PVA Technology for High Performance LCD Monitors

Kyeong Hyeon Kim and Jun Hyung Souk
AMLCD R&D, Samsung Electronics, Kiheung, KOREA

Abstract

We have developed a high performance vertical alignment TFT-LCD, that shows a high light transmittance, and wide viewing angle characteristics with an unusually high contrast ratio. In order to optimize the electro-optical properties we have studied the effect of cell parameters, multi-domain structure and retardation film compensation. With the optimized cell parameters and process conditions, we have achieved a 24" wide UXGA TFT-LCD monitor (16:10 aspect ratio 1920X1200) showing a contrast ratio over 500:1, panel transmittance near 4.5 %, response time near 27 ms, and viewing angle higher than 80 degree in all directions.

1. Introduction

Recently, many new wide viewing angle technologies such as film compensated TN [1], IPS [2], MVA [3] and ASV modes have been commercially used for large size, high resolution TFT-LCD monitors. However, each technology has its own limitation either in the manufacturing difficulties or the insufficient performance. While these new technologies improve the viewing angle characteristics significantly, there are some trade off in other properties such as panel transmittance or response time. Therefore, it is believed that a single dominant wide viewing angle technology does not exists at this moment suitable for multi-media application that satisfies all the requirements in high panel transmittance, fast response time and high contrast ratio simultaneously. Consequently, the technological breakthrough and continuous researches on this subject are required.

Under these circumstances, we have developed another vertical alignment mode to solve the viewing angle problem without sacrificing other electro-optical properties. In this paper, we have discussed its principle, the cell parameters, the concept for multi-domain structure, and electro-optical properties.

2. The Features of the PVA mode

The multi-domain structure is usually used in vertical alignment mode to avoid its prevailing limitation such as asymmetric viewing angle characteristics, color shift problem, and gray scale inversion. Previously the multi-domain structure has been fabricated by reverse rubbing method, photo-alignment, or the formation of protrusion. However, all of these methods complicate the manufacturing process or increase the numbers of photolithography process. In this regard, we concentrate on the forming of fringe field by patterning a certain shape on the ITO electrodes. Such patterns on the ITO electrodes make the multi-domain structure spontaneously formed by the electric field (see Fig.1). Accordingly, we name this mode as "Patterned Vertical Alignment Mode", or "PVA" for abbreviation.

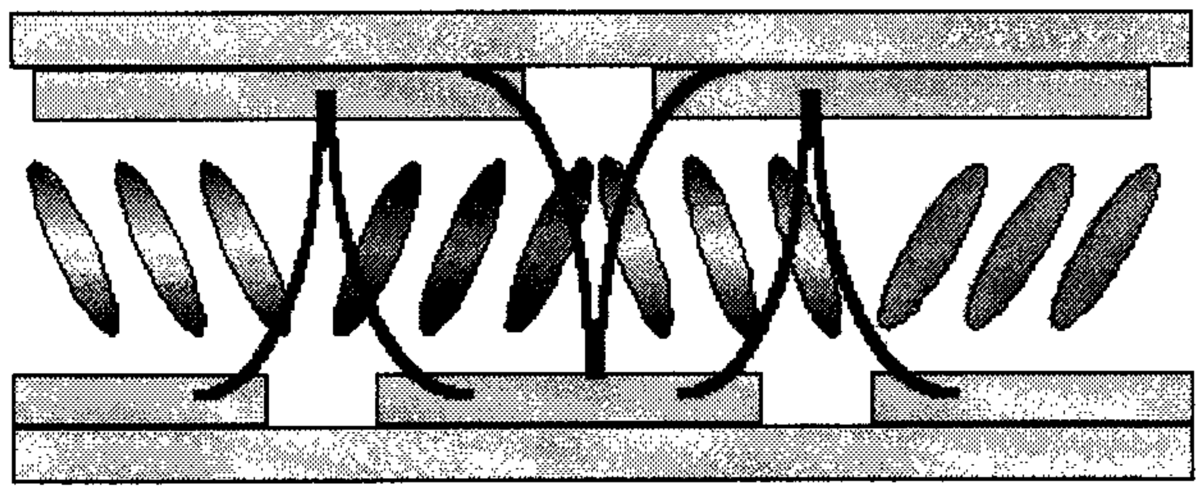

Fig. 1 Multi-domain structure formed by the fringe field in PVA sub-pixels.

During the development of PVA mode, we have observed the following advantages compared to the conventional wide viewing angle technologies;

(1) Same TFT Process and High Yield

Only ITO patterning process on color filter side is added to the existing TN fabrication process. However, since the rubbing process is eliminated, the overall process remain almost identical to the TN process. This not only facilitates the PVA fabrication but also enhances the process yield.

This mode also has a inherent advantage in the area of pixel defects. The structure has less chance of having conductive impurities that generate short circuits in the pixel area.

(2) High Transmittance

The width of domain boundaries formed in the pixel is very narrow. Since PVA mode is normally black mode, the black matrix to cover the disclination line is not necessary. Therefore, we can increase the aperture ratio significantly. With optimized cell parameters, the panel transmittance reaches to 75% of TN mode.

