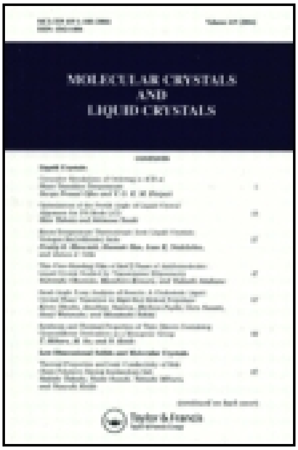

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Modeling and Simulation on Poly-Rubbing for Multi-Domain LC Mode

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In this paper, we report our numerical study on a novel poly-rubbing process which employs more than one rubbing condition on the same boundary surface of liquid crystal for implementing a multi-domain. A compact surface anchoring model was implemented in a commercially available 3D finite element method (FEM) numerical solver, TechWiz LCD, for calculating the director distribution of molecules and optical characteristics of a pixel structure. Our surface anchoring model was tested by investigating the director distribution of the Vertical Alignment (VA) and Electrically Controlled Birefringence (ECB) mode cells with poly-rubbed surface. The size of each pixel was $88 \times 264\,\mu m^2$ while the cell gap is $4\mu m$. Our numerical simulation implied that LC mode with poly-rubbed surface can provide a viewing angle as good as that of the conventional PVA cell having a complicated electrode structure.

Keywords: ECB mode; FEM; multi-domain; poly-rubbing; surface anchoring; VA mode

I. INTRODUCTION

Multi-domain mode has attracted a great deal of attention due to its superior viewing-angle characteristics especially for LCD TVs. Many researchers devised novel schemes for implementing the multi-domain

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mode such as PVA (Patterned Vertical Alignment), MVA (Multi domain Vertical Alignment), IPS (In-Plane Switching), FFS (Fringe Field Switching), and so forth. Since these novel schemes, however, are based on a quite complicated electrode structure, the fabrication process becomes more sophisticated and comprises a further advanced process step like a protrusion.

Now, the alignment of liquid crystal (LC) molecules at the interface between the electrode and the liquid crystal layer is controlled by the so-called rubbing process [1,2]. Recently, some research groups tried to realize the multi-domain in the LC region through making the alignment of LC molecules at the interface in an inhomogeneous manner, which we call poly-rubbing. For instance, the surface can be divided into two regions and different rubbing directions are provided for each region for implementing two domains of director distribution. Therefore, the pre-tilt of LC alignment, which is a tilt angle of the LC axial director away from the plane of the surface [1], can be adjusted differently for each region for its own domain formation by independent rubbing directions.

In this paper, we present our theoretical study on the implementation of multi-domain mode through a poly-rubbing technique for the first time according to our knowledge. Our surface anchoring model for poly-rubbing was embedded into the commercial 3D FEM solver, TechWiz LCD [3].

II. SIMULATION AND RESULTS

In this work, we chose two exemplary pixel structures, the Vertical Alignment (VA) and Electrically Controlled Birefringence (ECB) mode [4], in order to verify the validity of our model. Figure 1 is a schematic diagram illustrating the initial LC alignment for VA and ECB modes, respectively, with the present poly-rubbing technique. It is noted that the disclination region of LC molecules, which is produced by domain wall, is depicted at the center of each cell. In case of the VA mode, which is normally black, LC molecules are pre-tilted with θ degrees from the x-axis through the rubbing process. As a consequence, multi-domain of LC molecules is formed through the vertical electric field at the on-state.

For the case of ECB mode, which is normally white, the LC molecules are similarly pre-tilted with θ degrees from the x-axis through the rubbing process. However, it should be noted that the LC molecules have multi-domain through the initially pre-tilted alignment at the off-state.

