New technologies for advanced LCD-TV performance

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Abstract — Samsung intends to be the world leader in LCD-TV through a combination of superior product technology, advanced process execution, and aggressive capitalization. This paper explores and updates Samsung's latest developments toward its goal of ultimate LCD-TV performance and market leadership. Samsung's development of Super PVA (S-PVA) represents a key performance achievement. S-PVA is a new technology which enables screen quality advantages over S-IPS and MVA, including high transmittance, >1000:1 contrast ratio, and wide angle of view with no off-axis image inversion. This new technology is described in detail. This paper also addresses the other remaining performance issues facing LCD-TV, including Samsung's plans for addressing these challenges. Until recently, inter-gray response time and associated motion blur were significant issues for achieving quality LCD-TV images. Samsung has invented DCC-II technology to achieve sub-10-msec response time, and this achievement is described. Other technology advancements, including next-generation color performance and ultra-low black performance, are discussed. Samsung has announced the development of a 57-in. full-HD (1920 × 1080) LCD-TV panel, the world's largest, based on S-PVA technology. This product represents the culmination of many technical breakthroughs, and is discussed herein. Samsung's LCD manufacturing strategy, which includes the world's first generation 7 LCD fab, is also described.

Keywords — *LCD, LCD-TV, VA, PVA, S-PVA, EBU, RTC, DCC.*

1 Introduction

Demand for large-area flat-panel-display television (FPD-TV) has dramatically increased as a result of expansion of the digital-TV market. Among the various FPD TVs, PDPs and projection TVs have been in the market for years. The market launch of TFT-LCD television occurred in 2002, when Samsung Electronics also decided to enter the LCD-TV market in earnest, using Patterned Vertical Alignment (PVA) technology[1,2] in a wide range of HDTV products including 17-, 19-, 23-, 26-, 32-, and 40-in. WXGA. Samsung's 46-in. and 57-in. full HD resolution (1920 × 1080) models have also commenced initial volume production. The 57-in. model[3] is currently the world's largest LCD-TV.

Compared to other FPD TVs, TFT-LCDs have the advantages of high resolution, light weight, slim size, and low power consumption. However, all LCD-TV manufacturers face a challenge in meeting demanding performance requirements. Drawbacks of TFT-LCDs have included slow response time, high manufacturing cost, and limited viewing-angle performance, all of which have needed improvement for mass production. In this paper, Samsung presents S-PVA (Super PVA) technology, which has upgraded properties and overcomes those issues successfully. To achieve better off-axis image quality and greater angle of view, we have developed a new polarizer and have optimized cell parameters, and to minimize motion blur, we have developed DCC-II technology. We have also achieved higher contrast ratio, greatly improved black-state uniformity, and unprecedented color performance. Samsung's generation 7 line is designed for the most effective use of substrate glass, which is an essential factor for cost competitiveness.

2 Improvement of off-axis image quality

LCDs have had a key limitation compared to other display devices, namely, image-quality deterioration as a function of viewing direction. Image consistency over a wide angle of view is one of the most important properties needed for TV applications. For TN mode, off-axis image deterioration is so severe that TN is rarely utilized for TV applications. PVA and S-IPS modes have significantly improved off-axis image integrity; however, these modes still have some unresolved weak points.

To achieve the best off-axis image quality, lower off-axis black level and minimized color changes according to viewing direction are needed. We adopted a new polarizer structure to the S-PVA panel, consisting of optimized c-plate and a-plate compensation films. PVA mode has traditionally just used biaxial films to compensate off-axis viewing anomalies. The biaxial films are not perfect, because they are stretched in two directions and are very easily affected by mechanical variation during the stretching process. Therefore, the viewing angle of PVA panels had not been fully optimized. However, the c-plate used in the S-PVA panel, manufactured by a new coating-type structure, can be adjusted to a wide retardation range compared to biaxial film. So, it is possible to more precisely optimize viewing angle. The S-PVA panel, using this new polarizer