(3) Extremely High Contrast Ratio

In the vertical alignment (VA) mode, the light leakage near the spacer is very small compared with other modes. And all the LC molecules, including the vicinity of the substrates, are aligned homeotropically, so that there is no retardation in the normal direction. Also in the PVA mode, nearly perfect homeotropic alignment is obtained due to its planarized surface geometry. This explains its unusual high contrast ratio from

500 : 1 to 750 : 1.

*(4) **Flexibility in forming Multi-Domain***

In the conventional multi-domain method, the process becomes more complicated as the number of domains increases. Therefore, there have been some restrictions for the applications to the wide viewing angle mode. In the PVA mode, on other hand, forming the multi-domain is decided by ITO patterning shape regardless the number of domains.

The Fig.2 shows electro-optical performance of PVA mode,compared with that of other wide viewing angle technologies.

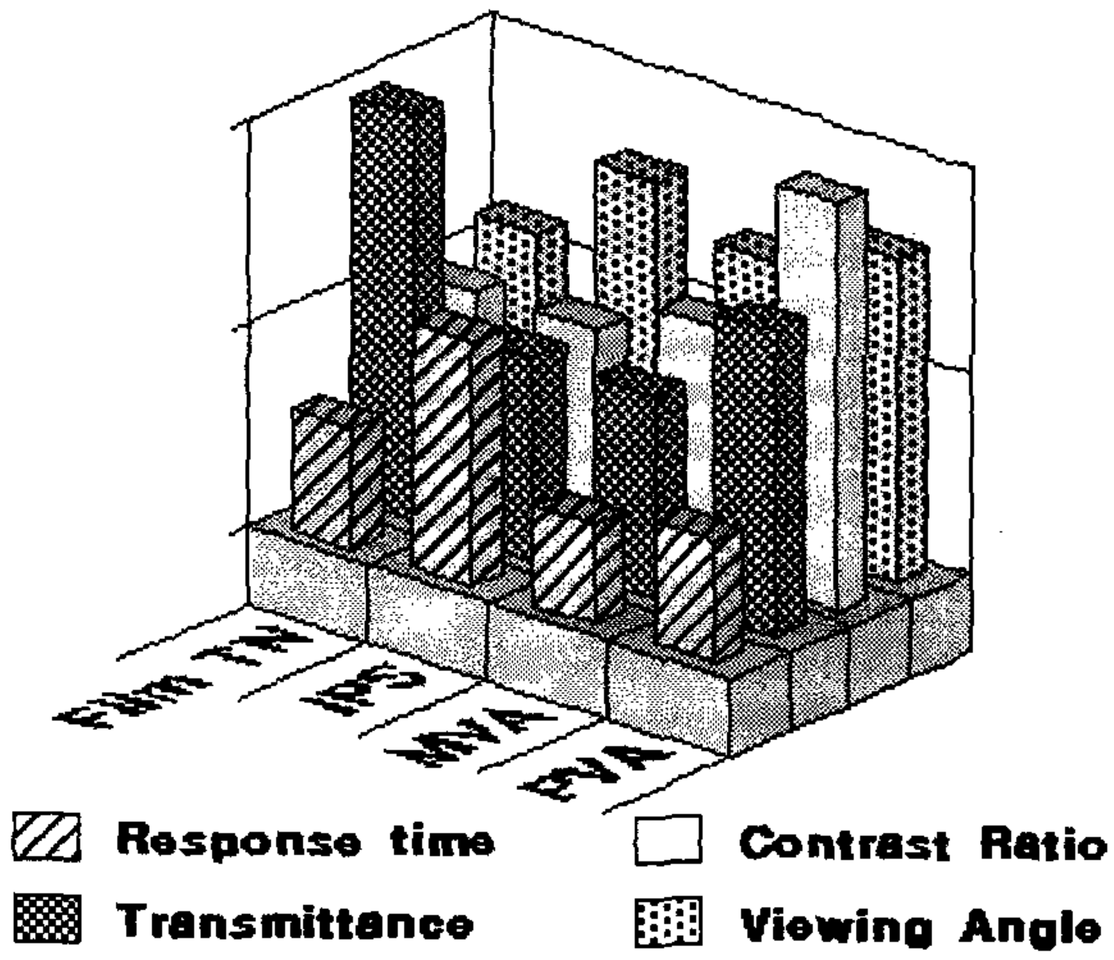

Fig.2 Comparison of electro-optical performance of PVA mode with that of other technologies.

