Viewing Angle Switching using Hybrid Aligned Nematic Liquid Crystal Display Driven by a Fringe-Field

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Abstract

Conventional viewing angle switching electrode requires pixel division and additional liquid crystal panel. Hence the conventional viewing angle switching has low aperture ratio and high thickness. In this paper we proposed new viewing angle switching using hybrid aligned nematic mode by fringe-field electrode field (named HAN-FFS) with single liquid crystal panel. The fringe-field switching electrode is located at the bottom, and the additional common electrode is located at the top of the cell to control viewing angle. The proposed device is free from additional liquid crystal panel and pixel division. Consequently, the suggested structure has not only high aperture ratio but also show an excellent potential for viewing angle switching.

1. Introduction

Recently, as increasing the range of application for portable displays, the narrow viewing angle display had developed to protect personal privacy. In that case, a hybrid aligned nematic liquid crystal driven by a fringe electric field was reported for narrow viewing angle display.[1-3] But the application range of display with narrow viewing angle is limited only for using privacy protection. So, to satisfy both privacy protection and wide viewing angle, many studies of viewing angle switching were suggested, in which outside of main panel together with other liquid crystal panel and double backlight system were employed.[4-6] But these methods have a weak point of rising thickness and high production cost due to additional process. Recently, one pixel is divided into two sub-pixels such that the one pixel is for displaying the main image and the other for controlling viewing angle.[7-8] But this approach decreases aperture ratio and luminance.

Recently, to solve this problem, we suggested viewing angle switching using conventional HAN-FFS mode with negative dielectric anisotropy.[9] In this paper, we are reporting the optimization conditions for cell structure of HAN-FFS mode to control the viewing angle with high aperture ratio.

2. Cell structure and switching principle

The transmittance in which uniaxial medium exists under crossed polarizer is given by

$$T/T_0 = \sin^2(2\psi)\,\sin^2(\pi d\Delta n/\lambda)$$

where ψ is an angle between the transmissive axis of polarizer and the liquid director, d is cell gap, Δn is the birefringence of liquid crystal, λ is the wavelength of the incident light. In this equation, the maximum transmittance is dependent on cell retardation ($d\Delta n$) at wavelength of the incident light. In this device, without bias voltage, ψ is zero at normal direction so that it gives a perfect dark stat for display. But, the situation becomes different at off normal axis, that is, the crossed polarizer condition does not apply anymore due to change of effective angle between absorption axes of those polarizers in accordance with observation direction and also the effective birefringence is strongly dependent on the liquid crystal direction. With homogenous orientation of the liquid crystal in the dark state, the effective liquid crystal retardation in oblique viewing directions is much smaller than that with hybrid alignment. Therefore, the liquid crystal orientation with homogenous alignment is a key requirement for the wide viewing angle mode while on with hybrid alignment is a key requirement for the narrow viewing angle mode.

In LCDs, the degree of light leakage defines a degree of contrast ratio in all directions. If the light leakage in dark state is low in all directions, the contrast ratio of proposed device could rise in all directions. However, if the degree of light leakage is high it results in narrow viewing angle.

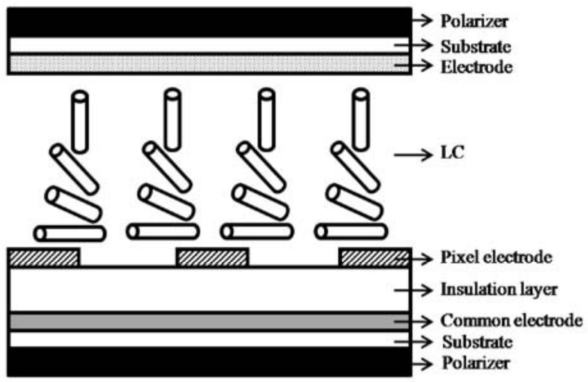

Figure 1. Schematic cell structure of suggested viewing angle switching.

Figure 1 shows a proposed viewing angle switching using one liquid crystal cell. The liquid crystal molecules with negative dielectric anisotropy are initially hybrid aligned with homogenous and vertical alignment on the bottom and top substrates, respectively. The top substrate has an electrode of which the potential can be controlled. Using the field distribution, we could realize wide viewing angle and narrow viewing angle using hybrid aligned nematic liquid crystal. When the voltage in top common electrode is same as bottom common electrode, the dark state of narrow viewing angle mode has strong light leakage due to hybrid aligned liquid crystal director in oblique direction, resulting in narrow viewing angle characteristics. However, when the potential difference between the top and bottom common electrode is applied, the liquid crystal director rotates almost in plane by horizontal field, resulting in wide viewing angle.

3. Results and discussion

In order to study the electro-optic characteristic of viewing angle switching, a computer simulation was performed using the commercially available software, LCD master (Shintech, Japan) on 2 X 2 Jones matrix. [10] The transmittance of single and parallel polarizers was assumed to be 41%, and 35%, respectively.

