An Ultra-Low Power FFS LCD Using Zero-Anchoring Interface

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Keywords: LCD; FFS; Low-power-consumption; zero-anchoring; slippery.

ABSTRACT

Using a novel zero-anchoring (ZA) interface, we have realized an ultra-low power consumption FFS LCD with low voltage drive and higher transmittance. We have improved the response time, image sticking and other optical performance, which have been issues for zero anchoring FFS, by developing the alignment layer materials and the optimum liquid crystal materials. In addition, ZA technology is useful for reflective FFS as well as transmissive FFS.

1 Introduction

In the mobile display market, LCDs are one of the most widely used devices. Especially, FFS mode is a suitable LCD mode because they have not only better image quality but compatibility with in-cell touch technology. We have previously reported the low frequency driving technology to reduce power consumption [1]. However, the recent trend towards higher brightness and higher resolution is causing the increase of the power consumption of backlight units and panel driving. Due to the limited battery capacity of mobile devices, it is still strongly desired to suppress the power consumption of FFS LCDs.

In order to achieve both higher light transmission efficiency and lower driving voltage, the new LCD mode using zero-anchoring interface technology has been proposed. Yamamoto et.al. invented the principle of "Slippery" interface and reported its characteristics [2]. Sato et.al. and Noda et.al. reported a one-side zero-anchoring in-plane switching [3][4][5][6].

In this paper, we report an ultra-low power consumption FFS LCD with low voltage drive and higher transmittance than n-FFS by using a zero-anchoring interface. In addition, we have improved the response time, image sticking and other optical performance, which have been issues for ZA-FFS, by developing the alignment layer materials and optimizing liquid crystal materials. Besides, we introduce refractive FFS with ZA interface. ZA technology is useful not only for the transmissive FFS but also for reflective FFS.

2 Panel Configuration

Figure 1 shows the schematic illustrations of LCD cells we have built. We used FFS electrode design and liquid crystal materials with positive dielectric anisotropy for our zero-anchoring LCD. CF substrate is coated by novel zero-anchoring material. The TFT substrate with FFS electrodes is coated conventional photoalignment material, which shows strong anchoring energy. In general, the image sticking and electrical characteristics such as Vcom drift are strongly influenced more by the materials of TFT substrates than that of CF substrates. As described later, figure (b) configuration enables all the characteristics of high transmittance, better image sticking property and response time. As an aside, it is noted that the same TFT substrates can be used as conventional strong anchoring FFS, which means that this new LCD mode needs no additional cost for revised photomask at all.

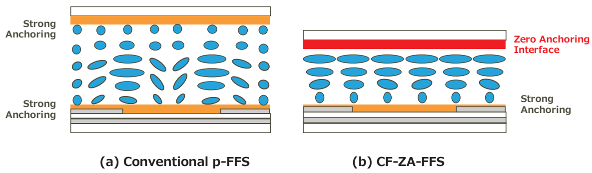


Fig. 1. Cross-sectional view of the LCDs

3 Display Performances

3-1. Optical Performance

Figure 2 shows Voltage-Transmittance (VT) characteristics. p-FFS is suitable for low voltage driving relative to n-FFS because of high material flexibility in LC molecular structure design which have high $\Delta\varepsilon$. But p-FFS could not get high transmittance due to unrotated molecules. Although n-FFS has the advantage of high transmittance, it is not easy to drive at low voltage because high $|\Delta\varepsilon|$ lead to low reliability in LCDs. Compared to them, ZA FFS shows high transmittance (~90%) than n-FFS and can be driven by lower voltage (~3V) than p-FFS even though ZA FFS uses pLC materials with relatively lower $\Delta\varepsilon$. LC molecular motion is lubricated by ZA interfaces, so that both lower driving voltage and higher transmittance is realized. Since the applied voltage for source lines is generated by boosting it in a circuit, generally from 3.3V to 5V, it is important for LCDs to be driven by around 3.3V to suppress power consumption.

