Optimization of Transflective PVA Cell Structure for High Resolution Display

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Abstract

We optimized a patterned-vertical-alignment (PVA) transflective liquid-crystal (LC) cell for small pixel application. To achieve the high resolution display performance in the mobile communication equipments such as mobile phones, personal data assistants, and tablet personal computers, we optimized the parameters of liquid crystal and the electrode structure. Both the transmittance and the reflectance are maximized at the same time.

1. Introduction

A PVA mode liquid crystal display (LCD) has been studied as a useful transflective LCD mode [1-3]. Because of the vertical alignment and patterned eletrode, PVA mode can achieve the perfect dark state. The fringe field provides symmetric director distribution, which results in two domain structure naturally. In addition, the single cell-gap structure and rubbingless fabrication provides various merits in the fabrication processes [1-4].

Lately, since the mobile devices are one of the major issues, the research on a transflective LCD has been of wide interest [5-10]. Especially, as the digital multimedia broadcasting (DMB) services are emerged, the high resolution mobile display is required. However, the conventional pixel size (about 100 um) is too large to apply this mode to mobile display devices requiring high resolution performance. To achieve high resolution characteristics, we optimized device structure and parameters to apply to a small pixel. Parameters optimized for conventional structures cannot be applied to small pixel application, since small pixel size results in very different field distribution. So we varied LC parameters and the electrode pattern size to optimize the PVA mode for small pixel application.

2. Conventional transflective PVA cell

Figure 1 shows the conventional transflective PVA mode structure. The patterned electrode of the bottom substrate induces the fringe field which lays the director in different two directions. As use of the patterned electrode and LC alignment without rubbing process, the perfect dark state can be achieved. Multi-domain structure confirms wide viewing angle properties if the additional compensation films are employed.

The patterned electrode forms the periodic distribution of retardation in a LC cell. The small retardation region on the insulated mirror is used as the reflective part (r-part), while the large retardation region on the patterned electrode is used as the transmissive part (t-part). Both the t-part and the r-part are in the dark state initially because of the vertically aligned LC molecules and $\lambda/4$ wide-band retardation films (WRFs) between crossed polarizers.

With the electric field applied to the LC layer the retardation of the r-part over the insulated reflector is about $\lambda/4$, while the retardation of the t-part over the ITO is $\lambda/2$. The ambient light passed through the top polarizer is linearly polarized, which becomes circularly polarized light after passing through the WRFs. Its polarization direction changes during the round trip through the LC layer. Polarization of this light matches to the transmission axis of the top polarizer. So we can obtain the bright state in the r-part. In the t-part, although the top polarizer and WRF are crossed to the bottom polarizer and WRF, the LC retardation of t-part changes the polarization state resulting in the bright state in the t-part. With an additional negative C-plate, we could achieve the wide viewing angle properties of about 180° (CR = 30). By using WRFs we can obtain good spectral characteristics in both parts.

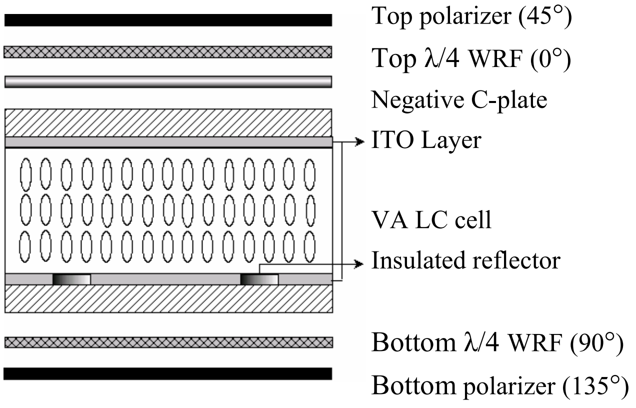


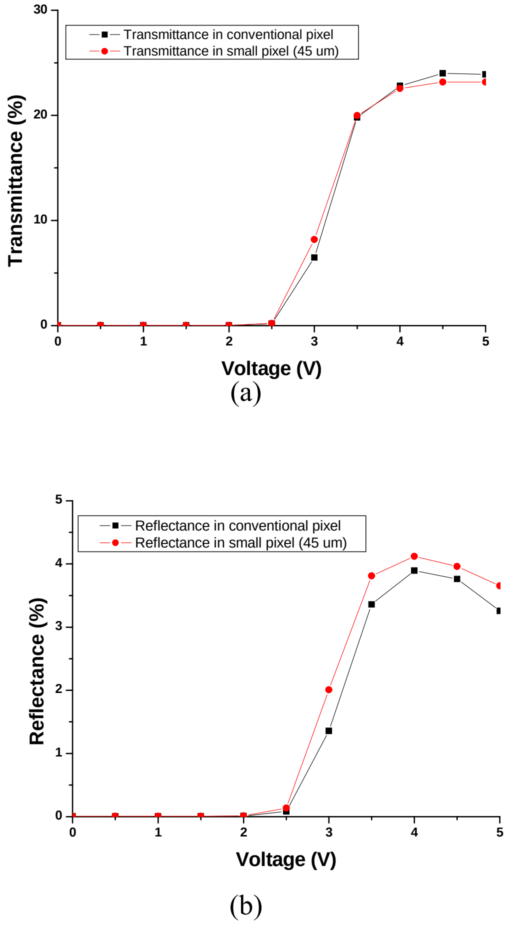
Fig. 1. Conventional transflective PVA mode structure.