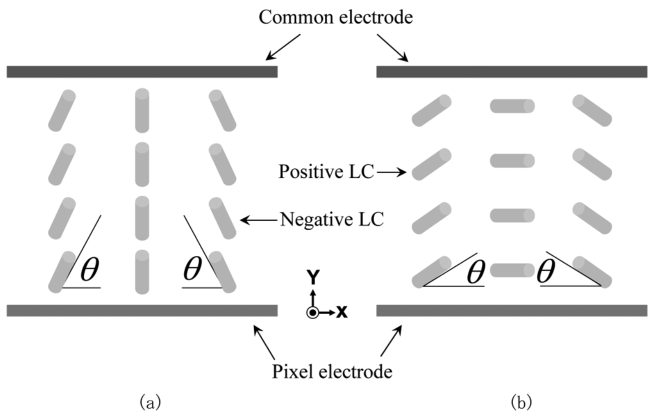


FIGURE 1 Schematic diagrams of initial LC alignment for VA and ECB mode: (a) VA mode, (b) ECB mode.

Figure 2(a) is a schematic diagram illustrating the layout of the cell structure employed in this study. It should be noted that the cell structure for the VA and ECB mode is the same. The size of each cell is $88 \times 264\,\mu m^2$ while the cell gap is $4\,\mu m$. The pixel electrode is located at the top while the common electrode is located at bottom substrate. Furthermore, we implemented a black matrix (BM) at the center and along the peripheral edge of the cell in an effort to block the light leakage between data line and pixel electrode, domain wall by LC molecules. Figure 2(b) is a schematic diagram illustrating the rubbing directions (poly-rubbing) for multi-domain in each cell. In this example, our cell has four different rubbing directions in each of four segments, A, B, C, and D.

In Table 1 is shown a list of boundary conditions for LC molecules located at each of four different regions with different rubbing directions. Here, θ represents a pre-tilt angle of LC molecules at the top and bottom electrodes, while Φ represents a twist angle of LC molecules. The pre-tilt angles are set $\theta = 89^\circ$ for VA mode and $\theta = 1^\circ$ for ECB mode, respectively. In case of the ECB mode, surface anchoring of LC alignment affects director distributions for the on-state because the directors at the surface of electrode are fixed with an anchoring energy [5]. Consequently, the anchoring energy for the strong anchoring case is assumed to be 10^{-3} N/m strong while 10^{-5} N/m for the weak anchoring case in order to consider the ECB mode.

