Advanced Cell Structure for High Contrast Ratio in Charge Share S-PVA Monitors

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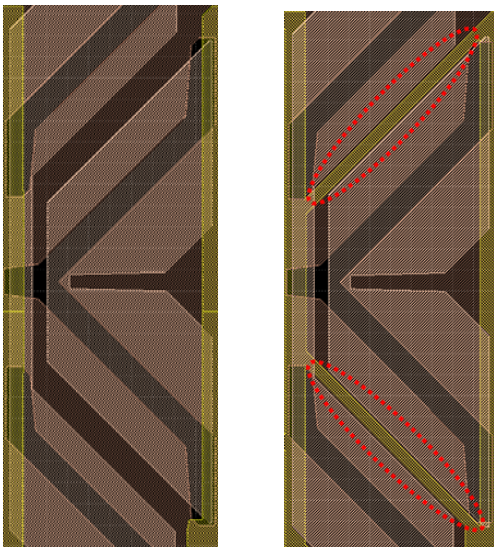
Abstract

This paper describes a new S-PVA cell structure which achieves enhanced contrast ratio by adopting a step-like patterned common electrode between the high sub-pixel and low sub-pixel electrodes without loss of transmittance. A 24-inch panel was developed for monitor applications and measured contrast ratio and white luminance were over 2500:1 and 400cd/m2, respectively.

1. Introduction

Liquid crystal displays (LCD) occupy a prominent position in the fast growing flat panel display (FPD) market [1]. Samsung has developed its own PVA technology, called super-PVA (S-PVA), adopting a multi-domain structure formed by a fringe-field effect and optical compensation by retardation films [2]. Even though Samsung's PVA mode has achieved high contrast ratio (CR), high brightness, wide viewing angle without gray inversion, and fast response time, technologies for further enhancement of CR and brightness have been studied.



(a) Conventional (b) Pixel-COM

Figure 1. S-PVA pixel structures

CR is defined as the brightness ratio between the full white and the full black levels of the display. Therefore, to increase CR, darker black and/or brighter white should be achieved. Our research efforts have been focused on reducing the brightness of the black by avoiding light leakage without any loss of white luminance. Referring to Figure 1(a), conventional S-PVA cells have two separate sub-pixels to reduce off-axis gamma distortion [3]. Recently a new structure, which is called pixel-COM, has been proposed to increase aperture ratio by adopting a gate metal layer as a common electrode between the two sub-pixels as shown in Figure 1(b) [4]. This pixel-COM cell structure induces strong electric fields between the two sub-pixels and enables the pixel electrode gap to be reduced from 10um to 6um, resulting in high brightness.

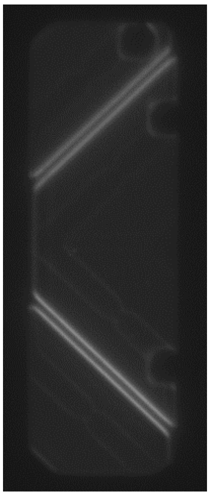


Figure 2. Light leakage in Pixel-COM structure

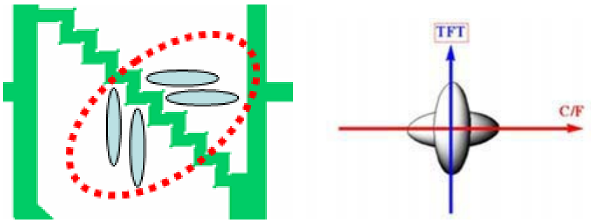
However, the taper angle of the gate metal layer causes the liquid crystal (LC) molecules to be tilted at the pixel common electrode boundaries and light leakage occurs as shown in Figure 2. Furthermore, because the azimuthal angles of the slopes are 45° and 135°, and the absorption axes of the polarizers are 0° and 90°, control of light leakage is critical in the pixel-COM structure.

Here we report on a new pixel structure, called step-COM, for complete removal of light leakage. An optimized structure and properties of the new step-COM are described in detail.

2. Results and discussion

2.1 Step-COM design concept

To reduce light leakage in the pixel-COM structure, a key point is that azimuthal angles of the LC should be the same as the absorption axes of the polarizer. Figure 3 describes the concept and mechanism for a new pixel structure with a common electrode gate metal layer formed in a step-like pattern, which has been named step-COM. Even though this structure also causes LC molecules to be tilted, the azimuthal angles of LCs match the absorption angles of the polarizers and light leakage is minimized achieving a darker black display with high CR.



(a) (b)

Figure 3. Design concept for new pixel structure: (a) step-COM structure and tilted LCs, (b) mechanism for minimizing light leakage

Generally, the metal photo and etch processes have a skew value. For an optimized step-pattern, we choose two parameters which are step-pitch and step-angle as shown in figure 4.

