The Analysis of Yellowish Gravity-Mura in FFS Mode

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Abstract
In this paper, we confirmed the yellowish gravity-mura phenomenon in Fringe-Field Switching (FFS) mode using 2-D simulation. As the cell gap increases, while the LC efficiency of blue wavelength remains almost same, that of red and green wavelength increases continuously. As a result, yellowish phenomenon occurs.

1. Introduction
Recently, the demand for large-size LCD panel has increased significantly owing to cost-down and wide-viewing characteristic with authentic color despite competition with PDP panels. So, LCD panels with large-size and high quality for TV application are developed by many LCD makers using various LC modes (Patterned Vertical Aligned (PVA) mode by Samsung, In-Plane Switching (IPS) mode by LG-Philips LCD, Fringe-Field Switching (FFS) mode by BOE HYDIS).[1.2] Especially, FFS mode (patent owned by BOE HYDIS) is very prominent owing to advantages of low power consumption, high transmittance, low color shift in mobile application, table application as well as TV application. In standing FFS–TV panel as well as other panels, the yellowish color of the bottom region after some time goes by is observed. This phenomenon is called gravity-mura as shown in Fig. 1. In this paper, the work for finding out the cause of yellowish gravity-mura phenomenon in white state is done from analysis of transmitted R, G, B light efficiency. After finding the cause of yellowish color, the improvement for yellowish color of gravity-mura occurring only in ODF process significantly dependent on LC drop amount may be achieved.

Figure 1. Photograph of gravity-mura in 26” FFS-TV.

2. Results and discussions
Generally, in the ideal case, the switching of the homogeneously parallel aligned cell such as FFS and IPS mode is described as bellows.

$$T = \frac{1}{2}\sin^2 2\Delta\phi \sin^2 \frac{\Gamma}{2} \qquad (1)$$

$$\Gamma = \frac{2\pi}{\lambda}\int_{z=0}^{z=d}[n_e(\theta) - n_o]dz = \frac{2\pi}{\lambda}\Delta n_{eff}\cdot d \qquad (2)$$

$$\frac{1}{n_e^{\,2}(\theta)} = \frac{\sin^2\theta}{n_o^{\,2}} + \frac{\cos^2\theta}{n_e^{\,2}} \qquad (3)$$

Where $\Delta\Phi$ is the twist angle relative to the transmission axis of the polarizer by the applied field, Γ is the phase retardation of the LC cell and Θ is the tilt angle of the LC director.

When $\Delta\Phi$=45° and $\Delta n_{eff}\cdot d=\lambda/2$ conditions are satisfied, maximum transmittance is achieved. [3]

However, $\Delta\Phi$ can not reach to 45° owing to strong anchoring force near surface, no existence of horizontal E-field in top substrate and the center of pixel electrode. Compared with IPS mode, in FFS mode, LC twist on center of pixel electrode occurs more owing to strong E-field near the edge of pixel electrode. As a result, FFS mode has the higher transmittance than IPS mode.

We used 2DIMmos simulator (by Autronic melchers) for simulation. The parameters of used LC is for fast-response time (low γ_1, low $\Delta\varepsilon$) in FFS-TV. For the simulation of representative wavelength, λ=436 nm, 546 nm, 633 nm are selected to blue, green, red, respectively. The Δn of LC are 0.0981, 0.0908, 0.0881 in λ=436 nm, 546 nm, 633 nm, respectively. And we obtained V-T curve regarding blue, green, red wavelength and LC efficiency.

Figure 2 shows LC efficiency and operating voltage in blue, green, red wavelength regarding cell gap. As shown in Fig. 2, the LC efficiency of red is relatively lower compared with green and blue. And the operating voltage of each R, G, B is all different and can not be optimized due to the birefringence characteristics of LC. Because optimum LC efficiency is achieved in $\Delta n_{eff}\cdot d=\lambda/2$ condition, it is expected that optimum LC efficiency of blue with small λ and high Δn is obtained in low cell gap, while that of red with large λ and low Δn is obtained in high cell gap. And operating voltage of blue is significantly proportional to increase of cell gap than green and red. From the result of Fig. 2, as cell gap increases, the LC efficiency of blue remains almost same and then decreases gradually, while that of green and red increases continuously. As a result, yellowish phenomenon occurs. In blue wavelength, optimum cell gap is 3.4 μm (dΔn=333 nm) as shown in Fig. 2 and this optimum value is almost same as present cell gap. From $\Delta n_{eff}=\alpha\Delta n$ condition due to tilt-up effect by fringe-field, α is 0.653 significantly lower compared with that of IPS mode which vertical component of E-field exists weakly. If it is assumed that α remains constant in both green and red wavelength, in other words, the distribution of LC molecules is same regardless of cell gap, the optimum dΔn of green and red wavelength are 417 nm (d=4.6 μm), 484 nm (d=5.5 μm), respectively. [4,5] Presently, the well-known optimum dΔn and operating voltage of FFS mode (~375 nm) can be acquired from average of each R, G, B optimum value.

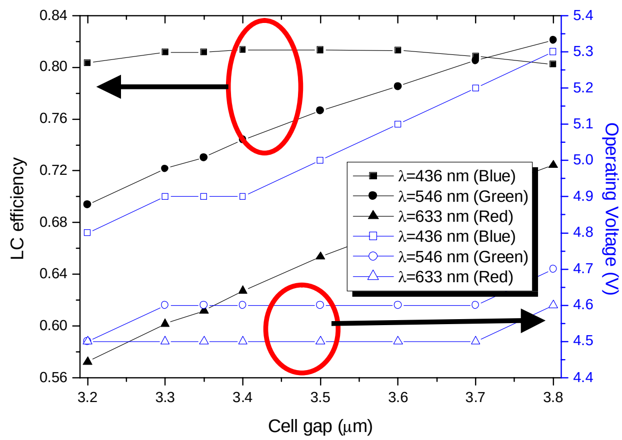

Figure 2. dΔn-LC efficiency curve regarding each wavelength.