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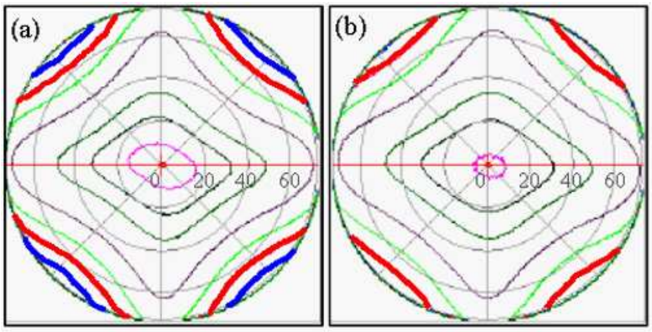


FIGURE 1 — Viewing-angle performance of (a) PVA using biaxial retardation film and (b) S-PVA using a-plate/c-plate film. The maximum polar angle is 80°, and the blue and red lines correspond to contrast ratios of 20:1 and 30:1, respectively.

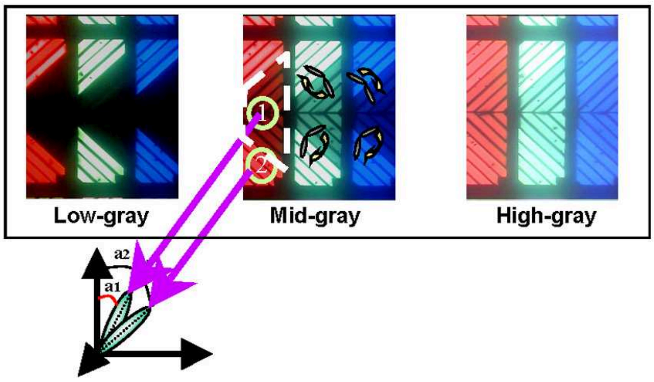


FIGURE 2 — Multi-domain S-PVA cell.

system, has a lower and more uniform off-axis black level independent of panel size, enabling better off-axis dark images. The viewing-angle performance along the diagonals has also been improved by the new optical design and optimized compensation films.

Moreover, for minimized color changes according to viewing angle, we optimized the cell structures. That is, the cell-gap has been redesigned to reduce color changes. Viewed off-axis, TN mode has very serious color inversion, and IPS mode has less serious but still visible dark image inversion, while S-PVA has no image inversion at any gray level. Figure 1 shows a comparison of PVA and S-PVA viewing-angle performance.

S-PVA represents a fundamental advancement in the LC cell structure. Compared to PVA, S-PVA divides each subpixel into two parts. This concept is illustrated in Fig. 2. The subpixels consist of two separate, capacitively-coupled sub-domains, zones 1 and 2. Zones 1 and 2 have different electric fields and therefore different tilt angles. The two divided domains effectively construct an eight-domain VA cell, which can compensate and minimize gamma distortion for images viewed off-axis.

To compare S-PVA with PVA technology, we have defined an off-axis image distortion index $[D(\theta, \varphi)]$ as

$$D(\theta,\varphi) = \left\langle \frac{\left|\Delta B_{i,j(on-axis)} - \Delta B_{ij(off-axis,\theta,\varphi)}\right|}{\Delta B_{ij(on-axis)}} \right\rangle_{i,j=0-255} .$$

Here, $\Delta B_{i,j}$ means brightness difference between gray-i and gray-j, and < > means the average for all cases of arbitrary grays. $D(\theta, \varphi)$ value can range from 0 to 1. A smaller value means smaller image distortion, that is, better off-axis image quality.

As a result of the above improvements, S-PVA delivers a great reduction in off-axis gamma distortion. Referring to Fig. 3, the off-axis gamma curves for S-PVA are much closer to the on-axis curve. At (60°, 0°) viewing direction, a typical PVA panel has a D value of about 0.30, but this figure has been improved to below 0.20 in S-PVA mode.

