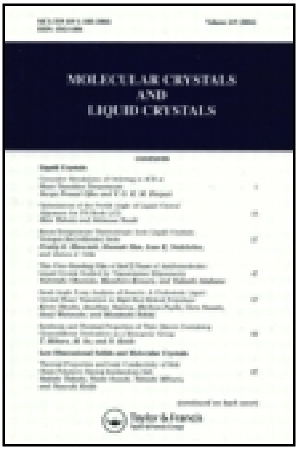

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Patterned Vertically Aligned Mode with a Single Cell Gap for Transflective Operation

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In this paper, we propose a novel patterned vertical alignment (PVA) architecture with a single cell gap for transflective operation of an LC cell. The proposed architecture has a feature wherein a chevron-shaped electrode is rotated by 90 degree in the counterclockwise manner in an effort to significantly improve the aperture ratio. Since the data line is located under the pixel electrode, we can efficiently eliminate the space between the data line and the pixel electrode. Our numerical simulation revealed that the aperture ratio of the proposed transflective PVA cell improves approximately by 4.8% over the conventional transmissive PVA cell.

Keywords: high aperture ratio; single cell gap; super-PVA; transflective mode

I. INTRODUCTION

Recently, the transflective-mode operation, which utilizes both transmissive mode and reflective mode, of liquid crystal (LC) display has attracted a great deal attention for the mobile displays because it is considered to improve the aperture panel characteristics under the natural light condition. More recently, the electrode architecture with patterned vertically aligned (PVA) electrodes has been proposed as a scheme to realize the periodicity of the fringe field distribution for the single cell gap transflective LCD operation [1–3]. The PVA

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architecture has a feature in that the initial vertical alignment of liquid crystal (LC) molecules guarantees the high contrast ratio (CR) in the regions for reflective operation as well as the regions for transmissive operation. We have undertaken this study in an effort to implement the transflective PVA mode with only a single voltage by optimizing the geometry of the electrode. We can also expect wide viewing angle property with using a C-plate for compensating the dark states of the vertical alignment [4].

II. ARCHITECTURE OF THE PIXEL UNIT

Figure 1(a) is a schematic diagram illustrating a cell layout of the conventional PVA architecture for transmissive operation. In Figure 1(b) is shown a cross-sectional view of the conventional transimissive PVA cell along the A-B line. We assumed that the pixel and common electrodes are made of transparent metal ITO (i.e., Indium-Tin Oxide) and an opaque metal is used for data line as well as the gate line. Referring to Figure 1(a), we also note that the region other than the data line and the gate line is the aperture region. Referring to Figure 1(b), we can see that many design parameters are defined. Here, W_C is the width of one pixel while W_P and W_D are the width of pixel electrode and data line, respectively. Further, W_M is the distance between the adjacent electrodes which should be optimized for the minimization of the interference due to fringing field.

Figure 2(a) and (b) are schematic diagrams illustrating the cell layout and the cross-section view of the proposed PVA cell. Referring to Figure 2(b), we can notice that the chevron-shaped ITO pattern of the proposed transflective PVA cell has been rotated by 90 degree in the clockwise manner and the data line is located under the pixel electrode at the center of the cell while the other device parameters such as the width of the ITO pattern, data line, and gate line are equal to those of the conventional transmissive PVA cell. Since the data line is located under the pixel electrode, we can efficiently eliminate the space between the data line and the pixel electrode. It should be noted, however, we should process an extra lithography step because the data line is not formed in the same plane with the pixel electrode.

If the cell size of transmissive PVA (Figure 1) is identical to that of the transflective PVA (Figure 2), the aperture ratio will be also the same. We should note, however, the aperture ratio will be affected by the size of the black matrix (BM) in practical situation. In order to protect a light leakage due to the inter-electrode disclination, we should inevitably employ the BM pattern as shown in Figures 1(b) and 2(b). Referring to Figure 1(b), we can see that the A-B horizontal

