World's Largest 54-inch TFT-LCD for HDTV Application Using PVA Technology

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Abstract
The technology and performance of the world-largest 54-inch LCD TV using PVA mode have been introduced from two points of view: one is to manufacture large-size panels, the other is to improve electro-optical performance required for multimedia applications. Current ongoing research activities that have been explored include new stitching design, one drop filling with column spacer, response time less than one frame rate, color performance and light efficiency enhancement.

1. Introduction

PVA mode which originated in December of 1996, has experienced several technological phases. For three years of R & D period, its technological levels have evolved into a practical wide viewing angle mode, characterized by multi-domain structure using fringe-field effect and optical compensation by retarder films [1-3].

Since the successful launch of the 24" WUXGA monitor in 1999, the PVA process has been set up in the 4^{th} (730x920mm) and 5^{th} (1100x1250mm) generation lines, and various kinds of PVA monitors and multi-function monitors, such as 17.0"/19.0" SXGA and 19.0"/21.3" UXGA, are under mass production on those lines.

On the other hand, the demand for large-area FPD-TV has remarkably increased by the expansion of the digital-TV market. Among FPD-TVs, PDPs and projection-TVs have already existed in the market; TFT-LCD has launched into the market since 2002. Compared to PDPs and projection TVs, TFT-LCDs have the advantages of high resolution, light weight, slim size and low power consumption, while they have disadvantages of slow response time, high manufacturing cost, limited viewing angle performance which have to be improved for mass-production. In 2002, Samsung Electronics also decided to enter the LCD-TV market in earnest, using the PVA technology and currently wide range of HDTV products such as 17", 22", 26", 32", 40", 46" WXGA and 17", 20" VGA are under initial stage of volume production. Furthermore, recently, we have developed world-largest 54" TFT-LCD HDTV using PVA technology. In this paper, its performance and key technologies will be reported, related to the manufacturing process for large-size panel and electro-optical performance required for multimedia application.

2. Advance of PVA Technology

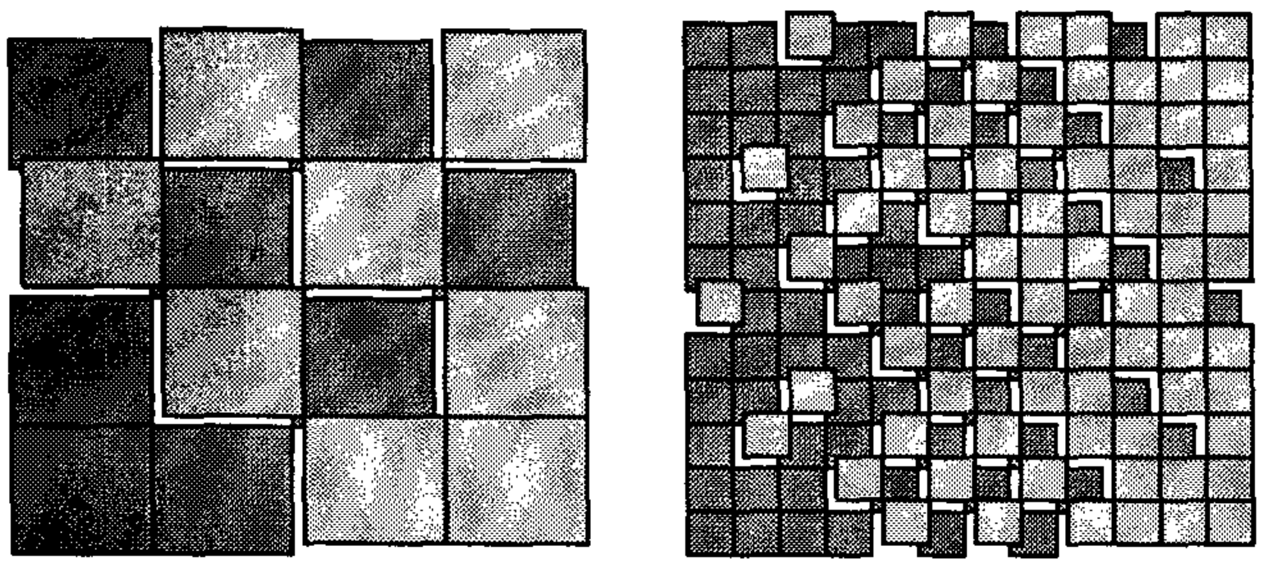
2.1. Manufacturing Approach

2.1.1 New stitching Design

Since photo exposure in photolithography process is carried out in the ratio of 1 ~ 1.25:1 depending on photo-equipment, proper stitching design and process are required for the development of larger panel than the mask size. Stitching defect is defined as a defect resulted from electric or mechanical variation, which are caused by misalignment between photo exposures when more than 2 photo shots are applied to a panel. The factors causing electric variation are as follows; (1) kick back voltage variation by C_{gs} difference between shots, (2) V_{rms} variation by data-pixel coupling capacitance. The factor for mechanical variation is the difference of aperture ratio caused by critical dimension variation.

