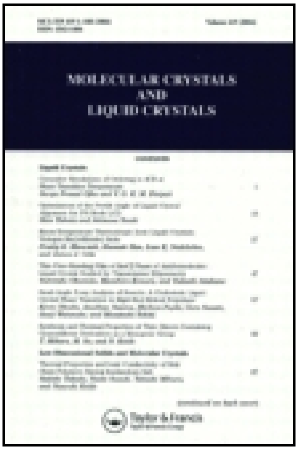

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Improvement of Viewing Angle Properties of IPS-Mode LCD by using Super-Wide-Viewing-Angle Polarizer

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IMPROVEMENT OF VIEWING ANGLE PROPERTIES OF IPS-MODE LCD BY USING SUPER-WIDE-VIEWING-ANGLE POLARIZER

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We propose a new wide-viewing-angle polarizer that has extremely low light leakage in all directions and a large wavelength range. Application of this polarizer to the IPS-mode LCD results in a high-quality liquid crystal display with a wide viewing angle and high contrast ratio.

Keywords: biaxial retardation film; IPS-mode LCD; large wavelength range; wide-viewing-angle polarizer

INTRODUCTION

Recently, several transmissive liquid crystal displays (LCDs) with wide viewing angles and high contrast ratios have been proposed, such as the in-plane switching (IPS) [1], vertically aligned (VA)[2], and optically-compensated bend (OCB) [3] modes. However, each of these modes can exceed a viewing angle of 140 degrees only in the horizontal and vertical directions. Accordingly, light leakage from the crossed polarizer, in the off-axis, is a serious problem in high-quality LCDs that require a wide-angle view and high contrast ratio in all azimuthal directions.

This light leakage is explained as follows. Stack two polarizers with their absorption axis at azimuth $\phi = +45^\circ$ and $\phi = -45^\circ$. Observe the polarizers from the plane at azimuth $\phi = 0^\circ$. Note that the effective angle between the absorption axes of the two polarizers (polarizer and analyser) increases with the polar angle of the observing direction, θ_i, as shown in Figure 1. Hence, at oblique observation angles, light leakage from the crossed polarizer is noticeable.

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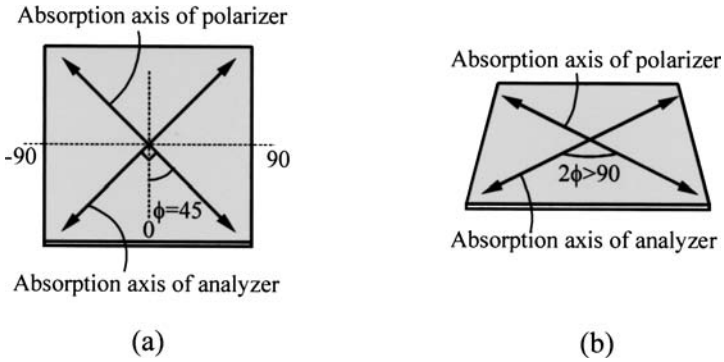

FIGURE 1 Change in the effective angle between the two polarizer absorption axes (polarizer and analyser) as the direction of observation changes. (a) Normal observation ($\theta_i = 0$), (b) Oblique observation ($\theta_i > 0$).

Chen has reported that the light polarization state P_1 must be rotated to position A_1 before the light passes the analyser to suppress the light leakage, as shown in Figure 2, and this rotation can be achieved using a combination of an A-plate and a C-plate, or a single biaxial retardation film [4,5]. Here, $\mathbf{P_1}$ is the polarization state of light passed through the polarizer and $\mathbf{A_1}$ is the absorption axis of analyser at oblique observation, respectively.