3. Simulation Conditions and Results

We varied conditions such as the width of electrode, cell-gap, and optical anisotropy of LC, etc. We used the commercial software 'LCD master' for numerical simulations. The pixel size for high resolution displays is assumed to be 45 um. Because the PVA mode uses the fringe field effect of patterned electrodes, this effect becomes more dominant as the pixel size is smaller. We need to change the conditions optimized for the conventional pixel size for small pixel application. In addition, because only a small number of periods of the t- and r- parts can be included in a small pixel, the period is also needed to be optimized.

First, we calculated the transmittance and the reflectance of the t-part and the r-part as we vary the electrode width. We started with the LC material MDA-01-2306 (Merck Ltd., K_{11} = 14.7 pN, K_{33} = 16.8 pN, $\Delta\varepsilon$ = -5, Δn = 0.1204).

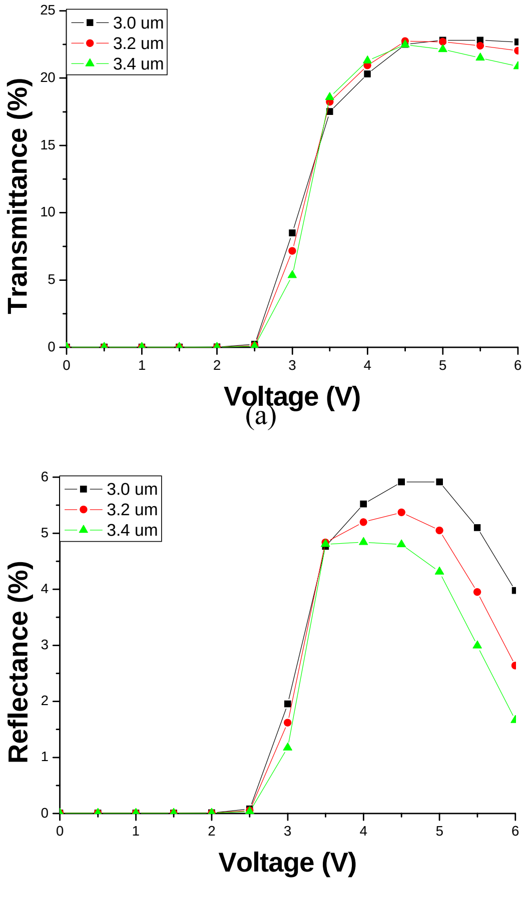
When we applied the previous pattern period to small pixel, the maximum transmittance and reflectance are different from the conventional size case as shown in Fig. 2. To ensure not too small reflective area, we calculated at the transmissive and reflective ratio of 3:1 and 4:1. We found that the electrode width of 10 num and gap of 5 um provides the best performance. Under this condition, other parameters were also optimized. We varied the cell gap to find the optimized condition. Figure 3 shows the optical properties with the electrode width and the cell gap, 10 um and 5 um, respectively, which exhibit the best optical properties, transmittance and reflectance. The reflectance is more sensitive to the cell gap variation.



(a)

(b)

Fig. 2. Optical properties of a small pixel (45 um) with parameters optimized for a large pixel (>100 um). (a) transmittance, (b) reflectance.



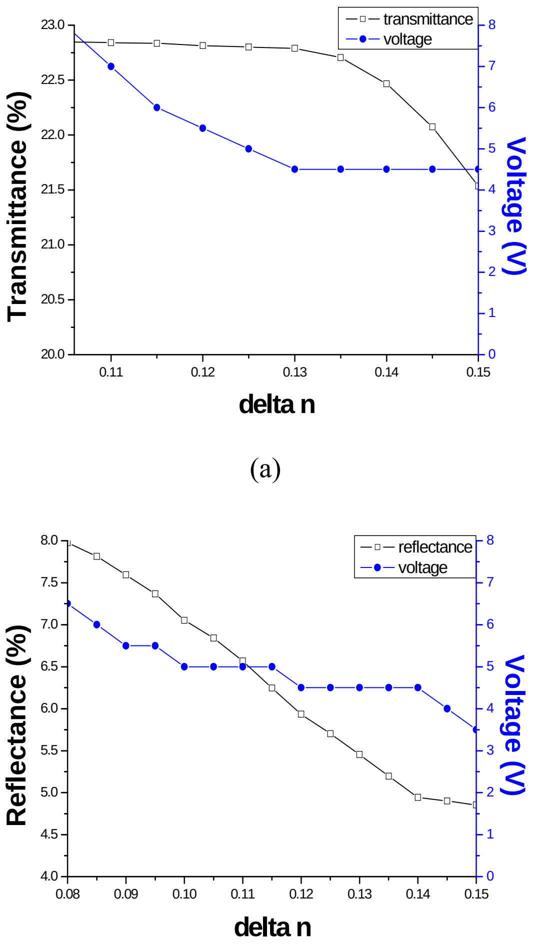
(a)

