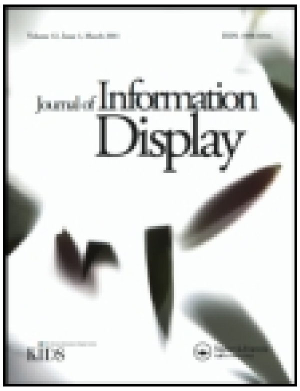

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Effect of the electrode edge on the viewing angle property of a patterned vertical alignment liquid crystal cell

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Effect of the Electrode Edge on the Viewing Angle Property of a Patterned Vertical Alignment Liquid Crystal Cell

Jung-Min Choi[**], **Seung-Hoon Ji, and Gi-Dong Lee**[*]

Abstract

This paper investigates the effect of the electrode edge of a patterned vertical alignment (PVA) liquid crystal (LC) device on the viewing angle characteristics. In general, a transmissive LCD applies an LC layer with half-wave retardation for a bright state and with zero retardation for a dark state. The retardation of the LC layer would be distorted in each point, however, when a voltage is applied because of the non-uniform voltage distribution in the electrode edge effect. In this paper, the feasibility of the full effect of the electrode edge on the viewing angle property is considered, and the optical viewing angles of the VA LCD with a uniform half-wave LC layer and the PVA LCD with a practical non-uniform LC layer are compared.

Keywords : PVA LCD, electrode edge effect, bright state, viewing angle

1. Introduction

The share of flat-panel devices in the display market is continually increasing. Liquid crystal displays (LCDs) are currently widely used. They range from small panels for mobile applications to large panels for LCD TVs. To exhibit high image quality, various kinds of advanced LC modes such as in-plane switching (IPS) [1], patterned vertical alignment (PVA) [2], multi-domain vertical alignment (MVA) [3], and fringe field switching (FFS) [4] have been developed. Despite these efforts, however, the image quality of LCDs is still insufficient for large-screen products because of their narrow viewing angle compared to emissive display devices.

The PVA LC mode, developed by Samsung Electronics, provides an excellent contrast ratio at a normal direction because the LC director is perfectly vertically aligned against the substrate. Its optical performance at an oblique direction deteriorates, however, with the viewing angle, which can increase the off-axis light leakage in a dark state [5-6]. Many efforts have been made to reduce the light leakage of the VA LC cell [7-8] using optical compensation films such as *A*-plates, *C*-plates, and biaxial films. Tto verify the optical property of the LC cell, the exact calculation of the dark and bright states in the PVA LC cell is critically required for contrast ratio analysis.

In this paper, the optical viewing angle property of the PVA LC cell is reviewed in terms of different cases of LC layers in which one has a uniform half-wave LC director and the other has a non-uniform LC director via a patterned electrode in a bright state. The latter, which is complicated, is more practical than the former. To represent an accurate contrast ratio, the entire LC director should be considered according to the effect of the electrode edge on the PVA LC cell.

2. Exact Contrast Ratio Calculation in the PVA LCD

The transmittance of the LC cell through the crossed polarizers, in which the LC directors are assumed to have an approximately homogeneous parallel alignment, by neglecting the thin boundary layers at the surfaces, can be defined as follows [9-10]:

$$T = \frac{1}{2}\sin^2(2\Delta\phi)\sin^2\left(\frac{\pi\Delta nd}{\lambda}\right), \quad \text{Eq. 1}$$

wherein $\Delta\phi$ is the twist angle relative to the transmission axis of the polarizer due to the applied field, λ is the wavelength of the incident light, and Δnd is the retarda-

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tion of the LC cell. In the electric field-off state, $\Delta\phi = 0$, the transmittance, yields a dark state, with T = 0. The maximum value of the transmittance is at $\Delta\phi = 45^\circ$.

In general, the LC layer was assumed to have been a uniform half-wave medium with one domain when the bright state of the LC cell was calculated. Fig. 1 (a) shows the optical configuration of the normal PVA LC cell that was composed of the VA LC layer and two crossed polarizers. The LC director was vertically aligned in the absence of an electric field and showed a dark state due to the zero-retardation of the VA LC. The applied electric field gave the LC director a downward tilt because of its negative dielectric anisotropy. It showed a bright state, and its transmittance depended on the extent of the application of the voltage. The VA LC cell with a uniform half-wave LC layer represented a dark state and a bright state in terms of the viewing angle, as shown in Figs. 1 (b) and (c).

