Development of Ultra-Narrow-Border LCDs Using Transparent Polyimide Substrates

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ABSTRACT

We have been investigating in-plane switching liquid crystal displays using transparent polyimide film substrates, which are called sheet LCDs. An ultra-narrow-border LCD, i.e., an LCD with almost invisible border, was fabricated by bending the sheet LCD along the backlight frame and using the lens effect of the cover glass.

1 INTRODUCTION

LCDs are widely used in TVs, laptops, smartphones, and other electronic devices. Recently, narrow-border LCDs have gained prominence in the pursuit of the miniaturization of electronic devices and improvement in designability. However, the conventional LCDs that use glass substrates have the limitation of a border width owing to the seal and driver integrated circuit (IC) areas. Therefore, we propose a new structure of ultranarrow border LCDs using plastic substrates.

We have been investigating an in-plane switching (IPS) LCDs that are fabricated on transparent polyimide (PI) film substrates, which are called sheet LCDs [1]. Sheet LCDs are extremely thin and flexible compared with the conventional LCDs. Therefore, we propose sheet LCDs as a promising solution for realizing narrow-border LCDs taking the advantage of bending the non-display area.

2 EXPERIMENT

2.1 Structure of the sheet LCD

Figure 1 shows the cross-sectional structure of the sheet LCD. Some options of a transparent plastic substrate for sheet LCDs were proposed as follows: polycarbonates, polyethylene terephthalate, triacetylcellulose, fiber-reinforced plastic, and PIs [2-7]. Among these options, we selected the transparent PI because of its high thermal stability, high transmittance, and high durability. The PI film thickness was designed to be 10 µm, which provided sufficient durability. However, the PI film exhibited retardation along the thickness direction. A PI film with a high optical retardation negatively influences the viewing angle property of LCDs. To reduce the retardation of the PI film, an optical compensation film was applied to sheet LCDs [8]. Additionally, an inorganic barrier layer was deposited on the PI film substrate to prevent the intrusion of water vapors into the LC layer. The barrier layer thickness was optimized to counter the influence of the internal stress in the PI film. An oxide semiconductor was applied to thin-film transistors (TFTs) to reduce the temperature of the manufacturing process, as follows. First, the transparent PI was coated onto a glass substrate. Next, the inorganic barrier layer was deposited on the transparent PI film, and TFT or CF was formed on it. Both the substrates were adhered with a sealant after dropping the LC. The glass substrate was then released by laser ablation. Finally, polarizer films were attached on the PI substrate to complete the process.

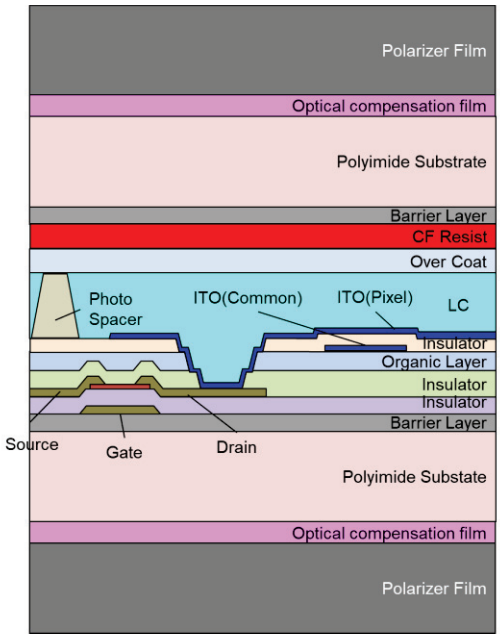


Figure 1. Cross-sectional structure of a sheet LCD.

2.2 Concept of ultra-narrow-border LCDs

The border width of LCDs is determined by the non-display areas such as the sealant width area, terminal-width areas of the driver IC and flexible printed circuit (FPC). The concept of ultra-narrow-border LCDs lies in hiding these non-display areas by bending the sheet LCDs along the backlight frame. Figure 2 shows a sheet

LCD before the bending of the non-display area. Although the non-display area before the bending is wider than that of the normal LCDs, it is fixed on the back side of the backlight after the bending. Four corners were cut to allow bending along the backlight frame. The driver IC and the FPC were thermally press-bonded on PI substrate. Figure 3 shows the sheet LCD after bending along the backlight frame. The border viewed from the display side is extremely narrow so that it becomes almost invisible as shown in Figure 3 (a). Figure 3 (b) shows back side of the display after bending. The non-display areas on the four sides are adhered to the back side of the backlight. Moreover, the driver IC and the FPC are placed behind the display by this structure. We have investigated some issues of the bending structure to realize this concept.