The compensation process for conventional wide-viewing-angle polarizer is shown in Figure 3. However, in these configurations, the polarization state of the three primary colors (R, G, and B) differe after passing through the retardation films, because of their wavelength dispersions of

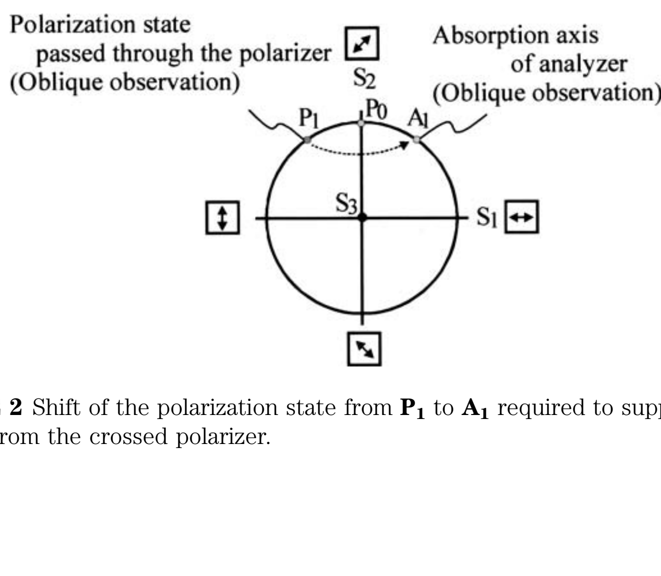

FIGURE 2 Shift of the polarization state from $\mathbf{P_1}$ to $\mathbf{A_1}$ required to suppress light leakage from the crossed polarizer.

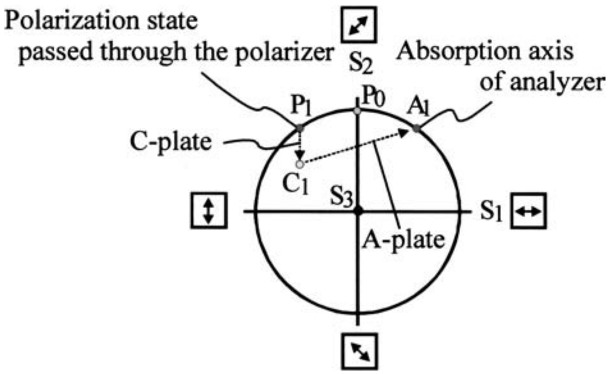

FIGURE 3 Compensation process for conventional wide-viewing-angle polarizer using A-plate and C-plate.

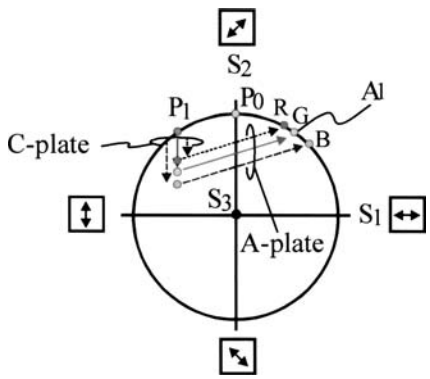

FIGURE 4 Wavelenth dependence of conventional wide-viewing-angle polarizer. (R: 650 nm, G: 530 nm, B: 450 nm).

retardation, as shown in Figure 4. This is the cause of light leakage with crossed polarizers.

In this paper we discuss the design of a wide-viewing-angle polarizer with a large wavelength range for use in high-quality LCDs.

THE CONFIGURATION AND COMPENSATION PROCESS OF THE NEW WIDE-VIEWING-ANGLE POLARIZER

We propose a new wide-viewing-angle polarizer with a large wavelength range using two biaxial retardation films. Figure 5 shows the compensation

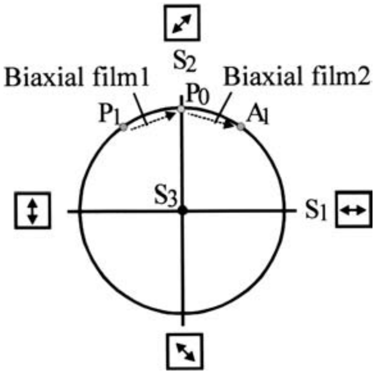

FIGURE 5 Compensation process for super-wide-viewing-angle polarzier.

