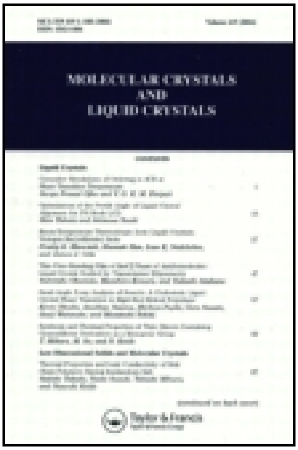

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Patterned Vertical Alignment Liquid Crystal Cell with Crossed Stripe-Electrode Patterns

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We propose crossed stripe-electrode patterns for a vertically-aligned liquid crystal (LC) cell. The proposed electrode structure forms the radial LC distribution with the point singularity $S = +1$ in the presence of the applied electric field, resulting in the wide viewing angle characteristics as well as the reduced color-shift compared to the conventional patterned vertical alignment (PVA) cell. Moreover, the radial LC distribution with the point singularity results in an increased transmittance compared to the conventional PVA cell, because the region with zero transmittance only occurs at the singular point.

Keywords: color shift; liquid crystal display mode; patterned electrode; vertical alignment

Liquid crystal displays (LCDs) have various advantages such as thinness, lightness, and low power consumption compared to the conventional cathode-ray-tube (CRT) display devices. Such merits make them possible not only to lead the mobile display devices but also to join as a candidate for the large-sized display markets. To compete with CRTs in TV markets, many efforts have been invested to overcome the problems of LCDs such as response time, viewing

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angle, contrast ratio, color-shift, etc. Advanced driving methods and optical compensation methods solve much of these problems, whereas the color-shift phenomenon at off-axes is still required to be improved to reach the superior color sense of CRTs [1–6].

LCD modes based on vertical switching show bigger color-shift than those based on horizontal switching, such as the in-plane switching (IPS) and the fringe-field switching (FFS) modes [7–8]. Because the retardation value for a specific gray level varies more sensitively with the incident angle, the vertical switching modes show relatively poor performance in the color-shift point of view, than that of the horizontal switching modes. For the patterned vertical alignment (PVA) case, the multi-domain structure has been investigated to reduce the color-shift, so-called super PVA (S-PVA) mode [9]. In S-PVA mode each pixel is divided into two domains and each of them has different tilt angles in grey, *i.e.*, θ_A and θ_B, so that the color-shift is depressed at off-axes. Nevertheless that problem in the PVA mode is still an issue.

In this article, we propose a PVA mode with crossed electrode patterns as shown in Figure 1. The stripe-patterned electrodes are aligned perpendicular to each other so that the symmetric fringe-field is induced with applied voltages, resulting in radial liquid crystal (LC) distribution with the point singularity $S = +1$. Continuously formed tilt angles and radial LC distribution in a grey level are expected to result in reduced color-shift. Moreover, by using our electrode structure for the PVA mode, the transmittance is also expected to be increased. Areas between domains in the conventional PVA mode remain dark even in the bright state, which is caused from the artificial formation of 4-domains, *i.e.*, $\pm 45^\circ$ and $\pm 135^\circ$, while our

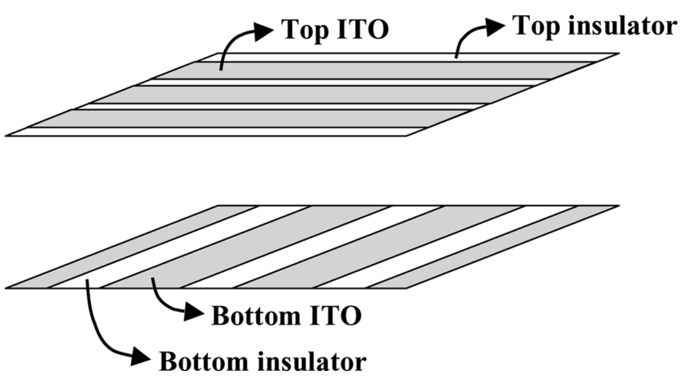


FIGURE 1 Proposed electrode structure for the PVA mode, where the stripe patterned top and bottom electrodes are perpendicular to each other.

structure can induce multi-domain structure without division of domains. With the illustrated electrode structure, we used the circular polarizer to prevent the decrease of brightness caused from the radial domain structure.