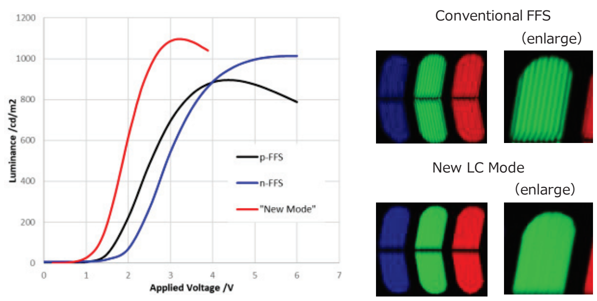
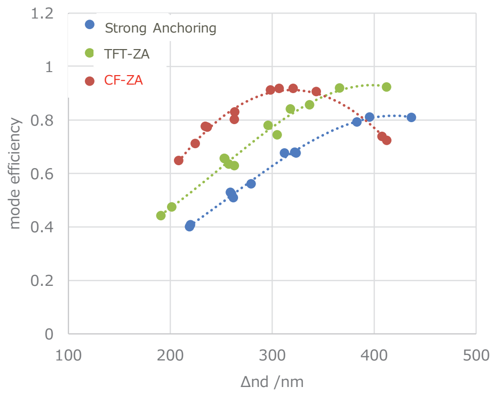
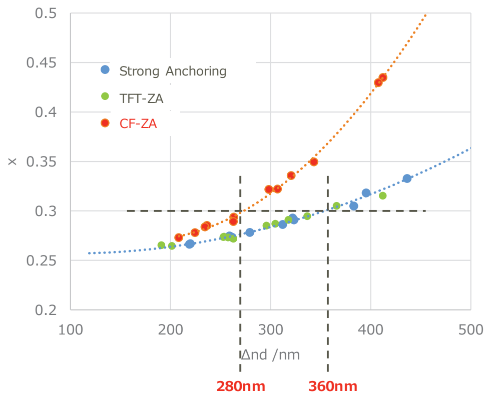


Fig. 2. VT characteristics and POM image at white state

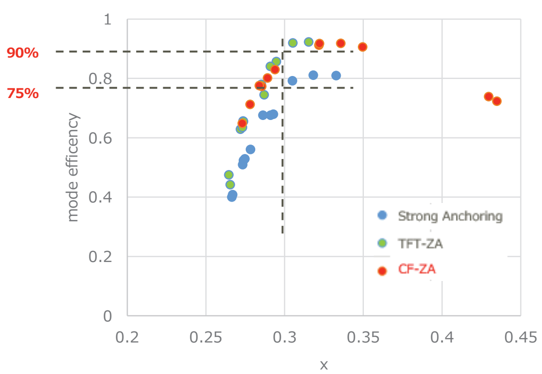
We have also evaluated the transmittance dependence and white color chromaticity dependence on Δnd of liquid crystal layer. According to Figure 3(a), CF-ZA FFS shows the highest transmittance at Δnd~300nm, which is lower than the values of conventional p-FFS and TFT-ZA FFS. Figure 3(b) shows white chromaticity distributions at different LC Δnd. In order to get same white color coordinate as conventional LCD, we have designed the Δnd~280nm for CF-ZA FFS. Even with such a Δnd design, CF-ZA-FFS get higher transmittance compared to conventional FFS as shown in Figure 3(c). This means that the response time can be improved thanks to narrower cell gap.



