High Resolution System on Glass Displays

Fujio Okumura

SOG Research Laboratories, NEC Corporation,

1120, Shimokuzawa, Sagamihara, Kanagawa, 229-1198 Japan

e-mail: f-okumura@cd.jp.nec.com

Abstract

This paper describes low temperature poly-Si (LTPS) TFT system on glass (SOG) technology developed in NEC. High resolution SOG-LCDs such as a 230 ppi reflective type LCD, a 2.5", 333 ppi 2D/3D autostereoscopic LCD, and a 2.1" single voltage driven full integration LCD for mobile applications and a 0.9", XGA light valve for projectors are reviewed from the perspective of the high resolution technologies.

1. Introduction

Recently, System-On-Glass technology has been recognized as a key technology for the next generation displays. In this technology, various functional circuits such as a gate driver, a data driver including DAC, and a power supply circuit are integrated on a display substrate with LTPS TFTs. The SOG technology offers the advantages of high resolution, narrow picture-frames, compact size, low cost, and highly reliable electrical terminal connections since the interconnection between a pixel array and drivers are avoided. It requires, therefore, high performance LTPS TFTs, fine processing technology, and high level circuit design technology to realize high performance circuits in a small area.

As the name of our laboratories indicates, we have developed a variety of SOG displays, such as a high resolution LCD [1], a full integration LCD [2], an SOG-OLED and liquid crystal light valves [3, 4]. We are studying both the mobile displays and the light valves. These two types of research help each other. Since the light valves have extremely high resolution, they play a role as a process driver to develop the fine processing technology for all SOG displays. In the mobile displays, system integration technologies have been studied. The advancement of the system integration causes a strong demand for smaller circuit area with a variety of functions. This demand gives us a motivation to develop more advanced fine processing technology. This paper mainly reviews recent progress of SOG displays developed in NEC. Especially, I will review them from the perspective of the high resolution technologies.

2. High Resolution Display Technologies

The fine processing technology is essential for high resolution displays. Moreover, following technologies should be considered as well.

Storage capacitor structure : The first thing we have to consider is a storage capacitor structure when we design a high resolution pixel. The storage capacitor is incorporated at each pixel to reduce a pixel voltage offset by a gate pulse feedthrough and a pixel voltage drop by a TFT leakage current. However, there is a tradeoff relationship between the aperture ratio and the storage capacitor. A larger storage capacitor makes the aperture ratio lower. Therefore, the design of the storage capacitor is very difficult and important in high resolution displays.

Planalization : There are two reasons to consider the planalization. The first reason is reduction of the capacitance between the pixel electrode and the data-line [5, 6]. This allows the pixel electrode to be extended over the gate and data lines. The second reason is reduction of the liquid crystal discrenations. In an extremely high resolution display, the discrenation caused by the roughness can not be ignored.

Color filter on TFT structure : To obtain higher aperture ratio, the color filter on TFT structure is attractive in direct view LCDs [7]. This structure avoids a miss-alignment between a TFT substrate and a counter electrode substrate.

The first two technologies will be discussed later in the light valve section. By using these technologies, a variety of high resolution displays have been developed. Figure 1 shows a plot of high definition LCDs [1, 3, 4, 8-12]. To compare different structure displays, I selected sub pixel area as a parameter. The direct view LCDs have RGB color sub pixels in each pixel. On the other hand, the light valves do not have sub pixels because they are monochrome LCDs. Therefore, in case of light valves, the whole pixel was treated as the sub pixel. The definition of the resolution is given by:

$$R = \frac{25400}{\sqrt{3A}} \qquad (1)$$

where R is the resolution and A is the sub pixel area in square μm. In case of the direct view LCDs, the resolution R is the same as the real resolution.