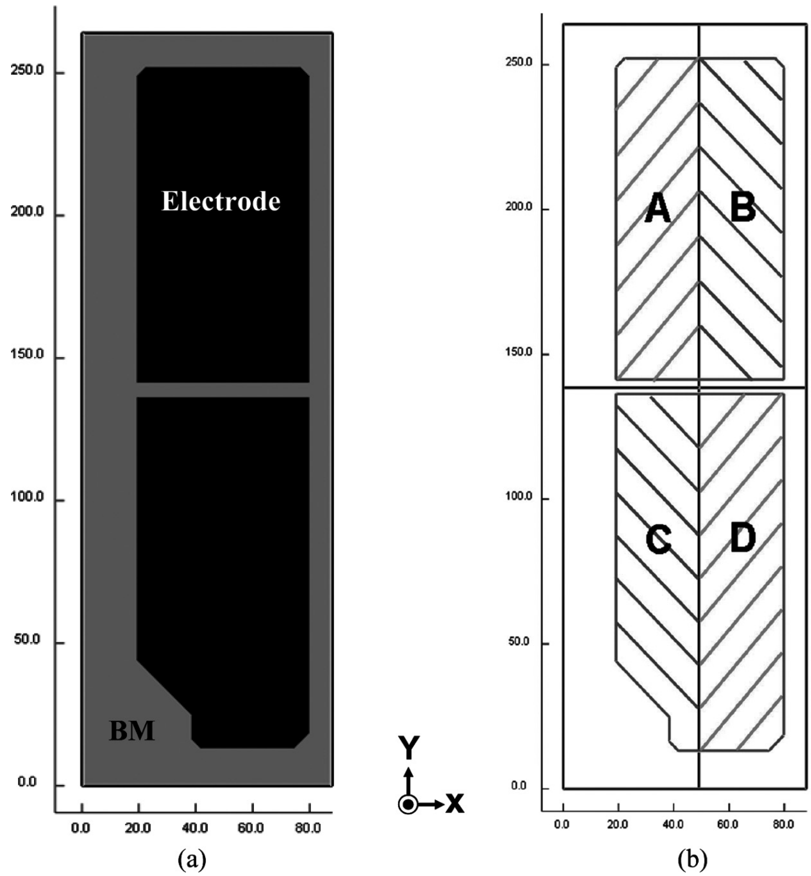


FIGURE 2 Cell structure and rubbing directions: (a) structure of VA and ECB mode, (b) Rubbing directions for multi-domain.

TABLE 1 Boundary Conditions of LC Molecules by Different Rubbing Directions

	A	B	C	D
VA mode	$\Phi=45^\circ$ $\theta=1^\circ$	$\Phi=135^\circ$ $\theta=1^\circ$	$\Phi=-45^\circ$ $\theta=1^\circ$	$\Phi=-135^\circ$ $\theta=1^\circ$
ECB mode (10^{-5} N/m weak anchoring)	$\Phi=45^\circ$ $\theta=89^\circ$	$\Phi=135^\circ$ $\theta=89^\circ$	$\Phi=-45^\circ$ $\theta=89^\circ$	$\Phi=-135^\circ$ $\theta=89^\circ$
ECB mode (10^{-3} N/m strong anchoring)	$\Phi=45^\circ$ $\theta=89^\circ$	$\Phi=135^\circ$ $\theta=89^\circ$	$\Phi=-45^\circ$ $\theta=89^\circ$	$\Phi=-135^\circ$ $\theta=89^\circ$

For estimating the dynamic movement of LC molecules, the finite element method was applied to solve the Erickson-Leslie equation. Optical characteristics were extracted by employing the conventional 2×2 Jones Method for wide range of wavelengths. A light transmission, contrast ratio, viewing angle dependence, and so forth were monitored for each mode cell with poly-rubbing.

Figure 3 is a diagram illustrating the light transmittance for the VA cell at the on-state and for the ECB cell at the off-state, respectively. It seems like the BM effectively blocks the light leakage at the disclination region between the pixel and data line as well as in the domain wall region of LC molecules due to the effect of the poly-rubbing technique. Moreover, the simulation results reveal that each mode cell exhibits the similar transmission distribution.

