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Novel Patterned Vertical Alignment LCD for Mobile Application with High Transmittance and Reliability

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We developed a novel Patterned Vertical Alignment (PVA) LCD for mobile application with high transmittance and reliability by optimizing the design rule, fabrication process and LC materials. Our new design rule enabled an increase of 36% aperture ratio (A/R) and better electro-optical performance compared with those of the conventional PVA structure. Image sticking and edge smudge level also were reduced by using newly developed alignment material and ultraviolet (UV) sealant.

Keywords: edge smudge; high aperture ratio; image sticking; PVA LCD

1. INTRODUCTION

Recently, the demands for portable electronic devices such as mobile phones, digital multimedia broadcasting (DMB) phones, personal digital assistants (PDAs), navigator system and digital still cameras (DSCs) have dramatically increased as a result of expansion of digital mobile market. Liquid crystal displays (LCDs) represent the dominant trend in personal information displays because of light weight, compact and low power consumption. The majority of LCDs in the market is the twisted nematic (TN) mode owing to its excellent stability in

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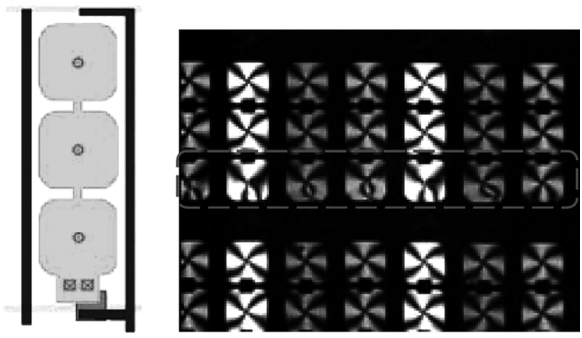
structure and wide process margin. However, it has a problem in viewing angle and contrast ratio. Many kinds of display modes are suggested to improve the image quality of TN mode such as optically compensated bend (OCB) [1], in-plane switching (IPS) [2], fringe-field switching (FFS) [3] and vertical alignment (VA) [4]. The IPS and FFS modes show a wide viewing angle and a high contrast ratio but response time is rather slow. The multi-domain VA (MVA) mode with optical compensation film also shows a wide viewing angle, high contrast ratio and a relatively faster response time than IPS mode but aperture ratio is rather low for a small mobile display with high resolution.

In this article, we adopted a novel PVA LCD for mobile application to overcome these problems. A new design rule and LC materials are suggested to improve the aperture ratio and reliability such as image sticking respectively.

2. PIXEL DESIGN

Figure 1(a) shows the schematic view of conventional PVA pixel for mobile LCD. Each pixel is divided into three sub-pixels and has round shaped pattern in common electrode of color filter side to control the LC molecular alignment easily.

Electric field direction is along the circumference of round shape pattern in common electrode when the voltage is applied. The LC molecules are inclined vertically to electric field direction.



(a) (b)

FIGURE 1 Schematic view and LC textures of conventional PVA pixel for mobile LCD: (a) 3-sub-pixel design, (b) microscopic LC textures with crossed linear polarizer.

LC textures instability is happened by electric field's distortion between sub-pixel and contact hole as shown in the red square of Figure 1(b). LC molecules in this area are not controlled well by the electric field and not responding instantly to the data change. The momentary image retention is obtained in a viewing direction.

To avoid this problem, sufficient space between sub-pixels and contact hole is needed and brings a decrease of aperture ratio (A/R). Figure 2 shows our new design of PVA pixel for stabilizing the LC textures and improving the A/R.

To minimize electric field's distortion between sub-pixel and contact hole, 2-sub-pixel design is introduced (Fig. 2(a)). The contact hole is shifted to center of pixel and each pixel is divided into two sub-pixels. Very stable LC textures are achieved and the momentary image retention is removed regardless of electric field condition as shown in Figure 2(b).

3. ELECTRO-OPTICAL PERFORMANCE

Figure 3 shows the simulation results of LC molecules movement with an applied voltage for two types of VA mode. In case of RVA mode (Fig. 3(a)), rubbing process is needed and the light leakage is appeared around the pixel electrode boundary. So, blocking layer should be emplaced under the data line to prevent the light leakage. However, in case of PVA mode as shown in Figure 3(b), not only rubbing process but also blocking layer is not necessary owing to stable LC molecules movement. On the basis of this simulation result, we fabricated two types of sample as shown in Figure 4.