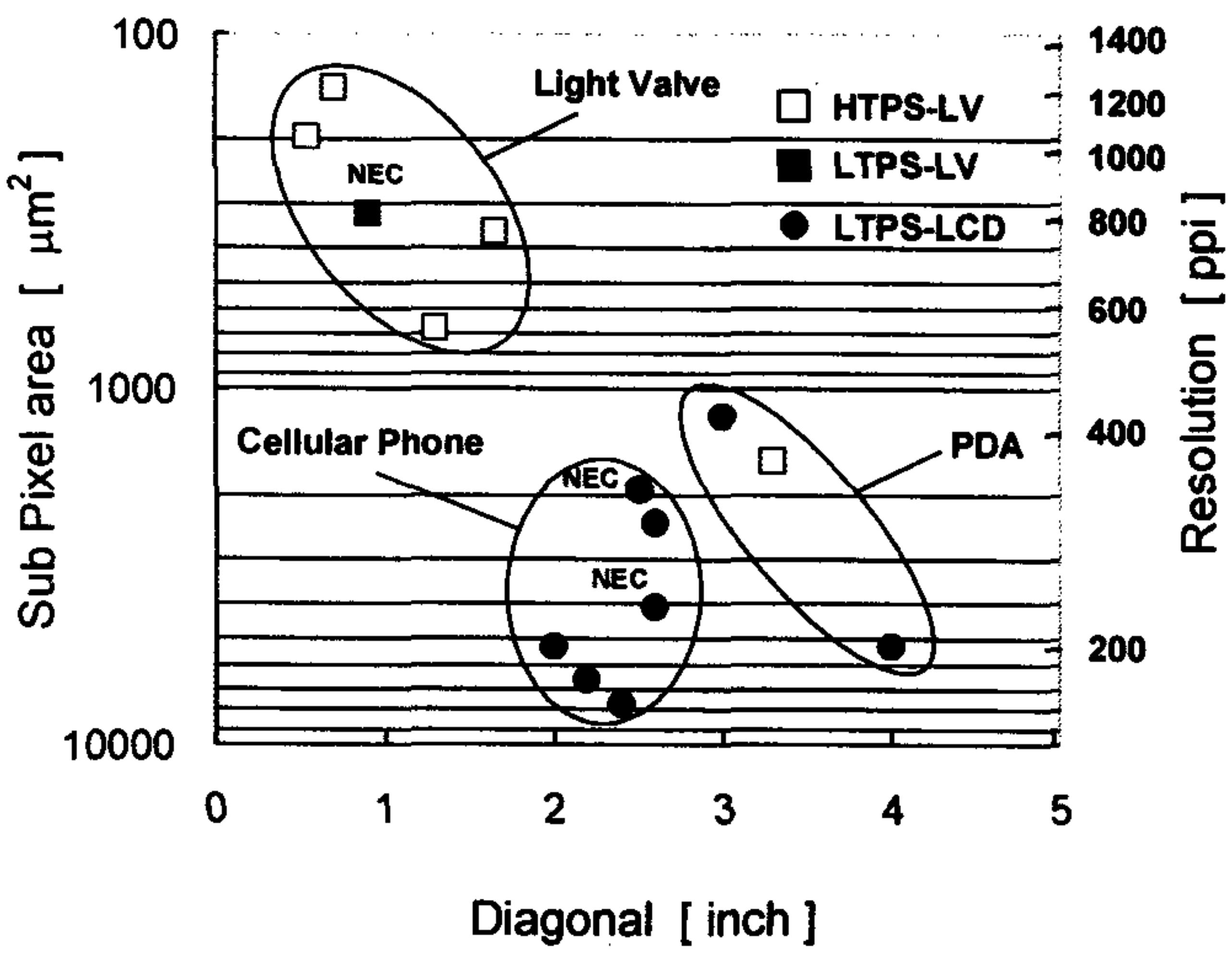


Figure 1. High resolution LCDs

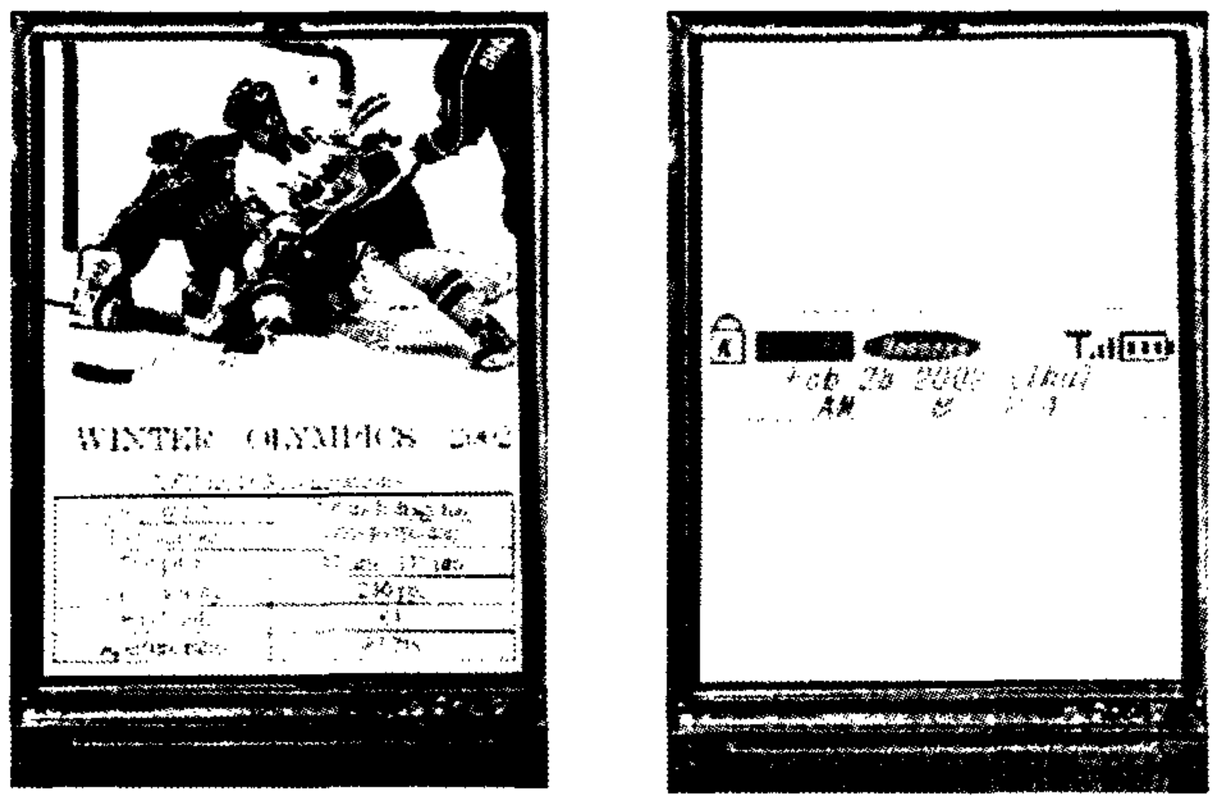
The state-of-the-art cellular phones in Japan have QVGA LCDs. These LCDs are from 2.2 to 2.4 inch diagonal in size and from 170 to 180 ppi in resolution. The largest size for cellular phone is about 2.6 inch. The current highest resolution direct view LCD is 3 inch, 427 ppi. panel [8].

The light valve resolutions are definitely superior to that of these direct view LCDs. At present, high temperature poly-Si (HTPS) TFT light valves dominate the light valve market. Although the highest resolution direct view LCD has only 20 % aperture ratio, the current light valves have from 60 to 70 % aperture ratio with much higher resolution. These facts indicate that higher level fine processing technologies are required for the light valve fabrication.

This figure clearly shows our high resolution LCD development activities. We have already developed 230 and 333 ppi LCDs for cellular phones. Here, I would like to emphasize that our LTPS light valve shows the highest resolution as an LTPS LCD. We are using the light valve as a process driver because of these reasons.

3. SOG LCDs for mobile applications

As mentioned above, we have developed several high resolution mobile displays based on these fine processing technologies. Moreover, we have developed several low power consumption circuit technologies. Figure 2 shows one example. This is a 2.6", 230 ppi reflective type SOG-LCD [1]. This LCD features not only high resolution but also low power. The SOG-driver integrated on the panel has a partial drive operation function. With the partial driving scheme (see Figure 2(b)), the total power consumption was reduced from 15.2 mW for the normal display mode to 1.7 mW at a frame frequency of 30 Hz.