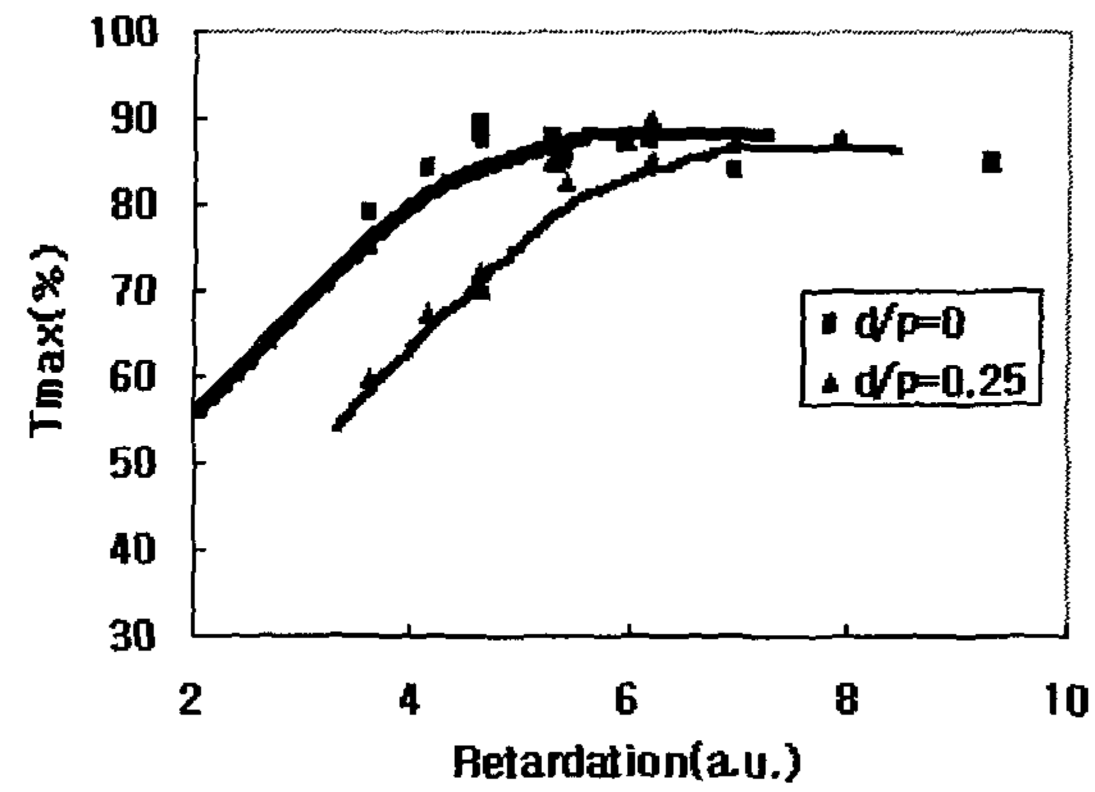

Fig 3. The transmittance as a function of VA cell retardation and chiral dopant concentration.

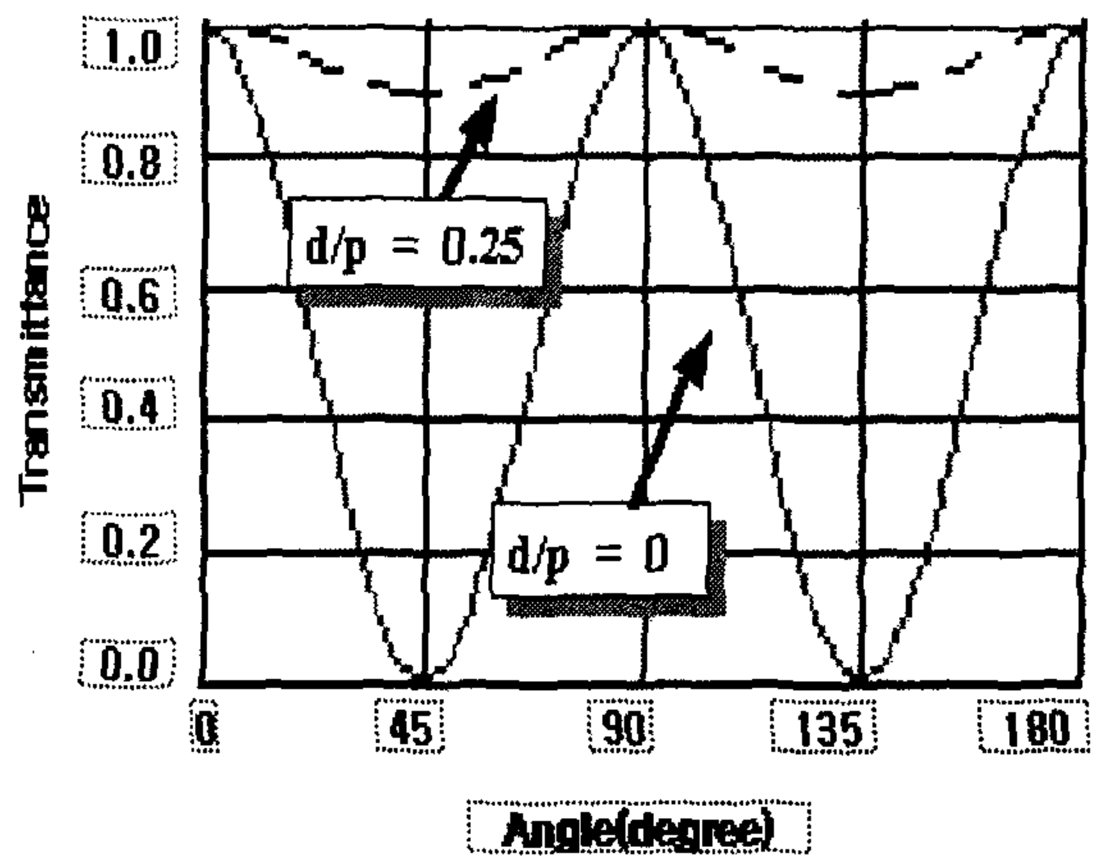

Fig.4 The transmittance variation with the VA cell rotation angle under the cross polarizer in the field-on state.