In this case, the pixel electrode with and the distance between them are 3 and 4.5 um, respectively. The passivation thickness is 0.29 um with dielectric constant of 6.5. The retardation of cell (dΔn) is 0.595. The dielectric anisotropy of the liquid crystal is -4.0. The surface tilt angle of cell is 2° and 90° for homogenous and vertical alignment, respectively.

The voltage dependent transmittance curve of viewing angle switching is shown in Figure 2. In figure 2(a), the operation voltage in narrow viewing angle mode is low such as 3.5V between top and bottom substrates, due to hybrid nematic arrangement. But the operation voltage of wide viewing angle was found to be 7V with 28% of transmittance as shown in Figure 2(b). So, the power consumption can be reduced in narrow viewing angle.

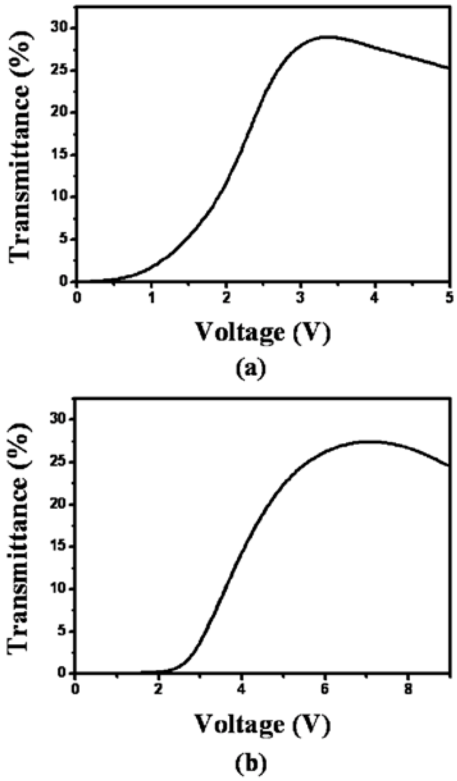

Figure 2. Voltage dependent transmittance curves in suggested viewing angle switching: (a) Narrow viewing angle mode, (b) Wide viewing angle mode.

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A man's eye has good sensibility for luminance of dark stat. So, general display uses to evaluate the display's quality due to the ratio of white luminance and dark luminance. Figure 3 is shows the viewing angle dependent contrast ratio in horizontal direction perpendicular to the alignment axis of the HAN-FFS mode cell. The contrast ratio in both narrow viewing angle and wide viewing angle has over 2500 at normal direction. But, the contrast ration of the wide viewing angle mode is larger than narrow viewing angle in all viewing angle direction. In narrow viewing angle mode, the region in which contrast ratio is over 10 observes within polar angle of 15°. On the other hand, in wide viewing angle mode, the term in which contrast ratio are 10 exhibits until polar angle of 45°. As a result, the viewing angle can be controlled from a wide viewing angle mode to a narrow viewing angle in the horizontal direction while keeping a high image quality at the normal direction.

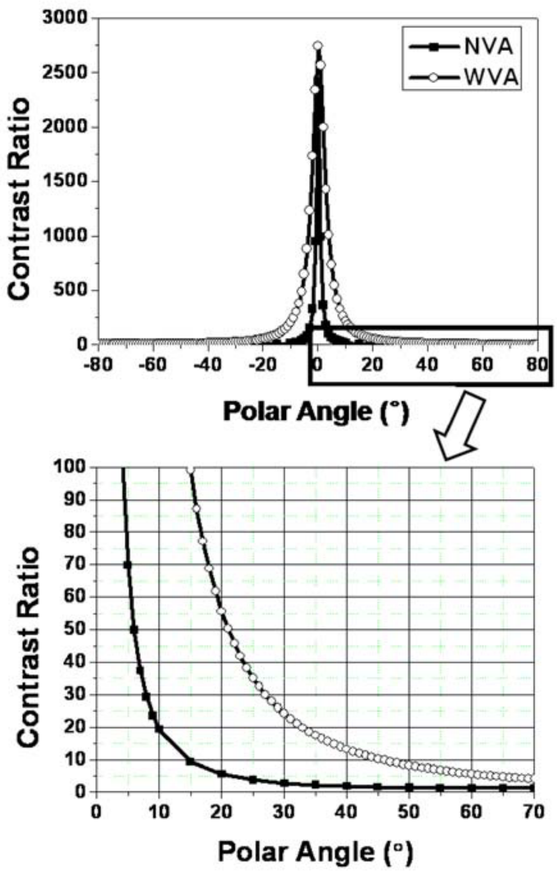

Figure 3. Viewing angle dependent contrast ratio of HAN-FFS viewing angle switching display in horizontal direction.

Figure 4 shows iso-lumiance curve in white and dark stat and iso-contrast ratio in wide viewing angle and narrow viewing angle. For iso-luminance curve in white state, relative transmittance of 70%, 50% and 30% with respect to the maximum transmittance was calculated. In both wide viewing angle mode and narrow viewing angle mode, the light leakage of dark state is 0.014778, 0.010556 and 0.006334. In white state of wide viewing angle mode, the region at which the transmittance exceed over 30% with respect to the maximum transmittance exists about 60° of polar angle in all directions. In dark stat, a light leakage is smaller than narrow viewing angle mode. On the other hand, the white state of narrow viewing angle mode has a narrow transmittance distribution due to original viewing angle characteristics of HAN mode in oblique direction. In dark stat, the strong light leakage occurs except for vertical directions.