S-PVA technology is so effective for improving wide-viewing-angle performance that off-axis image degradation in this mode is barely detectable. S-PVA has achieved superior viewing angle performance in comparison to other LCD modes. Figure 4 shows the off-axis image views of S-PVA mode, demonstrating minimal deterioration of color and contrast ratio.

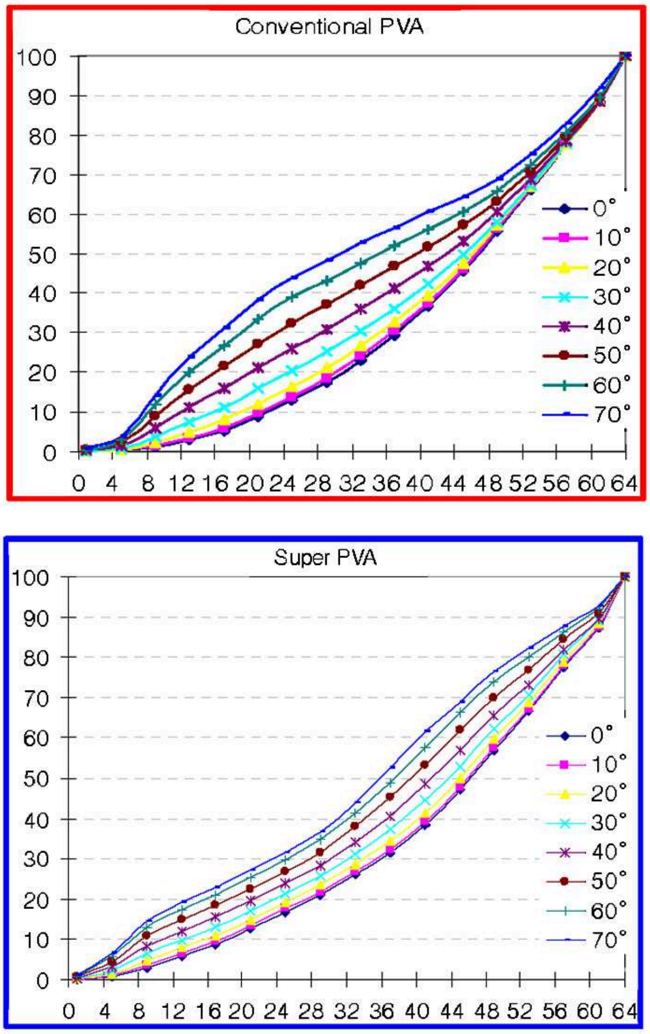


FIGURE 3 — Off-axis gamma improvement of S-PVA.

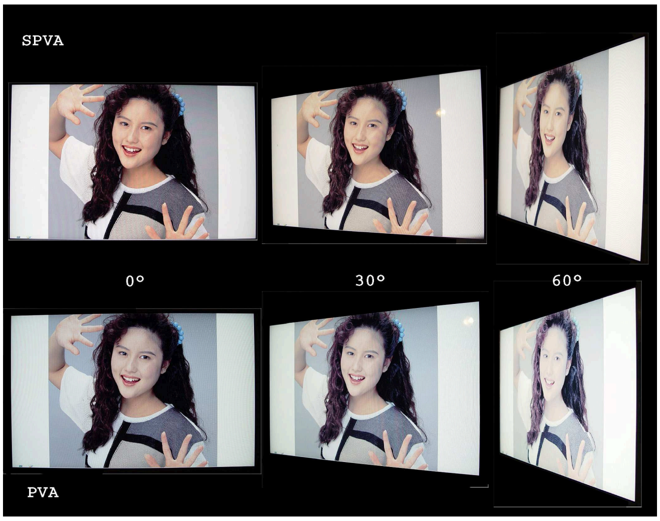
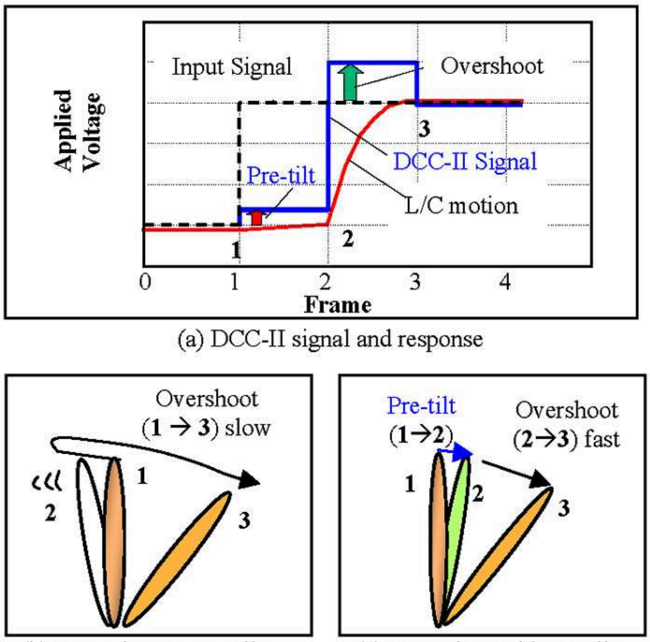