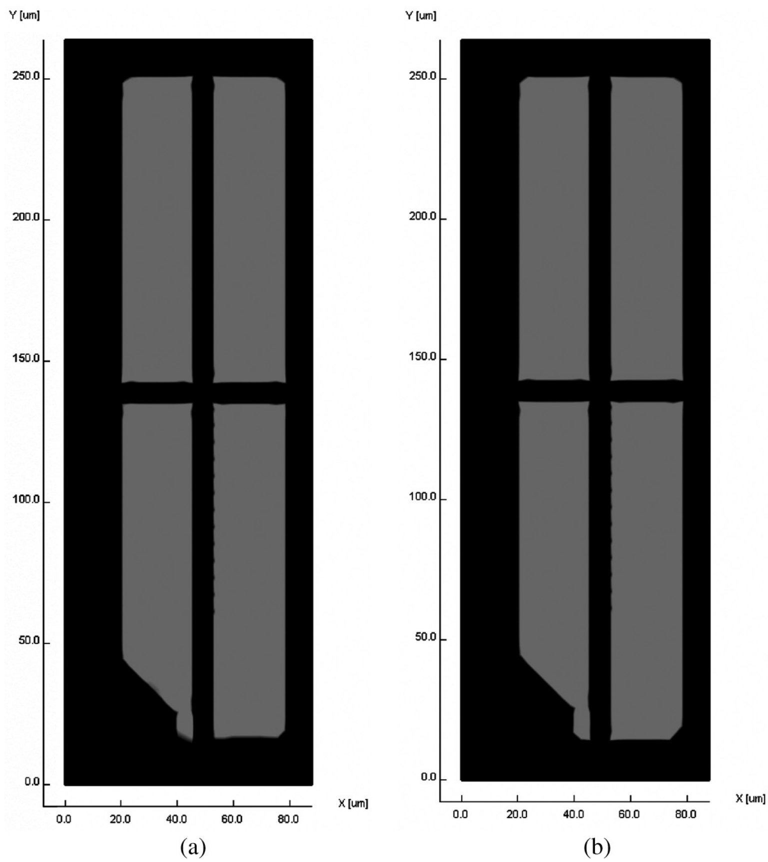


FIGURE 3 Light transmission: (a) VA mode, (b) ECB mode.

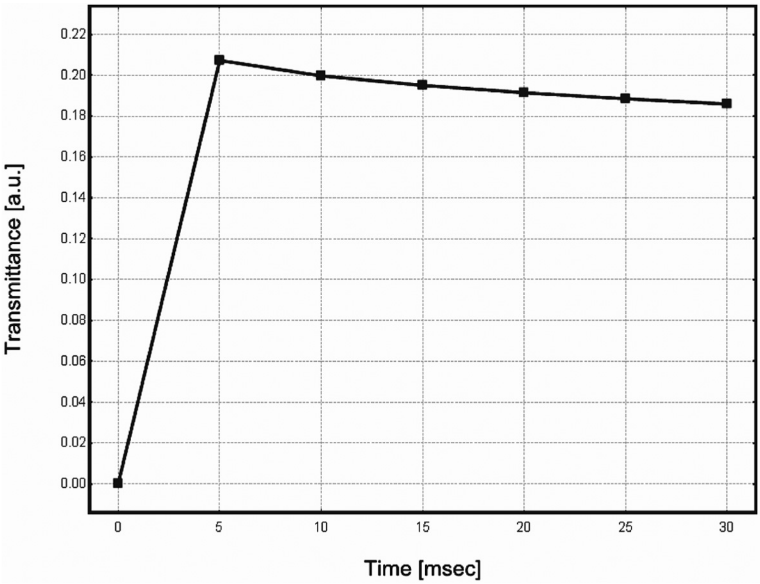


FIGURE 4 Transmittance data of VA mode.

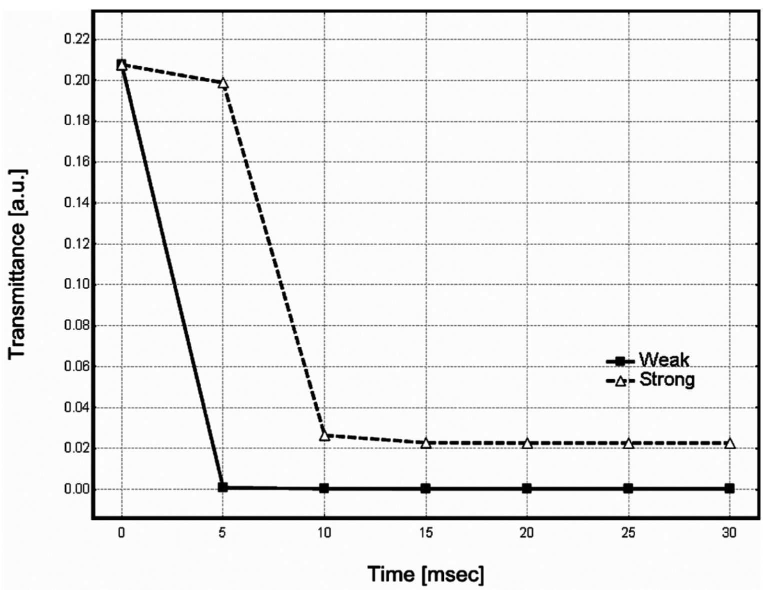
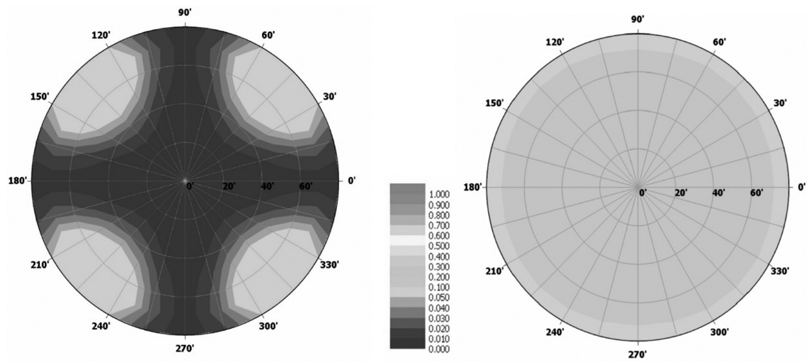


