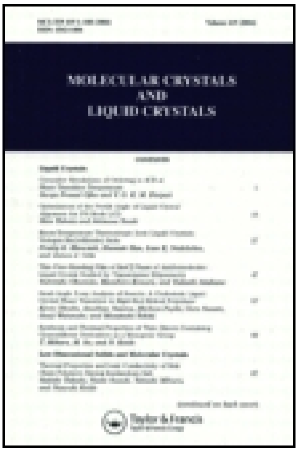

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Axially Symmetric Continuous Domain Vertical Aligned LCD: Poincare Sphere Analysis of Brightness Enhancement by Using Circular Polarizer

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This paper proposes a novel vertical alignment liquid crystal display with a structure having the axially symmetric continuous domain. By stacking a pair of crossed circular polarizer, the brightness could be dramatically enhanced compared with stacking a pair of crossed liner polarizer instead. The Jones matrixes calculation results and Poincare sphere analysis illuminate that the transmission depends only on the phase retardation, but has no relationship with the orientations of the LC molecules. Thus the continuous domain vertical alignment LCDs provides a more uniform display performance at various viewing angles, hence, the best wide-viewing angle performance.

Keywords Circular polarizer; Jones matrixes; poincare sphere; vertical alignment

1. Introduction

With the quick development and expansion of the liquid crystal display market, fast response time, high contrast ratio and wide viewing angle are critically required in large size monitors and television (TV) applications [1–9]. Fujitsu Display Technologies first reported the automatic domain formation (ADF) technology [10–12] for achieving a high quality multi-domain vertically aligned liquid crystal display (MVA-LCD) in 1998. ADF technology involves creating physical ridges on the substrates to obtain an inclined LC alignment near the protrusion surfaces.

Fujitsu proposed their second-generation Premium MVA-LCD [13] which is comprised of chevron-patterned protrusions on color filter (CF) substrates and comprised of slits on TFT substrates for controlling the LC molecules alignment. When

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the voltage is applied across the two substrates, the oblique electric fields around the protrusion will assist the LC molecules to tilt along the ridges slopes, as a result, the LC molecules are divided into two alignment domains with complementary viewing characteristics that help widen the viewing angles. Furthermore, the chevron-patterned protrusions can form a four-domain liquid crystal orientation. Recently, the eight domains divided method was proposed where each of four domains mentioned above is divided into two with different voltages.

Typically, the standard MVA stacked with a pair of crossed liner polarizer and the standard transmittance is around 5%. On the other hand, the transmittance of a TN-LCD is around 7% or 8% and has been used for various types of screens. Conventional MVA configuration has a reduced aperture ratio due to the exist of opaque physical protrusions, near which the LC molecules tilted in the opposite directions to form the distortion lines, which will result in the light-shielding. In order to increase the transmittance of VA-LCDs, several new techniques, such as change the shape of the chevron-pattern protrusion, were presented.

Fujitsu Display Technologies reported a new MVA configuration for introducing nipple-shaped protrusions and form uniform symmetrical alignment in 2004 SID [14]. The viewing angle of more than 160 degrees and the transmittance of over 7% were obtained. Advanced-Super-View (ASV) LCD was developed by Sharp Corp. as published in 2001 SID [15]. At white state, it is twist and molecules nearly rotate continuously 360° along an axis like a pinwheel to avoid the disclination lines, does not require to form a light-shielding area, applying the circular polarizer, a high transmittance can be achieved. Recently, Hiap Ong proposed the amplitude intrinsic fringe field mode MVA (AIFF-mode MVA) [16–18], which doesn't require any physical features on the substrate (such as protrusion and ITO silt), depends on the fringe field effect induced by the special designed sub-pixel structure and dot inversion driving approach, continuous multi-domain regions can be obtained, with the application of circular polarizer, high transmittance could be achieved.

All the above mentioned new wide viewing angle structures, has the same characters that the orientations of the LC molecules are directed to incline in various directions when the voltage is applied across the two substrates, not like the traditional MVA, only incline in four direction of 45°, 135°, 225° and 315°. Thus the crossed liner polarizer is no longer effective, due to the light lose in the other directions and the brightness is decreased at the bright state. To improve light transmittance, circular polarizer instead of liner polarizer can be considered, the trade off is that circular polarizer are more expensive than liner polarizer.

In this paper, we first present the conventional panel configuration with quarter wavelength films and analyze the viewing angle character dependence on the azimuthally angle of the circular polarizer angle. Next, in order to clarify the light enhancement mechanism by applying the circular polarizer, we designed a pixel model and do the three dimensional simulation to prove the result. Finally, base on the calculation of Jones matrix and Poincare sphere analysis, we give a detail explanation for this phenomenon.