3. Results and Discussion

3.1 Two choice in PVA TFT-LCDs

Fig.3 shows the maximum transmittance variations with d/p ratio and Δnd value of the panel. As expected, the $\Delta n*d$ value where V-T curve reaches the saturation point (Tmax) is greater in R-TN mode (d/p=0.25) than the ECB mode (d/p=0). However, the optimum $\Delta n*d$ values are notably deviated from the theoretical ones ($\Delta n*d=\lambda/2$, or $\Delta n*d/\lambda = \sqrt{3}/2$, for ECB and R-TN mode, respectively), because the alignment of the LC molecules are not perfectly ECB or R-TN mode [4]. Both the R-TN and ECB type can be used for PVA mode, depending on electro-optical performance we want.

Fig.4 shows how the transmittance changes when we rotate the VA cells (d/p=0 and 0.25) under the cross-polarizer in the field on-state. As shown in this figure, the transmittance largely depend on the angle between LC director and cross-polarizer direction in the undoped case, while the variation is relatively small in the other case. Therefore, higher transmittance is obtained in R-TN multi-domain structure where the LC molecules are distributed to a certain degree.

As for the response time, the ECB type shows faster behavior, since low viscosity LC can be used and its switching motion is simpler than the R-TN type which has twist re-orientation of liquid crystals.

The characteristics of two kinds of PVA-LCDs are summarized in Table I.

R-TN-PVA	1) LC with chiral dopant (d/p=0.25) 2) Higher Transmittance (75% of TN) 3) Fast response time (~ 35 ms) 4) Pattern A
ECB-PVA	1) LC without chiral dopant (d/p=0) 2) High Transmittance (69% of TN) 3) Faster response time (< 25 ms) 4) Pattern B for more uniform LC alignment in the sub-pixel.

Table.I Characteristics of two kinds of PVA-LCDs

3.2. Concept of designing multi – domain pixel structure

Multi-domain structure in VA mode is indispensable to avoid its prevailing limitations such as asymmetric viewing angle characteristics, color shift problem and gray scale inversion. Therefore the ITO pattern shape in PVA mode is one of the key factors to determine the optical performance. We have designed the pattern shape with special attention to following three points :

(a) **Minimize and Stabilize Disclination Line ;**

Since PVA is normally black mode, the disclination lines formed in field on-state does not affect the contrast ratio as significantly as in TN mode. However, if the improper disclination lines are formed a lot as shown in Fig.6, it decrease the panel transmittance. Furthermore the unstable disclination line moves with electric field strength. The duration time for the disclination lines moving amounts up to the order of seconds and eventually it looks like a residual image. To stabilize the disclination line, we have optimized the ITO pattern shape taken the following facts into consideration; mis-alignment between C/F and TFT substrates, and the distance between patterns, pattern width, and d/p ratio of the liquid crystal.