On the other hand, Fig. 2 shows the optical property of the advanced PVA LC cell, the optical compensation films of which were two negative *C*-plates and one positive *A*-plate to eliminate the off-axis light leakage in the dark state. The dark property of the viewing angle of the advanced LC cell increased far beyond that of the normal LC cell. The bright property decreased at the oblique incidence compared to that of the normal PVA LC cell, which could cause the deterioration of the contrast ratio. These calculated results, however, did not exactly coincide with the values for the real PVA LC cell, in which the bright property of the normal LC cell at the viewing angle is almost the same as that of the advanced LC cell. Therefore, to exactly simulate the bright state of the real LC cell in the PVA LC cell, the effect of the electrode edge in the PVA LC cell on the viewing angle characteristics must be investigated.

Figs. 3 (a) and (b) show one pixel of the PVA LC cell and a cross-sectional view of the PVA LC cell with the LC configuration in the bright state. The data of the LC director of the PVA LC cell was extracted using *TechWiz LCD* 3D, in which the distribution of the LC director was calculated based on the Ericksen-Leslie. The area was assigned two regions--the bulk and edge areas--and the numbers ①, ③, and ⑤ that represented the LC director in the edge electrode areas ②, ④, and ⑥ showed the LC director in the bulk electrode area. The distribution of the LC director in the edge area differed from that in the bulk area because the tilting direction of the LC director was determined by the fringe field generated by the patterned electrodes. The bulk area showed a bright state because the LC director was mostly aligned with $\Delta\phi = 45^\circ$, whereas the edge area represented an almost dark state because the LC director did not tilt down in the fringe field.

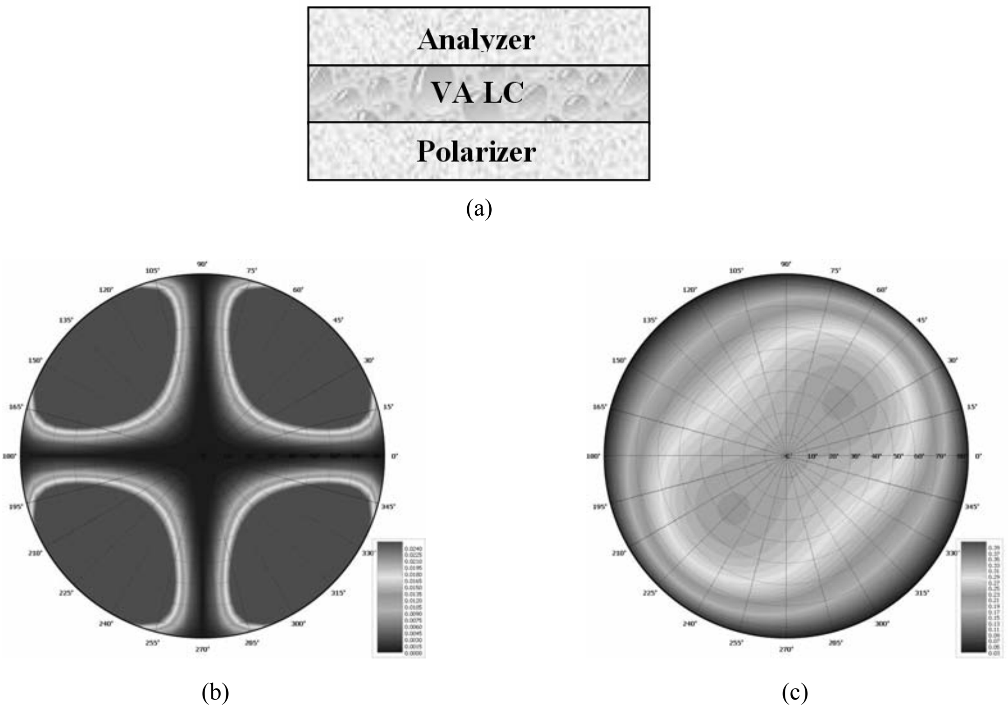
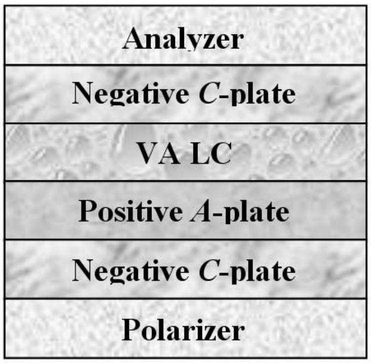
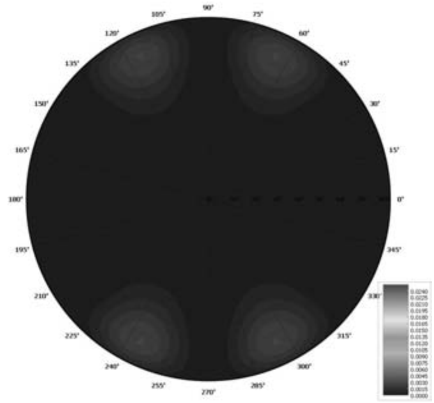
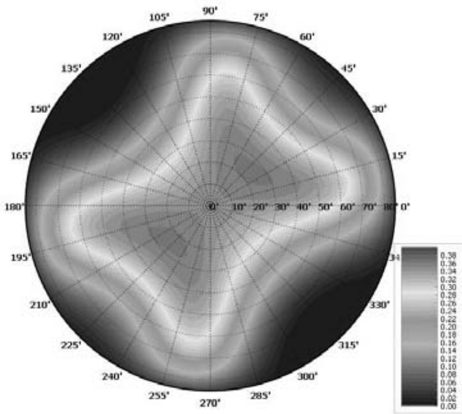


