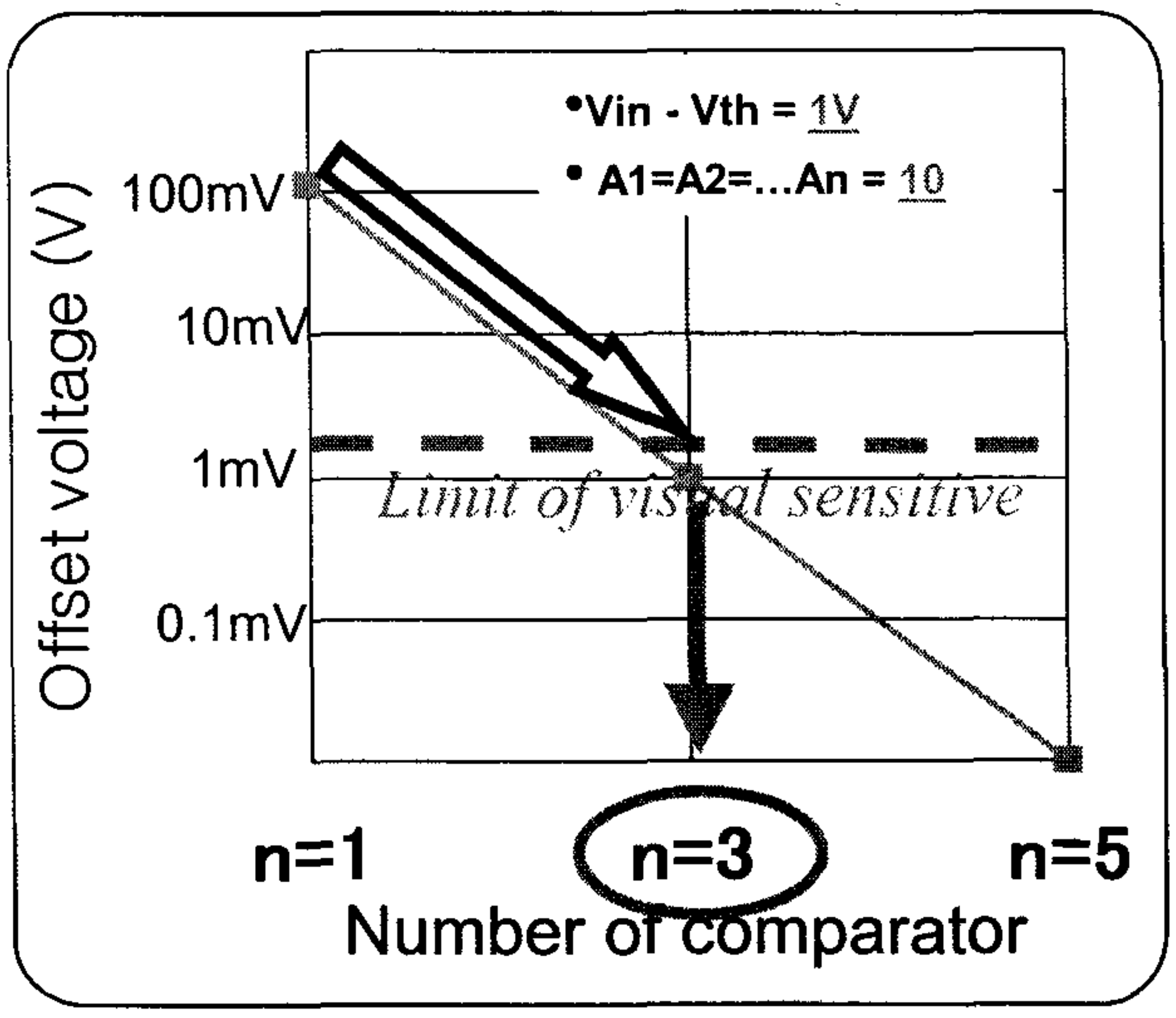

Figure 4 Offset voltage of Analog amplifier circuit by the number of comparator

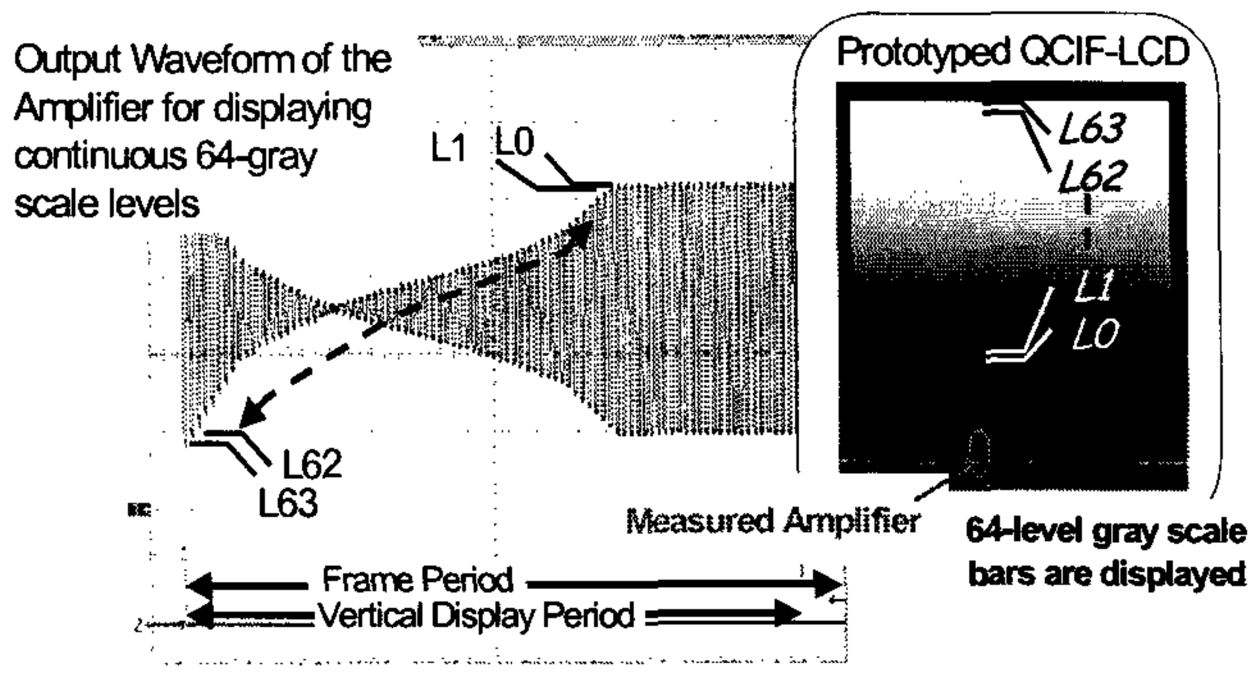

Figure 5 Output waveform of integrated data driver and display image

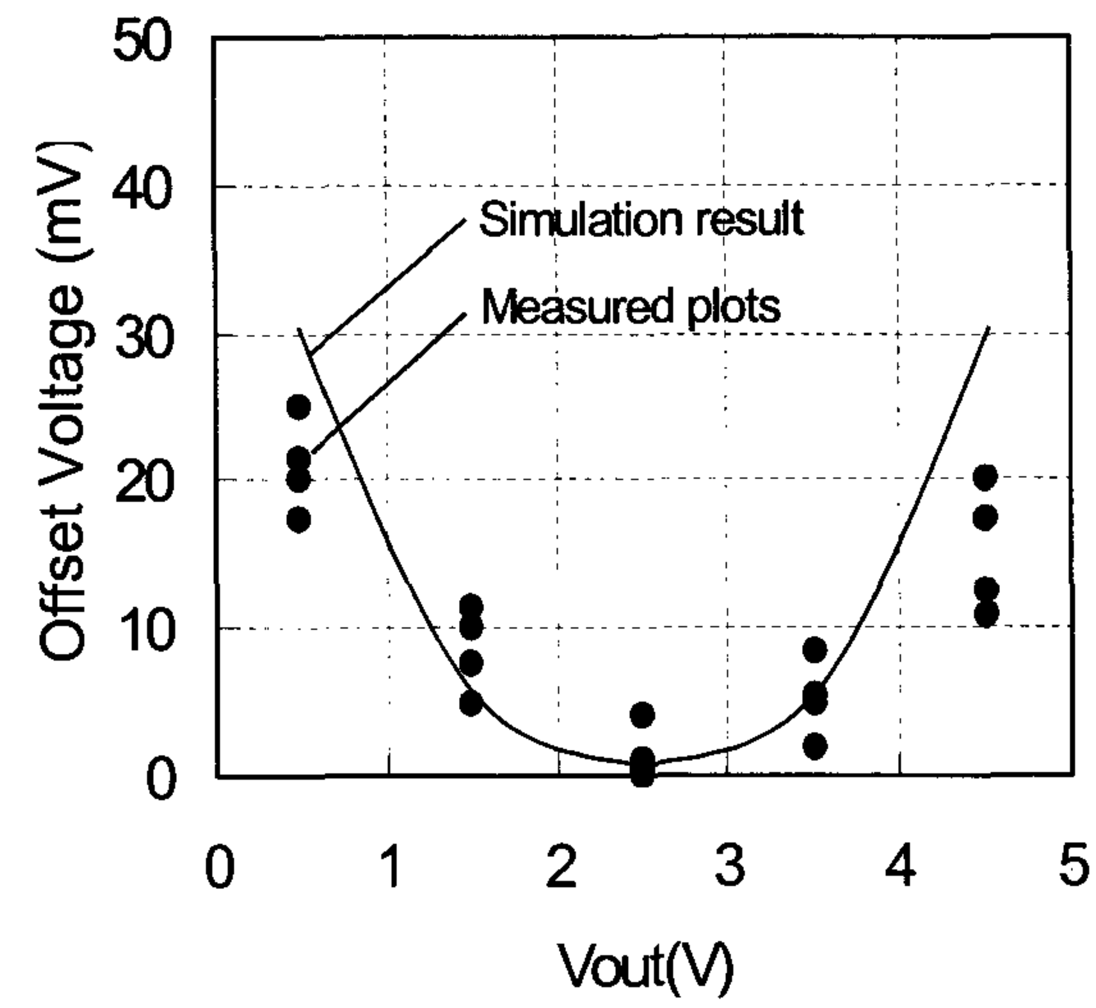

Figure 6 Measured offset voltage and simulation result of a data driver

4. Smart pixel

The integrated circuits by the SOG technology are divided into peripheral circuits and a pixel circuit. The integration of the peripheral circuits is reduction of ICs on the PCB and cost reduction.
On the other side, integration of a pixel circuit is integration of new function and can be realized low power consumption by integration of a memory in a pixel or capturing function by integration of a sensor in a pixel. The smart pixel which integrates a new function to a pixel is the new concept of the SOG technology.

4.1 Memory in pixel

The power consumption of display is estimated by CFV^2 and static power, depends on the driving load capacitor (C), frame frequency (F) and the driving circuit voltage (V). Although it is most important to lower driving voltage for reducing power consumption, there is limitation by the driving voltage of TFT circuits and liquid crystal materials.

Since many displays except for TV set's and monitor indicate a still picture more for a long time than a moving, integrated memory in a pixel for low power consumption can be applied to many displays. The relation of a required line and space rule is shown with the number of bits of the integrated SRAM type memory on a pixel in Fig. 6. It is dependent also on the resolution of a pixel and the line and space rule of about 1-micrometer is required for the integrated 6-bit memory device on the 200ppi resolution.

Although there are an SRAM type and a DRAM type of memory cells [3] [7], the density of integrated memory depends on the integration capability of the circuit. Specifically, they are 'line and space rule', the thickness and the dielectric constant of an insulated film for the storage capacitor and the layout of a unit cell including a memory and a refreshment circuit.

It is also possible to integrate a buffer memory on the peripheral circuit other than the method of integrating memory in a pixel. By holding the image data of a partial display [8], the number of times of re-writing of image data can be reduced.