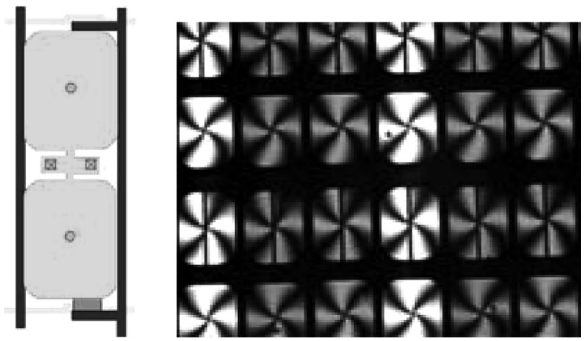


FIGURE 2 Schematic view and LC textures of novel PVA pixel for mobile LCD: (a) 2-sub-pixel design, (b) microscopic LC textures with crossed linear polarizer.

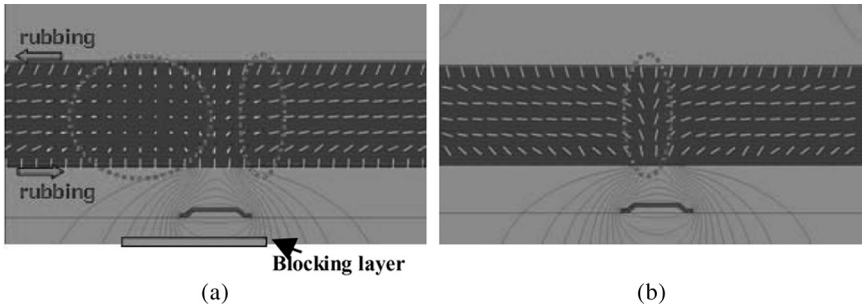


FIGURE 3 Simulated LC molecules movement at pixel boundary area: (a) rubbing-VA (RVA), (b) PVA.

Type A, 2-sub-pixel design, has a blocking layer under the data line for preventing light leakage and aperture ratio is 59%. However, the aperture ratio of type B is increased up to 64% by eliminating blocking layer.

Table 1 compares measured electro-optical properties for a conventional panel with new types of PVA panel. Type B shows an increase of 36% aperture ratio and better electro-optical performance compared with those of the reference structure. The A/R of 4.3 inch WQVGA PVA LCD is 64%, the contrast ratio (CR) is 620:1, the viewing angle (CR $>$ 10) is over 160 degrees in the horizontal and vertical viewing azimuth and no gray scale inversion are also obtained.

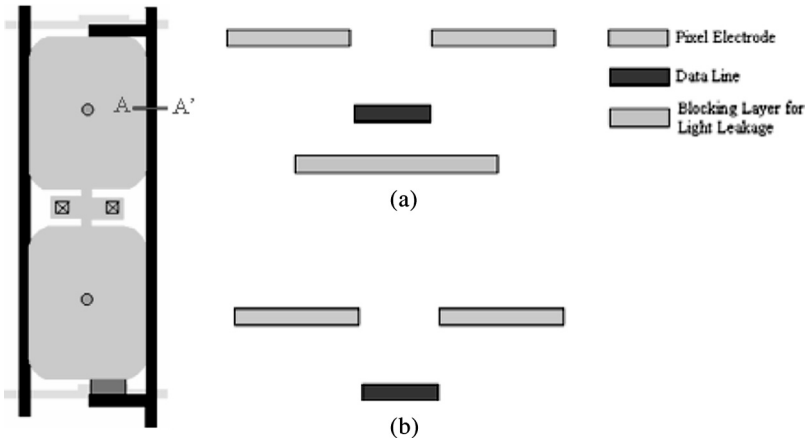


FIGURE 4 Cross-section (A-A′) view of novel PVA pixels: (a) type A, (b) type B.