FIGURE 5 Transmittance data of ECB mode for the case of weak and strong anchoring.



(a) (b)

FIGURE 6 Polar plots for transmittance of PVA mode as a function of the viewing angle: (a) Off-state, (b) On-state.

In order to clearly define the transmission characteristics among each mode cell, the transmittance data is presented as a function of time in Figures 4 and 5. Referring to Figure 4, we observe that the transmitted light is about $19 \sim 20\%$ at the on-state. Referring to Figure 5, we observe a dissimilar light transmission for the ECB mode. In Figure 5, the solid and dash lines represent the light transmittance for the cases of weak anchoring and strong anchoring, respectively. The transmittance for the ECB mode with taking the weak anchoring into account is calculated to be about 2% higher than that for the strong anchoring case at the on-state. This seems to be due to the fact that the directors at the surface on the top and bottom electrodes are reluctant to rotate toward the targeted directions.

In order to investigate the viewing-angle performance of the proposed poly-rubbing technique, the transmittance was calculated as a function of viewing angles for each cell. Figure 6 are polar plots illustrating the transmission for different viewing angles. In addition, we compared our simulation results for the poly-rubbing technique with the viewing-angle characteristics of the PVA mode in an effort to demonstrate validity of our implementation scheme for different rubbing directions. The PVA mode has the same cell size as the VA and ECB cell. The pre-tilt angle of initial LC alignment is assumed to be 90°.

Figure 6 is a polar chart illustrating the transmittance for PVA mode as a function of the viewing angle. For the on-state, Figure 6 illustrates that the PVA mode has quite a uniform transmittance distribution for wide viewing angles.

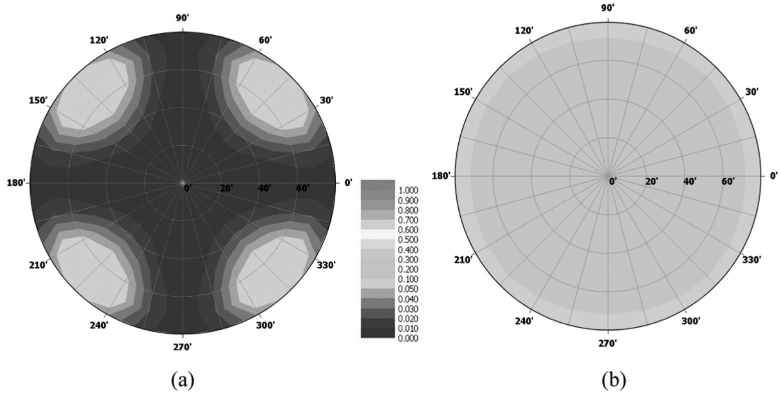


FIGURE 7 Polar plots for transmittance of VA mode as a function of the viewing angle: (a) Off-state, (b) On-state.

