Dual Domain Effect on a Rubbing Mura in a Fringe-Field Switching (FFS) Liquid Crystal Display

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Abstract
The fringe-field switching (FFS) mode associated with a transition from a homogenously aligned to twist deformation require rubbing process. In this devices, 1^o of misalignment in an azimuthal direction could cause voltage-dependent transmittance (V-T) to be different from that in a normal area and consequently results in a rubbing mura. According to our studies, the single domain FFS cells are much more sensitive to the rubbing mura than the dual domain FFS cell. Moreover, the FFS cells with negative LC are much more sensitive to the rubbing mura than the FFS cells with positive LC.

1. Introduction

Recently, the image quality of the LCDs has been greatly improved with development of the new LC modes. Among them are both in-plane field switching (IPS)[1-4] and the fringe-field switching (FFS)[5-9] modes although the first is partly replaced by the latter. The reason that both devices exhibit a high image quality is that the homogenously aligned LC with an optic axis coincident with one of the crossed polarizer axes shows a good dark state before applying bias voltage and rotates almost in plane with bias voltage, giving rise to transmittance with excellent luminance uniformity. However, both devices require a rubbing process to align the LCs in one direction, which is a demerit compared to multi-domain vertical alignment (MVA)[10] mode which does not require a rubbing process.[11]

In general, the rubbing process is performed by moving a rotating cylinder roll covered with cotton or rayon. Unfortunately, this process sometimes causes non-uniformity in surface tilt angle or azimuthal anchoring direction so that the rotating angle of the LC directors could be different depending on the position, when voltage is applied. This induces non-uniformity in transmittance in a displayed area, and since this is caused by the rubbing process, it is called a rubbing mura.

In the IPS and FFS modes, an in-plane and fringe-electric field rotates the LC almost in-plane, respectively. Although both devices show excellent viewing angle characteristics, if the LC directors rotate in one direction, it causes a yellowish and bluish color shift depending on the viewing direction. To prevent this, a wedge shaped electrode, especially for large size LCDs, is introduced such that in one pixel there are two field directions, forcing the LCs to rotate clockwise and anticlockwise similar to a dual domain.[12-13]

In this paper, we investigated how electrode shapes for single and dual domains in the FFS mode can affect the display uniformity when we assume that there is 1^o of misalignment in azimuthal direction compared to the normal areas by calculation. In addition, rubbing mura depending on positive (+) LC and negative (–) LC dielectric anisotropy of the LC is studied.

2. Simulation Condition

In the FFS mode, the LCs are homogeneously aligned with an optic axis coincident with one of the crossed polarizers. Therefore, the normalized light transmission of the cell can be described by:

$$T/T_o = sin^2\,(2f\,(V))\; sin^2\,(\text{p}d?\,n\,/?) \quad (1)$$

where f is an angle between one of the transmission axes of the crossed polarizers and the LC director, *d* is a cell gap, *?n* is the birefringence of the LC medium, and *?* is the wavelength of an incident light. From this equation, one can understand that *f* is a voltage dependent value, that is, without bias voltage (off state), f is zero and the cell shows a dark state. With bias voltage (on state), the f starts to deviate from the polarizer axis, showing light transmittance. Theoretically, the f must be zero to show a complete black state before applying a voltage.

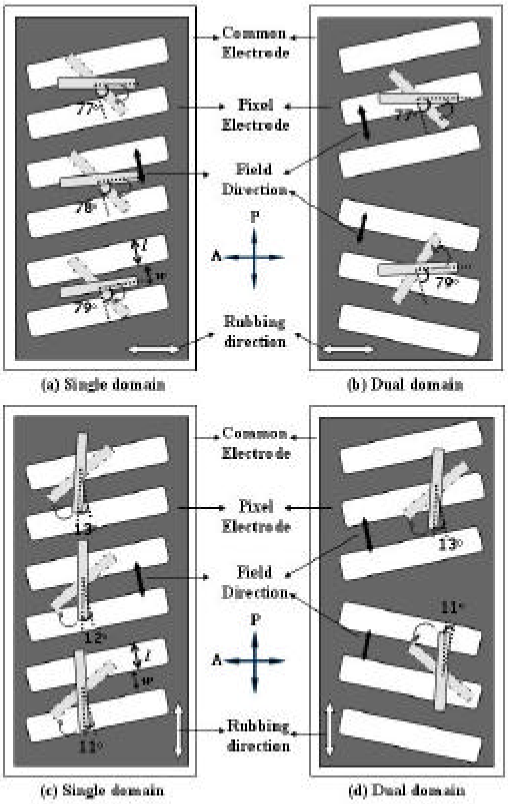

Figure 1. Schematic drawings describing orientation of the LC with rotating directions and the field direction in (a) single and (b) dual domain with positive LC, (c) single and (d) dual domain with negative LC where P and A indicates the polarizer and analyzer, respectively.