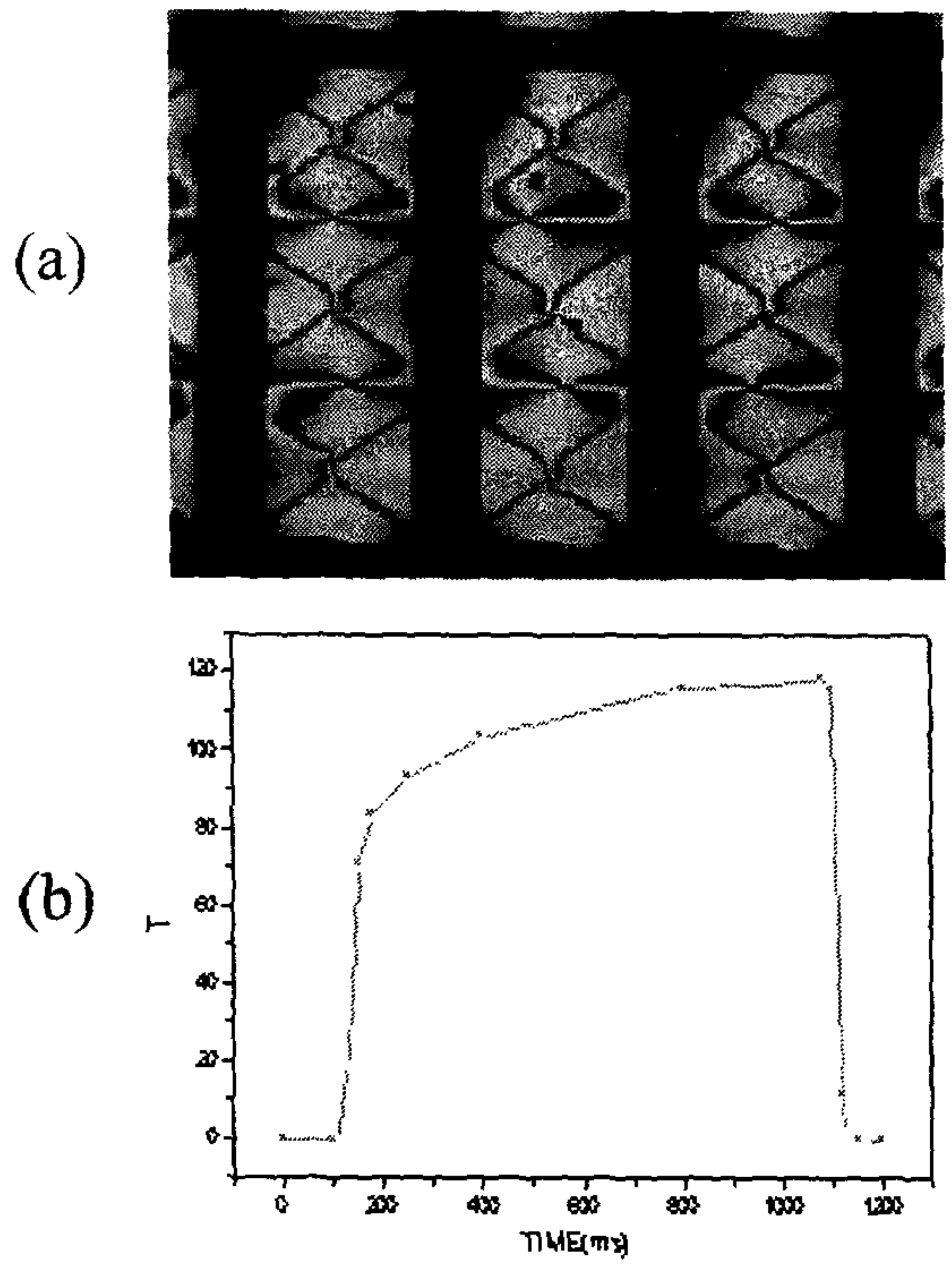

Fig.6 The example of the improper disclination line (a) and transmittance variation with time (b) when a pulsed electric field is applied to the VA cell with unstable disclination line.

(b) Maximize Light Transmittance ;

In order to improve the panel transmittance, the uniform LC alignment in a sub-domain is also important in addition to the minimization of disclination lines. As shown in Fig.6 and Fig.7, the orientational distribution of LC molecule depends significantly on the pattern shapes. Therefore R-TN mode exhibit the potentially high transmittance as mentioned in 3.1. (see Fig.4).

(c) Reduce the Response time ;

Since the response time depends mainly on the distance between patterns and the pattern shape, the proper pixel configuration was optimized. We also optimized the cell parameters such as the cell thickness, elastic constant/ viscosity of LC, and applied electric field strength to minimize the backflow effect which occurs in rising response. Fig.8 shows the rising response of VA cell with the electric field strength. The otpical bump resulting from the back flow effect occurs in strong electric field and it depend on the physical properties of LC.