Fig. 1. Normal VA LCD with a uniform half-wave LC layer: (a) optical configuration, (b) iso-dark contour, and (c) iso-bright contour.



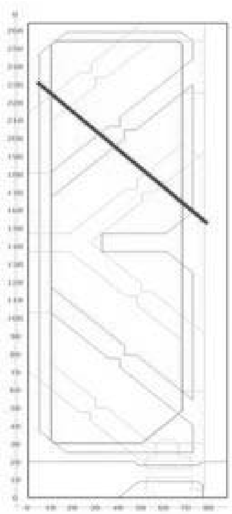
(a)

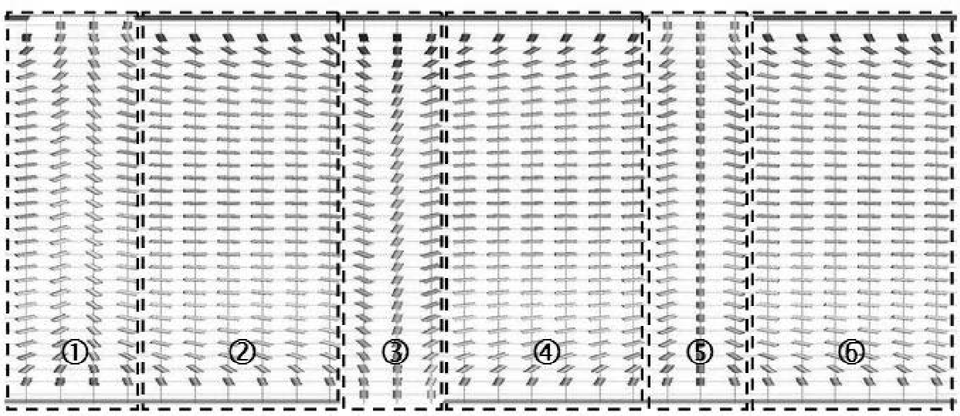




(b) (c)