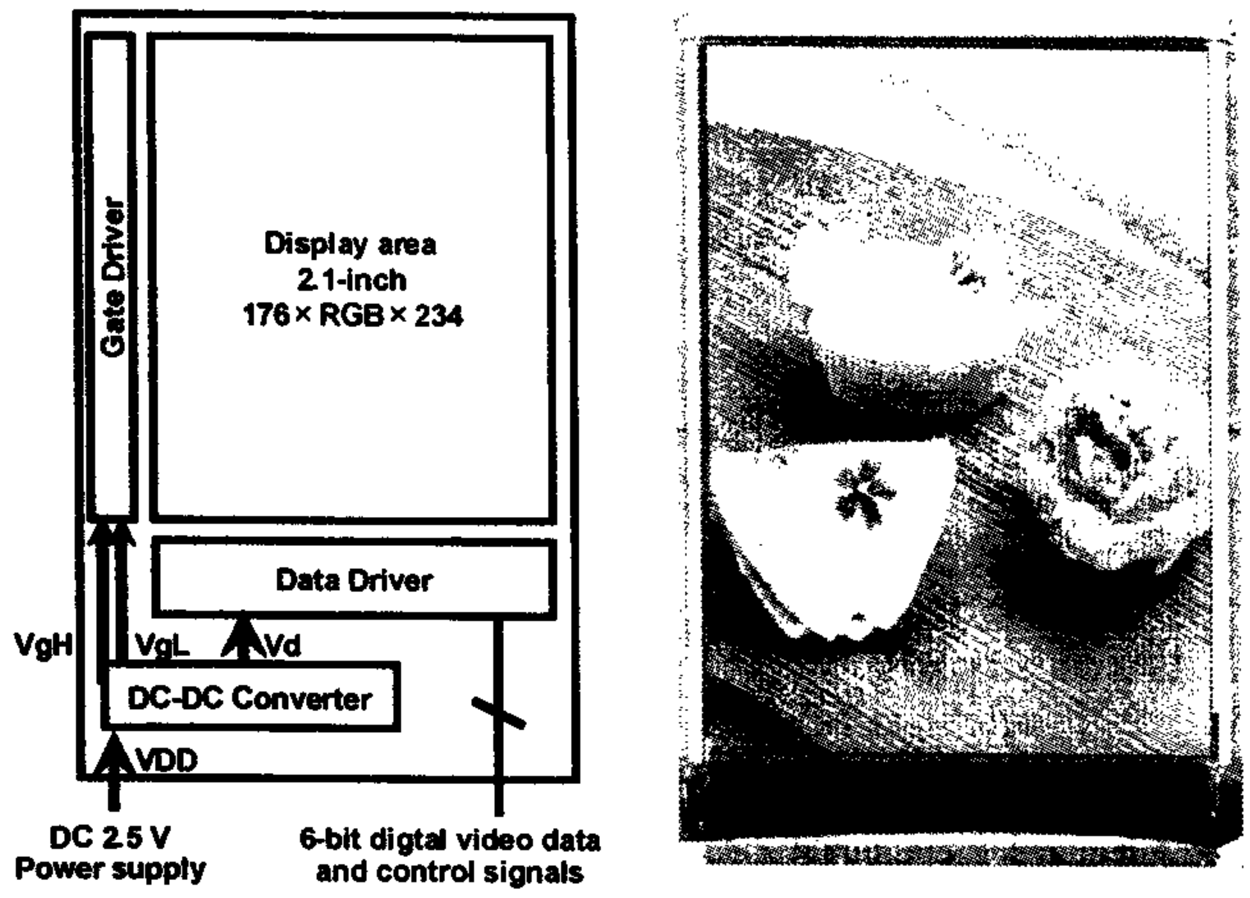
(a) Normal mode (b) Partial mode

Figure 2. Sample image of the high definition LCD

Another high resolution LCD from our laboratories would be presented in this conference (Session 24-2: S. Uehara, et.al., "470 x 235 ppi poly-Si TFT LCD for High-Resolution 2D and 3D Autostereoscopic Display.") [9]. It is a 2.5" diagonal 2D and 3D autostereoscopic LCD with a novel pixel arrangement called HDDP (Horizontally Double-Density Pixels). In the HDDP arrangement, the horizontal pixel density is twice that of the vertical. The vertical resolution is 235 ppi and horizontal resolution is 470 ppi, respectively. And the resolution given by the definition in formula (1) is 333 ppi. This value is the highest in cellular phone LCDs.

