Transflective Liquid Crystal Display of In-Plane Switching (IPS), Using Patterned Retarder on the Side of the Upper Substrate

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Abstract

We propose a transflective In-Plane Switching mode in which patterned retarder is placed only on the reflective area of the upper substrate side. By selecting optic axes of Half Wavelength Plate and Liquid Crystal as 24 and 90 degree with respect to polarizer, condition of low reflectance for visible wavelength range at black state is found.

1. Objectives and Background

Recently, usage of Liquid Crystal Display (LCD) for mobile application is increasing. For mobile application, readability in the bright outdoor environment is an important requirement. As a result, various transflective LCD structures have been designed which utilize the ambient light as well as backlight.[1-3] Among these, a few transflective structures using in-plane electric field, have been suggested for the purpose of wide viewing angle. [4-6] However, previous structures show limited viewing angle characteristics for transmissive area as various retarders in transflective LC modes are designed not for the purpose of viewing angle improvement but for the purpose of low spectral reflectance at black state.

In most of reported transflective IPS, a few retardation layers are placed between LC layer and reflector. Though retarders can be placed either outside LC cell or inside LC cell, optical configuration can be quite simplified when retarder is placed inside LC cell. Materials and process for such an in-cell retardation layer have been reported, in which retarder is made by coating and curing process of reactive mesogen. [7,8] Higher standard for process compatibility is required when in-cell retarder is placed on the lower substrate of TFT than on the substrate of C/F side. Due to these reasons, we propose a new structure of transflective IPS where retarder is patterned and placed only on the reflective region of upper substrate of C/F side. Its structure is illustrated in Fig.1. As there is no retarder for transmissive area, transmissive area is designed to have the same optical structure as the transmissive LCD. Therefore performance of transmissive part would be equivalent to typical IPS mode and is not separately considered in this paper.

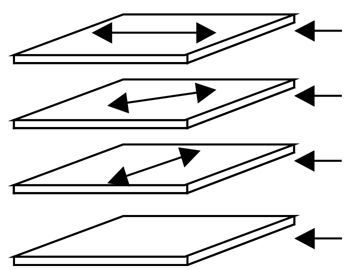

Figure 1. Schematic optical configuration of proposed transflective IPS structure for reflective part.

2. Results

The reflective area at black state can be treated as configuration of two retarders where LC cell corresponds to the second retarder. These two layers can be defined by direction of optic axes and retardations (R_1, θ_1) and (R_2, θ_2). Optic axis of LC, θ_2 is determined to be parallel or perpendicular to optic axis of polarizer from the configuration of transmissive area. LC cell gaps for reflective part can be different from that of transmissive area. So, number of independent parameters is four, though θ_2

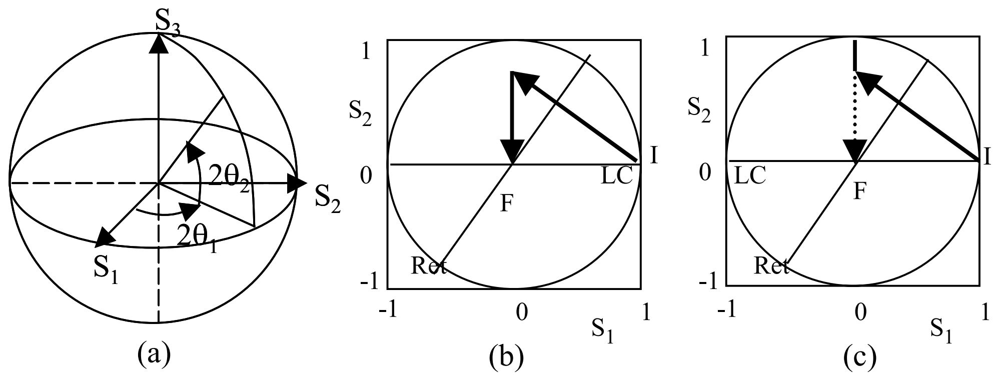

Figure 2. (a) Stokes vector on Poincare sphere representation (S_1, S_2, S_3) = ($\cos^2\theta_2\cos^2\theta_1$,$\cos^2\theta_2 \sin^2\theta_1$, $\sin^2\theta_2$) (b)Trajectory of phase state when 1st retarder has optic axis of around 22.5 degree and optic axis of LC s 90 degree and (c) trajectory for LC optic axis of 0 degree. 'I' represents incident linear polarization. 'LC' and 'Ret' represent axes of rotation for LC and 1st retarder. 'F' represents final state after passing through 1st retarder and LC. Thick solid line and dotted line represent trajectory on the upper and lower hemisphere.