Figure 3 shows LC efficiency curve regarding cell gap considering operating voltage. As shown in simulation result, operating voltage of blue wavelength is significantly higher than that of other two wavelength. So, in real module, because same voltage is applied to pixels of three color, we compared LC efficiency of R, G, B at same voltage. In this case, LC efficiency of blue is decreased compared with previous value. We fixed operating voltage of green which have the higher resin transmittance than that of two resins.

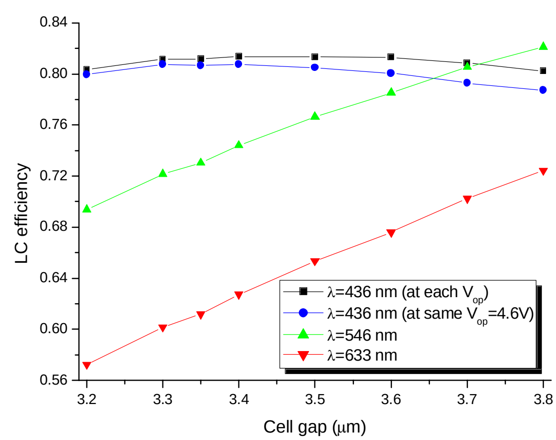

Figure 3. dΔn-LC efficiency curve regarding each wavelength considering operating voltage.

Figure 4 shows dΔn-LC efficiency curve in blue, green, red wavelength using extrapolation method. As shown in Fig. 2, the optimum LC efficiency increases as optimum cell gap increases. To improve LC efficiency of FFS mode, improvement of blue efficiency and optimization of optimum dΔn values of R, G, B is needed. Though we set $\Gamma=\pi$ in eq. (1), $\Delta\Phi$ changes regarding cell gap. As the cell gap increases, $\Delta\Phi$ increases due to decrease of anchoring force and relative decrease of tilt-up portion of LC molecules near pixel electrode. [6]

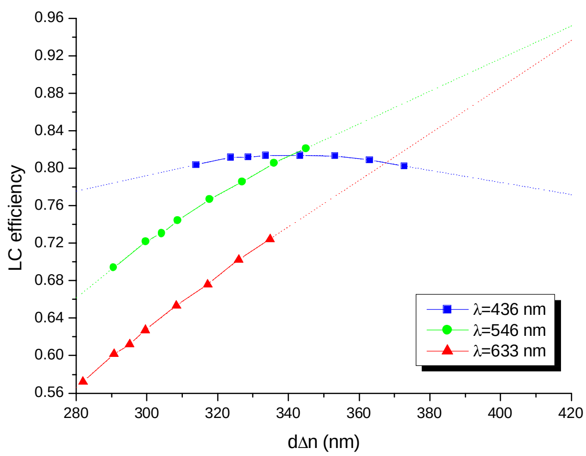

Figure 4. The LC efficiency and operating voltage regarding cell gap.

The relative decrease of tilt-up portion means the increase of twist angle in position of pixel electrode center as shown in Fig. 5. In both fringe-field switching and in-plane switching, the LC twist in position of electrode center occurs not by horizontal E-field, but by elastic torque resulting from neighborhood LC rotation. As the cell gap increases and then the twist angle in pixel electrode center increases, LC efficiency increases as shown in Fig. 5. The twist angle distribution in this position is almost same compared with that in pixel electrode of IPS mode. A little difference is that z/d value for maximum twist angle in FFS mode is near 0.4 compared with 0.5 in IPS mode (approximation to sine function).

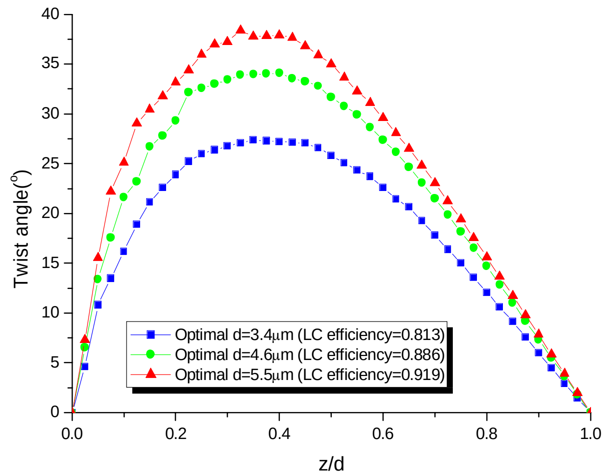

Figure 5. Twist angle distribution in position of pixel electrode center in each optimum dΔn.

3. Conclusion

The conventional FFS mode has the higher optimum dΔn (~375 nm) compared with IPS mode (~300 nm). This value is acquired from the average of optimum R, G, B dΔn. To improve LC efficiency of FFS mode, improvement of blue efficiency and optimization of optimum dΔn values of R, G, B is needed. If this is realized, display of gravity-mura is weakened. Especially, in TV application, optimum dΔn is not easily achieved due to low cell gap for fast response time and high backlight temperature. Therefore, the respective change of R, G, B pixel designs is necessary for optimum LC efficiency and authentic color. And because optimum dΔn in each wavelength is acquired, optimum cell design of R, G, B pixel for improved LC efficiency may be achieved.

4. References

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