The circuit design technology is also important to develop high resolution displays. Because it requires high level fine processing technologies to integrate small and value-added circuits. Since our objective devices are small LCDs for mobile use, we have been developing low power consumption circuits. Figure 3 shows a block diagram and a sample image of a newly developed 2.1" QCIF SOG-LCD just presented in SID'04 [2]. This LCD fully integrates gate driver, 6-bit DAC data driver as well as a DC-DC converter. The DAC consists of a resistance DAC (R-DAC) and pre-charge buffers. This circuit scheme reduced power consumption to less than one fourth. The DC-DC converter steps up supply voltage of 2.5 V to higher voltages for the data and gate drivers at an efficiency of over 70%. Then, the total power consumption was suppressed to less than 5 mW.

The next target is to add various functional system circuits, such as memories, signal processors, sensors, and even a CPU. However, expansion of the function makes the circuit area larger. Actually, a prototype device presented in SID'04 had unacceptable large peripheral circuit area [13]. Although this is an extreme case, the demand to narrowing the edge frame is so strong in the mobile displays. This is a significant issue for the SOG technology. To overcome this problem, a design rule reduction and improvement on process technology should be necessary. The progress in this technology not only makes the circuit smaller but also realizes higher resolution displays.



(a) Architecture (b) Sample image

Figure 3. 2.1" diagonal low power SOG-LCD

4. Light Valve

As mentioned in the first section, the highest resolution SOG LCD is our light valve. The light valve itself is a small, monochrome LCD embedded in a projector. At first, comparison of other display technologies will be discussed since it is not so popular compared with other direct view displays.

4.1 HTPS vs. LTPS

HTPS can not be ignored when discussing light valves because only HTPS light valves have been used for commercialized projectors [14-16]. Then, why was the HTPS selected for the light valves? In the late 1980s when the light valve development started, the LTPS was a premature technology. However, now, we are rushing into the SOG era. LTPS can compete with HTPS! Table 1 shows the comparison of HTPS and LTPS.

In HTPS process the gate insulator is a thermal oxide. This high temperature process requires expensive quartz substrates. As long as HTPS uses LSI line, the maximum substrate size is limited up to 300 mm ϕ. On the other hand, LTPS allows fabrication on inexpensive large glass instead of small quartz substrates because the maximum process temperature is less than 600 C. For example, Gen 4 glass substrate is about 10 times larger than 300 mm ϕ quartz wafer. Therefore, the productivity and cost are dramatically improved by LTPS.

Some people think that HTPS TFTs are high performance in comparison with LTPS TFTs. However, reality is different. In general, excimer laser annealed (ELA) TFTs used in LTPS show higher mobility than that of solid phase crystalized (SPC) HTPS TFTs. If they are not, we can not use them for the SOG displays.

Table 1. Comparison between HTPS and LTPS

	HTPS	LTPS
Process Tech.	LSI	LCD
Process Temp.	<1200 C	<600 C
Gate Insulator	Thermal Oxide	CVD SiO_2
Crystallization	SPC	ELA
Substrate	Quartz	Glass
Substrate Size	< 300 mm ϕ	Gen.1 - Gen 4
TFT Mobility	< 100 cm^2/Vs	> 150 cm^2/Vs

4.2 Direct view LCD vs. Light Valve

The light valves are called ultimate LCDs because they operate in harsh environment and provide high quality images. Table 2 shows a comparison of direct view LCDs and light valves. Here, the illuminances are the value on the surface of the glass substrates. The direct view LCD has a luminance of 500 cd/m^2. The illuminance of 50 k lx means the value under the sun light. In case of the light valves, a 2500 lumen projector is assumed. The incident light to the light valves is 750 times greater than that of direct view LCDs. Even the reflecting light from the optical components of a projector is stronger than that of the sun light. The light valves must have very high contrast ratio even in this harsh environment.