In addition, PVA mode [1-2], using multi-domain structure, has an additional factor causing stitching defect. For VA mode with multi-domain structure, the area ratio between sub-domains is also changed by misalignment of the photo-process. This kind of area variation corresponds to the retardation change of the panel from the off-axis; therefore discontinuous brightness change can be easily observed near the photo-shot boundary from the side view.

In order to remove such stitching defect, we have proposed a new gradual stitching design where some of adjacent shot patterns are overlapped [3]. For note PCs and monitor panels with small pixel size, the gradual stitching was designed in a way of combining RGB sub-pixels into unit pixel. For a large-size pixel like LCD-TV case, however, stitching defects are easily detectable as a gradual lattice pattern even if gradual stitching technique is adopted. Therefore we have applied gradual stitching design to sub-pixel, not to unit pixel (namely, the number of each sub-pixel for red, green and blue in gradual stitching design of n x n unit are gradually decreased and gradually formed at relevant shot boundary), so that stitch defect is not visible in a specific color. In addition, we have also optimized the width of gradual lattice pattern to minimize the stitching defect near the boundary between the photo-shots.



(a) (b)

Figure 1. Gradual lattice patterns.
(a) unit pixel (b) sub pixel

2.1.2 One Drop Filling with Column Spacer

Since the filling speed of LC in vertically aligning cells is 3 ~ 4 times slower than that in homogeneously aligning cells, the heating treatment is usually adopted in the filling process for VA mode. However, there is a limit to shorten the filling time by the heating process, so we have applied one drop filling (ODF) technology to the large-size LCD-TV devices to enhance productivity in LC process: for example, the filling process can finish within 5 min. for 54 inches case, which is dramatically improved, compared with 3 days filling in vacuum process. Furthermore, we have succeeded in reducing the necessary amount of liquid crystal for filling process, up to 40 % of the conventional process, which strengthens the cost competitiveness of PVA technology. Elastic property and height of column spacer and LC drop amount have also been optimized to get the best quality, regarding to the panel uniformity.

2.2. Performance Approach

2.2.1. Response time less than one frame rate

For moving pictures in TFT-LCDs, reducing the response time has been one of the main issues in the LCD industry. In this regard, new LC materials with negative dielectric constant have been investigated to reduce on-off response time. In addition, the pixel structure has been optimized since there are several structural factors determining the response speed of LC molecules, such as the width of ITO pattern, the pattern shape and the interval between neighboring patterns [2].

Here it should be noticed that improving the response time between inter-grays is more crucial than on+off time for moving pictures, because it tends to be over 5 ~ 6 times slower than on/off response [4]. The main reasons are that (1) when weak electric field is applied, driving force for LC switching is small and thus rising time becomes very slow ($\tau_r = 1/(V_{appl}^2 - V_{th}^2)$), and (2) effective voltage applied to the liquid crystal changes with switching motion, because constant charge, not constant voltage, is maintained in current active matrix (AM) driving method.

Therefore we have proposed a novel driving method, called DCC (Dynamic Capacitance Compensation) [5-6]. In DCC driving, not only the voltage variation from the dynamic LC capacitance is compensated, but also LC molecules are accelerated by overshoot. When DCC driving scheme is applied, all the response time between inter-grays have been reduced into below 10 msec, except dark to white region switching which has speed under 16 msec. As a result, we could confirm that dynamic contrast ratio, stroboscopic motion and blurred edge images are considerably improved. Furthermore, several research activities including advanced DCC driving are vigorously ongoing to obtain the response time less than 10 msec.

2.2.2 Color Coordinate for true color

Comparing TFT-LCD with CRT for HDTV application, accurate color performance becomes a hot issue as displaying rich nature image is imperative. Therefore color coordinate of R/G/B, white balance, color gamut, and gamma correction which make a big difference in color reproduction have been re-designed for multi-media applications.

New color filters have been developed without significant loss of contrast ratio and luminance. In result, PVA-TV products solidly provide 72 % color gamut, EBU color space and 10,000 K color temperature simultaneously, for the first time, in the

LCD industry.

2.2.3 Color Tracking with gray levels

It is essential to maintain constant color temperature with the gray levels to exactly display nature image. However, color variation in the gray levels exists in LCDs because the transmittance is controlled by Δnd_{eff} which has wavelength dispersion. Therefore we have developed a novel Accurate Color Capture (ACC) driving scheme to compensate wavelength dispersion of Δnd_{eff} of LCs [6]. ACC changes RGB gamma curves separately to reduce color variation and it comprises a data expansion step for suitably changing gamma curve and a bit reduction step for drive IC data format. In addition, color filter and polarizer performance have been optimized to achieve true black color which can not be controlled by driving circuits. Figure 2 shows the color temperature variation with the gray level from the normal direction. The variation in color tracking has been dramatically suppressed within 1000 K, which is superior to other WV technologies.