Step-pitch is best if kept as short as possible. If the pitch is long, the edge of the step pattern would overlap with the pixel IZO pattern causing loss of transmittance. We designed and prepared three structures, 5µm, 7µm, and 10µm. The 5µm step-pitch structure was found to be unsuitable because the step pattern was smoothed during the metal etch process, resulting in no improvement in CR. The 7µm and 10µm pitch lengths were good enough to be patterned and etched and we were able to measure the various resultant properties (CR, transmittance, response time etc.) of these structures. The other parameter, step-angle, is optimally 90°, because control of light leakage relies on this azimuthal angle. We designed 60° and 90° patterns. We expected that the 60° step-angle would result in a 90° step-angle upon completion of the etch process. But the final pattern was like a saw, the pattern uniformity was not good, and therefore its properties were not significantly improved. Finally we chose the 7µm step-pitch and 90° step-angle as optimal for the step-COM. Next, we will describe the data and results.

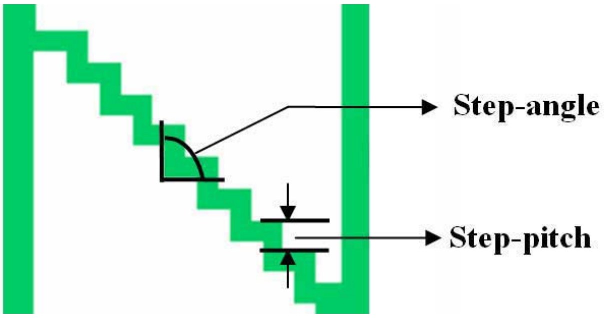


Figure 4. Design parameters for optimized Step-COM structures

2.2 Optimized design of the step-COM

We designed 5 different gate patterns and prepared them in a 17" SXGA monitor for testing. We took detailed measurements, and this data is summarized in table 1.

Table 1. Characteristics of split condition*

Split Condition	Contrast Ratio	White Luminance
Pixel-COM (Ref)	735:1	303
Conventional PVA	992:1 (35% ↑)	284 (6% ↓)
Step-Pitch 7µm	913:1 (24% ↑)	303 (0%)
Step-Pitch 10µm	962:1 (31% ↑)	298 (2% ↓)
Step-Angle 60° **	913:1 (24% ↑)	302 (0%)

* These panels used bead spacers instead of column spacers, and IZO thickness is different from Samsung mass production monitor panels. Therefore, final values will be different.

** Step-pitch was 7µm.

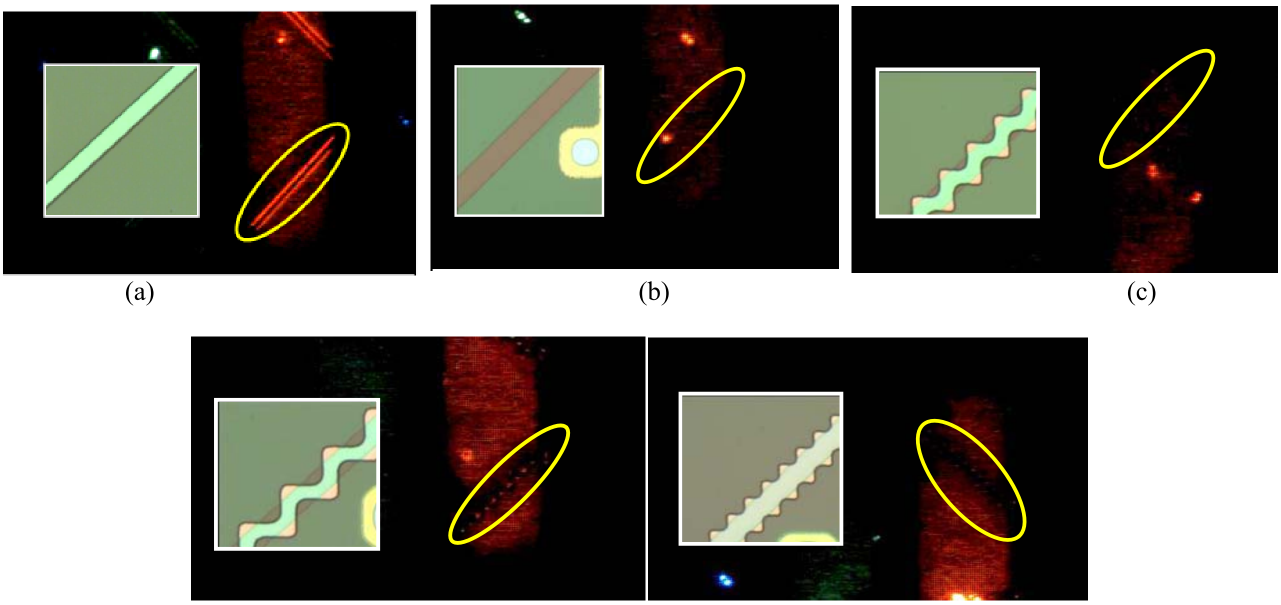

(a) (b) (c)
(d) (e)