2. Pixel Design and Simulation

Figure 1 (a) shows the conventional panel configuration with quarter-wavelength films [19–20]. A right-handed circular polarizer and left handed circular polarizer are stacked. The absorption axes of polarizer are directed to the upper-lower and

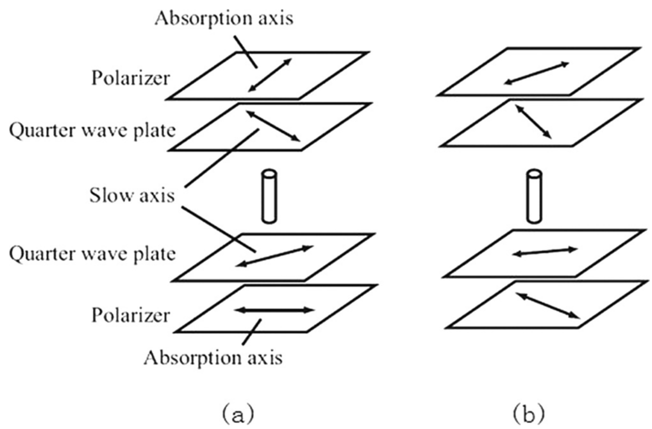

Figure 1. Schematic diagram of setup of optical components for crossed circular polarizer: (a) Standard configuration; (b) Angles are modified.

left-right azimuth, which is has the similar setup with the conventional configuration of crossed liner polarizer. Figure 2 and Figure 3 show the viewing angle characteristics for the conventional crossed liner polarizer and crossed circular polarizer MVA-LCD respectively. The red area indicates the viewing range where contrast ratio (CR) is over 30. The yellow lines show the viewing angle at which the CR is 10. The radius shows the viewing inclination angle and the largest angle is 60 degrees. A wide viewing angle characteristic is realized for the circular polarizer type. However, the azimuth with the maximum viewing range has deviated from the upper-lower or the left-right azimuth, and rotated about 30 degrees in a clockwise direction. We tend to look at the display in the upper-lower or left-right azimuth and it is necessary to correct the viewing angle characteristics shown in Figure 3.

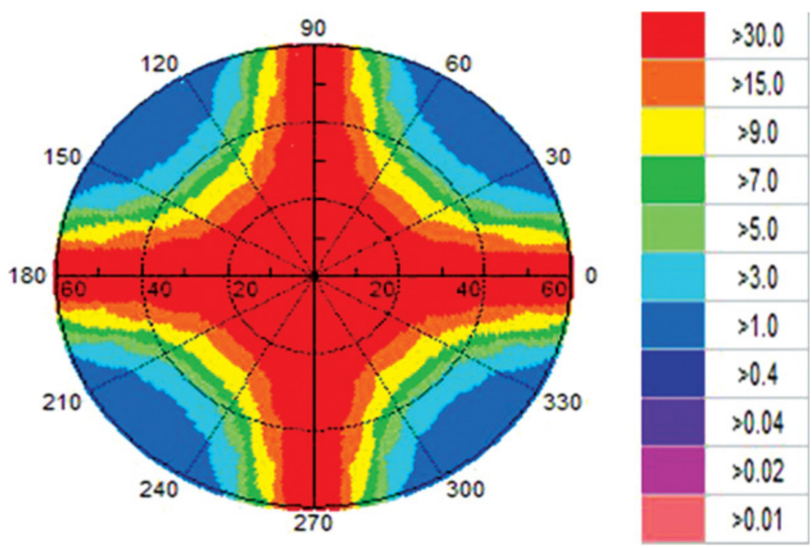

Figure 2. Viewing angle characteristic for the crossed liner polarizer VA-LCD. (Figure appears in color online.)

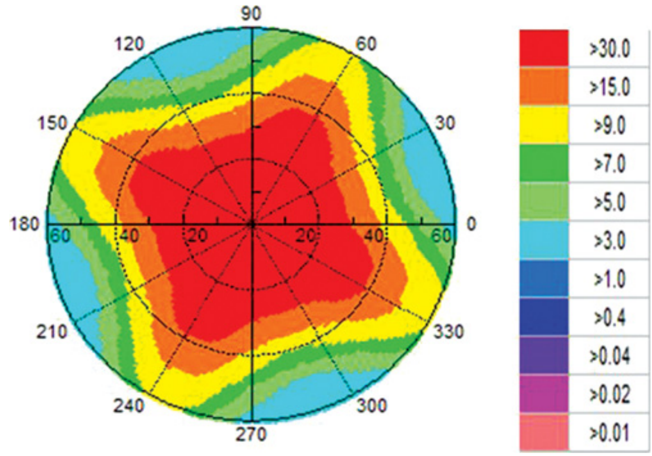

Figure 3. Viewing angle characteristic for the conventional crossed circular polarizer VA-LCD. (Figure appears in color online.)

We rotated the optical films by 25° in a clockwise direction (Fig. 1(b)) and realized quasi-symmetrical viewing angle characteristics (Fig. 4). The CR is over 10 even with an inclination angle of 60 degrees in the upper-lower and left-right azimuths. This specification is comparable to that of LCD monitors.