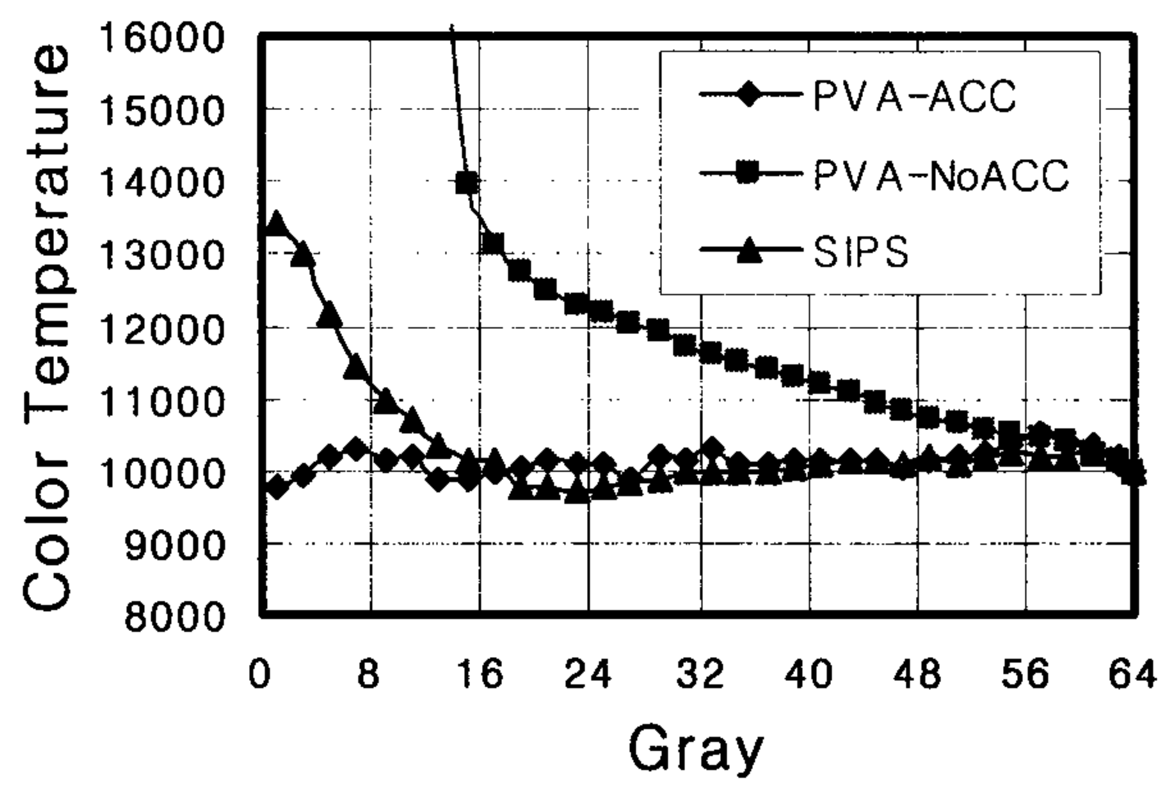


Figure 2. Gray level dependence of color temperature variation.

2.2.4 Color shift with viewing angle

Viewing angle performance of TFT-LCDs has been remarkably improved for a couple of years. At present, wide viewing angle implies small color shift as well as the contrast ratio over 10:1. It means that viewing angle independent of color performance is a key factor in LCDs in order to establish a dominant market share over CRT.

Meanwhile, the black color performance is especially important in HDTV application, because