For numerical calculation, commercially available 3-D software, TechWiz LCD, was used. The procedure starts with drawing the overall layout including transparent electrodes and insulated gaps for patterning. We assumed the width and the gap of electrodes as 60 μm and 5 μm, respectively, which make the stripe patterns. Stripe patterns of top and bottom electrodes are aligned perpendicular to each other so that we could induce the fringe-field with 4-fold symmetry in the presence of an applied electric field, resulting in the multi-domain distribution of LC in the bright state. The negative LC (MDA-01-2306, Δn: 0.1204, $\Delta\varepsilon$: -5) is used and the cell-gap is assumed to be 3 μm for numerical simulation.

The top views of LC directors are shown in Figure 2. When we see the directors of vertically aligned LC in the absence of applied voltages, they may seem to be a circle. Then, if the stripe patterned electrode forms 1-directionally symmetric fringe-field, the directors may lie along the direction of the stripe pattern, as shown in Figure 2(a). As one can see, the disclination occurs at the symmetric lines on the

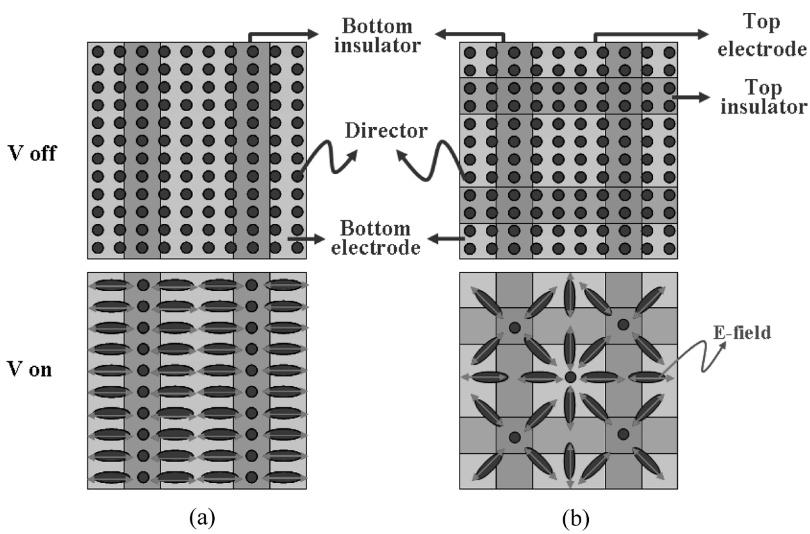


FIGURE 2 Top views of cells, (a) conventional stripe electrode pattern, (b) the proposed structure. The director of vertically aligned LC is indicated as a circle when the voltage is absent.

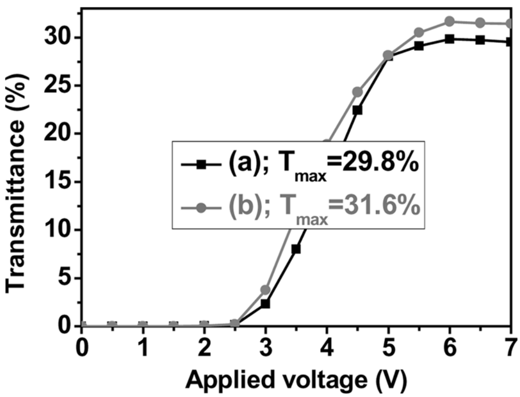


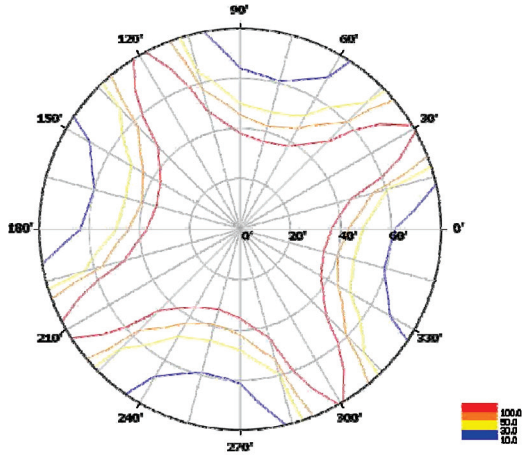
FIGURE 3 Simulated electro-optic characteristic of PVA cells, (a) conventional stripe electrode pattern, (b) the proposed structure. Both cells show maximum transmittance at 6 V and the transmittances at that voltage are shown in the box.

gaps of electrodes. On the other hand, if the proposed electrode structure is used, the directors may lie when the voltage is applied and they seem to be as shown in Figure 2(b). Actually, the light transmission with the LC distribution shown in Figure 2(a) is higher than that shown in Figure 2.