In order to describe the circular polarizer's brightness enhancement effect for the case of LC molecules incline in various directions. We have designed a special pixel structure to make the liquid crystal director distribution looks like a flower blooms. The typical pixel configuration in indicated in Figure 1(a), wherein, the pixel width is 180 μm, and the pixel length is 540 μm. The pixel was divided into three sub-circle pixels and arranged in the vertical direction. The black conic in the center and the outside black torus designate the protrusions disposed in the color filter substrate. The width of the protrusion is 14 μm, and the height is 1.4 μm, the slope angle of

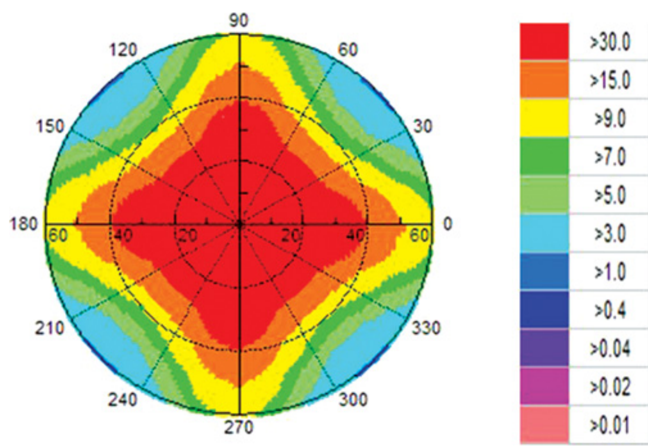

Figure 4. Viewing angle characteristic for the modified crossed circular polarizer VA-LCD. (Figure appears in color online.)

the protrusion is 60 degree. While at TFT substrate, the corresponding location of ITO pattern is opposite with the position of the protrusion. The width of the ITO pattern is 50 μm, the slit between the adjacent ITO patterns is 10 μm. The cross sectional view of the cell is show in Figure 5(b) and 5 (c), which illustrate the dark state and bright state respectively. LC material was adopted Merk-MJ08412, and the parameter is as following: ne = 1.57, no = 1.47, $\epsilon // = 3.5$, $\epsilon\perp = 7$, the cell gap is set as 3 μm view for the voltage off state, and (c) cross sectional view for the voltage on state.

We used the three dimensional liquid crystal simulation software premium 3D to simulate the optical characteristic of the axially symmetric continuous domain vertical aligned LCD. Liquid crystal director distribution is obtained with the finite element method (FEM). Base on the obtained LC director, we simulated the light transmittance for the case of stacking a pair of crossed liner polarizer and a pair of crossed circular polarizer respectively. The top view light transmittance of dark state and bright state for the crossed liner polarizer is shown in Figure 6 (a) and 6 (b). Correspondingly, the top view light transmittance of dark state and bright state for the crossed circular polarizer is shown in Figure 7 (a) and 7 (b).

As shown in Figure 6 (a) and 7 (a), light leakage appeared around the protrusions in the black state. LC molecules tend to be inclined near protrusions, causing the light leakage. As for the case of crossed liner polarizer, at the direction of 0 degree and 90 degree, which is parallel with the absorbing axis of crossed liner polarizer, although the LC molecules are no longer particular with the substrate at the edge of protrusions, but it is inclined along the direction of absorbing axis. Thus, the state of polarization (SOP) will not change while propagate through the liquid crystal layer, and will be absorbed by the front side polarizer, therefore, it still represent a black state at the upper-lower and left-right azimuth. While at the other azimuth exist the light leakage, especially at the azimuth of 45°, 135°, 225° and 315°, it has the largest light leakage.

But for the case of crossed circular polarizer, light leakage appeared at every azimuth around the protrusions in the black state. This is because of the effect of

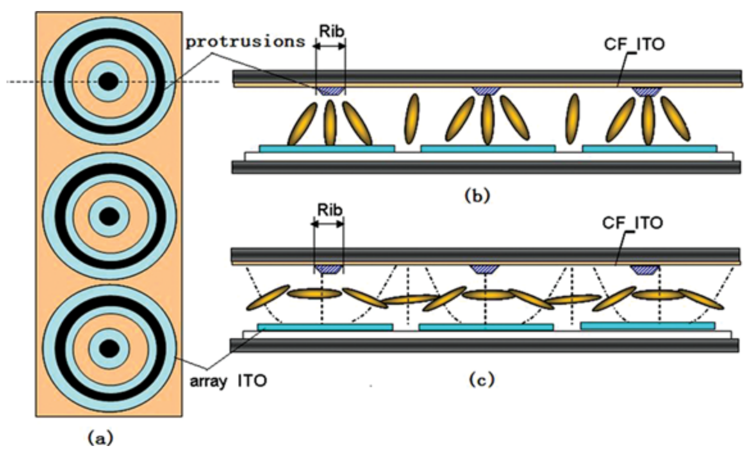

Figure 5. Simplified pixel profile of (a) top view configuration, and (b) cross sectional. (Figure appears in color online.)