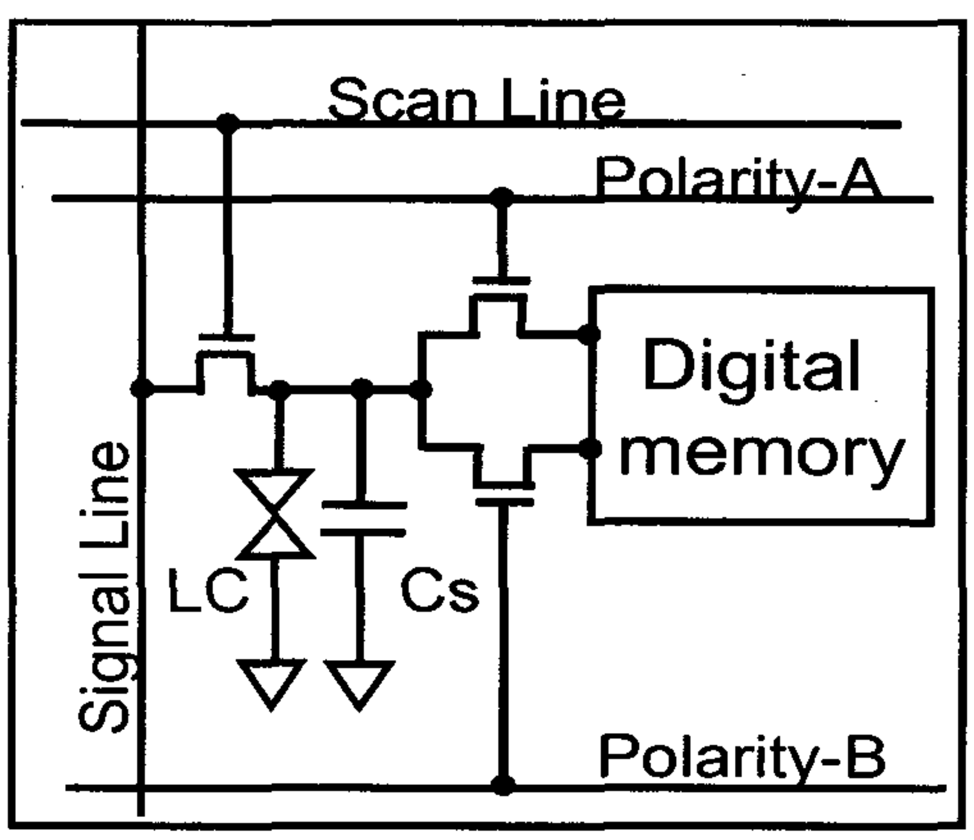

Figure 7 Circuit of the memory in pixel

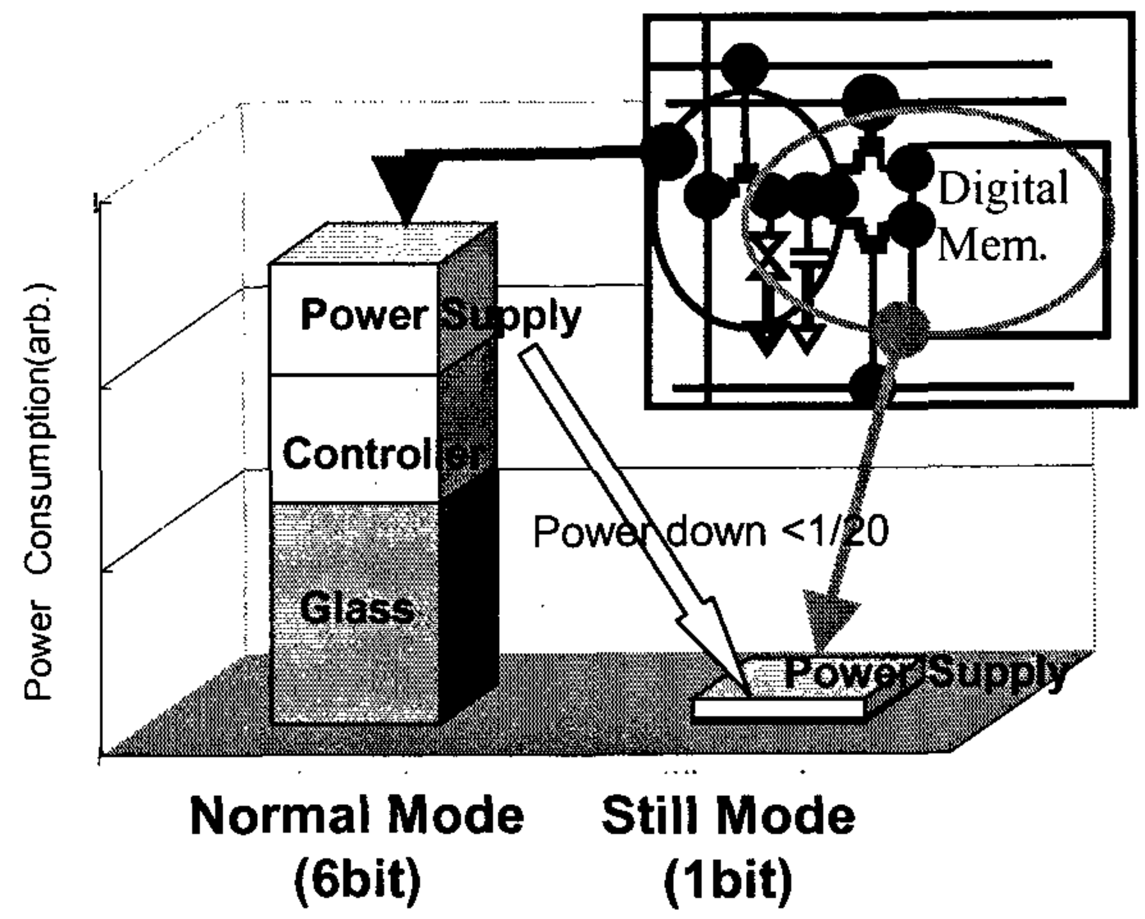

Figure 8 Comparison of 6-bit DAC power consumption and 1bit memory power consumption