Figure 5. Microscope images: (a) Pixel-COM, (b) Conventional PVA, (c) Step-pitch 7µm, (d) Step-pitch 10µm, (e) Step-angle 60°

As shown in table 1, the conventional PVA structure of figure 1(a) had higher contrast ratio than the pixel-COM structure but lower transmittance, about 6%. In order to control the dynamic texture in IZO open between the high and low sub-pixels, the distance must be wider than 10µm. If the IZO open distance is less than 10µm, the fringe field between C/F (color filter) ITO and pixel would not be good enough for control of the LC molecules in the IZO open area. The IZO open distance is 6µm in the pixel-COM. For this reason, the conventional PVA structure has lower transmittance. The step-COM (pitch 7µm) shows higher contrast ratio (24%) and the same transmittance compared to the pixel-COM structure. Although the step-COM (pitch 10µm) had higher contrast ratio (31%) than reference pixel-COM, its transmittance was decreased because the edge of the step pattern overlaps the high and low pixel sub-domains. The step-angle 60° had similar result as the 7µm pitch step-COM, but its step-pattern looked like a saw and uniformity was worse than the other step-COM structures. Based on these results, a step-COM pitch of 7µm offers the best design for high contrast ratio and transmittance. We obtained microscopic images of these panels and were able to analyze and interpret the CR properties of the designed structures as shown in figure 5. We could clearly see light leakage around the pixel-COM as shown in figure 5(a), and reduction in light leakage of the step-COM as shown in figures 5(b-e).

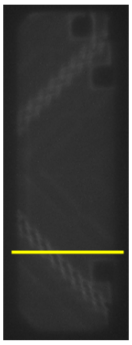
2.3 Characteristics of step-COM

According to this optimized design rule, the 7µm pitch step-COM structure was implemented in 24.0 inch monitor panels and the pixel-COM structure was prepared as well as a reference for comparison. Measured data are compared in Table 2. The measurements show that the 7µm pitch step-COM structure can increase CR by 22% without reduction in transmittance. These data are consistent with observations of the test panel images as shown in figure 5, wherein the step-COM structure has smaller light leakage dots compared to the pixel-COM. Additionally, we measured light leakage intensity using a ProMetric microscope. This data, shown in Figure 6, shows that light leakage of the step-COM has been dramatically decreased, resulting in a significant corresponding increase in the monitor's contrast ratio. In terms of response time and unstable texture, both structures had the same level. The conventional S-PVA structure has dynamic texture in the IZO open area, when the distance is less than 10µm. But these two structures didn't have unstable texture, because the fringe field is strong enough to control random motion in the IZO open area cause by COM electrodes between high and low sub-pixels.

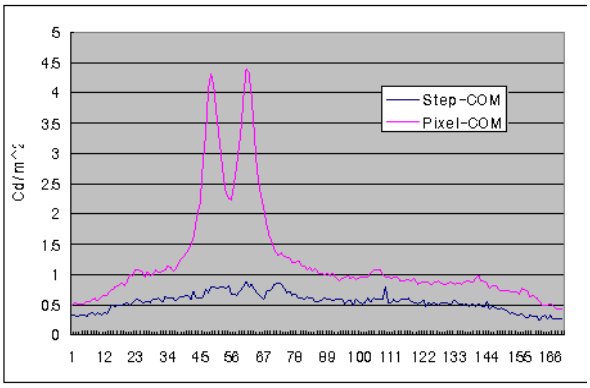
In the step-COM structure, overlap size between the pixel IZO and the edge of step-COM pattern is variable. Consequently, capacitance of the high and low sub-pixels could be changed due to misalignment. For this reason, we prepared an abnormal panel which purposely had a shifted overlay. The shifted overly panel had properties that were similar to those of a normal panel, which demonstrates that this structure has adequately robust margin against overlay shift between the gate and IZO layers.

Table 2. Comparison of pixel-COM and step-COM in actual panel condition

Item	Pixel-COM	Step-COM
Contrast Ratio	1800:1	2200:1
Black Luminance	0.231	0.187
White Luminance	417 cd/m^2	412cd/m^2
Unstable texture	As is	As is
T_{on} / T_{off}	17.0/5.7	17.2/5.6



(a) step-COM



(b) Light leakage comparison

Figure 6. ProMetric microscope images and light leakage intensity scans

3. Summary

We designed a new step-COM pixel structure to control the azimuthal angle of tilted LC molecules at the pixel-COM boundary and studied the effect of this new structure on black luminance levels. The new structure provides high CR of more than 2200:1, compared to 1300:1 for a conventional pixel-COM structure. The CR was further improved to 2600:1 by applying a new color filter photoresist (PR).

The design rules and properties of the step-COM structure are in the final stages of a patent application and will be discussed in greater detail at this paper's presentation.

4. References

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4. Y. S. Um, *IMID'07 Technical Digest*, p.403 (2007).