Design of Multi-domain Transflective LCDs for Large-sized Signage Applications

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ABSTRACT

With the ongoing proliferation of large-sized digital signage applications, the demand for outdoor visible displays is growing rapidly. Consequently, reflective and transflective LCDs, which use ambient light for display, are gaining increasing attention. In this study, we review the design concept of multi-domain transflective LCDs using UV^{2}A technology, which can provide good visibility at wide viewing angles under bright and dark ambient conditions

1 Introduction

Currently, we are surrounded by various digital signages in stations, airports, bus stops, hospitals, schools, shopping malls, convenience stores, and more. The installation purposes are also wide-ranging, such as service guidance, advertisement, and highly entertaining spatial presentation. Under the circumstances of the global power shortage in recent years, we believe that many users would like to reduce the power consumption of digital signage.

Generally, a reflective display that uses the sun or room light as a light source consumes less power than a self-emissive or transmissive liquid crystal display. Typical reflective displays include electrophoretic displays, electrochromic displays, reflective LCDs, and transflective LCDs. Although all the displays are based on excellent technologies, we have focused on transflective LCDs, which have good visibility under dark and bright ambient conditions.

In this study, we review the design concept of multi-domain transflective LCDs, which can provide good visibility at wide viewing angles under bright and dark ambient conditions.

2 Design Concept

2.1 Basic stack-up structure

Figure 1 shows the basic structure of a reflective LCD [1] [2] . From the observer side, the reflective LCD comprises a top polarizer, a retardation film, a color filter (CF) substrate, a liquid crystal (LC) layer, and a thin film transistor (TFT) substrate with an electrode having a micro reflective structure (MRS). The MRS reflective electrode efficiently reflects and scatters external light incident from a certain angle, resulting in a bright display [3] [4].

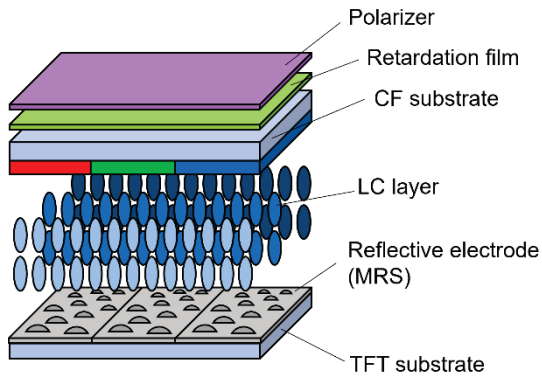

Fig. 1 Basic stack-up structure of a reflective LCD

2.2 Optical design of LC mode

The twisted planar aligned LC mode, called high reflective (HR)-TFT mode [5] [6] or mixed-mode twisted nematic mode [7], is a well-known LC mode for reflective LCDs. The reflectance of the HR-TFT mode in the white state is high because it is a normally white and achromatic LC mode. However, it is not low enough and highly angle-dependent in the black state, resulting in a low contrast ratio along the on- and off-axes. To resolve these issues, we consider employing a normally black twisted-VA mode with a well-optimized design [8]. We performed a numerical simulation and obtained the optimal orientation of the LC molecules, the optimal optical axis of the retardation films, and their retardation values. Figures 2, 3, and 4 show the conoscopic diagrams of the calculated reflectance or contrast ratio of each mode. They are simulation results when the ambient light is coming from the normal direction of the panel. The calculated values are normalized by those calculated in the normal direction. As shown in the figures, the range showing high reflectance in the white state of the twisted-VA mode is as large as that of the HR-TFT mode, although there are some differences in the shape of the bright areas. Additionally, the range showing low reflectance in the black state and the range showing a high contrast ratio of the twisted-VA mode are wider than those of the HR-TFT mode.