FIGURE 4 — Comparison of S-PVA and PVA images.

3 Improvement of motion blurring: DCC-II

Response time is another important factor for LCD TV. TV images generally consist of moving pictures, and most LCDs have slow response-time compared to other display devices. To correct this problem, response time compensation (RTC) techniques are needed. We have already developed and reported dynamic capacitance compensation (DCC) technology to reduce the motion blur problem.[4] DCC technology enables sub-10-msec gray-to-gray transitions. However, even with DCC, the transition from black to white still requires 16 msec. This transition time is not adequate to eliminate motion blur. The cause of this slower response time is specific to vertical alignment mode. In VA mode, the liquid crystals are vertically aligned (*i.e.*, normal to the glass) when there is no applied electric field. This static alignment creates a normally black state. Depending upon applied voltage and the distance between the ITO patterns, when the electric field is switched on, it is possible that the liquid crystals fall out of orientation prior to the propagation of the tilting wave throughout the VA domain. The first step motion, polar rotation, occurs quickly. However, the subsequent realignment process, which is a slower azimuthal rotation, takes time. This results in a delayed response time as shown in Fig. 5(b).

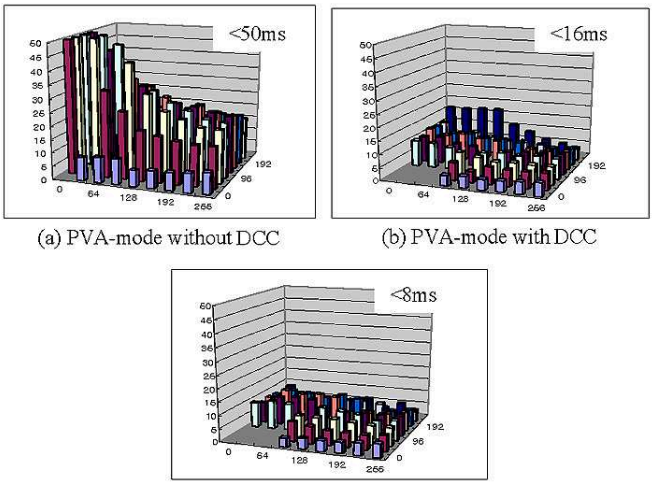


(a) DCC-II signal and response

(b) LC action: no pre-tilt

(c) LC action: with pre-tilt

FIGURE 5 — Basic concept of DCC-II technology.



(a) PVA-mode without DCC

(b) PVA-mode with DCC

(c) PVA-mode with DCC-II

FIGURE 6 — Gray-to-gray response speed in PVA-mode: (a) Without DCC, (b) with DCC, and (c) with DCC-II technology.