process of this polarizer. Polarization state $\mathbf{P_1}$ is rotated to $\mathbf{A_1}$ via $\mathbf{P_0}$, which is the polarization state for observation at the direction normal. Therefore, both the viewing angle dependence of light polarization passed through the polarizer and the crossed polarizer light leakage are suppressed. This rotation can be rewritten on the S1–S3 plane of the Poincaré sphere, as shown in Figure 6. Since biaxial retardation film 1 and 2 have the same retardation, the birefringence dispersion of biaxial retardation film 1 is compensated for by symmetrical rotation of biaxial retardation film 2. This rotation can be obtained by stacking biaxial retardation films 1 and 2, as shown in Figure 7. The arrows on the biaxial retardation films indicate the axis with maximum refractivity. The arrows are parallel to each other and are parallel or perpendicular to the absorption axis of the polarizer.

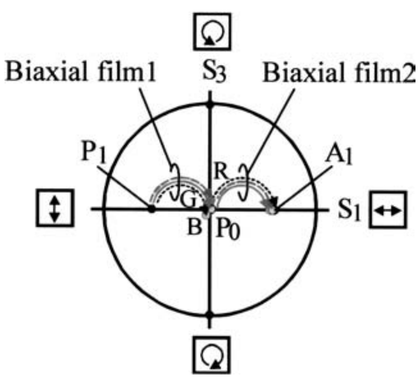

FIGURE 6 Wavelenth dependence of super-wide-viewing-angle polarizer on the S1–S3 plane of the Poincaré sphere. (R: 650 nm, G: 530 nm, B: 450 nm).

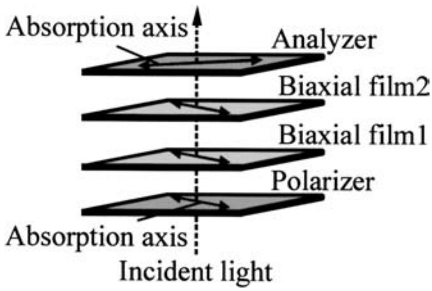

FIGURE 7 Configuration of super-wide-viewing-angle polarizer.

When observed obliquely, the slow axis of these films moves away from the polarizer absorption axis direction and the birefringence effects rotate the light polarization from $\mathbf{P_1}$ to $\mathbf{A_1}$ when a biaxial retardation film with suitable retardation is selected. We can also obtain a simple, low-cost wide-viewing-angle polarizer by using the two identical biaxial retardation films (films 1 or 2), but crossing their slow axes instead, although some of their viewing angle properties are sacrificed.

DESIGN CONDITION AND PROPERTIES OF THE WIDE-VIEWING-ANGLE POLARIZER

In order to design this wide-viewing-angle polarizer, we extended the representation of light propagation through biaxial birefringence media on the Poincaré sphere to the case involving oblique incidence. Using a small birefringence approximation, the difference between the ordinary

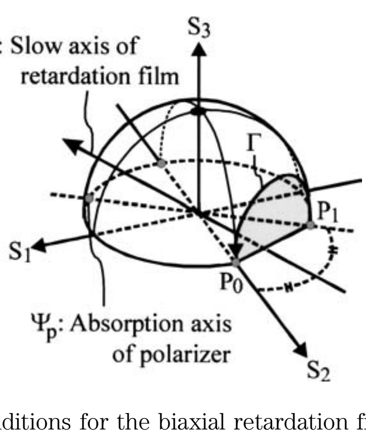

FIGURE 8 Required conditions for the biaxial retardation films.

TABLE I Parameters of the Biaxial Retardation Films

	$\frac{n_y - n_x}{\bar{n}}$	$\frac{n_y - n_z}{\bar{n}}$	$n = \frac{n_y + n_x + n_x}{3}$	d (μm)
Biaxial film 1	0.0018	0.0015	1.5011	100
Biaxial film 2	0.0018	0.0005	1.5016	100

and extra-ordinary wave vectors can be neglected [6]; therefore, the ordinary and extra-ordinary polarization vectors are expressed as follows.