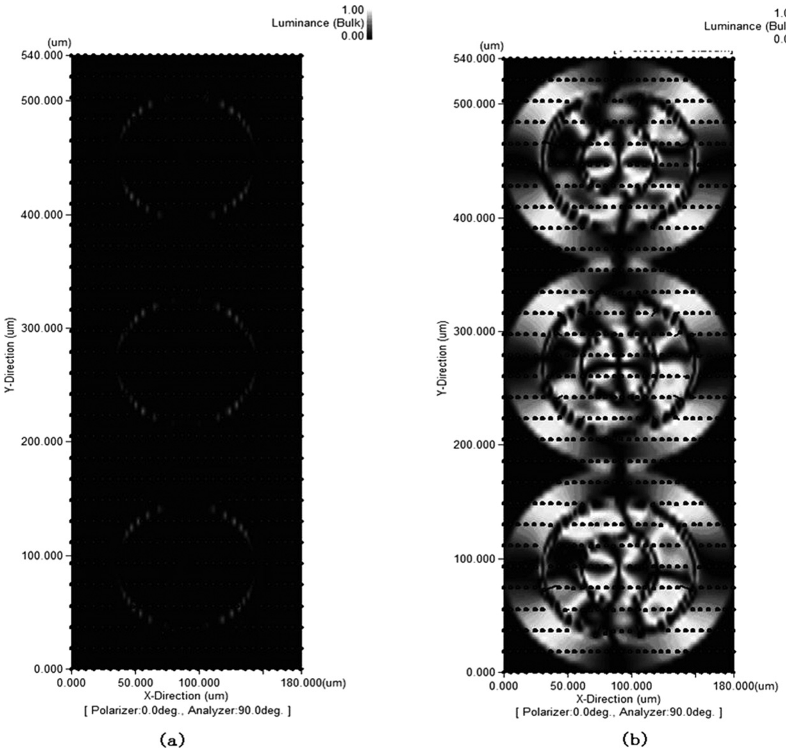

Figure 6. Brightness top view at the exterior surface of the axially symmetric continuous VA-LCD with crossed liner polarizer: (a) dark state brightness, and (b) bright state brightness.

quarter wavelength film, it converted the linearly polarized light into the circular polarized light before reach the entrance of liquid crystal layer, and the different orientation of LC molecules cannot recognize the SOP of the incident circular polarized light, because it varies at every direction with time. After transmitted from the distortion LC around the edge of protrusions and the second quarter wavelength film, it become the elliptic polarized state light at every azimuth, thus the same intensity of light leakage generate at every azimuth. This is a qualitative analysis for the light leakage around the protrusions.

Based on the foregoing analysis, for the LC molecules axially symmetric continuous distribution structure, it has a relative larger light leakage for the crossed circular polarizer structure than that of the crossed liner polarizer structure, which induce a lower contrast ratio, this is a disadvantage for the application of quarter wavelength film compensation, which has been taken much attention and some improvement, such as with no use of protrusion and ITO silt, said AIFF mode, has been proposed, which has a good black state.

Brightness with normal direction view at the exterior surface of the axially symmetric continuous VA cell with the crossed liner polarizer and the crossed circular polarizer are shown in Figure 6 (b) and 7 (b) respectively. It has the minimum light transmittance at the upper-lower and left-right azimuth for the crossed liner polarizer case, and has the maximum light transmittance at the azimuth of 45°, 135°, 225° and 315°. This is similar with the situation for the light leakage at the

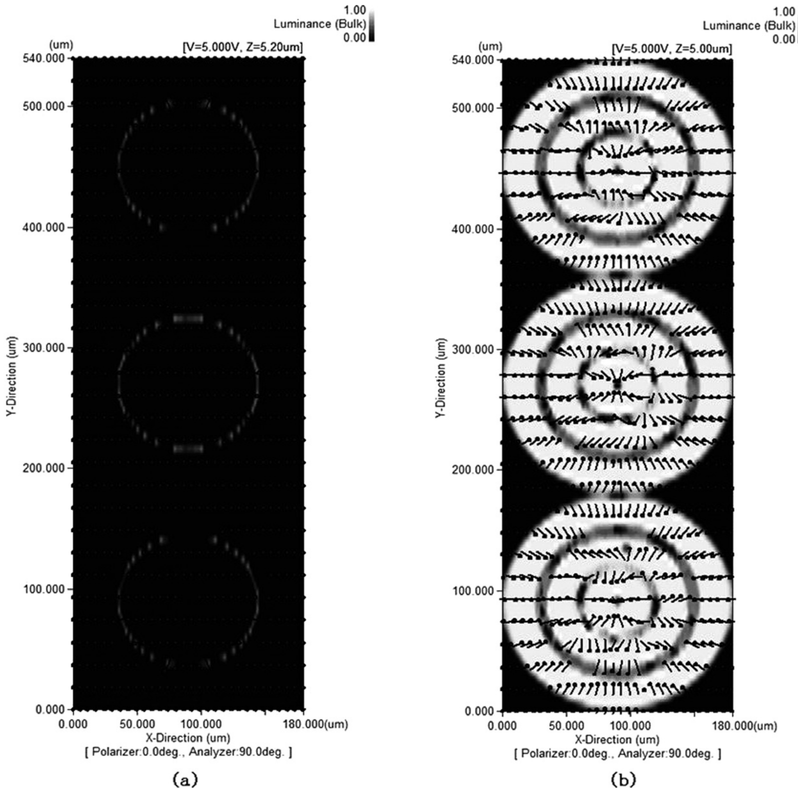

Figure 7. Brightness top view at the exterior surface of the axially symmetric continuous VA-LCD with crossed circular polarizer: (a) dark state brightness, and (b) bright state brightness.