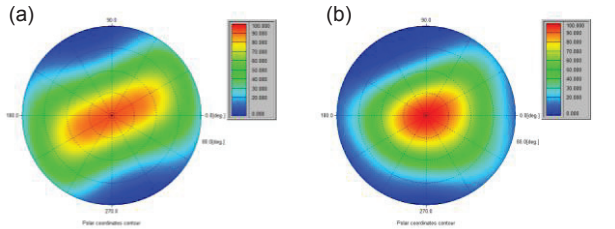

Fig. 2 Simulation results of reflectance in the white state: (a) HR-TFT mode, (b) twisted-VA mode

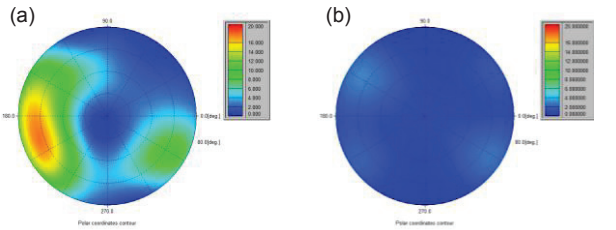

Fig. 3 Simulation results of reflectance in the black state:
(a) HR-TFT mode, (b) twisted-VA mode

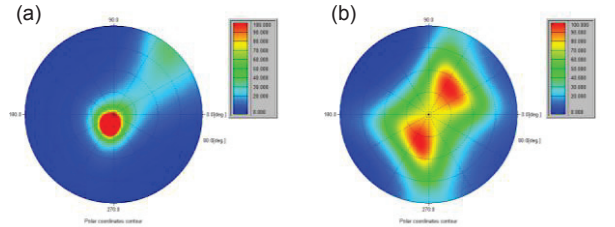

Fig. 4 Simulation results of contrast ratio:
(a) HR-TFT mode, (b) twisted-VA mode

Compared with the nontwisted-VA mode, the twisted-VA mode offers the following advantages when considering the realization of a transflective display: (1) an easy fabrication process and (2) high optical performance because of the high stability of the LC molecule orientation. These two advantages are derived from the fact that the same cell gap setting can be used for reflective and transmissive areas in the twisted-VA mode. Figure 5 shows the luminance variation as a function of the normalized cell gap for two modes in the white state: (a) the nontwisted-VA mode used in conventional transflective LCDs and (b) the twisted-VA mode we are studying. As shown in Fig. 5, we defined the cell gap of 1 as the gap when the brightest luminance was obtained in the reflective mode. For the nontwisted-VA mode, a cell gap of 2, i.e., twice the above gap, gives the highest luminance in the transmissive mode. In contrast, for the twisted-VA mode, the luminance reaches the highest at the same cell gap of 1 for the reflective and transmissive modes. Therefore, the twisted-VA mode can be designed with the same cell gap for the reflective and transmissive areas.

Figure 6 shows a comparison of the transflective LC panel structures: (a) conventional nontwisted-VA mode and (b) twisted-VA mode. In Fig. 6 (a), there is a step at the boundary between the reflective and transmissive areas. This step affects the LC alignment and decreases the optical characteristics, especially for high-resolution LCDs. However, in Fig. 6 (b), the structure of the twisted-VA mode has no steps, and a stable LC alignment suitable for high-resolution LCDs is obtained.

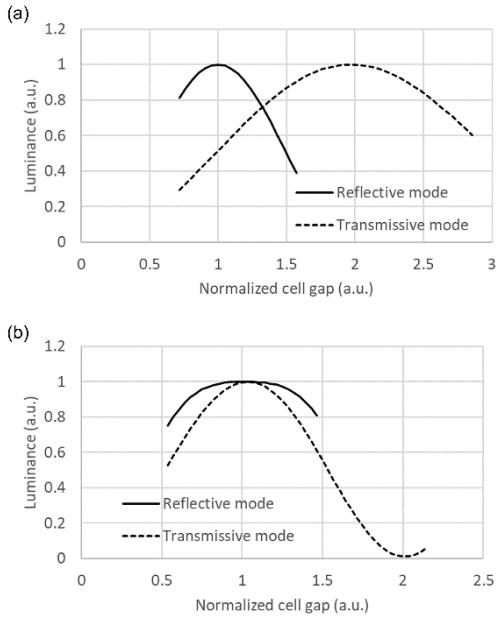

Fig. 5 Luminance variation as a function of cell gap:
(a)nontwisted-VA mode, (b)twisted-VA mode