would be either 0 or 90 degree. For the reflection to be minimum at zero voltage, incident light should be converted into circular polarization at the exit of LC layer. We derived the relation of these 4 parameters for such a case. Stokes vectors are represented on Poincare sphere as shown in Fig.2 (a). As trajectories of phase state in Fig.2 (b) and (c) illustrate, light can be converted into circular polarization by LC layer only if S_1 component of exiting light from first retarder is zero. Phase change of incident linear polarization by 1st retarder is derived by Jones matrix representation as follows.

$$W(\Gamma,\phi)\begin{pmatrix}1\\0\end{pmatrix}=\begin{pmatrix}\cos(\Gamma/2)-i\cos 2\phi\sin(\Gamma/2)\\-i\sin 2\phi\sin(\Gamma/2)\end{pmatrix}$$

$$=\begin{pmatrix}E_p\\E_s\exp(i\delta)\end{pmatrix}\times\exp(i\delta_0) \qquad (1)$$

where ϕ is angle, $\Gamma=\frac{2\pi}{\lambda}R$, R is retardation,

λ = wavelength

From eq.(1), relation between electric field and Stokes vector can be written as follows.

$$S_1=E_p^2-E_s^2, S_2=2E_pE_s\cos\delta,$$
$$S_3=2E_pE_s\sin\delta, E_p^2+E_s^2=1$$
$$S_1=\cos 2\theta_2\cos 2\theta_1, \qquad (2)$$
$$S_2=\cos 2\theta_2\sin 2\theta_1,$$
$$S_3=\sin 2\theta_2$$

When S_1 is zero, then $2\theta_1$ is $\pi/2$, $S_2 = \cos 2\theta_2$ and $S_3 = \sin 2\theta_2$. So relation between retardation and optic axis of the 1st retarder is derived from eqs. (1) and (2) as follows

$$\sin^2\frac{\Gamma}{2}=\frac{S_2^2+(1-S_1)S_3^2/2}{S_2^2+S_3^2}=\frac{1}{2}\left(\cos^2 2\theta_2+1\right),$$
$$\sin^2 2\phi=\frac{1}{\cos^2 2\theta_2+1} \qquad (3)$$
$$\sin^2\frac{\Gamma}{2}\sin^2 2\phi=1/2$$

One solution for eq.(3) is $\lambda/2$ and 22.5 degree. From eq.(3), optic axis of first retarder, θ_1 can be positive or negative. And θ_2, optic axis of LC is 0 or 90 degree. So 4 combinations of R_1 and θ_2 are possible for the same absolute value of θ_1. As trajectories on the upper and lower hemisphere of