Samsung has upgraded DCC technology to DCC-II. DCC-II is an advanced RTC method which reduces all response times, including the black-to-white transition, to under 8 msec (Fig. 6).[5] The basic concept of DCC-II technology is to apply a pre-tilt voltage just prior to application of the conventional overshoot voltage. This pre-tilt voltage allows the liquid crystals to align quickly through pure polar rotation, thereby enabling a rapid transition upon application of the actual white-state signal. By applying the pre-tilt voltage for only one frame time, DCC-II enables faster PVA mode response time without impacting other aspects of panel quality (*e.g.*, no loss of contrast ratio). DCC-II technology will be applied to TFT-LCD TVs to achieve blur-free moving images.

4 Contrast ratio and black-state uniformity

High peak luminance is a fundamental requirement for TV; therefore, LCD TVs generally employ bright backlights. However, the bright backlight can create an unpleasant amount of light leakage at the black state unless the display has a high contrast ratio. Accordingly, to create better dark detailed images, high contrast ratio for ultra-low black level is a critical factor for LCD TV.

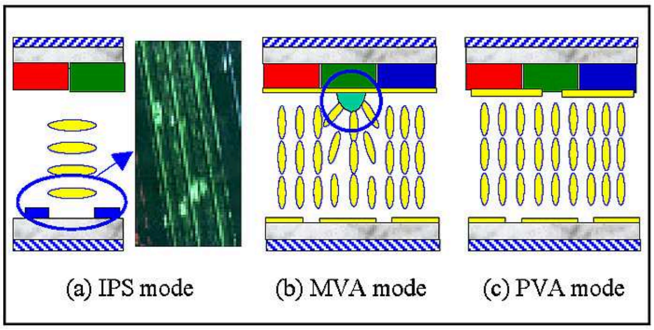


FIGURE 7 — Cross-sectional diagram of the various liquid-crystal cell structures in the black state.

One of the strengths of the PVA mode is an inherently high contrast ratio, as PVA mode has perfect vertical alignment of liquid crystals at the black state. Unlike other LCD modes, PVA has no residual retardation. For example, MVA mode is also a vertically aligned mode, but it has residual retardation near its protrusions because of uneven surface geometry, as shown in Fig. 5(b). Unlike IPS mode, PVA mode does not require a rubbing process to align liquid crystals at the alignment layer. Therefore, PVA does not have light leakage owing to non-uniform rubbing scratches, a key cause of light leakage in IPS mode as shown in Fig. 7(a).

To obtain even higher contrast ratio, new color filter materials have been developed for S-PVA. These new color filters reduce light scattering by controlling aggregated pigment particles from the material and coating process. Use of these materials has further reduced light leakage in the black state.

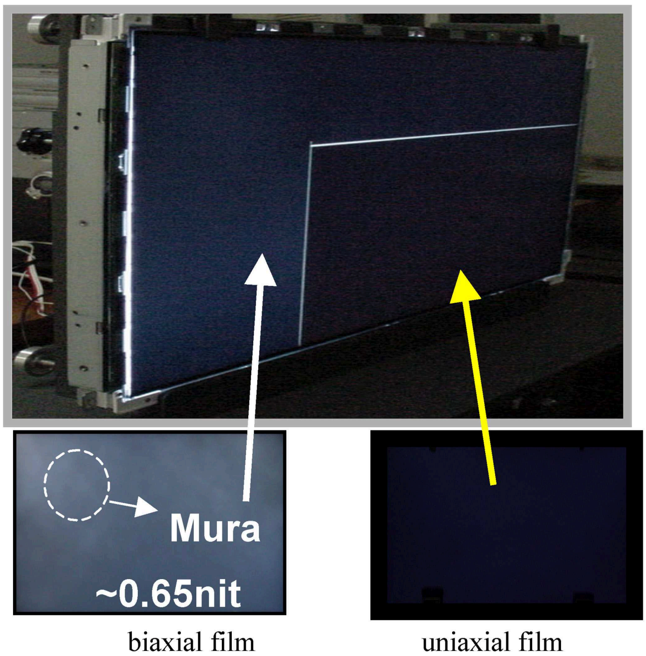


FIGURE 8 — Uniaxial film improvement of black uniformity.