However, in real cell fabrication the f may not be zero in some parts since the rubbing process is performed to align the LC, in which that case the transmittance on that area looks different compared to the normal areas, causing rubbing mura. Further, this value could be either positive mura. Further, this value could be either positive or negative depending on the case. The rubbing process causes non-uniformity in LC alignment such as polar and azimuthal anchoring direction. Here, we only consider misalignment of f = ±1^o in azimuthal anchoring direction from the defined direction, where + sign indicates a clockwise direction with respect to vertical axis. First, we consider the FFS electrode structures using the LC with negative and positive dielectric anisotropy, where one pixel is for a single domain and the other pixel is for dual domains, as shown in Fig. 1. Here, the field makes an angle of 78^o and 12^o with the LC director in a normal area for the +LC and –LC, respectively. When there is no misalignment, the LC director rotates clockwise with increasing voltage so that the transmittance increases continuously from a dark to white state. With the misalignment of –1^o in which the field makes an angle of 77^o and 13^o with the LC director for each case, the slight light transmittance already exists before applying any voltage. Also with increasing voltage, the transmittance keeps increasing. With the misalignment of +1^o in which the field makes an angle of 79^o, 11^o with the LC director, the slight light leakage also exists at zero voltage but with a slight increase in the applied voltage f becomes effectively zero, causing the cell to appear to be a dark state. With further increasing voltage, the transmittance starts to occur again.

3. Result and Discussion

For calculations, we performed a simulation using a "LCD Master" (Shintech, Japan) where the motion of the LC director is calculated based on the Eriksen-Leslie theory and 2x2 Jones matrix is applied for an optical transmittance calculation. In the FFS device, the electrodes exist only at the bottom substrate, where a common electrode exists as a plane and a pixel electrode in slit form with a gap (*l*) existing between them. The width of the pixel electrode (*w*) and the *l* is assumed to be 3µm and 4.5µm, respectively. The cell gap (d) is 4µm and the passivation layer with a thickness of 3000Å is positioned between the common and the pixel electrodes. Here, the LC with physical properties (+LC: ?e = 8.1, ?n = 0.099, K_1 = 9.7 pN, K_2 = 5.2 pN, K_3 = 13.3 pN; –LC: ?e = -4, ?n = 0.09, K_1 = 13.5 pN, K_2 = 6.5 pN, K_3 = 15.1 pN) is used and a strong anchoring for the LC to the surface is assumed. The surface pretilt angle for both substrates is 2^o.

Figure 2(a) shows calculated V-T curves when the rubbing direction is 78° (f = 0^o), and misaligned 77° (f = –1°) and 79° (f = +1°) in a single and dual domain structure, while Figure 2(b) shows calculated V-T curves when the rubbing direction is 12° (f = 0^o), and misaligned 11° (f = –1°) and 13° (f = +1°) in a single and dual domain structure.

Next, we evaluate how many grey scales could be different with the misalignment of f = ±1^o in the single and dual domains. We have used Eqn. 2 to calculate the transmittance with gray scale.[14]

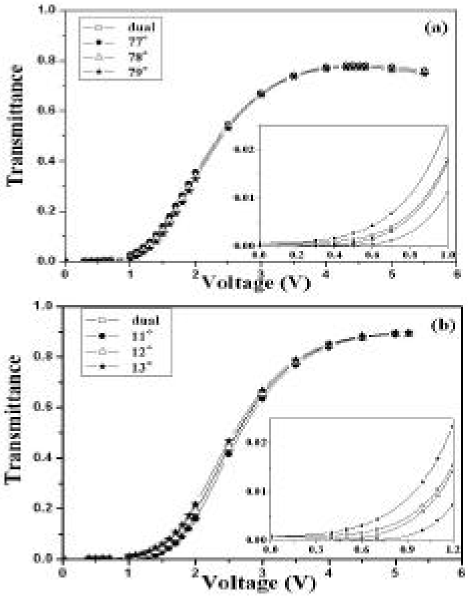

Figure 2. Calculated voltage-dependent transmittance curves depending an initial LC alignment and electrode structure in the FFS mode with (a) positive LC, and (b) negative LC.