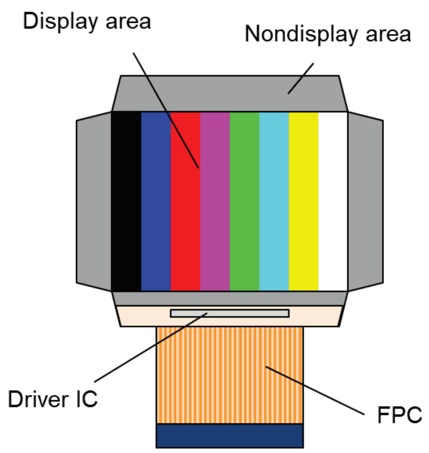
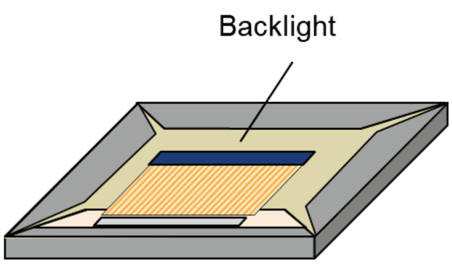


Figure 2. Sheet LCD before bending

(a) Display side.



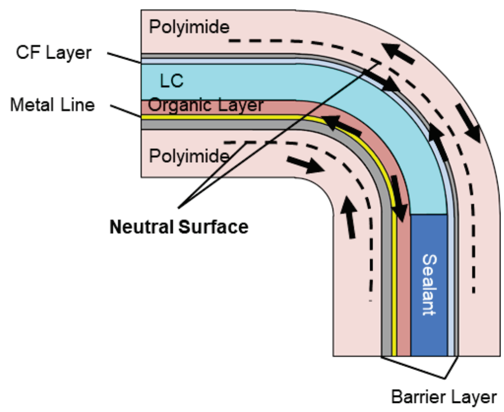
(b) Back side.

Figure 3. Sheet LCD after bending along the backlight frame.

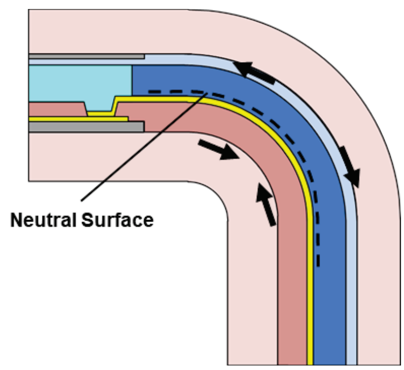
3 RESULTS AND DISCUSSION

3.1 Structure at the bending position

The LCD sheet structure at the bending position is important because it is the position is in which the bending stress is generated. Figure 4 shows the cross-sectional structure of a sheet LCD at the bending position. When the LCD sheet bends in the active area, it generates two neutral surfaces because of the LC layer between the two substrates, as shown in Figure 4(a). In this case, high bending stress is applied to the inorganic layers, such as the two barrier layers and metal lines, when the LCD panel bends, as they are placed away from the neutral surfaces. Therefore, the conventional structure is likely to have a poor reliability owing to the



(a) Conventional structure.



(b) Improved structure.

Figure 4. Cross-sectional structure of a sheet LCD at the bending position.

cracks. Figure 4(b) shows an improved structure to prevent cracks in the inorganic layers at the bending position. The barrier layers at the bending position have been removed. In addition, single neutral surface structure has been realized by extension of the sealant area. Moreover, the metal lines are positioned on the upper surface of the organic layer using a contact hole. Consequently, they get closer to a neutral surface compared with the conventional structure. We have prevented cracks at the bending point with this new structure and the decrease in the thickness of each layer.

Figure 5 shows the cross-sectional view of the bending of a sheet LCD at a radius of curvature of 0.1 mm. The upper polarizer film is placed only on the active area. However, the lower polarizer has slits made at the bending position by laser. Figure 6 shows the cross-sectional SEM image of a lower polarizer film with slits formed by laser. The film thickness of the polarizer in the slit is less than half of that for the conventional polarizer. This slit enables the sheet LCD to easily bend and achieve a radius of curvature of 0.1mm.

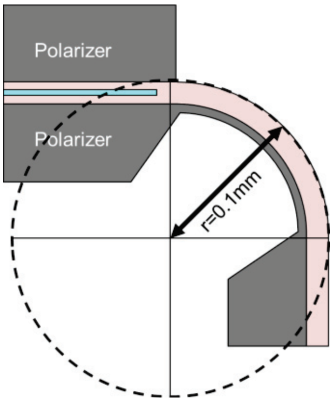


Figure 5. Cross-sectional view of polarizer film with a radius of curvature of 0.1 mm.