In the contrast ratio of wide viewing angle mode, the region in which the contrast ratio is larger than 5 exist over 60° of the polar angle in all directions. Also, in the narrow viewing angle mode, the region in which the contrast ratio is larger than 5 exist approximately 30° of polar angle except on vertical direction. Consequently, the control range of viewing angle can be perfectly driven from wide viewing angle mode to narrow viewing angle mode.

4. Summary

In this paper, possibility of viewing angle controllable display using HAN-FFS mode by driven fringe and vertical electric field is proposed. It is confirmed that viewing angle, in the horizontal direction, can be controllable from 120° to about 20° in terms of the contrast ratio equal to 5. So, it is possible to operate in both wide viewing angle and narrow viewing angle without additional cell and pixel division. So, this viewing angle switching is suitable for portable display to protect the privacy.

5. Acknowledgements

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6. References

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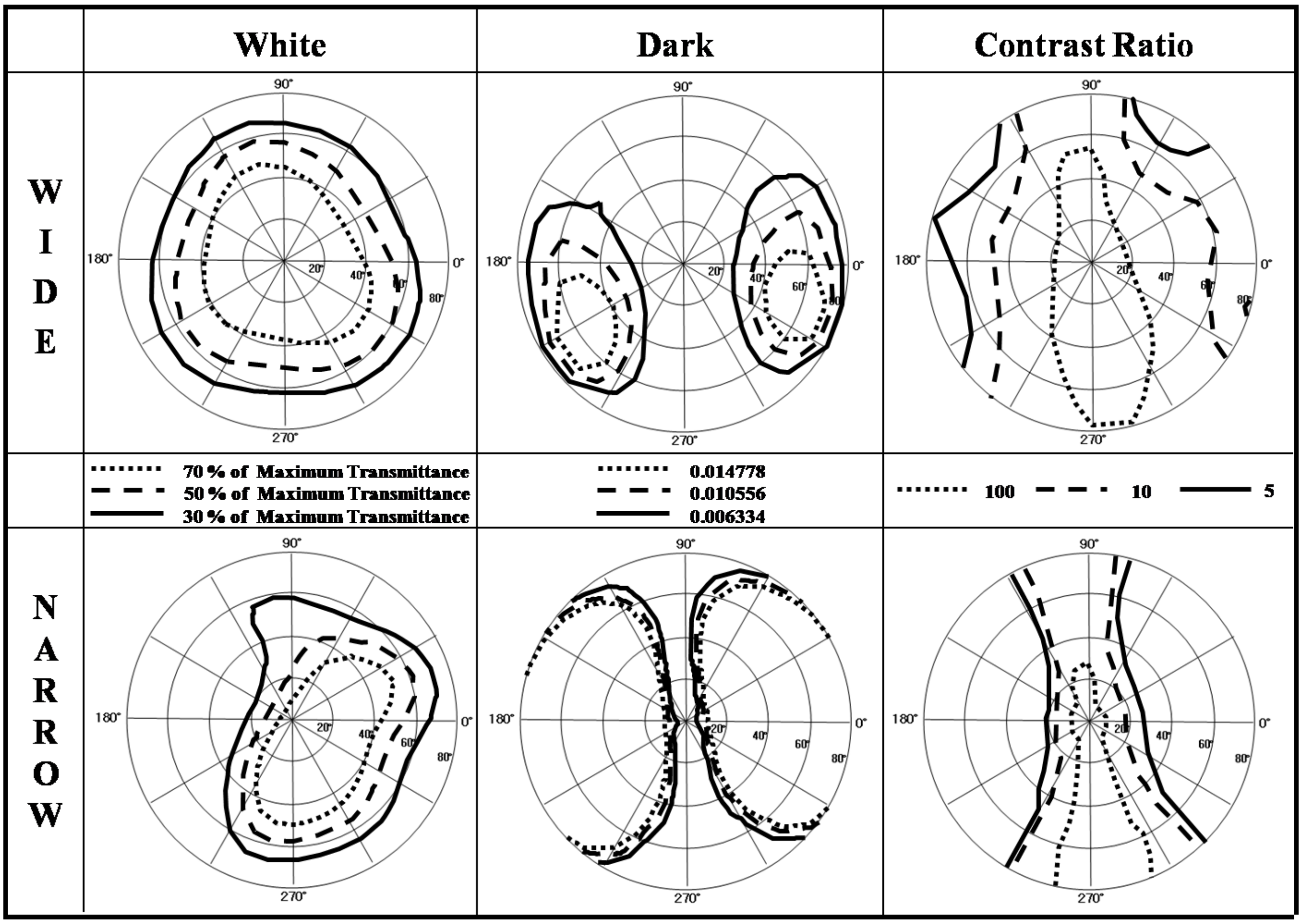

Figure 4. Iso-transmittance curves in the white state and dark state, and iso-contrast curves at an incident wavelength.