(a) Δnd-Transmittance characteristics



(b) white chromaticity distributions at different Δnd

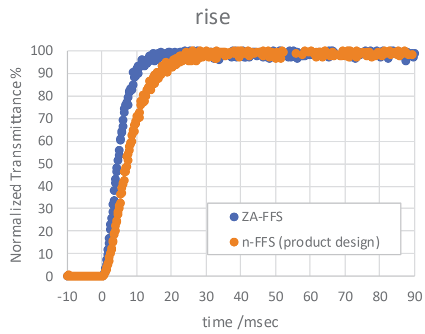


(c) chromaticity-Transmittance characteristics -

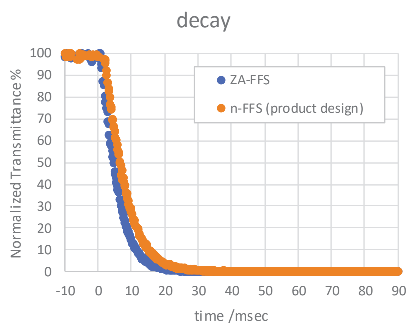
Fig. 3. Optical properties of CF-ZA-FFS

3-2. Response Time

The response characteristics of ZA FFS has been one of the big issues to be solved. In general, LC molecules are restored to initial alignment by the anchoring on the alignment layer during voltage-turning-off process, so that slower response time is inevitable in ZA FFS mode. Although it is reported that partially zero-azimuth anchoring IPS [5][6], it leads to complicated fabrication process and has several concerns related to monomer. Therefore, we have been optimized just panel configuration and LC materials in order to improve response time. As mentioned in the previous section, the suitable Δnd of ZA-FFS is lower than others, so that cell gap could be much thinner, which is advantageous for improvement of response time. And also, we have optimized LC materials which has lower γ1. As a result, we have achieved the same or faster response time than a conventional n-FFS commercialized for low power mobile LCDs.



(a) rise



(a) decay

Fig. 4. Response characteristics

3-3. Image Sticking

Another issue for ZA-FFS is image sticking. We have taken two strategies to suppress AC image sticking caused by inferior alignment regulation force. One is the panel configuration of CF-ZA. The alignment layer on the TFT substrate has strong anchoring energy, which can suppress AC image sticking. The other is to make anchoring energy of ZA interface as close to zero-anchoring as possible. Conventionally we have been developing alignment materials to strengthen the anchoring energy to suppress AC image sticking. On the completely opposite idea, however, when ileal slippery interfaces close to zero-anchoring is used as alignment layer, the LC molecular motion is lubricated by the interfaces and the anchoring effect disappears on the surface. With such a peculiar condition, AC image sticking cannot occur.

The image sticking properties are shown in Figure 5. Although the image sticking is also caused by Vcom Drift and flexoelectric effect [7] as well as AC image sticking, Figure 5 described only the component of AC image sticking. All of PAPI gen.1 to gen.3 are the photo-alignment materials with mass-production experience for tablets and notebook LCDs. The CF-ZA FFS shows better performance compared to TFT-ZA.

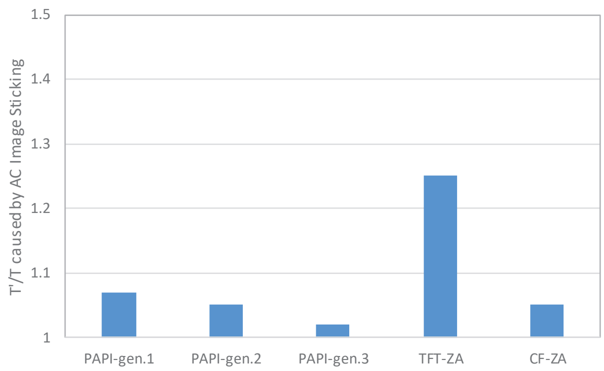


Fig. 5. AC image sticking obtained from the transmittance ratio between reference area and burned area after 24h driving

3-4. Power Consumption

We have simulated the power consumption for ZA-FFS LCD module. The calculation conditions are following. The brightness of LCD is 500nits. The size and resolution are 14-inch FHD. The LCD is driven by 60Hz at white state. Figure 6 shows calculated results. The lower driving voltage can reduce the power consumption of 70mW, and the higher transmittance can reduce that of 130mW. The effect is higher for products that require high brightness. And it could be further reduced by combining with 2D-mini-LED or low frequency driving for instance.