TABLE 1 Electro-Optical Properties (4.3 inch WQVGA PVA LCD)

Type	Brightness (cd/m^2)	Contrast ratio	Color purity (%), NTSC	Trans-mittance (%)	Power (mW) (Except IC)	Aperture ratio (%)
Reference	217	602	47	5.2	48	47
A	270	628	47	6.3	44	59
B	279	620	47	6.5	43	64

Figure 5 shows a suggestive result that there is no light leakage around data line because the difference of contrast ratio between type A and B wasn't found as the viewing angle changes.

We found that the experiment data of type A and B demonstrates a good agreement with the simulation result as shown in Figure 3 and the blocking layer can be eliminated without decreasing contrast ratio and color purity.

4. IMAGE STICKING

Image sticking is one of the very important qualities and is getting critical issue to LCD recently. After a long term static image display, the phenomenon that the previous image remains in the next pattern is so-called image sticking effect and has been considered as result from DC field unbalance by ionic charge effects.

To reduce the face and line image sticking level, novel alignment material and ultraviolet (UV) sealant were introduced. New alignment material is consisted of two different polyamic acids (PAAs) layers while the conventional alignment material is single PAA layer. Figure 6

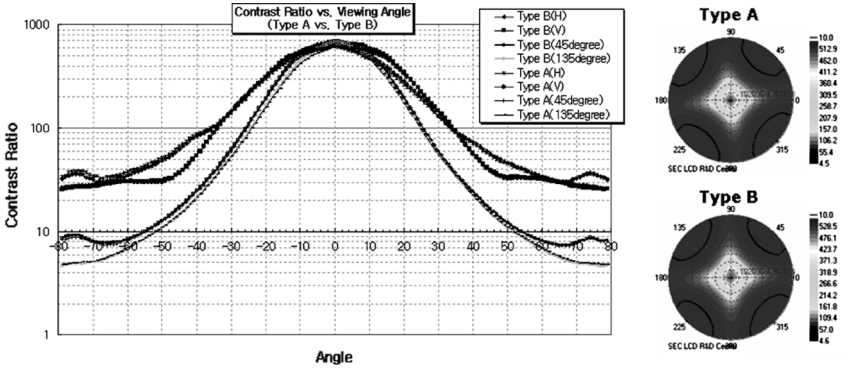


FIGURE 5 Viewing angle characteristics (type A, B).

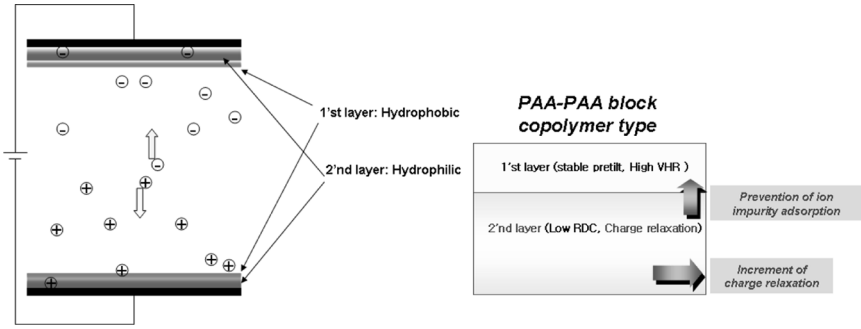


FIGURE 6 Basic concept of new alignment material.

shows the design concept of new alignment material. The structure is PAA-PAA block co-polymer that restrains the ion impurity adsorption to the hydrophobic 1'st layer and releases the adsorbed ion impurity in the hydrophilic 2'nd layer.

Table 2 shows comparison of the electrical properties for alignment materials. New alignment material has excellent electrical properties such as high voltage holding ratio (VHR), low residual DC (RDC) and high pretilt angle compared with the conventional one.

The face image sticking result for alignment materials is shown in Figure 7. We stressed for 60 hr at 25°C with checker pattern to evaluate the image sticking property. The result is that new alignment material is advantageous in terms of face image sticking and lowers the image sticking level from middle to weak in whole gray pattern.

Figure 8 shows the results of line image sticking and edge smudge. The new UV sealant material is advantageous in terms of line image sticking and edge smudge. The image sticking and edge smudge level are lowered from strong to weak due to prevention of water absorption and reduction of the reactivity between LC and sealant.