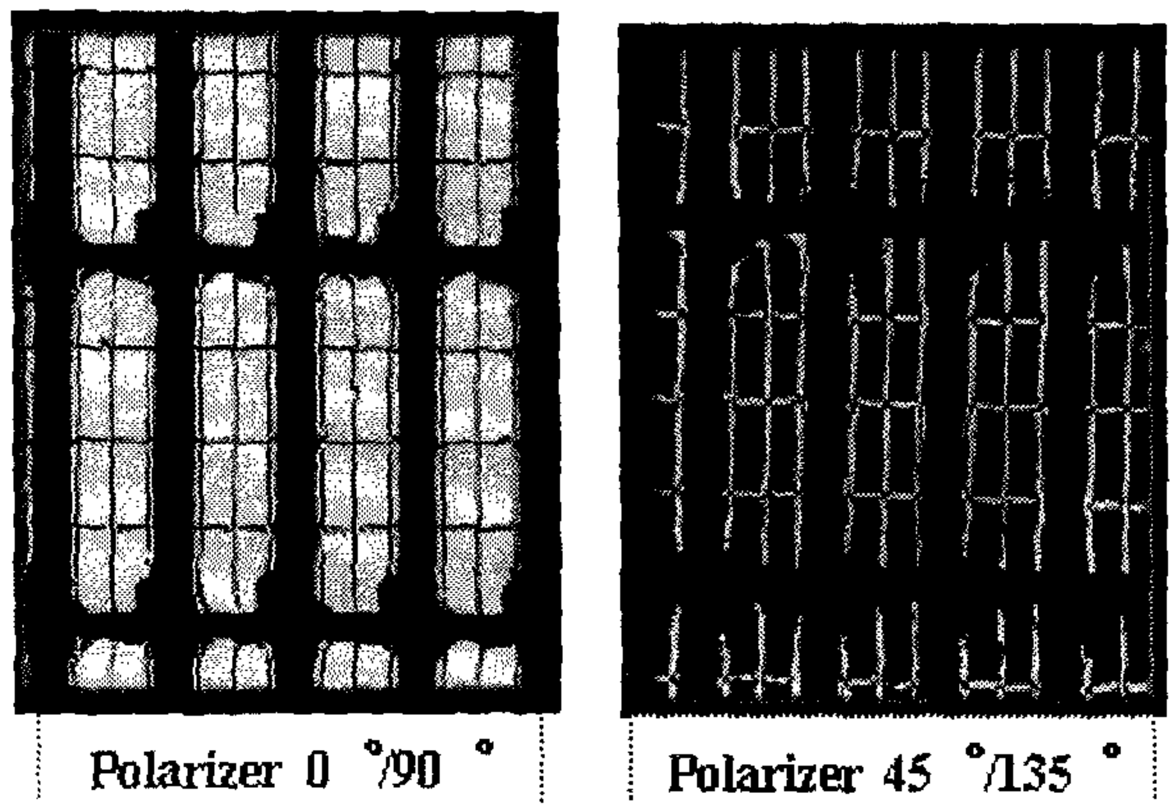

Fig. 7 Microscopic texture change with the cross -polarizer rotation

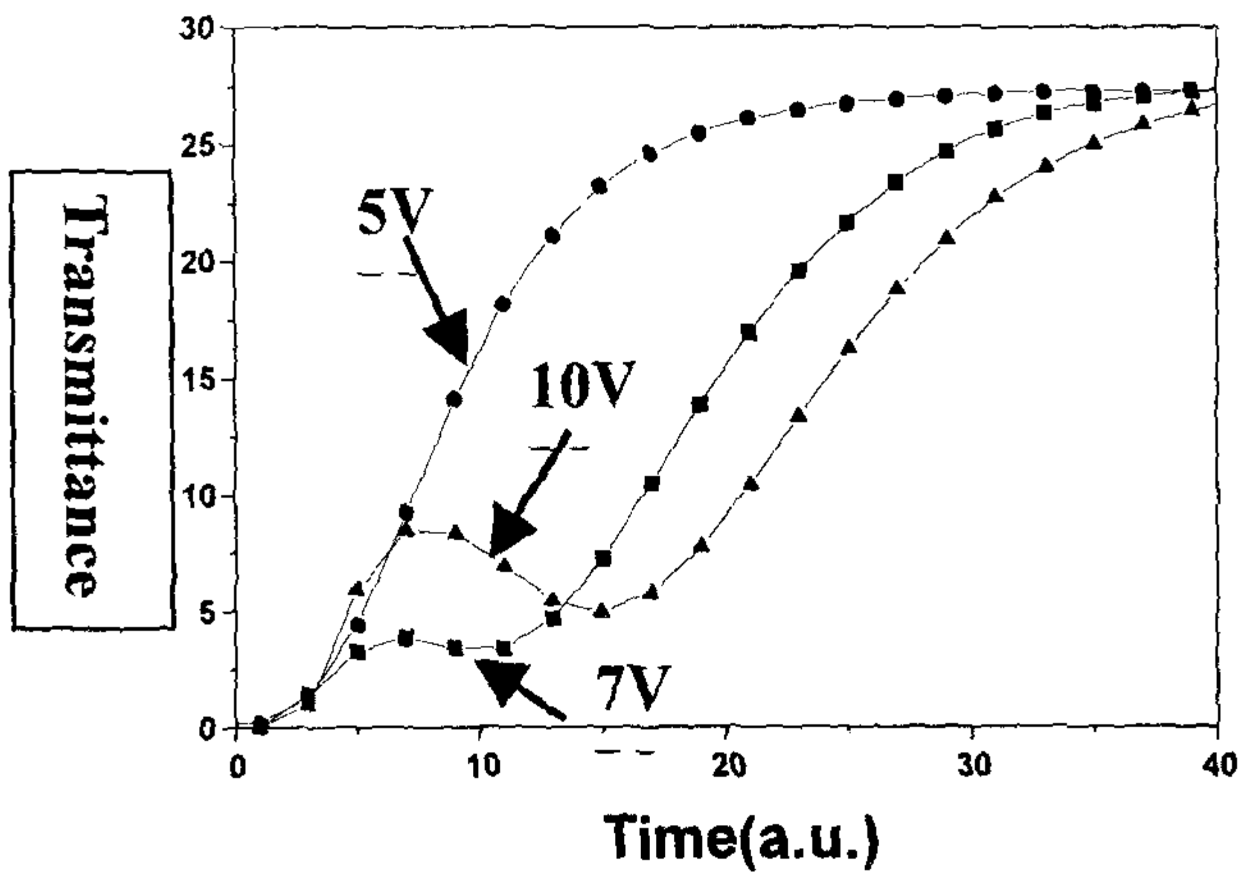

Fig.8 Rising response of VA cell with the applied electric field strenth.