(b)

Fig. 3. Simulated electro-optical properties with the cell gap as a parameter. electrode width: 10 um, cellgap: 5 um. (a) transmittance, (b) reflectance.

We varied the optical amisotropy of LC. With a fixed cell gap of 3.0 um, we varied the value of Δn from 0.08 to 0.15 with increment of 0.005. Figure 4 shows variations of transmittance, reflectance, and saturation voltages versus Δn. In the t-part, the saturation voltage is less than 7 V if Δn is bigger than 0.11. The reflectance is higher than 5.9 % if Δn is smaller than 0.12. We varied Δn and $\Delta\varepsilon$, simultaneously. Moreover, K values of LC are also taken into account. Final optimized parameters are found as follows, the electrode width is 10 um, the insulated mirror width is 5 um, the cell gap is 3 um, optical anisotropy is 0.12, dielectric anisotropy is -5, K_{11} is 11.7 pN, K_{22} is 7 pN, and K_{33} is 19.8 pN, respectively. With these parameters, the electro-optical characteristics are shown in Fig. 5.

To improve the viewing angle property, the compensation film conditions are optimized. A negative C-plate with parameters of Δnd = 160 nm (n_x = n_y = 1.5 and n_z = 1.4984) ensures the wide viewing angle property about 180° (CR=30), as shown in Fig. 6.



(a)

(b)

Fig. 4. Maximum transmittance and reflectance at the saturation voltage versus the optical anisotropy of LC.

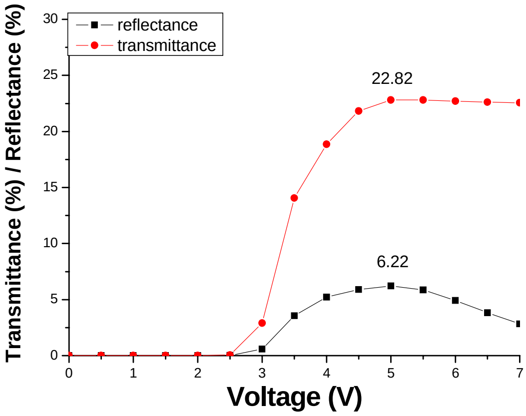
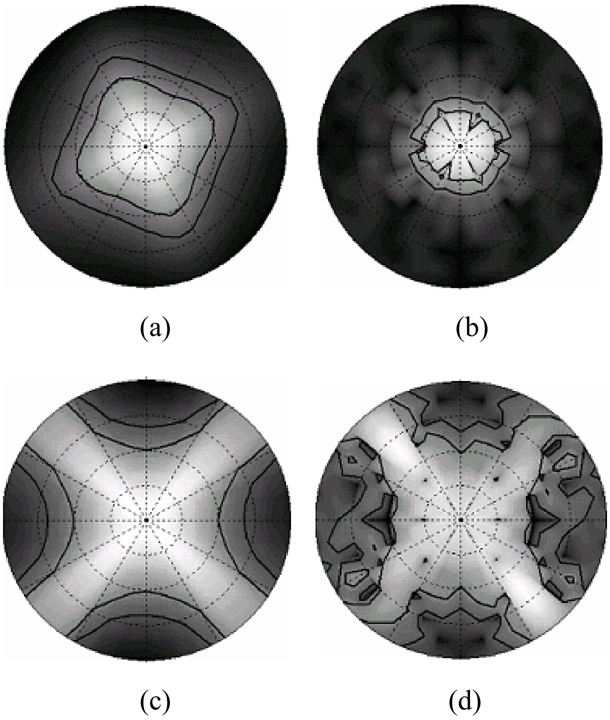


Fig. 5. Electro-optic characteristics with the optimized parameters.


(a) (b)

(c) (d)

Fig. 6. Viewing angle characteristics of the transmissive and reflective parts. Upper and lower figures are before and after compensation, left and right are t- and r-parts, and inner and outer lines correspond to CR of 30 and 10, respectively.

4. Conclusion

We have optimized the transflective PVA cell for high resolution displays. By optimizing optical anisotropy, dielectric anisotropy, etc. we achieved the transmittance of 22.82 % and reflectance of 6.22 %. Negative C-plate provided the wide viewing angle of 180° (CR = 30).

5. References

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