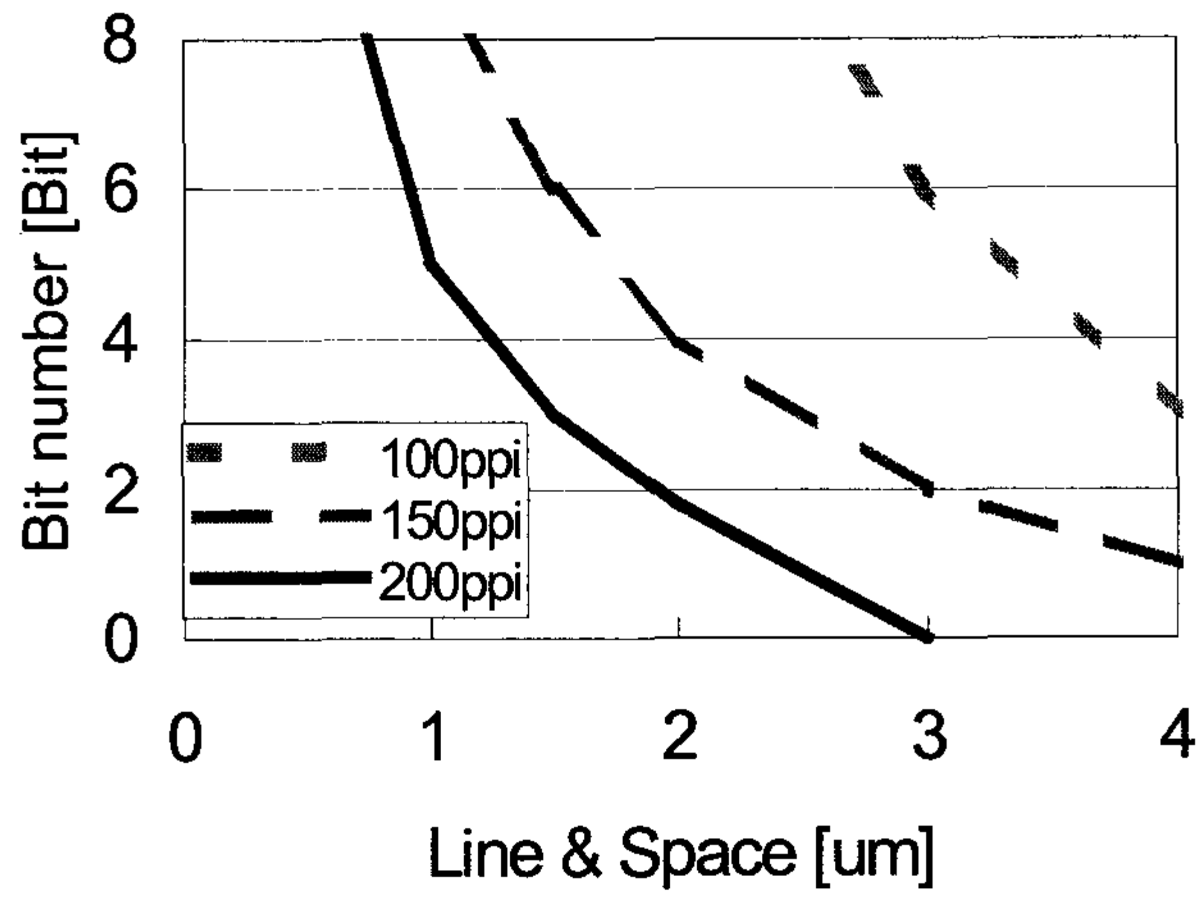

Figure 9 The number of bits can be integrated a pixel with calculating as a function of design rule for various pixel densities