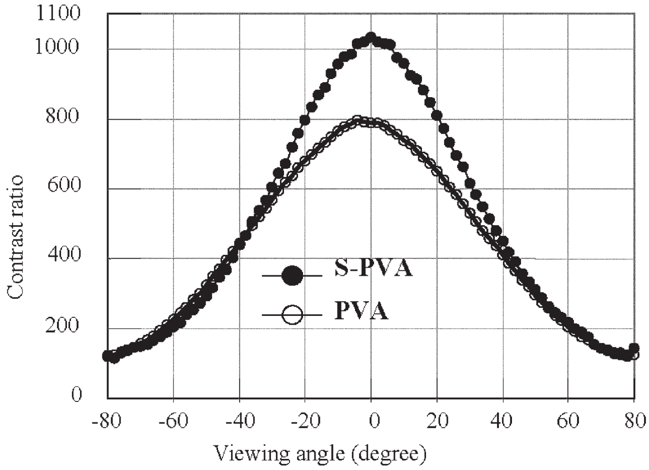


FIGURE 9 — Contrast ratio shown as a function of viewing angle along the horizontal axis. Front contrast ratio is >1000:1 in newly developed S-PVA panels, an increase of ~25% compared to PVA.

Additionally, the new a-plate/c-plate compensation films described earlier can minimize any directional differences between the polarizer and compensation film. Because the a-plate requires only one stretch process, it has a smaller directional variation. This new uniaxial film structure results in greatly improved black-state uniformity as shown in Fig. 8.

The combination of protrusion-less VA technology, improved compensators, and improved color filters have enabled Samsung to achieve over 1000:1 contrast ratio for the first time in the industry. This is illustrated in Fig. 9. Even with a white luminance level over 500 nits, the new S-PVA panel can control dark-state luminance to below 0.5 nits.

5 Color performance

Generally, white-color temperature variation with gray level exists in LCDs because the transmittance is controlled by $\Delta n d_{\mathrm{eff}}/\lambda$, *i.e.*, there is a dependence on light wavelength (λ). To more precisely display a natural image, it is important to maintain constant color temperature (white balance) at the different gray levels. We have adopted an accurate color capture (ACC) technology to compensate color variations across gray levels. ACC driving technology changes the RGB gamma curves separately to maintain white color balance at a fixed level. It comprises a data expansion step for suitably changing the gamma curve, and a bit reduction step to drive the source driver IC with the original input data format. In addition, performance of the color filter and polarizer has also been optimized so as to achieve true black color that cannot be achieved by ACC driving alone. Figure 10 shows color temperature variation with gray. Variation of white color tracking for S-PVA with ACC driving has been improved dramatically, to a level superior to that of other wide-viewing modes.

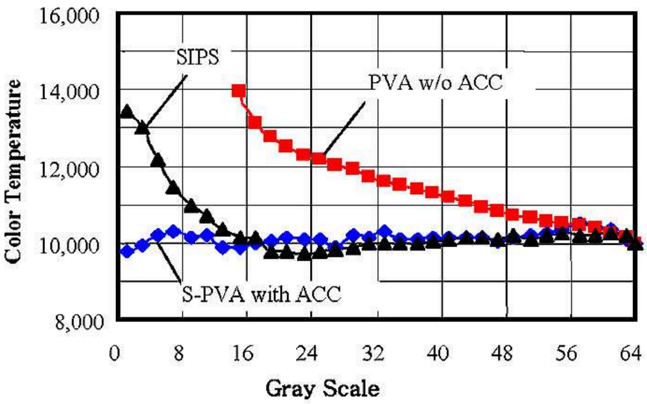


FIGURE 10 — White-color temperature dependence on gray level.