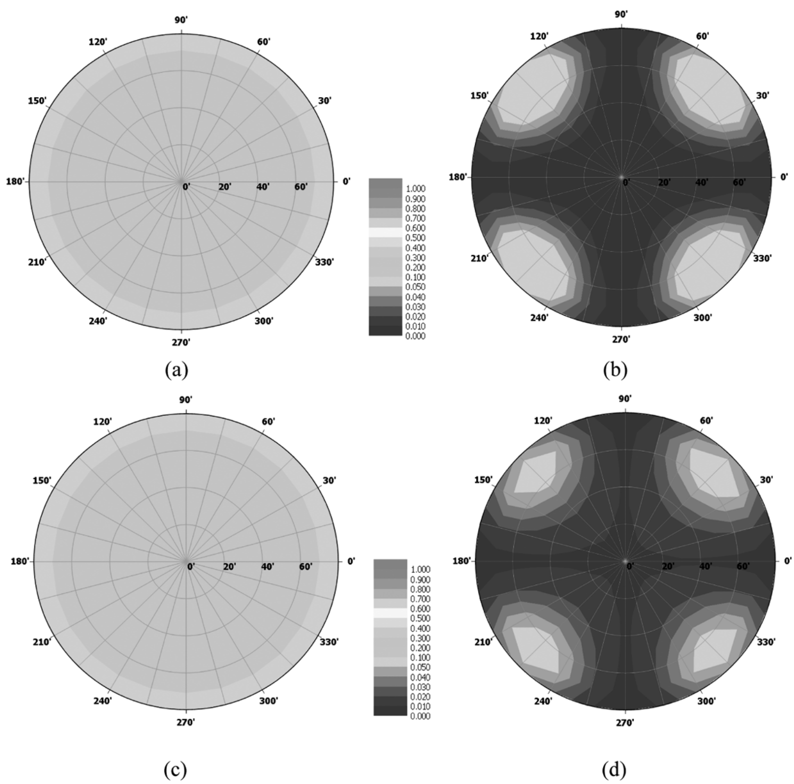


FIGURE 8 Polar plots for transmittance of ECB mode as a function of the viewing angle: (a) On-state (weak anchoring), (b) Off-state (weak anchoring), (c) On-state (strong anchoring), (d) Off-state (strong anchoring).

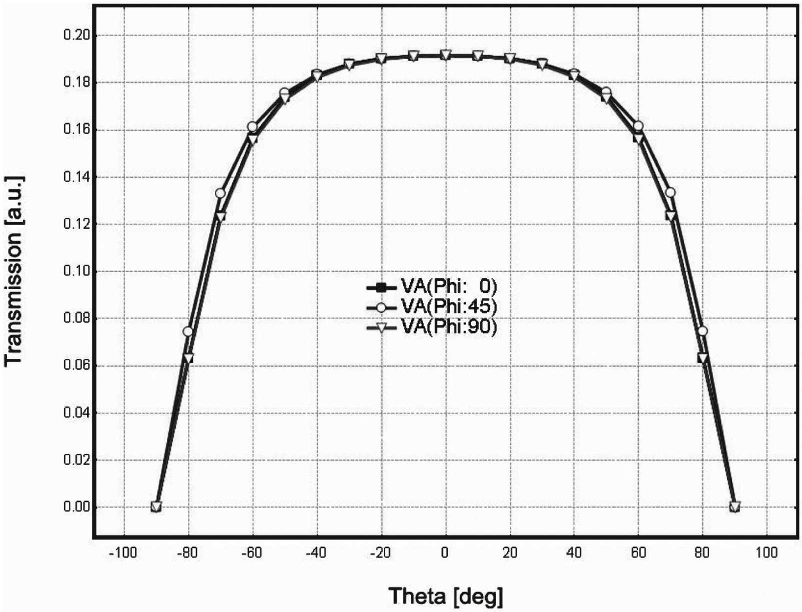


FIGURE 9 Transmittance data as a function of viewing angle in VA mode.