3.3 Optimum film compensation to improve viewing angle characteristics

In principle, PVA has a narrow viewing angle due to its vertical alignment in the black state. Unlike TN mode, however, LC molecules even near the surface of the substrates are aligned homeotropically, so it is possible to get a wide viewing angle properties by simple uniaxial films. However, the light leakage in the black state occur from the 45° direction of cross-polarizer and this is another factor for the narrow viewing angle properties in the diagonal direction. This can be also improved by adjusting the biaxiality of compensation films. When the biaxiality of the film is optimized, the viewing angle over 80 degree can be achieved in all directions as shown in Fig. 9.

3.4 Optimization of the TFT panel structure suitable for PVA

Using the PVA technology, we have developed 24 inch diagonal Wide UXGA TFT-LCD monitos for the first time. The panel structure has several characteristics as follows; (1) New process architecture using a low resistance material for gate and data bus lines has been developed to reduce RC delay times for large size, high resolution TFT-LCDs, (2) Common line structure has been optimized to shield the undesirable fringe field from the data and gate lines.

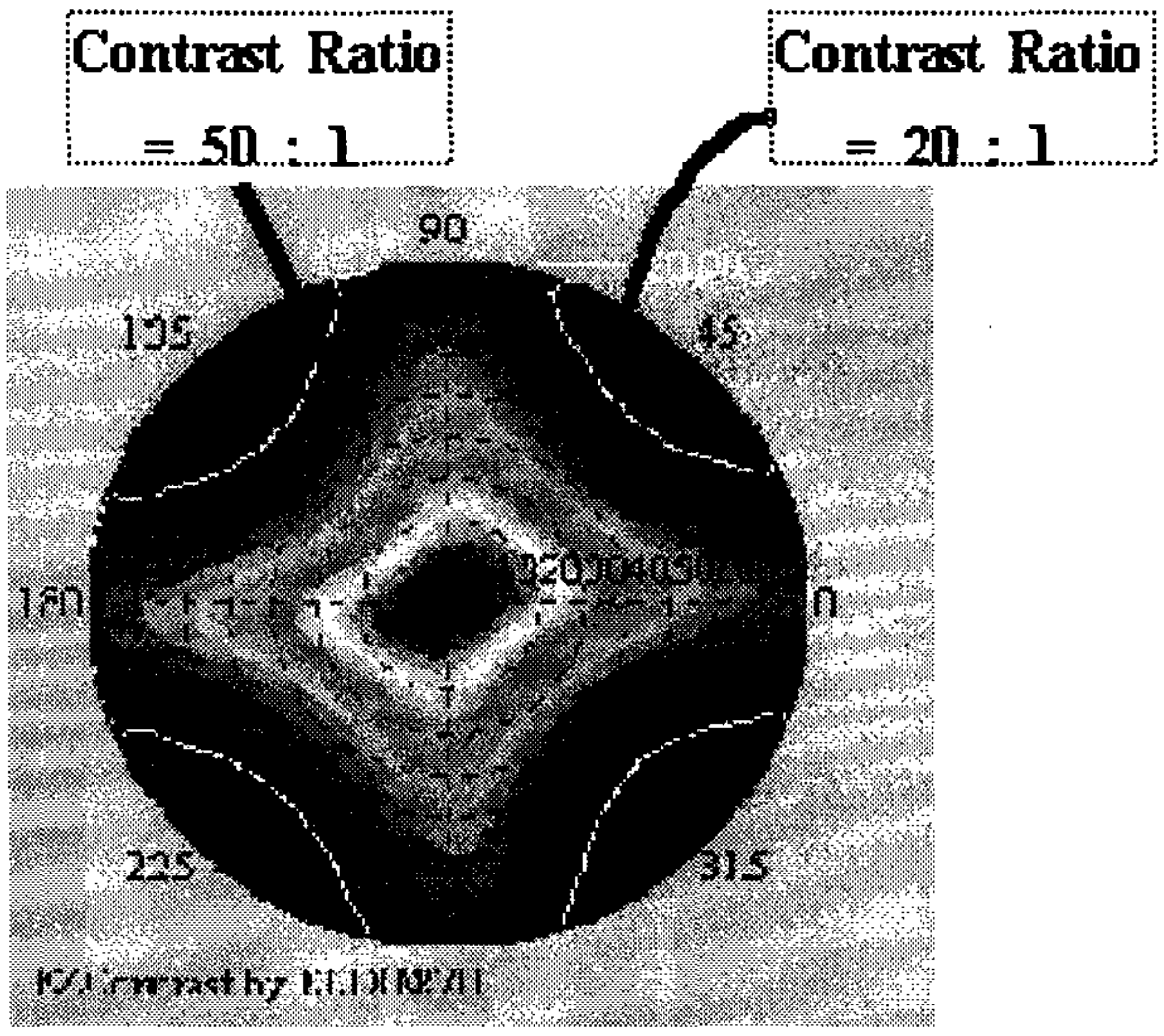

Fig. 9 3D iso-contrast curve of PVA panel with the optimized compensated film. The contrast with the viewing angle from 0 to 80 degree is shown

