Single-layer retarder for LCD

A. Lazarev, A. Geivandov*, I. Kasianova*, E. Kharatiyan*, P. Lazarev*, S. Palto*, **
Crysoptix KK, Japan, Level 15, JT Building, 2-2-1 Toranomon, Minato-ku, Tokyo 105-0001, Japan
*Kontrakt Ltd., Russia, Miusskaya pl. 9, bldg. 5, Moscow 125047, Russia
**Institute of Crystallography RAS, Leninsky pr. 59, Moscow 119333, Russia

ABSTRACT

We have developed a full set of coatable thin birefringent film (TBF^{TM}) retarders for LCD. New printable retarders allow efficient optical compensation in VA and IPS LCD modes using a single-layer film. Replacement of conventional stretched polycarbonate retarders with submicron, solution-processed TBF provides substantial cost reduction of LCD optical components.

1. INTRODUCTION

Crysoptix KK has developed a new class of thin birefringent films (TBF^{TM}), which provide optical compensation of LCD by a single layer of printable retarder film. A method of manufacturing of the retarder film is based on molecular engineering of self-assembling organic molecules. The coating technology enables mass production of low cost large-scale manufacturing retarder films.

2. BACKGROUND

The technological progress in LCD manufacturing sets new tasks for researchers and manufacturers. A growing size of LCD TV screen diagonal, which has already exceeded 100" size, imposes stronger restrictions onto quality of optical components and demands innovation in the manufacturing process. In the case of retarder films, very small color shift and higher contrast ratio at large viewing angles are required for high-quality viewing of large area displays.

Our target was to provide low-cost and efficient optical compensation for VA and IPS modes of LCD. We have developed several optical designs of VA LCD and IPS LCD and found that B_A-type and A_C-type retarders are the most promising for single layer compensation of IPS and VA LCD respectively.

Today Crysoptix KK can offer biaxial B_A- and A_C-type plates, as well as uniaxial negative C-type, negative and positive A-type plates. The detailed classification of retarders is presented in [1]. The set of Crysoptix retarder films provides great flexibility for an LCD optical designer.

3. COATABLE RETARDER

3.1 TBF^{TM} technology

We have developed a set of coatable TBF^{TM} retarder films with high retardation. The new TBF^{TM} retarders with functions of negative A-plate, negative C-plate, positive A-plate, biaxial B_A-type and A_C-type plates are based on low molecular weight aromatic compounds and rigid-core aromatic oligomers. The TBF^{TM} retarder films are produced by printing techniques (for example roll-to-roll, slot die, spray coating).

3.2 Variation of NZ factor in TBF^{TM}

The NZ factor is a value used to characterize the biaxiality of birefringent optical film. It is determined by the following equation:

$$NZ = \frac{Max(n_a, n_b) - n_c}{Max(n_a, n_b) - Min(n_a, n_b)},$$

where n_a, n_b, and n_c are the principal refractive indices. The subscripts a and b designate the principal axes directions belonging to the film plane, while c is for the normal direction to the film plane. The a direction coincides with TBF^{TM} coating axis.

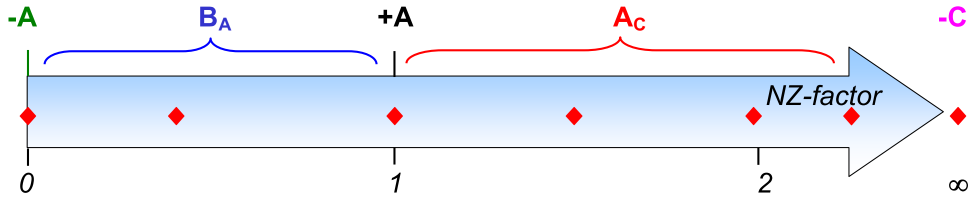
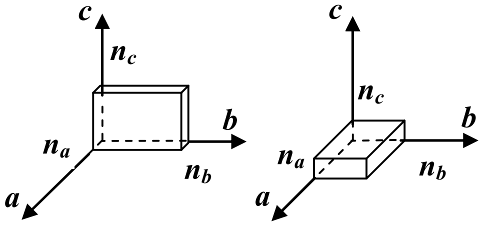


**Fig. 1 Types of retarders according to NZ factor.
Particular Crysoptix TBF^{TM} retarders are marked with ◆ signs**

Up to now the NZ values available to the optical engineers working with LCD designs were limited. Our materials provide control over NZ factor in biaxial plates, remove many constrains in optical design of LCD, and give more flexibility to designers.

We have developed a new approach that allows to tailor the degree of biaxiality of optical films in a wide range and produce TBF^{TM} with tunable NZ-factor matching certain designs [2]. The NZ factors for typical TBF^{TM} are shown in Figure 1. Moreover, we can design a plate with arbitrary pre-determined NZ factor value in a range from 0.0 to 2.5.