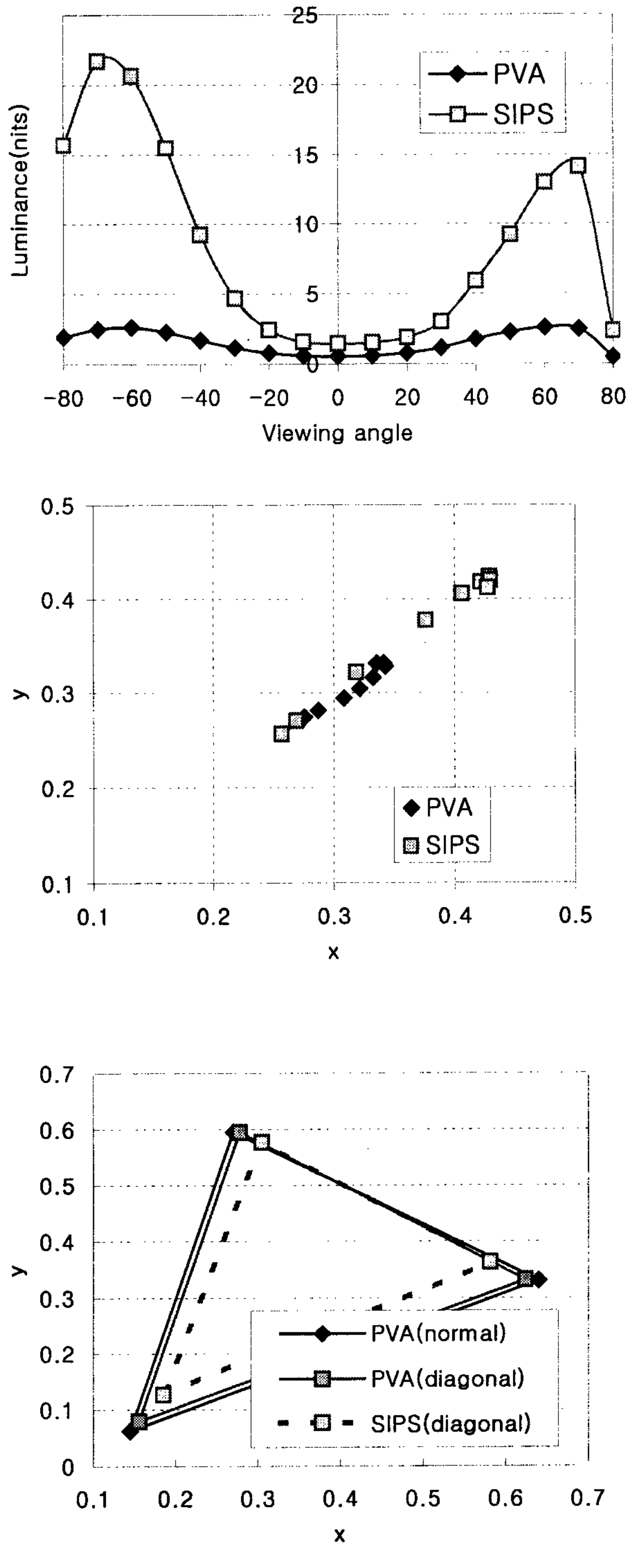


Figure 3. Viewing angle performance of PVA. (a) black luminance variation in diagonal off axis, (b) black color variation with the viewing angle from normal to 80 deg. off axis, (c) color gamut variation between normal and 60 deg. off axis.

there are a lot of chances to display dark image in movies and black areas usually remains at the both sides of panels, depending on the input data format such as 4:3 or 16:9 aspect ratio. In this sense, we have made much effort for improvement from the viewpoints of panel design, LC cell parameters and driving conditions. Figure 3 shows how the black luminance and color gamut change with the viewing angle. As shown in Fig. 3, we can get very good color performance in PVA LCD-TVs both from on- and off-axis, compared with S-IPS technology.

2.3 Light efficiency enhancement

LCD-TVs require bright luminance (>500nits), high contrast ratio (>800:1), high color gamut (>72% NTSC), high color temperature (>10,000K) and EBU color space simultaneously. Even though direct B/L system has been used in large-size LCD-TVs, the satisfaction of these requirements seems not so easy, because all these specifications accompany the luminance decrease. In addition, heat generation from the lamp is one of the hot issues, related to the thermal reliability of the devices. From these points of view, PVA has a strong merit in TV application, since high transmittance of the PVA panel makes it possible to use low lamp current in B/L system. High transmittance in the PVA panel is obtained by high aperture ratio due to narrow domain boundary between the sub-pixels and small black matrix free from the shield of disclination line owing to the normally black mode. Several research activities are also vigorously ongoing to maximize the aperture ratio and orientational efficiency of liquid crystals in the sub-pixels.

2.4 The performance of 54-inch PVA HDTV

We have developed world-largest LCD-TV (Fig. 4) with the high definition resolution (1920x1080), using the techniques mentioned above.

The following table shows the electro-optical performance of 54" TFT-LCD HDTV.

Size	54" diagonal (16:9 aspect ratio)
Resolution	HDTV (1920 x 1080)
White Luminance	550 cd/m^2
Response Time	< 16 ms (Gray to Gray)
Color gamut	> 72% NTSC
Contrast ratio	> 800 : 1
Viewing Angle	> 85 degree (all direction)

Figure 4. High performance 54" TFT-LCD TV using PVA mode and ODF technologies.

3. Conclusions

The performance of the world-largest 54 inches LCD TV using PVA mode and its key technologies not only to manufacture large size panel, but also to improve electro-optical performance were introduced. Based on 5 years experience for mass production and rapid progress of electro-optical performance, we believe the PVA technology, which has very good productivity even in the large mother glass size line as well as excellent performance, can be widely used for LCD-TV application.

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