TABLE 2 Comparison of the Electrical Properties for Alignment Materials

Item	Measurement condition	Conventional	New
VHR (%)	25°C	98.8	99.4
	60°C	96.3	98.2
RDC (mV)	Flicker	125	110
	C-V	481	371
Pretilt Angle (degree)		88	89.2

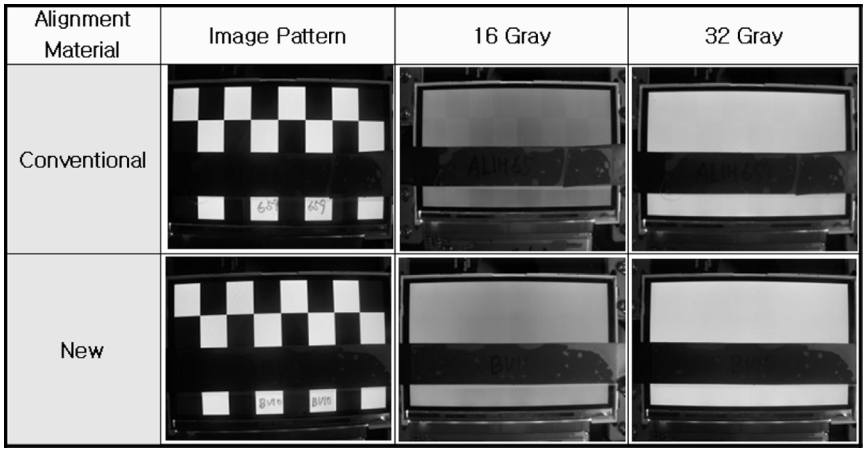


FIGURE 7 Face image sticking result for alignment materials (60 hr out at 25°C).

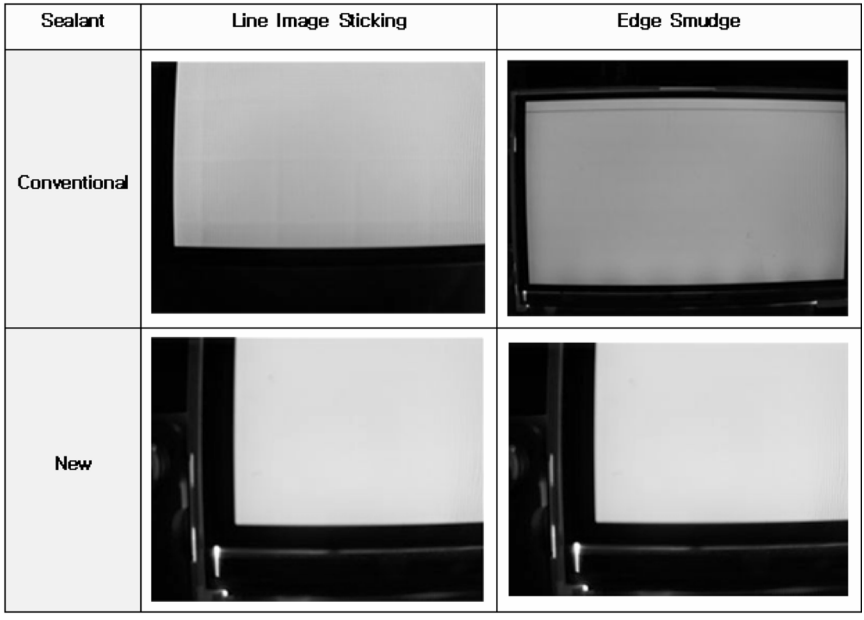


FIGURE 8 Results of line image sticking and edge smudge (8 hr out at 25°C).

5. CONCLUSION

In this article, we have proposed a novel PVA pixel design for mobile LCD to have a high optical performance and reliability. And we have developed 4.3 inch WQVGA PVA LCD. Very stable LC textures were achieved and the momentary image retention was removed regardless of electric field condition. The new PVA pixel design enabled an increase of 36% aperture ratio (A/R) and better electro-optical performance compared with those of the conventional PVA structure. The aperture ratio was 64%, the contrast ratio (CR) was 620:1, the viewing angle (CR > 10) was over 160 degrees in the horizontal and vertical viewing azimuth and no gray scale inversion were also obtained. Image sticking and edge smudge level also were reduced by using newly developed alignment material and ultraviolet (UV) sealant. This new design makes the PVA mode possible to have excellent advantage for mobile LCD applications.

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