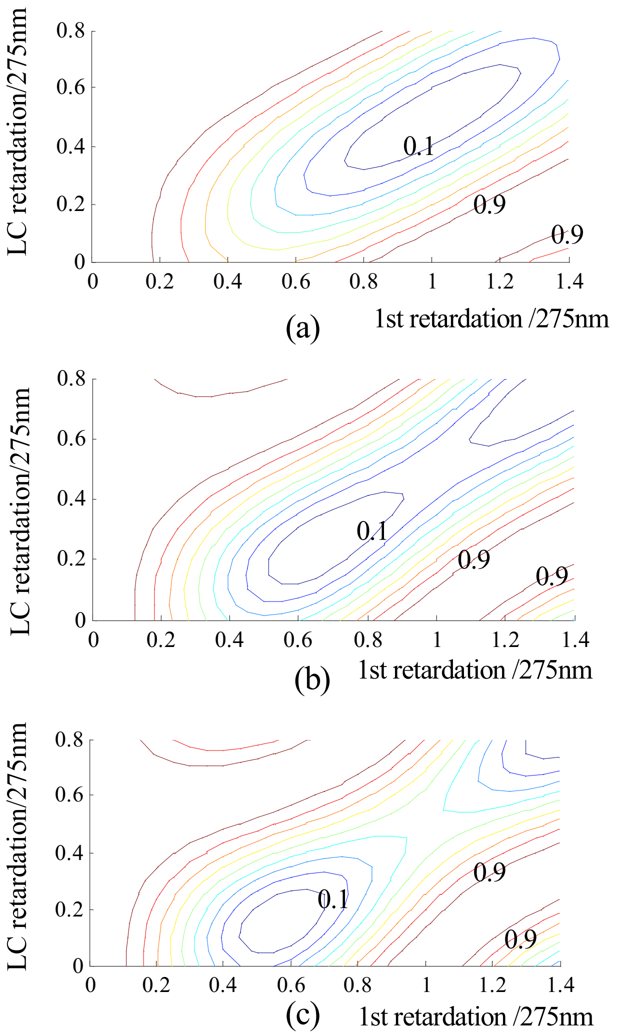

Figure 3. Contour map of reflectance as a function of retardations of 1st retarder and LC layer. Optic axes of 1st retarder are (a) 17. 5 (b) 27.5 and (c) 32.5 degree . Optic axis of LC is 90 degree. Horizontal and vertical axes represent retardation of 1st retarder and LC cell divided by 275nm.

Poincare sphere are equivalent, these 4 combinations can be categorized into two cases in which θ_2 is 0 or 90 degree for positive θ_1.

To see the reflectance characteristics under these parameter R_1, θ_1 and R_2, parametric space approach is used. Reflectance for structure of Fig.1 is calculated by Jones matrix method. 550 nm is selected as main wavelength. Ideal polarizer is assumed for the calculation. First, reflectance for $\theta_2 = 0$ and 90 degree are calculated as a function of retardation of 1st retarder and LC for θ_1 =22.5 degree. Condition of θ_2 = 0 shows strong dependence of reflectance on wavelength compared with θ_2 = 90 degree. Therefore, condition of 90 degree is chosen for the next step of calculation.

For θ_2 = 90 degree, we calculated reflectance for θ_1 of 17.5, 27.5 and 32.5 degree as Fig. 3 illustrates. Area of low reflectance is largest when θ_1 is around 22.5 degree. The analysis of reflectance dependence on θ_1 and θ_2 shows that lowest black condition for the condition of (22.5, 90).

Additional calculation is performed around θ_1 = 22.5 degree. Lowest reflection condition occurs at angles slightly higher than 22.5 degree, as decrease of reflectance at blue and red wavelength is larger than that increase of reflectance at green wavelength. Fig. 4 shows calculated spectral reflectance for conventional wideband QWP, 1 layer of QWP, combination of HWP layer and LC layer of QWP retardation. Configuration of HWP of 24 degree and LC layer of represents low reflectance comparable to conventional wideband QWP. [9]

As retardation of transmissive IPS cell is about 320nm, dual cell gaps are necessary.

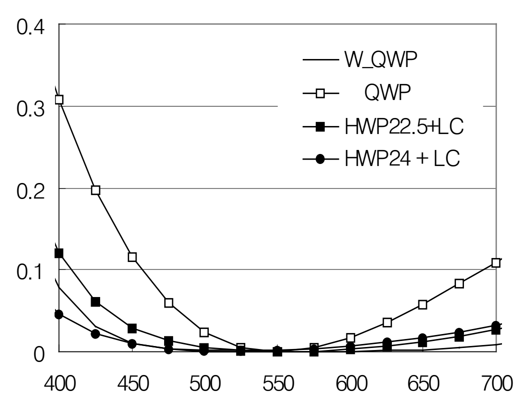

Figure 4. Calculated spectral reflectance where various configurations of retarders are placed between ideal polarizer and reflector. W_QWP and QWP represent conventional wideband QWP and typical QWP. "HWP+LC" represent structure of 1st retarder of HWP and second layer of QWP and 90 degree. Numbers behind HWP represent angles of optic axis.

3. Impact

In summary, we designed a simple optical structure for transflective IPS mode in which patterned in-cell retarder is located only on the upper substrate side of reflective area. Spectral reflectance at black state is lowest for the condition that optic axis and retardation of patterned retarder and LC is (λ/2, 24 degree) and (λ/4, 90 degree).

Transmissive part is equivalent to conventional IPS mode and wide viewing angle characteristic is possible. As black condition of transmissive part is made not by compensation of retardation films, luminance level at black condition is not affected by retardation variations such as cell gap and temperature change.

4. Acknowledgment

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