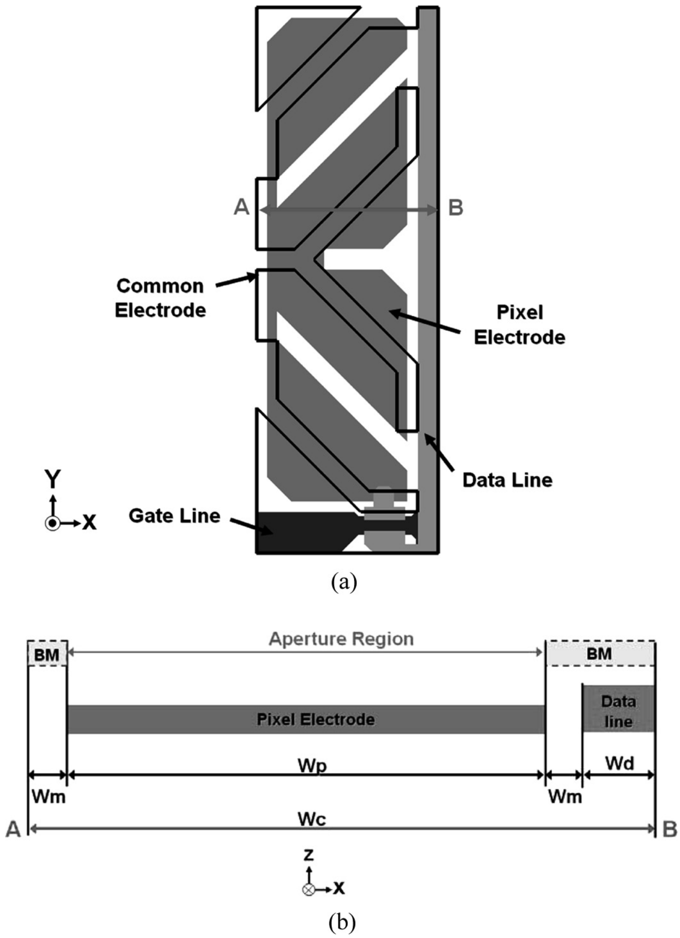


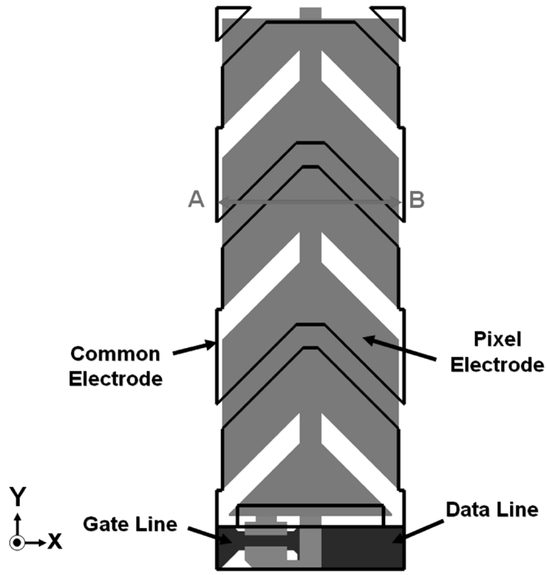
FIGURE 1 (a) Cell layout illustrating the conventional PVA architecture for transmissive operation; (b) Cross-sectional view along the horizontal A-B line in Figure 1(a) illustrating the device geometry for optimization process.

length of the aperture region for the conventional transmissive PVA mode is given by the following formula:

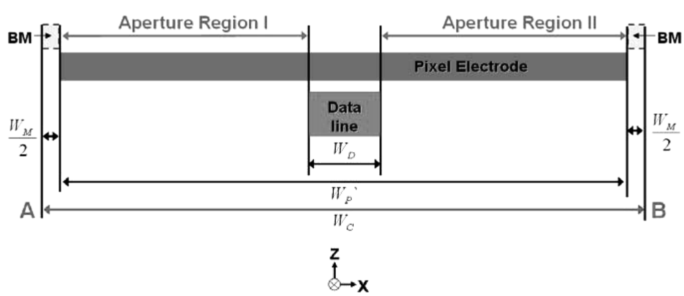
$$W_C - (2 \cdot W_M + W_D).$$

In the meanwhile, the A-B horizontal length of the aperture region for the proposed transflective PVA mode is given by the following formula:

$$W_C - \left(2 \cdot \frac{W_M}{2} + W_D\right)$$



(a)



(b)

FIGURE 2 (a) Cell layout illustrating the proposed PVA architecture for transflective operation; (b) Cross-sectional view along the horizontal A-B line in Figure 2(a) illustrating the device geometry for optimization process.