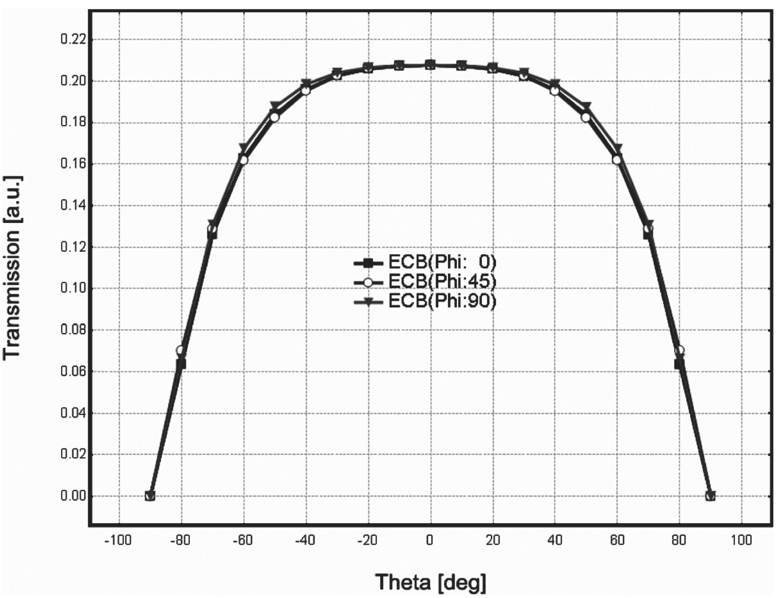


FIGURE 10 Transmittance data as a function of viewing angle in ECB mode.

Figures 7 and 8 are polar charts illustrating the transmittance for the VA and ECB mode. Referring to Figure 7, we can see that the polar distribution of the PVA mode is quite similar to that produced from the poly-rubbing samples. In order to clearly define the viewing angle characteristics between the VA and ECB mode, we present the transmittance data at Θ(phi) $= 0^\circ$, 45°, 90° in Figures 9 and 10. The x-axis represents theta while the y-axis represents the transmittance as a function of viewing angle. The calculation reveals that the transmittance characteristics as a function of the viewing angle are quite uniform for the VA and ECB mode. Consequently, the simulation implies that the wide viewing angle characteristic can be guaranteed with the poly-rubbing technique instead of using the complicated electrode structure.

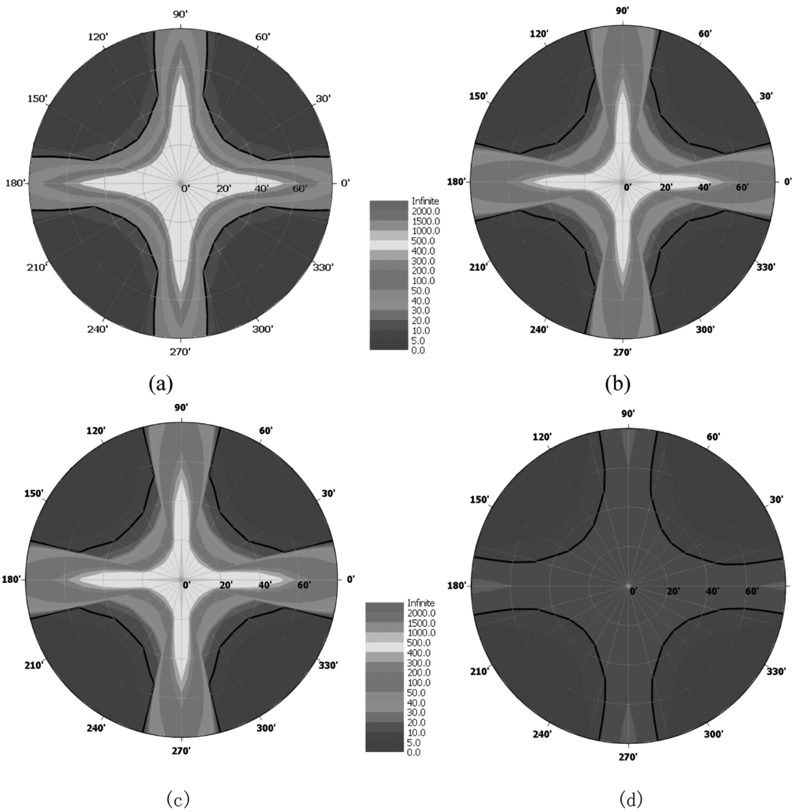


FIGURE 11 Polar plots for contrast ratio (CR) of each modes: (a) PVA mode, (b) VA mode, (c) ECB mode (weak anchoring), (d) ECB mode (strong anchoring).