black state, and can be explained by the following formulation:

$$T = \sin^2(2\alpha) \cdot \sin^2\left(\frac{\pi d \Delta n}{\lambda}\right) \tag{1}$$

Wherein, T is the through output light transmittance, d is the cell thickness, Δn is the birefringence of liquid crystal, λ is the incident light wavelength, the angle α designates the angle formed between the slow axis of liquid crystal layer and the transmission axis of the liner polarizer. From the above formulation, the light transmittance is the square of a sine function of the two times angle α. So it looks like a pinwheel for the normal direction view brightness at the bright state.

But for the case of crossed circular polarizer, the brightness is uniform at every azimuthal angle, and reaches the maximum value. So it recovers the light lost due to the effect of crossed liner polarizer, the brightness is dramatically enhanced, and almost twice of the brightness obtained in the case of stacking a pair of crossed liner polarizer. Light transmittance distribution for the cross sectional view at any direction that through the center of the conic is shown in Figure 8. It can be seen that the light transmittance is uniform and the largest for the region between the protrusions and ITO silts, while the light transmittance at the area of protrusions is the smallest for the light shielding effect of the protrusions, the light transmittance is medium at

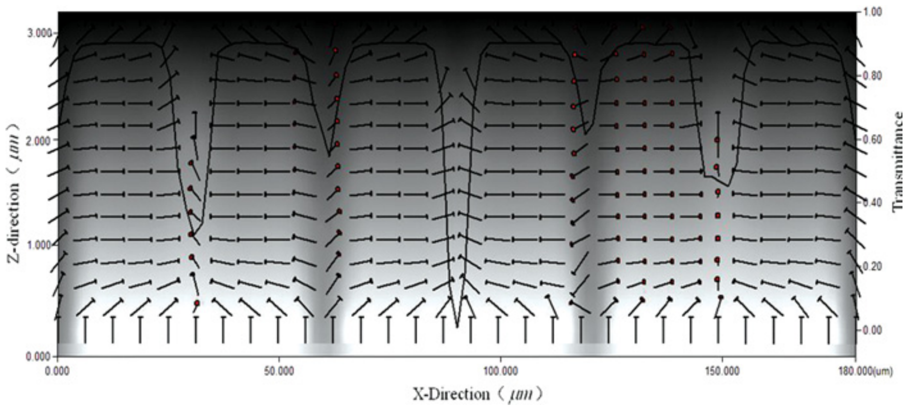

Figure 8. Cross sectional view of liquid crystal director distribution and transmittance. (Figure appears in color online.)

the area of ITO silts. Both at the area of physical protrusions and ITO slits, the LC molecules inclined at the opposite directions. But due to the slope of the protrusion, LC molecules inclined perpendicular to the edge of protrusion and form the ridge disturbing. But for the area of ITO slits, due to the extrusion from different side LC molecules, with the effect of the fringe field effect, it form the valley distribution, so the LC molecules will not inclined parallel to the substrate completely compared with adjacent regions, so it has a relative lower phase retardation difference, therefore, the light transmittance is deceased.

In order to give an analytic solution for the phenomena of transmittance enhancement by using a pair of crossed circular polarizer, in the next section, we made a detail derivation by the Jones matrix method, and Poincare sphere analysis can clearly clarify this fact.

3. Jones Matrix Calculations

For the phenomena of transmittance enhancement by using a pair of crossed circular polarizer, it not only suitable for the axially symmetric continuous domain vertical aligned LCD, but also suitable for the LC molecules continuous twist distribution structure LCD (take chiral MVA-LCDs for example), such as the ASV-LCD developed by Sharp corp. it is twist and molecules nearly rotate continuously 360° along an axis.