Moreover, an image is magnified in case of the light valves. Nowadays, the size of the light valves is 1 inch or less and a projected image is 50-150 inch in case of business use projectors. Therefore, picture quality imperfection is magnified several hundred times as well. These are the reasons why they called ultimate LCDs.

Table 2. Comparison of Direct View LCDs and Light Valves

	Direct View LCD	Light Valve
Illuminance (Light source side)	16 K lx	12000 K lx
Illuminance (Output side)	50 K lx	140 K lx
Contrast ratio	~500 (color) ~1000 (monochrome)	500 - 1000
Magnification (in diagonal)	1	Several hundred

4.3 0.9", XGA Liquid Crystal Light Valve

Major performance requirements for projectors are brightness and contrast ratio. As for these two demands, the higher the better. To obtain high brightness, the light valve must have high aperture ratio. In direct view LCDs, generally speaking, the storage capacitor consists of a high-doped poly-Si layer, a gate insulator layer, and a gate electrode layer. When we employ this structure, the aperture ratio of less than 45% can be achieved at the pixel pitch of 18 μm. This is far from the requirement. To overcome this problem we employed a stacked capacitor structure. Figure 4 shows a cross sectional view of the pixel [3]. The capacitor is formed above the pixel component area, such as a gate bus-line, a data bus-line, and a pixel TFT. Therefore, the storage capacitor can be formed without decreasing the aperture ratio. By employing this structure, the aperture ratio was improved from 45% to 65%.