$$\boldsymbol{o} = \frac{\boldsymbol{c} \times \boldsymbol{k}_{\mathrm{o}}}{|\boldsymbol{c} \times \boldsymbol{k}_{\mathrm{o}}|} \quad \text{and,} \quad \boldsymbol{e} = \frac{\boldsymbol{k}_{\mathrm{o}} \times \boldsymbol{o}}{|\boldsymbol{k}_{\mathrm{o}} \times \boldsymbol{o}|} \tag{1}$$

here $\boldsymbol{c}$ is the optical axis orientation of the biaxial media and $\boldsymbol{k}_{\mathrm{o}}$ is the ordinary wave vector. Neglecting the reflection at the consecutive media interfaces, the Muller matrix of the biaxial birefringence media is then expressed as a function of Γ and Ψ, where Γ is the retardation at the oblique incidence and Ψ is the angle between $\boldsymbol{o}$ and $\boldsymbol{s}$ ($\boldsymbol{s}$ is perpendicular to the plane of incidence).

The conditions required for biaxial retardation films to function effectively in super-wide-viewing-angle polarizer are expressed as follows (see Fig. 8).

(a) The retardation of the biaxial retardation films Γ must be identical and is always π or $-\pi$ for oblique observation
(b) The shift in the slow axis direction with oblique observation $\Delta\Psi_{\mathrm{f}}$ must be $1/2\Delta\Psi_{\mathrm{p}}$ and $-1/2\Delta\Psi_{\mathrm{p}}$ for biaxial retardation film 1 and 2, respectively ($\Delta\Psi_{\mathrm{p}}$ is the shift of the polarizer absorption axis).

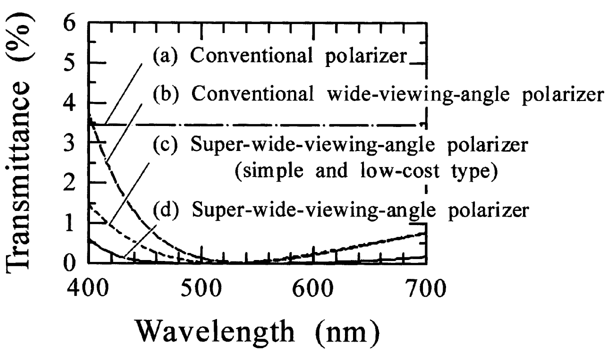

FIGURE 9 Wavelength dependence of the crossed polarizer transmittance (Observation angle: $\theta_{\mathrm{i}} = 60^{\circ}$, azimuth angle: $\phi = 0^{\circ}$).

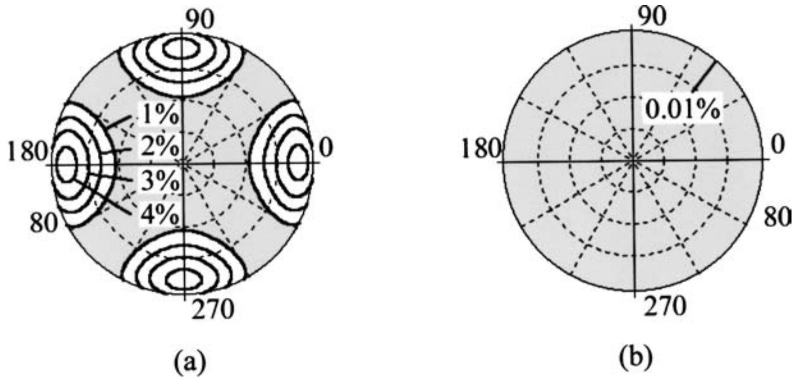

FIGURE 10 Calculated viewing angle properties of the crossed polarizer at a wavelength of 530 nm. (a) Conventional polarizer (b) Suer-wide-viewing-angle polarizer.

We designed biaxial retardation films according to these conditions. Typical parameters for biaxial retardation films are given in Table I. Figure 9 compares the wavelength dependence of crossed polarizers: (a) conventional polarizer, (b) conventional wide-viewing-angle polarizer, (c) super-wide-viewing-angle polarizer (simple, low-cost type), and (d) super-wide-viewing-angle polarizer with oblique observation. This figure shows that wavelength dispersion and light leakage are extremely low in our wide-viewing-angle polarizer.