Consequently, we can notice that the proposed transflective PVA cell will provide an architecture which has the wider aperture region than the conventional transmissive PVA cell. Referring to Figures 1(a) and 2(a) again, we assumed that the pixel size is $88\,\mu m \times 264\,\mu m$. The BM mask is designed in such a way that it is drawn $5\,\mu m$ inside the pixel electrode and $10\,\mu m$ width of the date line. The aperture ratio of the conventional tranmissive PVA cell is calculated to be 55.9% while the proposed transflective PVA cell come up with approximately 60.7%. Consequently, we can see that the aperture ratio of the proposed transflective PVA cell has been improved approximately by 4.8% over the conventional transmissive PVA cell.

Referring Figures 1(a) and 2(b), we can observe that the proposed transflective PVA cell comprises an ITO pattern of chevron shape which is rotated by 90 degree in the clockwise direction while the data line runs under the pixel electrode and at the center of the cell. Since the data line runs beneath the pixel electrode, we do not need extra space between the data line and the pixel electrode.

The reflector is prepared at the center of the cell vertically in such a way that it overlaps with the data line, which results in two advantageous outcomes. Firstly, we can eliminate the space between the adjacent electrodes to avoid interference due to fringing electric field, which makes it possible to achieve the wider aperture region than the conventional PVA cell with higher transmittance. Secondly, we can locate a reflector on the data line which causes the dark region in the transmissive mode [5].

In this work, we assumed that the reflector is made of an insulator, which implies that the electric field pattern from the chevron shape is not appreciably affected by the presence of the reflector. In case when the reflector is made of metal, we can eliminate the effect of the metal reflector on the electric field pattern by shaping the reflector to the chevron pattern. In addition, the width of the reflector is extended for the purpose of sustaining prior ratio of the reflect region.

Figure 3 is a schematic diagram illustrating the transflective PVA mode operation. The proposed transflective cell, which is interposed between the two glass substrates, is sandwiched by a couple of circular polarizer, one for linear polarizer and the other for broadband quarter-wave plate. Each broadband quarter-wave plate is comprised of a narrow-band half-wave film and quarter-wave film with their optic axes inclined at 60°. To compensate the dark state viewed at off-axis, a negative C plate is laminated between the broadband quarter wave plate and the top substrate.

For our numerical analysis of molecular behavior of liquid crystals, we employed three-dimensional finite element method (3D-FEM) numerical solver software, 'TechWiz LCD,' the numerical engine is based on the solution of Ericksen-Leslie equations and 2×2 Jones matrix scheme for the optical analysis [6,7].

Figure 4 is a plot illustrating the calculated light transmittance and reflectance as a function of voltage at $\lambda = 550$ nm. We depicted the V-T and R-T curves in an arbitrary normalized unit. Referring to Figure 4, we can see that T-mode as well as R-mode reaches its maximum when

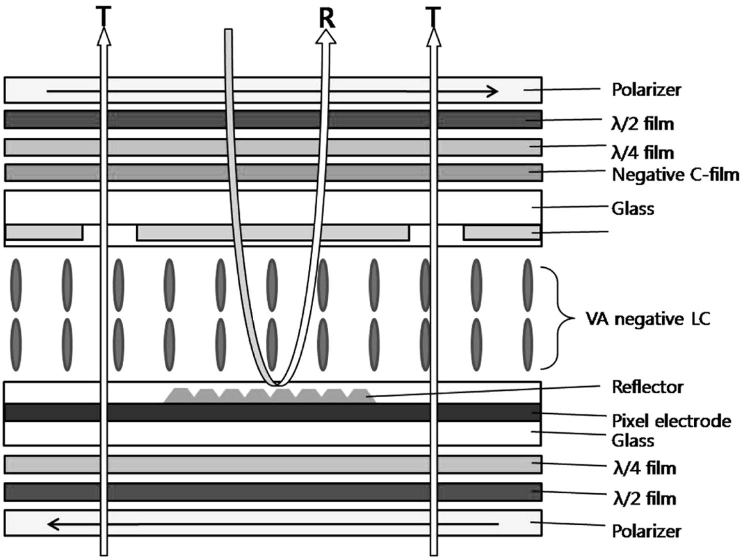


FIGURE 3 Schematic diagram illustrating the transflective PVA mode operation.