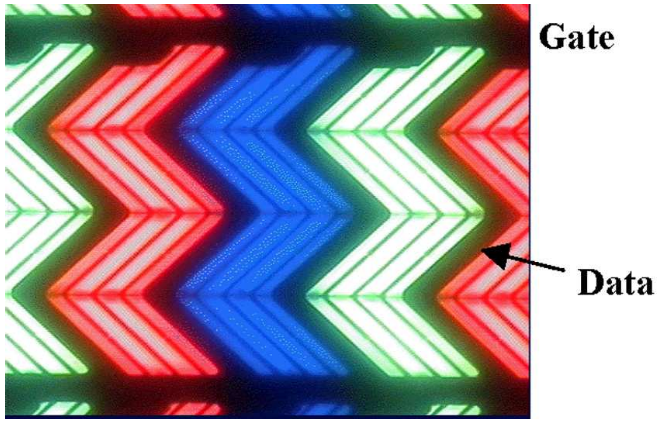


FIGURE 11 — Z-shaped pixel structure.

S-PVA technology also supports 100% EBU-compatible standard color with 72% of NTSC color gamut and higher color temperature, up to 13,000°K. These properties, namely 100% EBU color, high color temperature with a low color temperature dependence on gray scale, ultra-low black level with a true black color, have resulted in unprecedented LCD-TV image quality. The typical performance characteristics of PVA and S-PVA panels are summarized in Table 1.

6 Minimization of stitching defects

Next, we turn attention to some of the technologies used in Samsung's 57-in. LCD-TV panel. Large panels must be exposed with multiple shots, as the panel size exceeds that of the photomask. As indicated in Fig. 11, a Z-shaped pixel design has been developed to control stitching defects for the 57-in. LCD-TV panel. A stitching defect is defined as a boundary defect between two photo-shots. Misalignment in the boundaries of the photo-shots can cause electrical and mechanical variations, resulting in a discontinuity detectable by the naked eye.

The factors causing electrical variation are as follows: (1) kick-back voltage variation by C_{gs} differences between shots, (2) V_{rms} variation by data-pixel capacitance coupling. The mechanical variation factor is due to aperture ratio differences caused by critical dimension variations. In addition, another characteristic of the multi-domain VA mode contributes to the stitching defect: the area ratios between domains are changed by misalignment of the photo-process, resulting in off-axis brightness differences due to discontinuous retardation change of the pixels in the photo-shot boundaries.

TABLE 1 — Performance improvement of S-PVA.

Characteristics	PVA	S-PVA
Brightness (typical)	450 nit	500 nit
Black level	<0.65 nit	<0.5 nit
Contrast ratio (min.)	>700:1	>1000:1
Response time (g–g)	<12 msec	<8 msec
Response time (b–w)	16 msec	<8 msec
Gray inversion (any direction)	None	None
Off-axis image distortion index	<0.27	<0.20
Color gamut	72% NTSC	72% NTSC

For large-sized LCD-TVs, we have already adopted the gradual stitching design expanded into subpixels.[6] The number of each subpixel for red, green, and blue in the gradual stitching design of an $n \times n$ unit are gradually decreased and gradually formed at the relevant shot boundary, so that the stitching defect is not specific to a particular color. In addition, we have also optimized the width of the gradual lattice pattern to minimize stitching defects near the boundary between photo-shots.

However, it was still challenging to suppress the stitching defect. We have introduced another countermeasure, which is a partially covered storage capacitor structure aligned parallel to the data line in the Z-shape of the pixel. Then, half of the storage capacitor is vertically overlapped with the ITO output electrode. The open area of the storage capacitor out of the pixel ITO makes contributions to shielding the direct capacitance coupling between the data line and the ITO electrode. As a result, the contribution of data-pixel capacitance coupling to the stitching defect is diminished in the electric variation mentioned above. Also, the edge of the Z-shape pixel plays a role in protecting the side effect of the partially covered storage capacitor, preventing the appearance of undesired texture which reduces luminance in the traditional non-Z structure. Additionally, more-efficient TFT structures have been developed to minimize kickback voltage variation due to C_{gs} differences by misalignment.