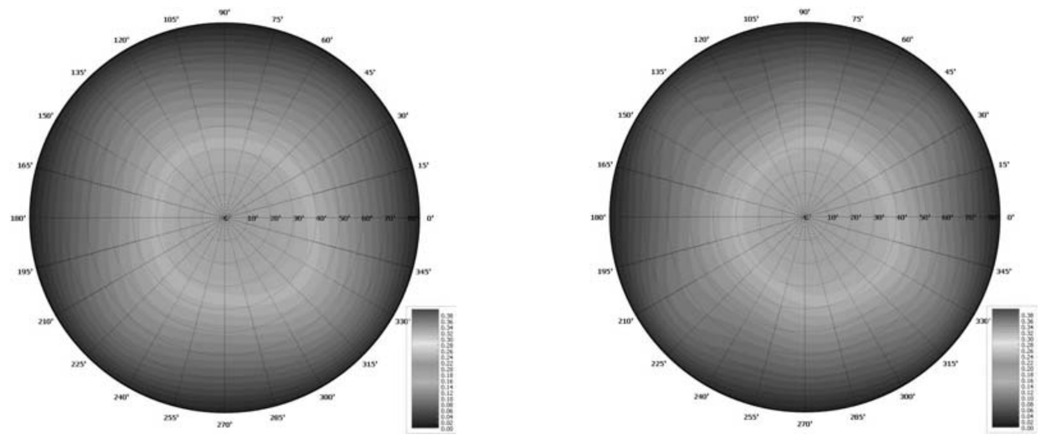
Fig. 2. Advanced VA LCD with a uniform half-wave LC layer: (a) optical configuration, (b) iso-dark contour, and (c) iso-bright contour.





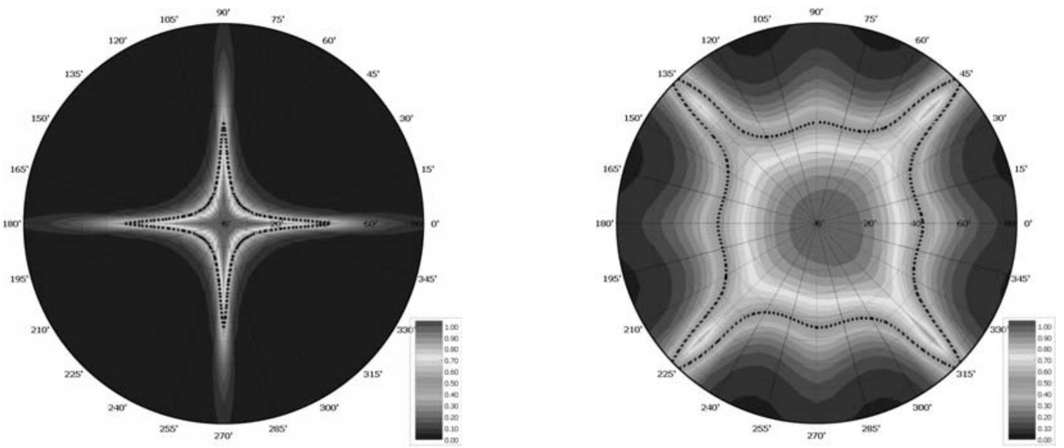
(a) (b)

Fig. 3. (a) One pixel of the PVA LC cell, and (b) schematic cross-sectional view of the LC cell with the LC configuration in the bright state.



(a) (b)

Fig. 4. Iso-bright contour of the PVA LC cell with a non-uniform LC layer: (a) the normal PVA LC cell, and (b) the advanced PVA LC cell.



(a) (b)

Fig. 5. Normalized iso-contrast contour with a non-uniform LC layer: (a) the normal PVA LC cell, and (b) the advanced PVA LC cell.

Fig. 4 shows the bright state of the PVA LC cell with a non-uniform LC layer. The optical property of the advanced PVA LC cell was almost the same as that of the normal PVA LC cell as to the viewing angle, even in the oblique direction. Fig. 5 compares the normalized iso-contrast contour of the normal configuration with the advanced configuration. The dashed line represents the position of the half-contrast ratio compared with the contrast ratio in the normal incidence. The advanced PVA LC cell yielded an improved contrast ratio both in the oblique and normal directions. From the calculated results shown in Figs. 4 and 5, it was confirmed that the LC director of the electrode edge in the bright state should be considered to obtain the exact optical property when the contrast ratio in the PVA LC cell is calculated.

3. Conclusions

The effect of the edge electrode area on the viewing angle characteristics in the PVA LC cell was investigated. The almost vertically tilted LC directors of the edge area in the PVA LC cell, which was caused by a non-uniform voltage distribution, improved the bright property. Therefore, to calculate the exact contrast ratio of the PVA LC cell, the edge electrode effect should be included in the bright state.

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