In Figure 11 are shown polar plots illustrating the contrast ratio (CR) of the reference PVA mode for the comparison with the performance of the multi-domain produced by the poly-rubbing approach. The black line in each polar chart represents the contrast ratio wherein the value of CR is calculated to be 10. The CR of the PVA is highest among the three modes, which seems to be due to the pre-tilt angle of LC molecules in the PVA mode. The pre-tilt angle of PVA mode is 90° while the pre-tilt angle for LC molecules with the poly-rubbing rubbing in the VA mode is 89°. Therefore, it can be inferred that the CR of PVA is higher than that of the proposed modes because the light leakage is generated by the initial LC alignment with 89° pre-tilt angle at the off-state. Moreover, the simulation results imply that the CR is low in the ECB mode when applied with strong anchoring because the light leakage is generated by the strong anchoring at the on-state.

Figure 12 is a schematic diagram illustrating the CR graph of the ECB mode as a function of the viewing angle. As mentioned earlier, the simulation results imply that the CR for the case of a strong anchoring is much lower than that for the case of a weak anchoring. Therefore, we can conclude that the ECB mode should take the weak

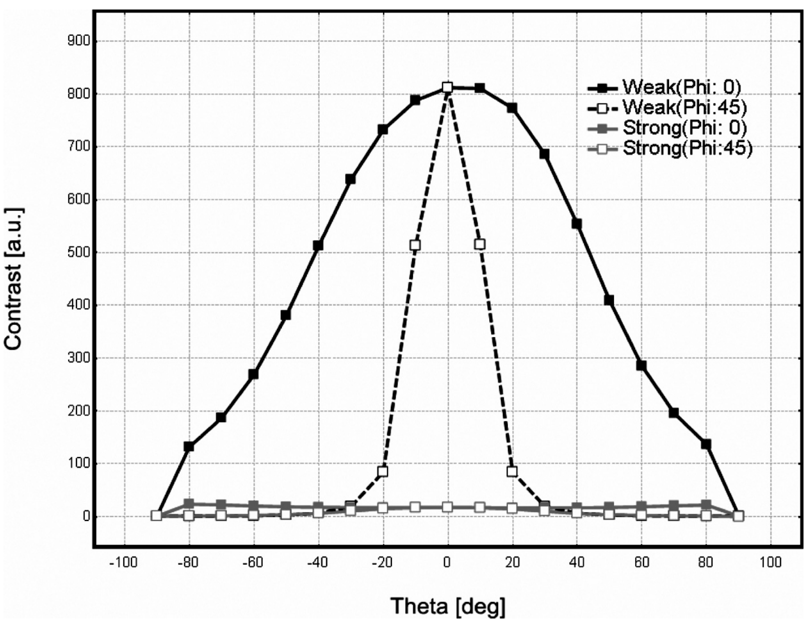


FIGURE 12 Contrast ratio (CR) graph of ECB mode as a function of the viewing angle.

anchoring model while the VA mode has a wide viewing-angle characteristic which is as good as the PVA mode though the proposed poly-rubbing technique. Furthermore, we can come with a conclusion that this poly-rubbing technique allows the implementation of multi-domain even without relying on the complicated electrode structure.

III. CONCLUSION

In this paper, we report our preliminary study on the theoretical model on the poly-rubbing scheme and the application to the VA and ECB mode. In order to implement a wide viewing angle characteristic, we devised two cells for the application of the proposed scheme. To demonstrate the validity of our model, we compared the calculated optical characteristics of the exemplary ECB and VA modes with the conventional PVA mode. Furthermore, we considered surface anchoring energy in the case of ECB mode because the anchoring energy affects the LC molecules distribution. The simulation revealed that wide viewing angle characteristic is sufficiently accomplished by poly-rubbing even without relying on the complicated process technologies like a pattered shaped electrode or protrusion.

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