4.2 Input Display

The demands of down sizing and lightweight for many mobile devices are very strong. Different type memories for example DRAM and FLASH memory are assembled in 1 chip module. The fundamental demands for integrating both of a display function and an input function exist for mobile FPD devices. The conventional low-temperature poly-silicone technology is used for display performances as a high definition and a high aperture ratio. Moreover, this technology is very effective also to realize a display function and to realize an input function.
By applying the most of circuit integration technologies, the display function and the input function can be integrated in the TFT-LCD. The input function (touch panel) and the display function are integrated on the same glass substrate with an optical sensor using amorphous silicon technology [11].

By our applying LTPS technology, the image capturing function and the display function are integrated on the same glass substrate.
Figure 10 is cross section of the proposed TFT-LCD (input display). Captured object is illuminated by the back light and reflective image is read out by the optical photo sensor integrated into the each pixel on the glass substrate. The capturing color image is separated RGB image by color filter currently used for the display and the RGB images detect with the photo sensors.
The integrated circuits on the glass substrate are scanning gate driver, data driver and sensor driver which has the control of the sensors and reads out of the sensor signals (figure 11) and specification of prototype input display is table 1[9][10].
Each photo sensor signal is converted to the digital signal by the AD converter in the each pixel and the photo sensor signals are read out as serial data by the sensor driver including parallel to serial conversion circuit.
After capturing a certain photograph and reading out the photograph image, the example displayed the photograph image on the input display is the photograph of Fig. 11. By carrying out right-and-left reversal of the read-out image, it is considering as the same arrangement as the capturing photograph.
Since the display function and the input function can be unified, the compact and lightweight mobile device is realizable further using this technology.

Table 1 Specification of input display

	Display	Input Function
Size	8.9cm (3.5 inch)	
Pixel Resolution	320(RGB)x240	
Color	260K color	
Type	Transparent	2D photo sensor