Figure 10 shows the calculated viewing-angle dependence of the crossed polarizer transmittance at a wavelength of 530 nm. These figures illustrate that super-wide-viewing-angle polarizer has extremely low light leakage in all directions.

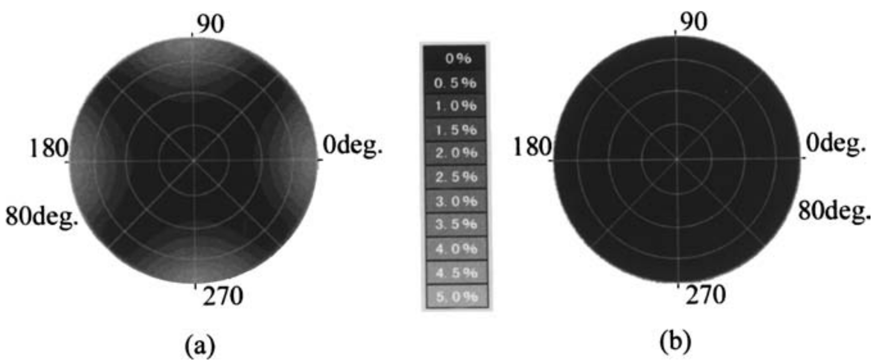

FIGURE 11 Viewing angle dependence of luminous characteristics of the crossed polarizers. (a) Conventional polarizer (b) Super-wide-viewing-angle polarizer.

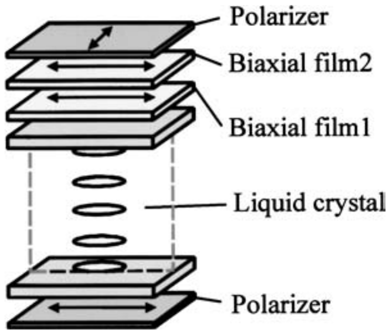

FIGURE 12 IPS-mode LCD using super-wide-viewing-angle polarizer.

We fabricated the wide-viewing-angle polarizer according to the above-mentioned conditions. Figure 11 compares luminous characteristics of the light leakage of crossed polarizers. This figure shows super-wide-viewing-angle polarizer has extremely low light leakage in all azimuthal and polar directions.

APPLICATION OF SUPER-WIDE-VIEWING-ANGLE POLARIZER TO LCDS

A super-wide-angle polarizer can be applied to all LCDs that use a polarizer. For example, we applied this polarizer to an IPS-mode LCD and calculated

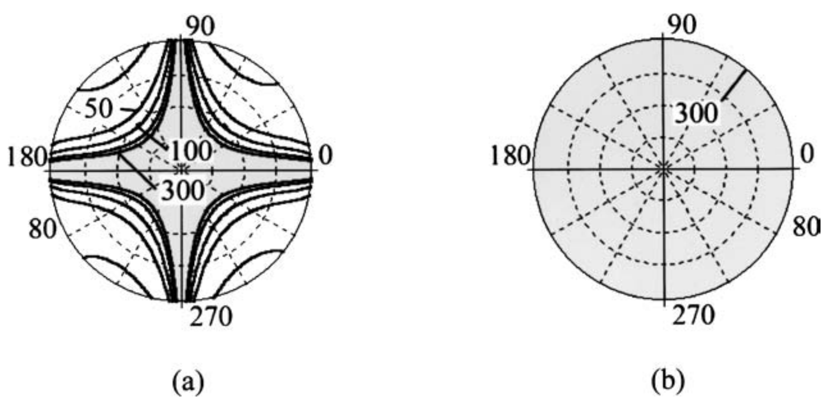

FIGURE 13 Calculated viewing angle properties of contrast ratio of the IPS-mode LCD at a wavelength of 530 nm. (a) Conventional polarizer (b) Super-wide-viewing-angle polarizer.