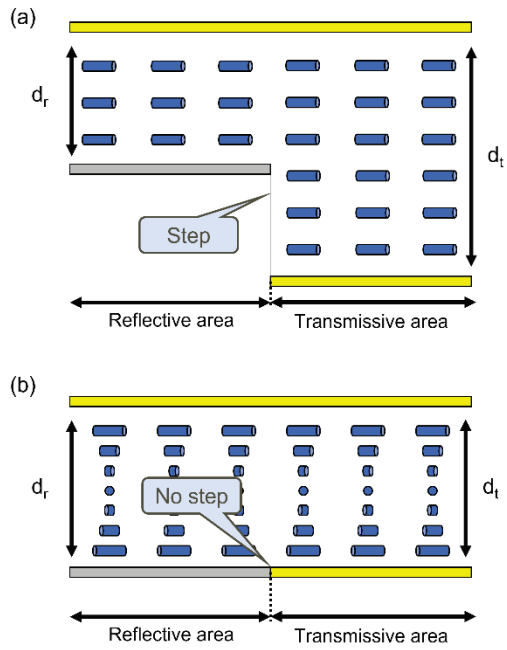

Fig. 6 Cross-section of the transflective LCD:
(a) nontwisted-VA mode, (b) twisted-VA mode

2.3 Challenges for large-sized applications

For large-sized applications, such as 90-inch, we first observed and analyzed the viewing angle characteristics of the twisted-VA mode that we developed in the past. The photographs in Fig. 7 show the viewing angle dependence of the 32-inch transflective LCD in the twisted-VA mode when operating as a reflective mode. We took photographs from a polar angle of 40°. The angle numbers in the photograph indicate the azimuthal angle of observation. As shown in the photograph, the display was dark at azimuthal angles of 90° and 120°, similar to the simulation results. These dark areas depend on the orientation direction of the LC layer.

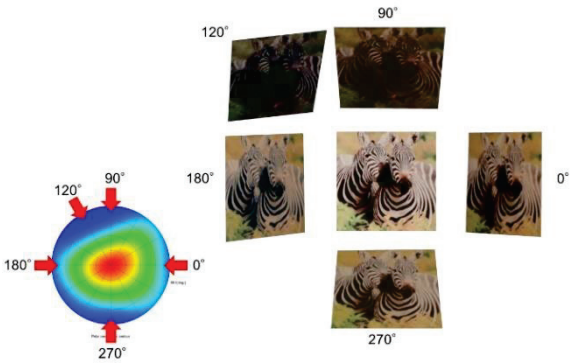

Fig. 7 Viewing angle characteristic of the twisted-VA mode when operating as a reflective mode

The viewing angle characteristics need to be improved because a large-sized display is viewed by multiple people. In this study, we attempted to apply our ultraviolet-induced multi-domain vertical alignment (UV^2A) technology to widen the viewing angle characteristics. UV^2A is a multi-domain photo alignment technology [9]. Figure 8 shows that the orientation of the photosensitive side chains is controlled by irradiating the photo-alignment layer formed on the substrate with P-polarized UV light from an oblique direction. When UV irradiation is performed several times using photomasks, a plurality of regions with different orientation directions are formed, and the LC molecules are oriented according to the photosensitive side chains. Therefore, a plurality of regions with different alignment directions of LC molecules are formed, and these regions compensate for each other's viewing angle characteristics. In this manner, UV^2A technology is used to widen the viewing angle characteristics of the transflective LCD.

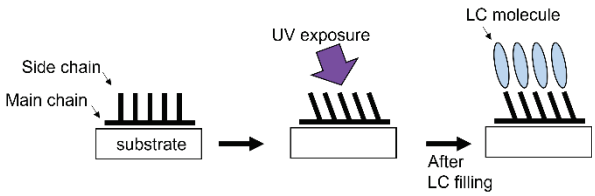

Fig. 8 Schematic illustration of alignment behavior

3 Design of Multi-domain

3.1 Reflective mode

We performed numerical simulations for two domains (domains 1 and 2) with different LC alignment directions. The alignment directions of the LC layers of domains 1 and 2 were set so that the azimuth angles of the dark viewing angles were symmetrical. Figures 9(a) and 9(b) show the calculated reflectance of domains 1 and 2 in the white state, respectively. Figure 9(c) shows the average of domains 1 and 2. As shown in Fig. 9(c), we found the darkest areas in domains 1 and 2, which disappeared with the multi-domain design, and the viewing angle characteristics became symmetric.