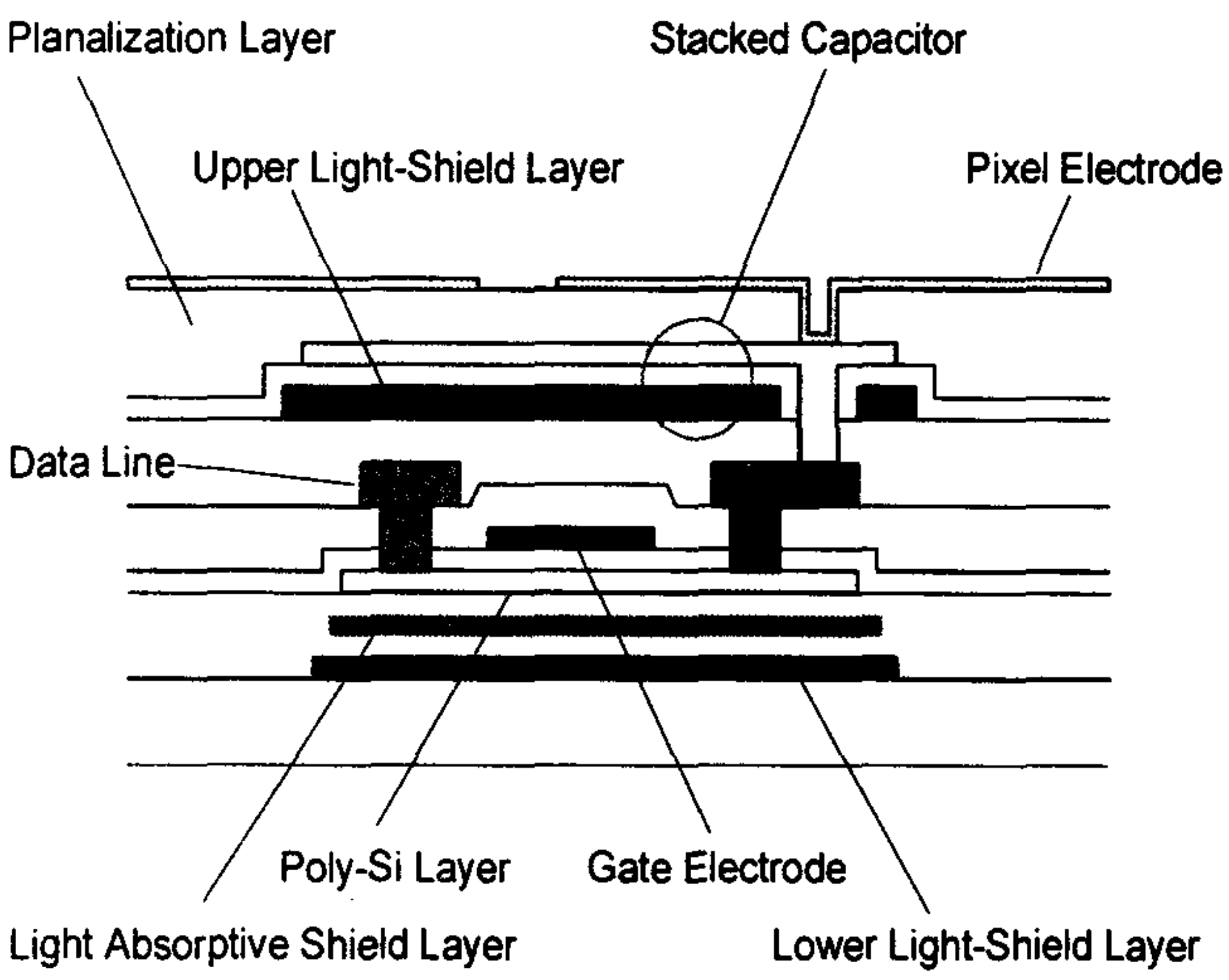


Figure 4. Cross sectional view of the pixel.

In addition to the storage capacitor structure, we have to care about the planalization structure mentioned in the first section to obtain both high aperture ratio and high contrast ratio. This stacked capacitor structure increases the roughness of the pixel surface because it requires additional layers to place the storage capacitor above the TFT. The roughness of the pixel surface might induce discrenations of the liquid crystal. The discrenation causes photo leakage. This results in reduction of the contrast ratio. In order to solve this problem, a planalization layer was formed on top of the upper capacitor electrode as shown in Figure 4.

As mentioned in the previous section, the light valves are exposed to extremely intense lights, therefore, a special care must be taken to reduce the TFT photo leakage current. In order to solve this problem, three kinds of light shield layers were fabricated [4]. The upper light shield layer blocks the light coming directly from the light source and the lower light shield layer does the reflecting light from the optical components (see Table 2). Moreover, an additional light absorptive shield layer was placed between the TFT active layer and the lower light shield layer. This light absorptive shield layer effectively blocks any incident light that might enter the space near the TFT active layer from the side of light shield layers, preventing the weaker light from reaching the TFT active layer. Since the layer is a-Si, it has not only high absorption coefficient but also low reflectivity. By inserting this layer, the contrast ratio was improved from 500:1 to 700:1.

The specifications of the light valve are listed in Table 3. An aperture ratio of 65% has been achieved by employing the stacked capacitor structure. Furthermore, with the improvement of the pixel roughness by planalization layer and the light shielding structure, a high contrast ratio of 700:1 (on screen) has been achieved without using optical compensation films. This value is much higher than that of commercially available projection displays whose contrast ratios are around 400:1. With optical compensation films [17], contrast ratio improves from 400:1 to 700:1 which has been realized in projection displays now available on the market, which is the same as a contrast ratio of this work.

Table 3. Specification of the light valve.

Didplay Size	0.9 inch
Number of pixels	1024 x 768 (XGA)
Pixel size	18 μm x 18 μm
Chip size	26 mm x 24 mm
Aperture ratio	65%
Contrast ratio	>700:1 (on screen)

Figure 5 is a real projected image on a screen achieved with the present light valves and exhibits an image with an excellent contrast ratio.

Figure 5. Projected image on a screen

5. Conclusion

In this paper, the SOG displays developed in NEC have been reviewed. Especially, we have concentrated on development of the high resolution display technologies and low power circuit design technologies. High resolution displays, such as the mobile LCD that has over 300 ppi resolution and the light valves that have the highest resolution as an LTPS LCD and low power display such as full integration LCD have been developed. To realize low power consumption mobile LCDs, several low power circuit technologies have been developed. Moreover, to realize high performance light valves, various kinds of high resolution technologies such as stacked capacitor, planalization layer, and light shield layer structures have been developed. The light valve showed higher contrast ratio than that of HTPS light valves with the same level aperture ratio. We believe that our SOG technologies will carve out a path to the new SOG era.

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