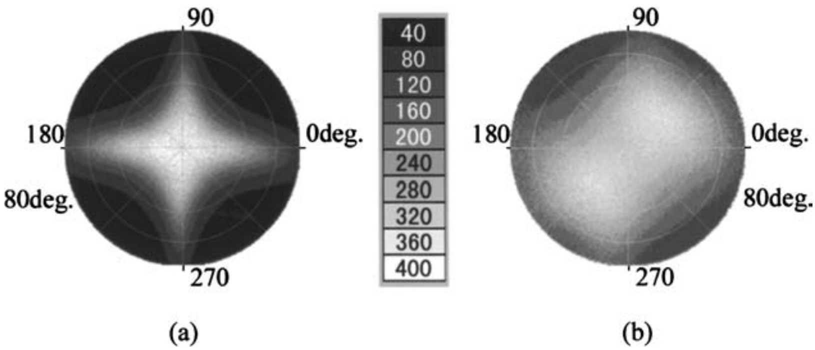

FIGURE 14 Viewing angle dependence of contrast ratio of the IPS-mode LCD. (a) Conventional polarizer (b) Super-wide-viewing-angle polarizer.

the viewing angle properties. Figure 12 shows the configuration of the IPS mode LCD using super-wide-viewing-angle polarizer. The polarizer absorption axis was placed parallel to the LC alignment, so that the polarization state resulting from the LC cell was the same as the polarization state from the polarizer. Biaxial retardation films 1 and 2 were placed on the LC cell.

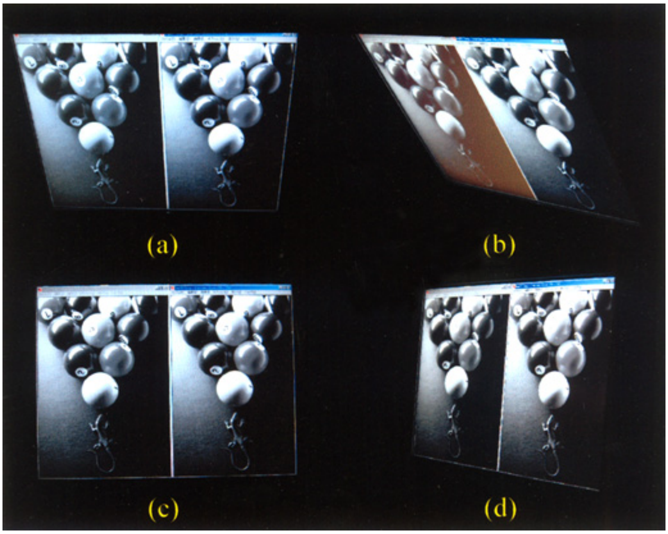

FIGURE 15 Photographs of the IPS-mode LCD. The left-side of the display is using conventional polarizer and the right-side is using super-wide-viewing-angle polarizer. (a) Upper view, (b) Upper-right view (c) Normal view, (d) Right view. (See COLOR PLATE IX)

Figure 13 shows the calculated iso-contrast curves for the IPS-mode LCD and shows that IPS mode LCD using super-wide-viewing-angle polarizer has an extremely wide viewing angle when compared to a conventional IPS-mode LCD. Finally, we fabricated the IPS-mode TFT-LCD using super-wide-viewing-angle polarizer. Figure 14 compares the viewing angle properties of contrast ratio. This figure shows our IPS-mode TFT-LCD has extremely wide viewing angle and high contrast ratio in all azimuthal directions. Figure 15 shows the photo of the IPS-mode LCD. The left side of the display is using conventional polarizer and the right side is using our wide-viewing-angle polarizer. This photo shows our IPS-mode LCD has wide viewing angle also in the right-upper direction and we realized a high quality LCD with wide viewing angle and high contrast ratio.

CONCLUSION

We investigated the design procedure necessary for reducing light leakage from crossed polarizers in the off-axis. As a result, we designed a super-wide-viewing-angle polarizer, using two biaxial retardation films, that has extremely low light leakage and a large wavelength range. IPS-mode LCD using super-wide-viewing angle polarizer has a wide-viewing angle over 160° in all azimuthal directions.

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