We built a 90-inch 2-domain reflective LCD prototype with the same configuration as the simulation results above and showcased the prototype at the Display Week 2023 venue (Figs. 10 and 11).

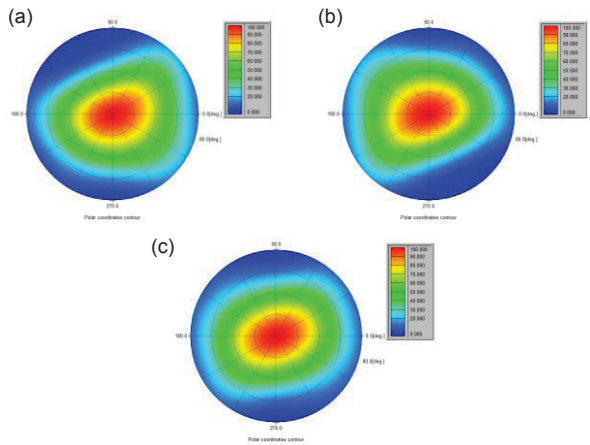

Fig. 9 Reflectance in the white state: (a) domain 1, (b) domain 2, and (c) 2-domain

Fig. 10 90-inch 2-domain reflective LCD prototype showcased at Display Week 2023

Fig. 11 Wide and symmetric viewing angle characteristics of a 2-domain reflective LCD prototype

3.2 Transmissive mode

As discussed above, the multi-domain approach is effective in improving the viewing angle characteristics of the reflective mode. Next, we will discuss whether the same approach can also improve the viewing angle characteristics of the transmissive mode. The photographs in Fig. 11 show the viewing angle dependence of the 32-inch transflective LCD when operating as a transmissive mode. The property is the same as that discussed for the reflective mode. Through numerical simulations, we found the darkest areas in domains 1 and 2, which disappeared with the multi-domain design (Fig. 12).

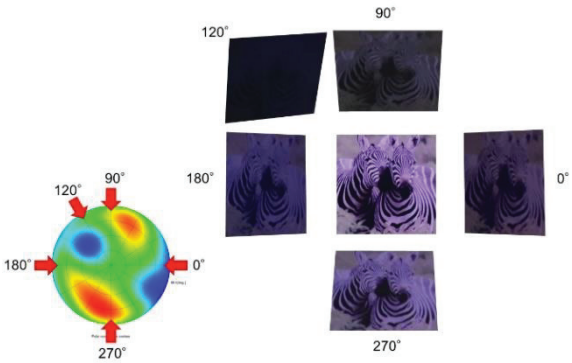

Fig. 11 Viewing angle characteristic of the twisted-VA mode when operating as a transmissive mode

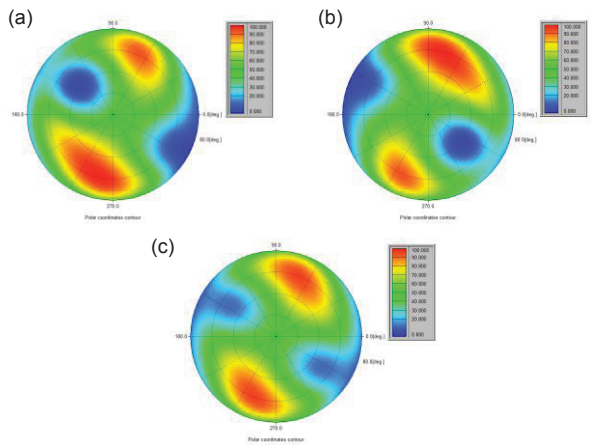

Fig. 12 Transmittance in the white state: (a) domain 1, (b) domain 2, and (c) 2-domain

4 Conclusions

In this study, we reviewed the optical design concept of wide-view transflective LCDs. We employed the twisted-VA mode in our new design to avoid the complexity of the multicell gap design and simplify the production process. We also proposed a multi-domain design utilizing UV^{2}A technology to expand the viewing angle for the reflective and transmissive modes. Based on these designs, wide-view characteristics and superior outdoor visibilities can be easily achieved. We truly believe that the newly-designed transflective LCD that combines the twisted-VA mode and UV^{2}A technology can be a promising candidate for large-sized outdoor signage applications.

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