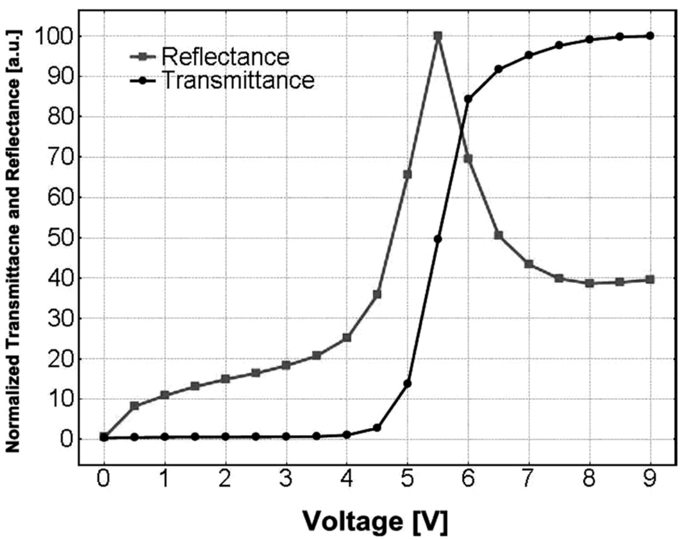
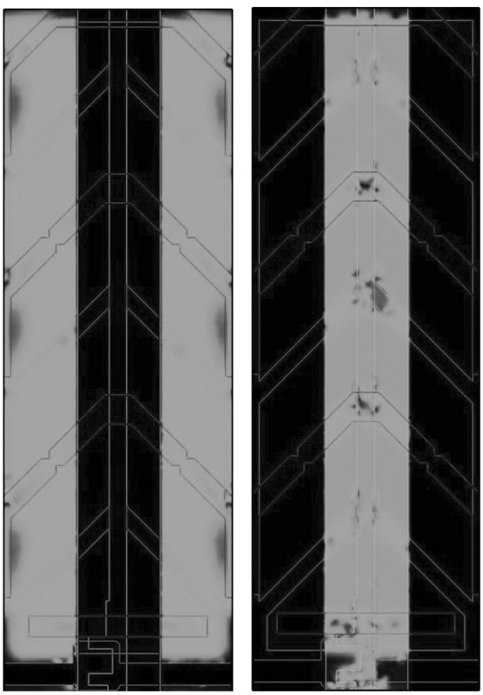


FIGURE 4 Plot illustrating the calculated V-T and V-R curves under normal incidence at a wavelength of 550 nm.

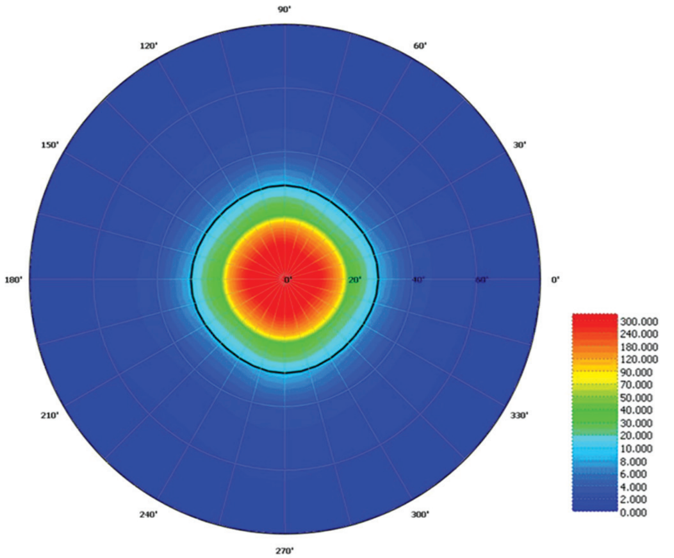
the applied voltage approaches 5.5 ~ 6 V. This implies that we can realize the cell architecture for transflective mode with only a single driving voltage. Referring to Figure 4, we can also recognize an appreciable disparity between the normalized transmittance of the transmissive part and the normalized reflectance of the reflective part, which is, however, can be suppressed by the optimization of the geometry of the chevron shape of the electrode in the reflection region.