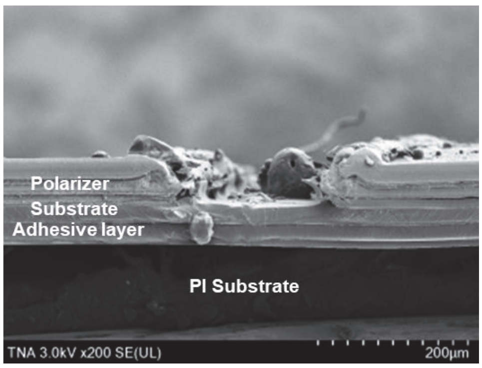


Figure 6. Cross-sectional SEM image of the lower polarizer film cut by laser.

3.2 A lens effect around the edge of the cover glass

The cross-sectional structure of an ultra-narrow-border LCD module is shown in Figure 7. The width from the active area to the edge of the LCD module is approximately 0.4 mm. The ultra-narrow-border LCD has utilized a lens effect from the cover glass to further reduce the border width. Figure 8 shows microscopic images of the edge of the active area at the ultra-narrow-border LCD. Figure 8 (a) shows no lens effect in the case of the LCD using a conventional cover glass. In this case,

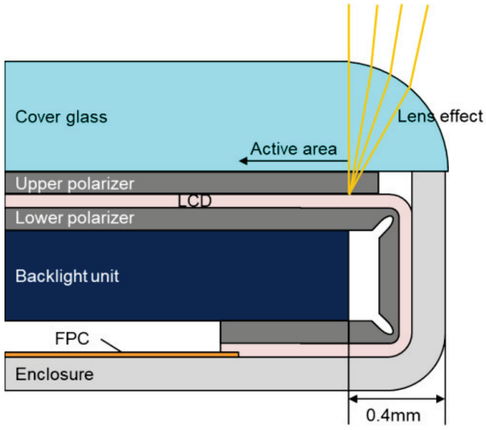
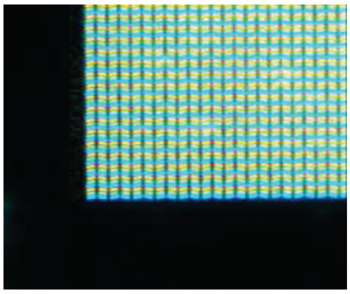
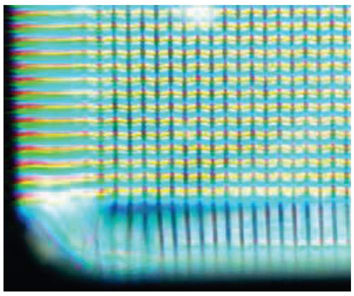


Figure 7. Cross-sectional structure of an ultra-narrow-border LCD module.



(a) No lens effect.



(b) Lens effect.

Figure 8. Lens effect with a cover glass.

there is a slight border at the edge of the LCD. Figure 8 (b) shows lens effect in the case of our ultra-narrow-border LCD using new cover glass with a lens shape. The lens of the cover glass magnifies the pixels of the edge. The magnification by the lens effect is approximately 0.4 mm. Consequently, our ultra-narrow-border LCDs have achieved an almost invisible border, as shown in Figure 9.

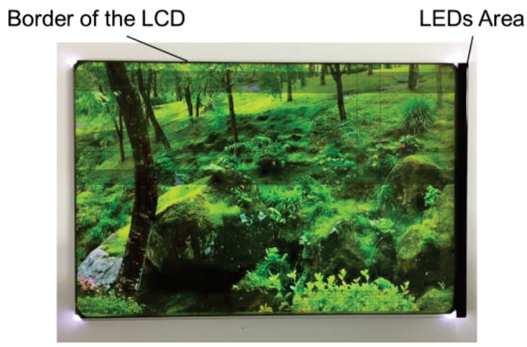


Figure 9. 4.1-inch ultra-narrow-border LCDs.

4 CONCLUSIONS

We developed an ultra-narrow-border LCD by bending the non-display area of the sheet LCD along the backlight frame. The crack of the metal line during the bending was prevented by optimizing the position of the neutral surface. We made slits on the polarizer film at the bending position by laser to bend the sheet LCD at a radius of curvature of 0.1 mm. Additionally, the cover glass on the LCD panel displayed a lens effect around the edge. By applying these technologies, we have produced a prototype of ultra-narrow-border LCDs with an almost invisible border.

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