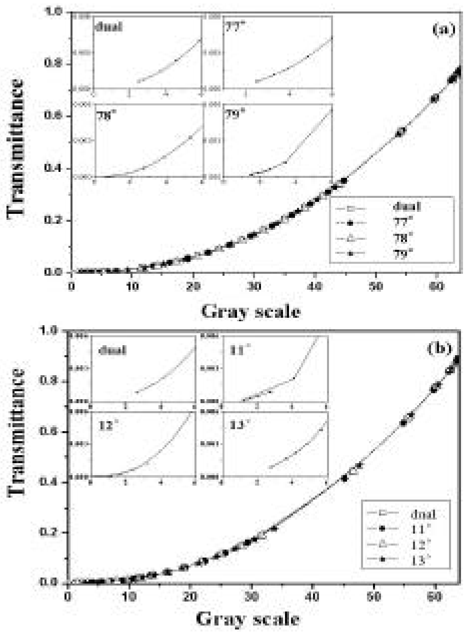

Figure 3. Calculated gray scale dependent transmittance curves with rubbing - misalignment of ±1° in single and dual domains in the FFS mode with (a) positive LC, and (b) negative LC.

$$T = T_{max} (Gray\# / max.\ Gray)^{?} \quad (2)$$

Fig. 3 shows the gray scale curve with transmittance for 64 gray scales when ? value is 2.2. As indicated, the gray scale curve is shifted by the V-T curve change because transmittance is in proportion with the gray scale, as appeared in the insets of Fig. 3. Fig. 4 shows calculated voltage-dependent gray scale difference with rubbing misalignment in the single and dual domain FFS mode with +LC and –LC, in which it is defined as the difference between gray scale number in a cell without misalignment and gray scale number in a cell with misalignment at a given voltage. At zero voltage, the misalignment gives rise to the gray scale difference more than 2 grays, irrespective of the single and dual domain. However, the single domain cell shows more than 2 gray scale difference up to 2 V and even at 3 V, about 1 gray difference is noticeable. However, in the dual domain when an applied voltage is 1.5V, the difference is already negligible. This results clearly indicates that the dual domain FFS mode has a greater advantage compared to the singe domain FFS in viewpoints of rubbing mura.

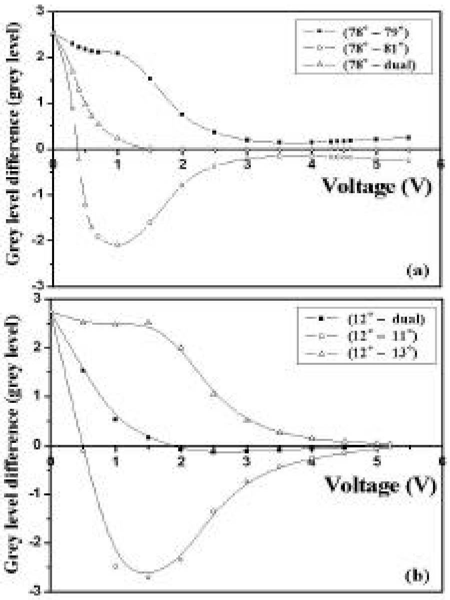

Figure 4. Calculated voltage-dependent gray scale difference with rubbing-misalignment of ±1° in single and dual domains in the FFS mode with (a) positive LC, and (b) negative LC.

Moreover, the FFS mode with positive LC shows less gray level difference by 0.5 than that with negative LC at a dark state, which is from the difference in light leakage due to differences in cell retardation values between two cells. Further, since ?e of +LC is larger than that of –LC in FFS mode, large ?e results in a fast reaction toward electric field. Consequently, the grey level difference disappears at 1.5 V for the +LC while it disappears at about 2 V for the –LC. In general, human eyes are much more sensitive to low gray scale than high gray one. So, the FFS mode with positive LC has a greater advantage than the FFS mode with the –LC in viewpoints of rubbing mura.

4. Conclusion

In this paper, we have studied how to reduce the rubbing mura on the LC device in which the LC director rotates almost in plane. We found that the single domain FFS cells are much more sensitive to the rubbing mura than the dual domain FFS cell. Moreover, the FFS cells with –LC are much more sensitive to the rubbing mura than the FFS cells with +LC.

5. Acknowledgements

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6. References

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