Figure 5(a) and (b) are schematic diagrams illustrating the calculated light transmittance of the aperture for transmissive region only with backlight as a light source, and for reflective region only with ambient light as a light source, respectively. The light transmission images were calculated with the same voltage being assumed to be applied. As shown in Figure 5, the particular dark region of conventional S-PVA cell disappears at chevron shape. The decreased dark

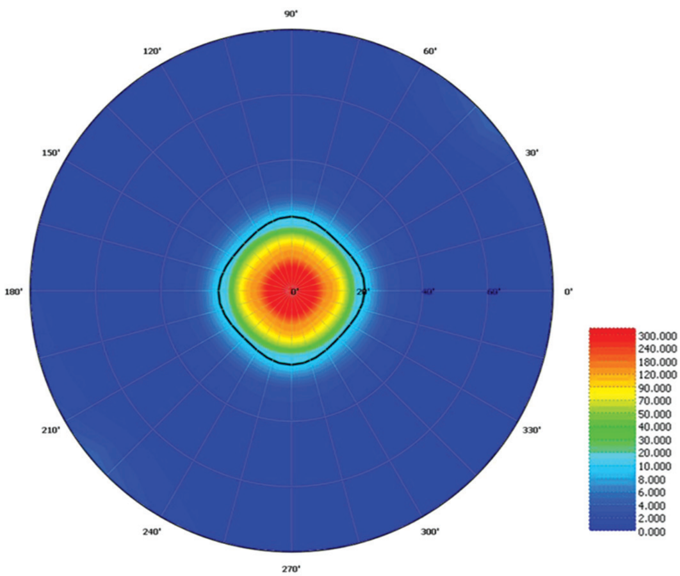


(a) (b)

FIGURE 5 (a) Schematic diagram illustrating the calculated light transmittance of the aperture for transmissive region only with backlight as a light source; (b) Schematic diagram illustrating the calculated light transmittance of the aperture for reflective region only with ambient light as a light source.



(a)



(b)

FIGURE 6 (a) Polar plot illustrating the contrast ratio (CR) for transmissive mode; (b) Polar plot illustrating the contrast ratio (CR) for Reflective mode.

region would increase transmittance and reflectance. Figure 6 is a polar plot illustrating the CR property for the proposed transflective LC cell. Figure 6(a) represents the CR calculation for the transmissive mode while Figure 6(b) exhibits the reflective mode. To compensate the contrast ratio, we employed an optical compensation film, negative C plate. The result shows that the contrast ratio and view angle are similar to each other. Furthermore, we can see the uniform contrast ratio characteristics of the polar angle.

III. CONCLUSION

In this paper, we propose a novel architecture for transflective PVA which ensures the improved aperture ratio, higher light transmittance over the conventional transmissive PVA mode cell. The proposed PVA cell employs a modified ITO patterns wherein chevron-shape electrode is rotated by 90 degree in the clockwise direction while the data line runs under the pixel electrode and at the center of the cell. Since the data line runs beneath the pixel electrode, we do not need extra space between the data line and the pixel electrode. The reflector is prepared at the center of the cell vertically in such a way that it overlaps with the data line, which results in two advantageous outcomes. Firstly, we can eliminate the space between the adjacent electrodes to avoid interference due to fringing electric field, which makes it possible to achieve the wider aperture region than the conventional PVA cell with higher transmittance. Secondly, we can locate a reflector on the data line which causes the dark region in the transmissive mode.

REFERENCES

[1] Toko, Y., Sugiyama, T., Katoh, K., Limura, Y., & Kobayasi, S. (1995). *J. Appl. Phys.*, *34*, 2396.
[2] Kwang, J. O., Shin, K. C., & Kim, S. S. (2000). *SID*, 256.
[3] Oh-e, M. & Kondo, K. (1995). *Appl. Phys. Lett.*, *67*, 3895.
[4] Takeda, A., Kataoka, S., Sasaki, T., Tsuda, H., Ohmuro, K., Sasabayashi, T., & Okamoto, K. (1998). *SID*, 1077.
[5] Lee, C. S., Yoon, H. J., Yoon, S. I., Jung, M. S., Kim, D. W., & Won, T. (2005). *SID'05*, 982–985.
[6] Yoon, S. H., Yoon, S. I., Lee, C. S., Yoon, H. J., Choi, M. W., Kim, J. W., & Won, T. (2003). *IDW'03 Proceedings*, 49–52.
[7] Youn, H. J., Lee, C. S., Jung, M. S., Yoon, S. H., & Won, T. (2005). *IMID'05 Digest*, 515–518.