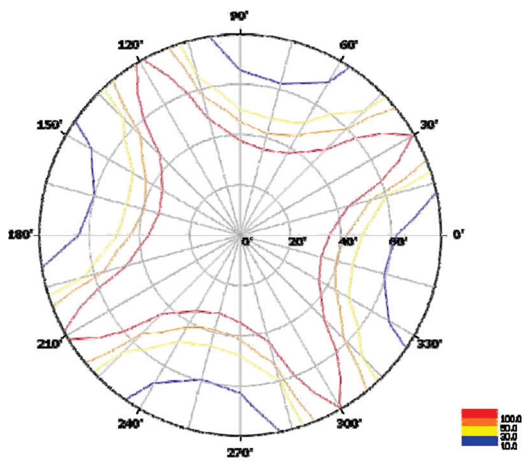
Figure 3 shows the electro-optic characteristics of simulated structures. The transmittance of a cell with proposed electrode structure is higher than that with the conventional stripe electrode pattern. As shown in Figure 2, the zero transmittance lines are gathered around specific points. As a result, the transmittance of proposed structure is higher than that of the structure with conventional stripe electrode pattern.

Figure 4 shows the viewing angle characteristics. Both structures show almost the same iso-contrast contours. For the viewing angle compensation, an optimized negative C plate is inserted into both cells. The color-shift characteristics are different as shown in Figure 5. The $\Delta u'v'$ values in CIE-1976 coordinate system versus the polar angle is calculated. From the figure, we can confirm the reduced color-shift in the cell with proposed electrode pattern. The radial and continuous multi-domain shows reduced color-shift without additional effort such as that used in the S-PVA mode.

The assembly of stripe-electrode patterned top and bottom substrates allows us to obtain increased transmittance and reduced color-shift, as described above. One additional advantage is that we



(a)



(b)

FIGURE 4 Simulated viewing angle characteristics of cells, (a) conventional stripe patterned electrode, (b) the proposed structure. The results show almost the same iso-contrast contours. Red (innermost), orange (inner), yellow (outer), blue (outermost) lines indicate the contrast limit of 100: 1, 50: 1, 30: 1, and 10: 1, respectively.

may be free from the error when aligning the both substrates. The errors in alignment causes unexpected and/or distorted operation such as reduced transmittance, slow response time, higher driving voltages.

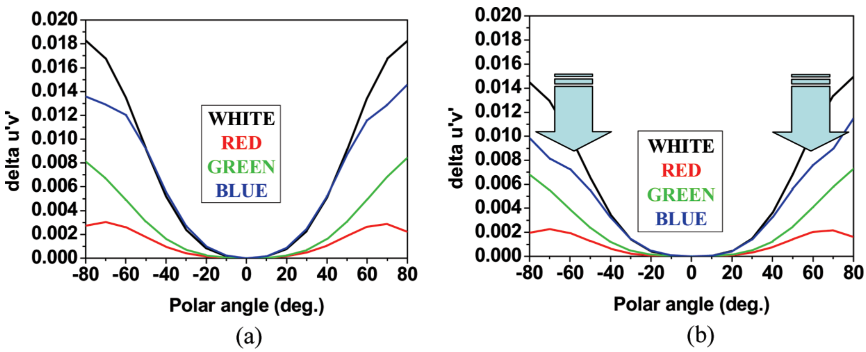


FIGURE 5 Color-shift characteristics at an angle of 45° to the transmission axes of crossed polarizers. (a) Conventional stripe patterned electrode, (b) the proposed structure.

Conventional chevron-shaped PVA pixels with stripe-electrode patterns require high precision of alignment, while mutually crossed top and bottom electrodes with both stripe electrode patterns perpendicular to each other is easier to align. The key effect of this structure is the formation of a fringe-field with the 4-fold symmetry so that the precision in assembling the substrates is relatively easy.

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