4. Electro-optical performance of 24" WUXGA panel.

The viewing angle characteristics of 24" WUXGA panel with a optimized compensation film are shown in Fig. 10. Higher than 35 : 1 contrast ratio has been achieved up to 80 degree off angle, and gray scale inversion free range has been expanded up to 80 degree. Contrast ratio more than 500 : 1, luminance around 250 cd/m2, and the high panel transmittance around 4.5% have been achieved. We also obtained response time of 27 ms at 6V, and flicker, crosstalk level similar to that of TN modes. The electro-optical properties of this panel are summarized in Table I.

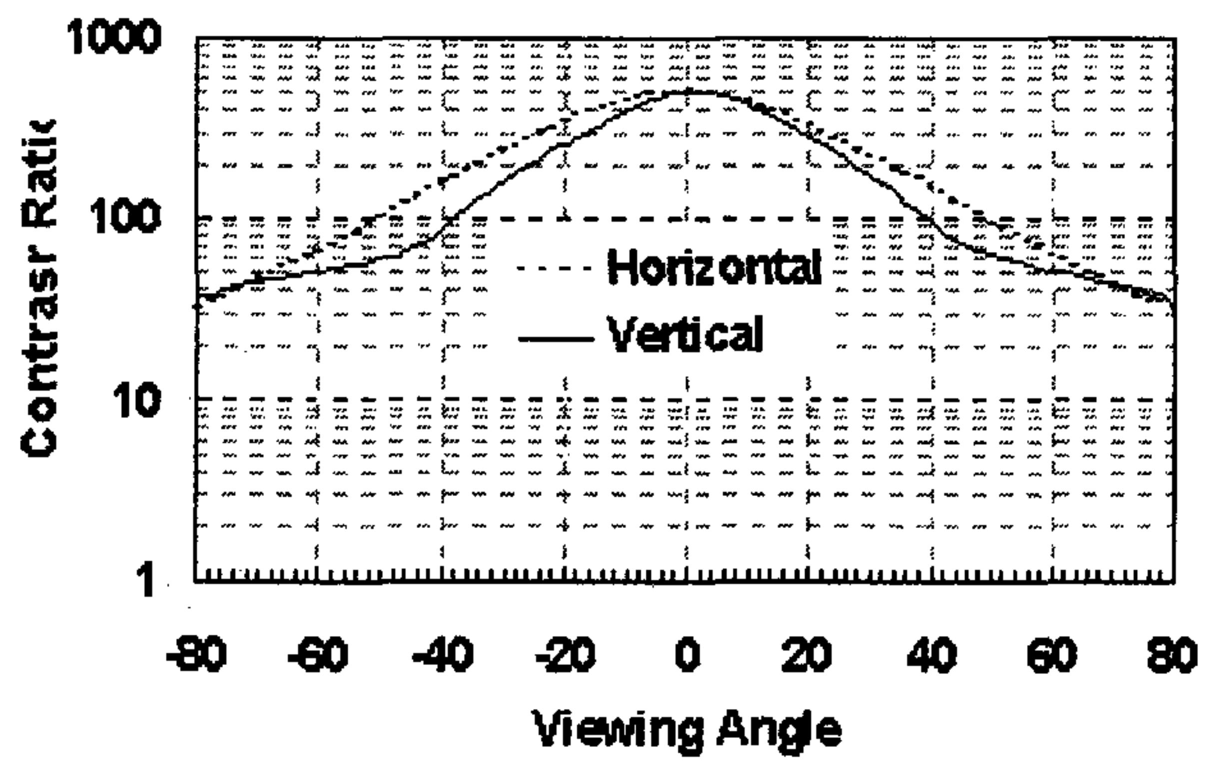

Fig. 10 The viewing angle characteristics with an optimized film compensation.

5. Conclusions

Using the PVA technology, we have developed 24 inch diagonal WUXGA TFT-LCD monitors for the first time. The electro-optical properties of the panel after optimizing the cell parameters, ITO pattern shape, and the compensation film demonstrate that this mode is a viable technology to improve viewing angle characteristics without sacrificing other electro-optical properties such as panel transmittance, contrast ratio and the response time. We believe that the PVA mode can be commercially applicable to the large size, high resolution TFT-LCD multi-media monitors with feasible mass-productivity.

Panel Size	24" Digonal (16 : 10)
Resolution	WUXGA (1920 x 1200)
Luminance	250 cd/m
Transmittance	4.5 %
Contrast Ratio	> 500 : 1
Response time	27ms
Viewing Angle T/B/L/R Digonal	 ➤ 80 ➤ 80
Gray scale Inversion	> 80
Flicker	< 2
Crosstalk	0.73 %
Color reproduction	> 50 %
Criving Voltage	6 V

Table 1. Electro-optical Properties of 24 inch WUXGA PVA TFT-LCDs.

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