If the director is parallel to the x axis as the light enters the liquid crystal cell, the Jones matrix of a uniform twist nematic cell can be represents as

$$\mathrm{M_{LC}} = e^{i\frac{\pi d(n_o+n_e)}{\lambda}} \begin{bmatrix} \mathrm{a} & \mathrm{b} \\ -\mathrm{b}^* & \mathrm{a}^* \end{bmatrix} \tag{2}$$

$$a = \cos\beta\cos\phi + \frac{\phi}{\beta}\sin\beta\sin\phi - i\frac{\delta}{\beta}\sin\beta\cos\phi$$

$$b = \frac{\phi}{\beta}\sin\beta\cos\phi - \cos\beta\sin\phi - i\frac{\delta}{\beta}\sin\beta\sin$$

$$\phi\beta = \sqrt{\delta^2 + \phi^2};\ \ \delta = \pi d\Delta n/\lambda;\ \ \Delta n = n_e - n_o$$

Where ϕ is twist angle, n_o and n_e are the ordinary and extraordinary refractive index of liquid crystals, λ is the central wavelength of incident light and d is the cell thickness. The output electric field component for x axis and y axis after passing through the rear polarizer, the first quarter-wavelength film, general twist nematic liquid crystal layer, and finally the second quarter-wavelength film, can be represented as

$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = R(45^0) \cdot R_{QWP} \cdot R^{-1}(45^0) \cdot R^{-1}(\alpha) \cdot M_{LC} \cdot R(\alpha) \cdot R(135^0) \cdot R_{QWP} \cdot R^{-1}(135^0) \cdot \begin{bmatrix} 0 \\ 1 \end{bmatrix} \tag{3}$$

Where in, if the slow axis of quarter wavelength film is parallel with the x axis (0 degree), it can be represented as the following form by 2×2 Jones matrix

$$R_{QWP} = \begin{bmatrix} i & 0 \\ 0 & 1 \end{bmatrix} \tag{4}$$

$R(135^0) \cdot R_{QWP} \cdot R^{-1}(135^0)$ represents converting the slow axis of quarter-wavelength film from 0 degree to 135 degree, and $R(45^0) \cdot R_{QWP} \cdot R^{-1}(45^0)$ represents converting the slow axis of quarter-wavelength film from 0 degree to 45 degree. α is the angle formed between the slow axis of liquid crystal at the entrance plane and the x axis of the reference frame. $R(\alpha)$ is the coordinate rotation matrix, which has the form

$$R(\alpha) = \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \tag{5}$$

Putting the Eqs. (2), (4) and (5) into (3), we can obtain the following form

$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} \frac{\delta \sin\beta}{\beta} e^{i(\frac{\pi}{2} - 2\alpha - \phi)} \\ (\frac{\phi}{\beta}\sin\beta\cos\phi - \cos\beta\sin\phi) + i(\frac{\phi}{\beta}\sin\beta\sin\phi + \cos\beta\cos\phi) \end{bmatrix} \tag{6}$$

Therefore, unify the x axis direction and the y axis direction output light intensity respectively

$$\frac{I_x}{I_x + I_y} = \left\langle |E_x|^2 \right\rangle = \frac{\delta^2}{\beta^2} \sin^2\beta \tag{7}$$

$$\frac{I_y}{I_x + I_y} = \left\langle |E_y|^2 \right\rangle = \cos^2\beta + \frac{\phi^2}{\beta^2} \sin^2\beta \tag{8}$$

The changed phase retardation at the x axis direction the y axis direction can be represented as

$$\varphi_x = \frac{\pi}{2} - 2\alpha - \phi \tag{9}$$

$$\varphi_y = \arctan\frac{\phi\sin\beta\sin\phi + \beta\cos\beta\cos\phi}{\phi\sin\beta\cos\phi - \beta\cos\beta\sin\phi} \tag{10}$$

As the direction of transmission axis of the front polarizer is parallel with the x axis in the reference frame, thus the output unitary light intensity from the front polarizer can be represented by the Eq. (7), and it depends only on the liquid crystal layer phase difference between the ordinary light and extraordinary light and the twist angle. As in our axially symmetric continuous domain vertical aligned LCD, It has no twist across the cell thickness at certain gray scale voltage, thus the twist angle is equal zero, and the unitary output light intensity can be simplified as

$$\frac{I_x}{I_x + I_y} = \left\langle |E_x|^2 \right\rangle = \sin^2\beta = \sin^2\delta = \sin^2\left(\frac{\pi d\Delta n}{\lambda}\right) \tag{11}$$

While at the direction of y axis, the output light intensity will be absorbed by the absorbing axis of front polarizer, and can be simplified as

$$\frac{I_y}{I_x + I_y} = \left\langle |E_y|^2 \right\rangle = \cos^2\beta = \cos^2\delta = \cos^2\left(\frac{\pi d\Delta n}{\lambda}\right) \tag{12}$$

It is more worthwhile to point out that the output light intensity from the front polarizer does not depend on the angleα, no matter what is the orientation of the liquid crystal director, the out light intensity is always unchanged at every direction. Compared with the crossed liner polarizer, it just has the same output light intensity at the azimuth angle of 45°, 135°, 225° and 315°, while at other directions, it has a light intensity attenuation coefficient of $\sin^2(2\alpha)$. It can be assumed that Δn in Eqs. (11) and (12) stands for the effective refractive difference. At the case of $\Delta n = 0$, that is to say, LC molecules are perpendicular with the substrates, and it represents a completely dark state. With the applied voltage across the two substrates increasing, the effective refractive difference will be larger, and the output light is an elliptically polarized light and the intensity increases correspondingly. Finally, when the voltage reached to saturation, then LC molecules inclined completely parallel with the substrate, and the phase retardation reaches the maximum, and equal toπ, and the output light is liner polarized light with its electric field vibrating at the direction of transmission axis of front polarizer, therefore, all the input light will be output. This is why output light transmittance is enhanced by using crossed circular polarizer at every direction, no matter the LC molecules is twist or non-twist type.