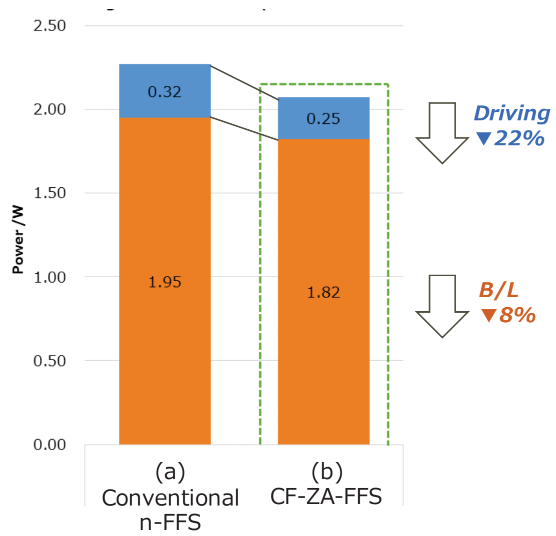


Fig. 6. Total power consumption of 14-inch FHD LCD modules at 60Hz white state for conventional n-FFS and CF-ZA-FFS (brightness: 500nits)

3-5. Prototype

We manufactured ZA-FFS LCD panels on our mass-production line. Demo picture shows in Figure 7. Even though the V255 voltage for this LCD module is 3V, it is confirmed that the brightness of this modules is higher than that of conventional LCDs driven by 5V in the case of using the same backlight.

Fig. 7. Demo picture of the prototype CF-ZA-FFS LCD

4. Reflective FFS LCD with ZA interface

ZA technology is useful not only for the transmissive LCDs but also for reflective LCDs. Simplified cell diagram is shown in Figure 8. Unlike the transmissive type, a reflector is formed in bottom substrate. Figure 9 shows Voltage-Reflectance (VR) characteristics. As with the transmissive LCDs, ZA LCD has lower driving voltage and higher reflectance.

Conventionally, it is difficult to obtain sufficient reflectance in FFS mode. Since the liquid crystal molecules don't rotate uniformly when applying voltage, sufficient phase modulation range cannot be obtained. For this reason, recent reflective LCDs adopt the vertical electric field mode like VA and ECB. However, using ZA technology, the modulation range of retardation can be increased, so that higher reflectance can be achieved. The reflective LCD is effective for low power consumption because it does not require backlight units, and when combined with memory-in-pixel (MIP) technology, further low power consumption is possible.

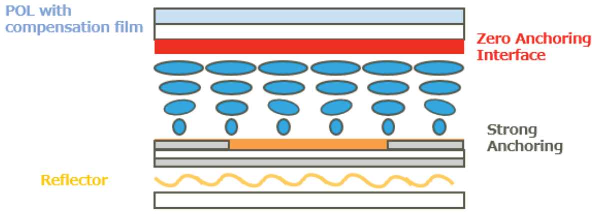


Fig. 8. Cross sectional view of reflective FFS LCD

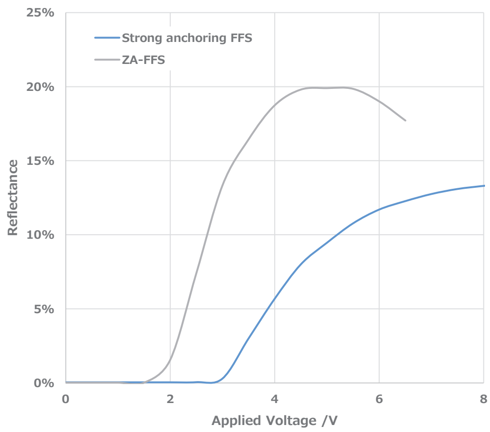


Fig. 9. VR characteristics

5. Conclusions

We have realized an ultra-low power consumption FFS LCD with low voltage drive and higher transmittance (reflectance) by using novel ZA interface. We have improved the response time, image sticking, and other optical performance by developing the alignment layer materials and the optimum liquid crystal materials. However, there are still some issues to be improved for ZA-FFS to replace common n-FFS. We need to verify reliability, mass-productivity and so on. These technologies we have reported are expected to be adopted for mobile LCDs requiring low power in the future. In addition, we believe this unique interface technologies can be applied to novel devices beyond LCDs.

Acknowledgements

The authors would like to gratefully acknowledge all associated members of Nissan Chemical Corporation and DIC corporation for providing us several materials, and also for useful discussions.

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