Tunable degree of biaxiality provides an advantage of a superior optical compensation of LCD with a single retarder film having desirable values of principal refractive indices. Potential of a single-layer compensation for IPS and VA LCD designs is described below.



a) $n_a < n_c < n_b$ b) $n_a > n_b > n_c$

Fig. 2 Relationship between principal refractive indices for (a) biaxial B$_A$-type plate, and (b) biaxial A$_C$-type plate retarders; *ab* is a film plane

3.3 Optical simulations

We performed the simulation of optical performance and optimization using special software (LCDTDK 3.0 by S. Palto). The principles of our numerical simulation approach are described in [3].

3.3.1 Optical design of IPS LCD

The IPS LCD design was optically compensated with a single-layer biaxial B$_A$-type plate TBF^{TM} (Fig.2a), having the following parameters: n_a=1.51, n_b=1.81, n_c=1.68 (*NZ*=0.5) at wavelength λ=550 nm.

Optical arrangement of the compensated IPS LCD is shown in Figure 3a. The angular orientation of principal axes of the optically anisotropic elements is as follows:

- transmission axes of the front and rear polarizers are at φ = +45° and φ = –45° respectively,
- LC alignment is at azimuth angle φ = +45°, and
- in case of biaxial B$_A$-type plate retarder the n_a direction is at φ = -45°.

In IPS LCD design the LC molecules have a planar alignment characterized by low pretilt angle (~1°) with respect to the layer plane. The optical retardation of the LC layer is 275 nm, which corresponds to a half-wave plate at a wavelength of 550 nm. In order to provide the driving in-plane electric field the liquid crystal should have a positive value of the dielectric anisotropy ($\varepsilon_{||}$-$\varepsilon_{\perp}$ > 0). The in-plane electric field applied along the *x*-axis orients the LC molecules preferably in the same *x*-direction, i.e. at an angle of 45° with respect to the polarizers axes. The last state corresponds to an optically bright state of the design.

We performed an optimization of a B$_A$-type retarder thickness for maximal contrast ratio (CR) at 550 nm. The optimized design with a single B$_A$-type retarder of 0.5 μm thickness possesses high contrast ratio — more than 100 — in 60° viewing cone [4]. The contrast ratio vs. viewing angle map is shown in Figure 3b.

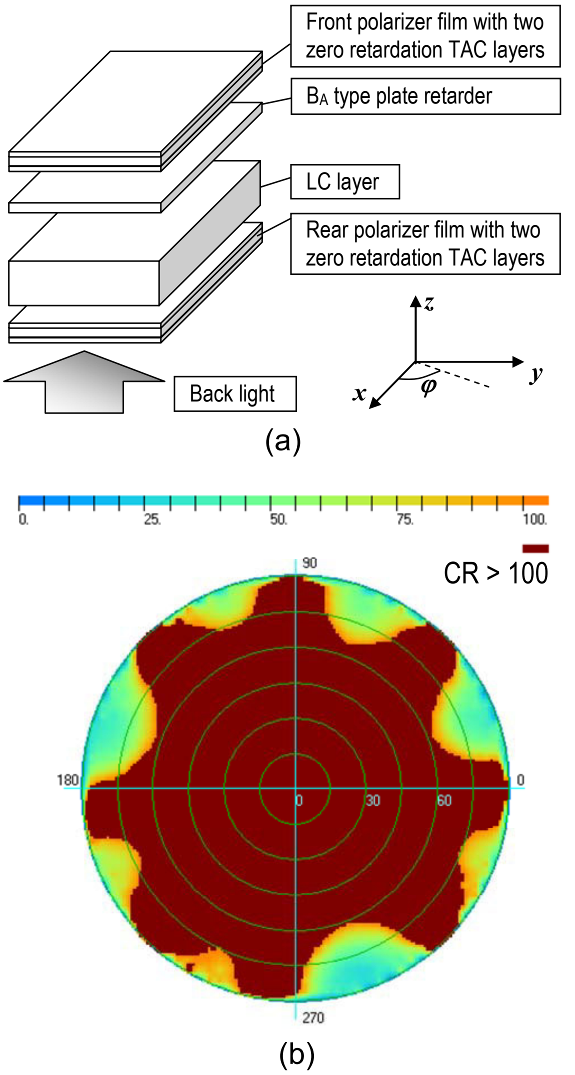
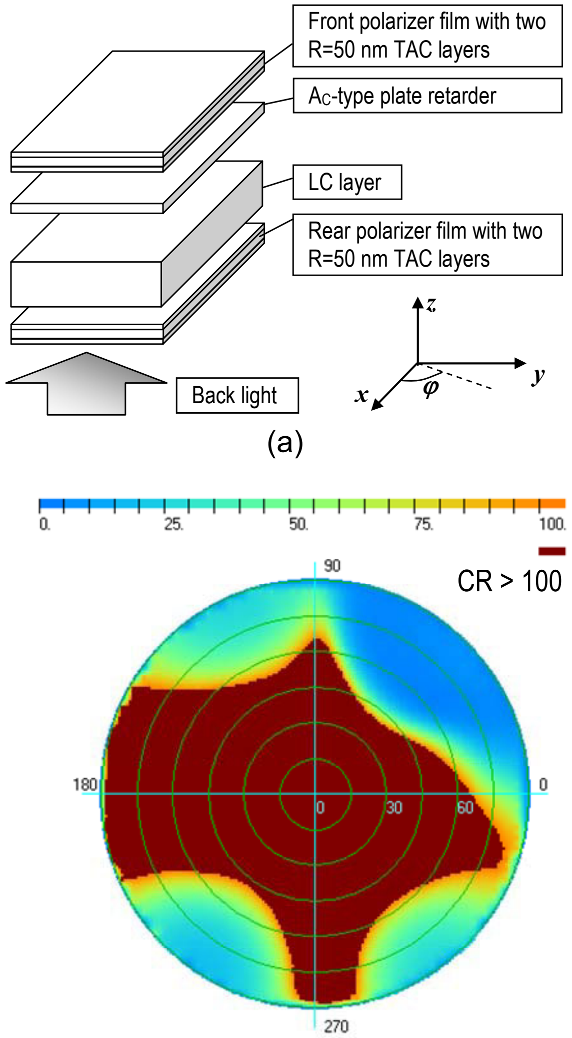