4. Poincare Sphere Analysis

In order to facilitate a deep understanding and describe the change of SOP while light propagation in the VA cell inserted between the crossed circular polarizer, a concept of Poincare sphere is employed. Poincare sphere is, as illustrated in Figure 9, a sphere having a radius S_0 (intensity) when S_1, S_2 and S_3 are axes of an orthogonal coordinate system, wherein, S_0, S_1, S_2 and S_3 expressing a polarized state of light. A point on the surface of Poincare sphere represents a polarized state of light. When Poincare sphere is regarded as a earth, a point on the equator designates linearly polarized light, and two points on the north pole and the south pole designate right-handed circular polarized light and left-handed circular polarized

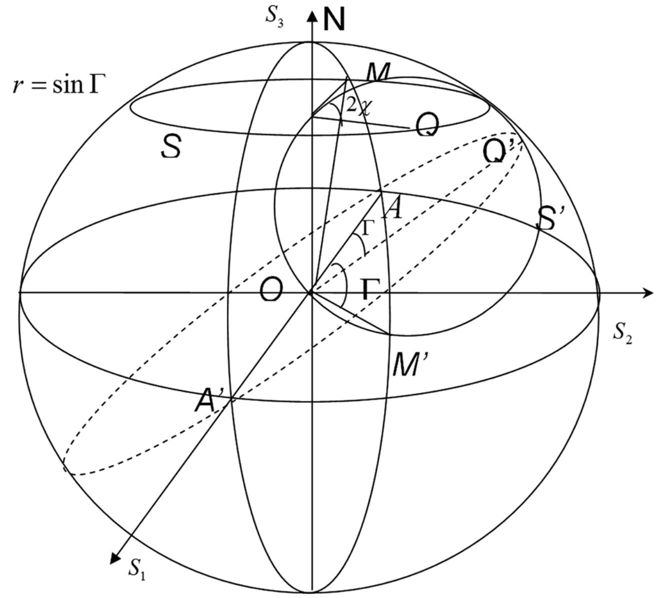

Figure 9. Poincare sphere representation for the change of state of polarization through the axially symmetric continuous alignment type LCD inserted between the crossed circular polarizer.

light respectively, In addition, the longitude designates twice of an elliptic long-axis azimuthal angle, an intersecting point of Poincare sphere with a positive side of the S_1 axis designates linearly polarized light which vibrates in the horizontal direction, and an intersecting point of Poincare sphere with a negative side of the S_1 axis designates linearly polarized light which vibrates in the vertical direction. Furthermore, an intersection point of Poincare sphere with S_2 axis designates the linearly polarized light which vibrates in the direction inclined at 45°or -45°.

One of the reasons for using Poincare sphere is that the effect of retardation films and the evolution of the polarization state can be easily visualized. However, it becomes more sophisticate to describe the light propagation in the twist nematic liquid crystal layer due to it can not be treated as an uniaxial film simply. Therefore, in order to conveniently describe the light propagation in the TNLC layer, we created an equal model to stand for the TNLC layer. As we know, no-loss optical system can be tread as the combination of plenty of retardation films and the polarizer rotation element. Thus, we instead the uniform twist nematic liquid crystal layer with a combination of a retardation film $WP(\Gamma, \gamma)$ and a polarizer rotation element $R(\chi)$, as the following form

$$\mathrm{M_{LC}} = R(\chi) \cdot WP(\Gamma, \gamma) \tag{13}$$

Wherein,
$$WP(\Gamma, \gamma) = R(\gamma) \cdot WP(\Gamma) \cdot R(-\gamma) \tag{14}$$

$$WP(\Gamma) = \begin{bmatrix} e^{-i\Gamma/2} & 0 \\ 0 & e^{i\Gamma/2} \end{bmatrix} \tag{15}$$

Considering with Eq. (2), we can obtain

$$\sin^2(\Gamma/2) = \frac{\delta^2}{\beta^2}\sin^2\beta \tag{16}$$

$$\tan 2\gamma = \frac{\phi}{\beta}\tan\beta \tag{17}$$

$$\tan\chi = \frac{\beta\sin\phi\cos\beta - \phi\cos\phi\sin\beta}{\beta\cos\phi\cos\beta + \phi\sin\phi\sin\beta} \tag{18}$$

Wherein, Γ is the phase retardation of the wave plate, and the angle γ is the angle formed between the slow axis of wave plate and the x axis. χ is the polarized light rotation angle operated by the polarization rotation element. Input Eqs. (13)–(18) into the Eq. (3), we can obtain the output electric field component for x axis and y axis

$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} \sin(\Gamma/2)\cdot(\sin(\chi+2\gamma) + i\cos(\chi+2\gamma)) \\ \cos(\Gamma/2)\cdot(-\sin\chi + i\cos\chi) \end{bmatrix} \tag{19}$$