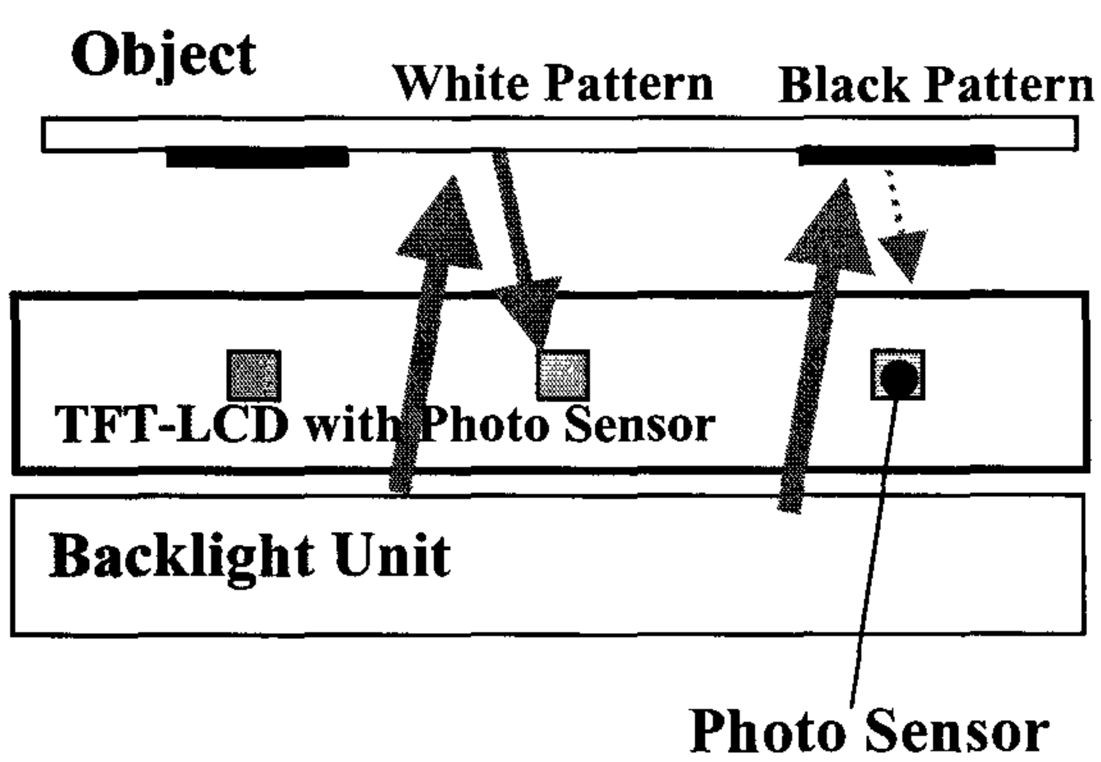

Figure 10 principal of object's image sensing

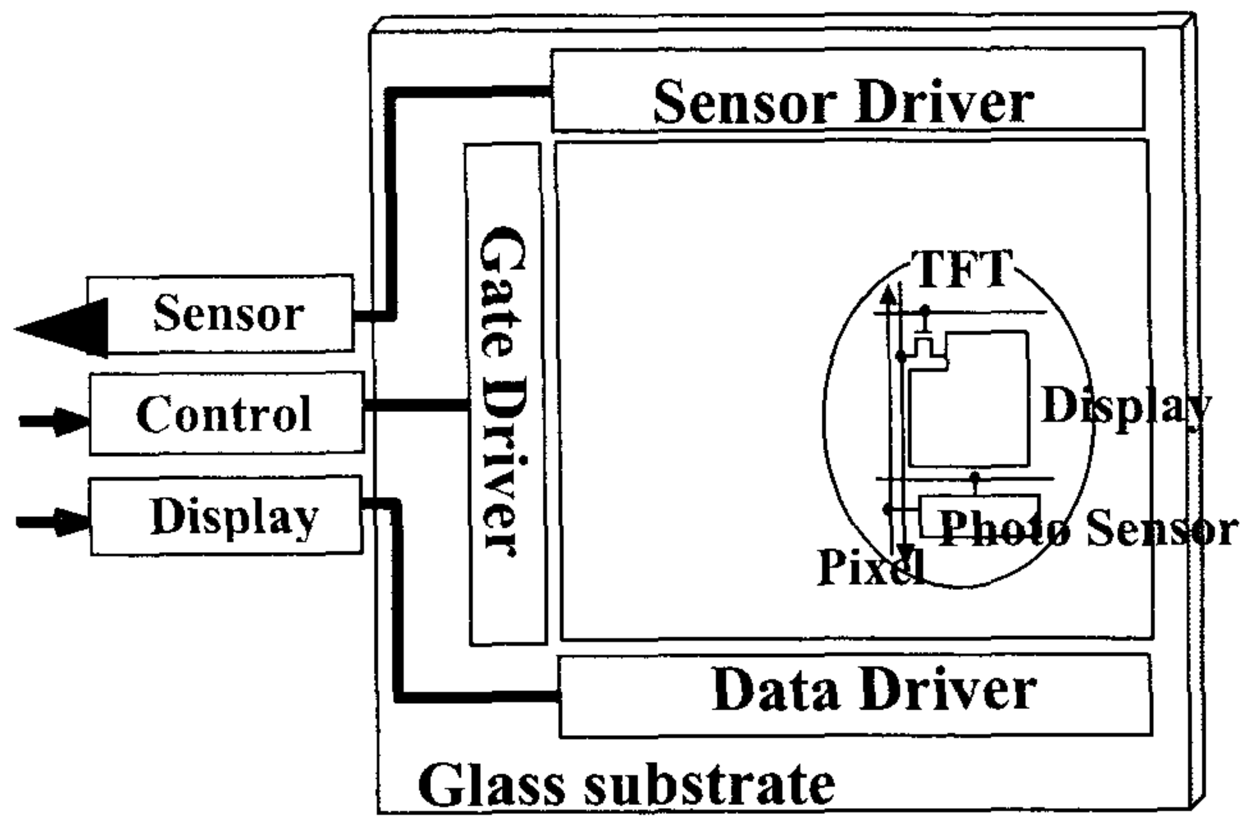

Figure 11 Schematic structure of input display.

Figure 12 Display result of capturing image

5. Conclusion

The higher integration and performance of the circuit on the glass substrate by the concept of SOG is realized more valuable display such as integration of the DAC, the memory in pixel, input display and so on. And in the feature of this concept, a sheet display will be realized.

6. Acknowledgments

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7. References

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