7 Other technologies for large-sized panels

From the viewpoint of LCD driving, large-sized LCD-TV panels at WUXGA resolution suffer from signal delay and distortion due to long address lines and data lines. For those problems, parameters and processes for metal lines have been redesigned. In order to reduce gate line load for addressing, a dual-sided driving method has also been introduced into the 57-in. LCD panel.

FIGURE 12 — The world's largest TFT-LCD (57 in.) with full HD (1920 × 1080) resolution using S-PVA mode.

TABLE 2 — Samsung fabrication strategy.

Generation	Gen. 4	Gen. 5		Gen. 6	Gen. 7
SEC's Fab.	L-4	L-5	L-6	*Skipped*	L-7
Substrate size (mm)	730 × 920	1100 × 1250	1100 × 1300	1500 × 1800 (1850)	1870 × 2200
17-in. W	6	12	12	24	36
19-in. W			12	21	32
23-in. W	2	6	8	12	24
26-in. W	2	6	6	12	18
30-in. W	2	3	3	8	12
32-in. W	2	2	3	8	12
37-in. W	1	2	2	6	8
40-in. W	1	2	2	4	8
42-in. W	0	2	2	3	6
46-in. W	0	2	2	3	6
max. size	40-in. W	54-in. W	57-in. W	81-in. W	95-in. W

The LC filling process and column spacer properties have also been improved. First, LC filling for vertically aligned panels in the vacuum chamber is 3–4 times slower than that for homogeneously aligned panels. Therefore, we have applied drop-filling technology to overcome the filling speed limitation for VA mode. The 57-in. TFT-LCD panel requires about 5 minutes for complete filling across the whole panel area, while the previous vacuum filling process needed at least 3 days. Furthermore, we have succeeded in reducing the quantity of liquid-crystal material required to complete the filling process, up to a 40% reduction, compared to the vacuum filling method. Secondly, the column spacer developed to eliminate light leakage associated with ball spacers has also been optimized for the drop filling process. The column spacer used in Samsung's 57-in. LCD panel offers improved immunity to vibration and external shock, and has provided wider margin in the drop-filling process. Figure 12 shows a photograph of the 57-in. S-PVA LCD-TV panel.

8 Challenges for the future of LCD-TV

Cost competitiveness of LCDs is strongly influenced by motherglass size. In the future, consumers will demand LCD-TV in larger sizes with relative cost effectiveness. From a cost point of view, a generation 7 fabrication facility offers the best glass utilization over a wide variety of sizes to meet those future needs. Our forecast is that the market will require large quantities of LCD-TVs not only in the 30s-of-inches range, but also in the 40s of inches. For this reason, Samsung has skipped over generation 6 in favor of going directly to generation 7.[7] Table 2 shows the number of panels from each motherglass size. The shaded table entries show products which can be mass produced with high glass utilization. Line 7 is optimized for all of 17-, 19-, 23-, 26-, 32-, 40-, and 46-in. This fab will be on-line in the fourth quarter of 2004.

As competing technologies attempt to commercialize larger sized LCD-TVs, other advantages of S-PVA will become apparent. For example, as PVA is a rub-free process, there is no issue around rubbing bar sagging and differential pressure, as will be the case for other modes which require rubbing.

9 Conclusion

In conclusion, Samsung has developed several technologies to make a quantum improvement in LCD-TV performance. S-PVA improves the quality of images viewed both at normal incidence and off-axis, resulting in next-generation color performance and ultra-low black level. As a result of the new S-PVA technologies, the next LCD-TVs will deliver more distinct and accurate color image reproduction. DCC-II, in combination with S-PVA, has resulted in sub-10ms response time, enabling blur-free motion pictures. Samsung has also developed large panel imaging and production technologies to deliver seamless images.

Samsung's 57-in. LCD-TV, the world's largest, is the culmination of technology and process development on multiple fronts. Samsung is also building the world's first generation 7 line at Tangjung to offer the most cost-efficient production capability.

Samsung LCD is committed to achieving greater technological innovations to drive the future of LCD-TV. We see greater affordability and ever-higher performance on the horizon.

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