Therefore, according to the above equation, we can derive the same results as the Eqs. (7) and (8)

$$\frac{I_x}{I_x + I_y} = \left\langle |E_x|^2 \right\rangle = \sin^2(\Gamma/2) = \frac{\delta^2}{\beta^2}\sin^2\beta \tag{20}$$

$$\frac{I_y}{I_x + I_y} = \left\langle |E_y|^2 \right\rangle = \cos^2(\Gamma/2) = \cos^2\beta + \frac{\phi^2}{\beta^2}\sin^2\beta \tag{21}$$

The detail light propagation and the change of the state of polarization are explained using Poincare sphere shown in Figure 9. When the unpolarized light from the backlight source passes the rear polarizer, it becomes linearly polarized and its polarization state is located at point A (intersecting point of Poincare sphere with the negative side of the S_1 axis). Then, such linearly polarized light successively pass through the first quarter wavelength film, whose slow axis is at the direction of 135 degree and the position is intersecting point of Poincare sphere with the negative side of the S_2 axis, the polarization state is rotated counterclockwise from point A to point N around the positive S_2 axis, and it becomes the right-handed circular polarized light. When this right-handed circular polarized light traverses the liquid crystal layer, it is equal to firstly pass through a wave plate whose phase retardation is Γ and the slow axis form an angle γ with the x axis, so such right-handed circular polarized light rotated from point N to the point M around the axis which deviates 2γ angle with the positive S_1 axis in the plane of equator in clockwise. OM axis and ON axis form an angle Γ. Point M is the second intermediate polarization light, which, in general, is elliptical. Such elliptically polarized light, then passes through a polarization rotation element, and rotate its polarization state with an angle of 2χ on the circle S, which is parallel with the equator and the radius is $r = \sin\Gamma$, and the polarization state is located at point Q. Both point M and point Q are lies on the circle S. Actually, if the liquid crystal layer have no twist, the distribution of liquid crystal director in our model is axially symmetric continuous alignment at certain voltage, it just equal to an unixial film at every direction, after the right-handed circular light passes through the above mentioned LC layer, the polarization state of the light is located on the circle S for every direction. Then the elliptically polarized light output from the LC layer, passes the second quarter wavelength film, whose slow axis is 45 degrees and located on the intersecting point of Poincare sphere with a positive side of the S_2 axis. Then polarization state is rotated clockwise from point Q to point Q' around the positive S_2 axis, Q' is lies on the circle S', which is rotated from the circle S by 90 degree around the positive S_2 axis in clockwise. Point A is the center of the circle S', OQ' axis and OA axis forms the angle Γ, the final polarization states at every direction after passed through the axially symmetric continuous alignment LC layer and the second quarter wavelength film are located on the circle S', designates the third intermediate polarization light which is elliptical. the line connected by any point on the circle S' and the center of Poincare sphere always form the angle Γ with the OA axis, such elliptically polarized on the circle S' finally passes through the front polarizer, whose transmission axis at the x axis, and the output light transmittance can be represented as

$$\frac{\mathrm{I}_x}{\mathrm{I}_x + \mathrm{I}_y} = \cos^2\frac{A'Q'}{2} = \sin^2\frac{AQ'}{2} = \sin^2(\Gamma/2) \tag{22}$$

Equation (22) is suitable for the general uniform twist type MVA-LCD, if the negative liquid crystal layer has no twist, then, it can be simplified as

$$\frac{\mathrm{I}_x}{\mathrm{I}_x + \mathrm{I}_y} = \sin^2(\delta/2) \tag{23}$$

Therefore, from the Poincare analysis, we also obtain the same results derived by the Jones matrix method, and approved the factor that the light transmittance enhanced by using a pair of crossed circular polarizer for the axially symmetric continuous alignment type LCD or chiral MVA-LCD.

5. Conclusions

To fully understand the mechanism of the light transmittance enhancement by using the crossed circular polarizer for the axially symmetric continuous alignment type LCD or chiral MVA-LCD, the Jones matrix method, Poincare sphere analysis, and mathematics calculation was conducted in the analysis. It was found that the light transmittance only depends on the effective phase difference across the liquid crystal cell thickness, but does not depend on the orientation of the liquid crystal director. Thus it has the uniform light transmittance at every direction for the different LC molecules inclined direction. By using the axially symmetric continuous alignment type LCD or chiral MVA-LCD design, it has the advantage of smallest color shift compared with the conventional MVA design. Although there still exists the disadvantage for simply stack a pair of circular crossed polarizers on the new type of MVA-LCDs due to the light leakage on the diagonal direction, however, some improvement has been made, such as using biaxial quarter wavelength film to replace the narrow bandwidth quarter wavelength film, wide viewing angle has been achieved. With the continuous development and cost down of the new type of circular polarizer, we believe it will have a great progress for the axially symmetric continuous alignment type LCD or chiral MVA-LCD in the near future.

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