Fig. 3. IPS LCD compensated with Crysoptix biaxial B$_A$-type plate retarder: (a) general scheme, and (b) simulated viewing angle contrast ratio map at wavelength λ=550 nm

3.3.2 Optical design of VA LCD

The VA LCD design was optically compensated with a single biaxial A_C-type retarder (Fig.2b) having the following parameters: n_a=1.72, n_b=1.68, n_c=1.62 (*NZ*=2.2) at wavelength λ=550 nm.



(b)

Fig. 4. VA LCD compensated with Crysoptix biaxial A_C-type plate retarder: (a) general scheme, and (b) simulated viewing angle contrast ratio map at wavelength λ=550 nm

The optical layers of the simulated design are shown in Figure 4a. The setup is based on a monodomain VA LC cell. The thickness *d* of the VA cell was chosen on account of the LC optical anisotropy Δn in order to provide a cell retardation of $\Delta nd \cong 275$ nm. The LC director pretilt angle with respect to the layer surface was 89°. The LC material with negative dielectric anisotropy ($\varepsilon_{||}-\varepsilon_{\perp} = -3.5$) and low birefringence ($\Delta n \cong 0.08$) was used. The elastic modules of the LC used in simulations were of typical values: K_{11}=10 pN, K_{22}=5 pN and K_{33}=15 pN. The state with transmission close to the maximal value with such LC parameters is achieved at an applied voltage of 8 V, which agrees with the experiment.

The angular orientation of principal axes of the optically anisotropic elements shown in Figure 4a is as follows:

- transmission axes of the front and rear polarizers are at φ = 90° and φ = 0° respectively,
- LC alignment is at an azimuth angle of φ = 45°,
- the n_a direction is at φ = 90° in case of biaxial A_C-type plate retarder.

We performed an optimization of an A_C-type plate thickness for maximal contrast ratio at 550 nm. The optimized design with a single A_C-type plate of 1.3 μm thickness provides a high contrast ratio — more than 100 in 45° viewing cone, and more than 50 in 60° viewing cone for an incidence plane at an azimuth φ = -45° [5]. The contrast drop at +45° diagonal corresponds to the LC molecules' reorientation axis and can be easily overcome by multi-domain pixel design. The contrast ratio vs. viewing angle map is shown in Figure 4b.

3.4 Environmental test

The reported TBF^{TM} retarders withstand wet environmental test in harsh conditions (temperature 60°C and relative humidity 90%). We have developed a special post-treatment procedure to impart high environmental stability to the TBF^{TM}. The procedure includes dipping the coated retarder film on the substrate into the bath with a developer solution.

3.5 In-cell capability

Furthermore, Crysoptix has developed biaxial B_A-type and A_C-type retarder films, which possess unsurpassed high temperature stability. The BA-HT-1000 [6] and AC-HT-1000 hold temperature up to 250 °C for 1 hour, which makes the in-cell retarder application feasible.

3.6 Wideband retarder

On the example of B_A-type plate TBF^{TM}, we have shown that modification of the host retardation material with a dye guest results in a desirable anomalous dispersion of refractive indices, which broadens the effective spectral range of the retarder [7], [8].

4. CONCLUSION

Application of the developed biaxial retarder films of B_A-type and A_C-type plates opens a new opportunity for further increasing the LCD viewing quality along with substantial cost reduction because of low cost of material and only one layer of retarder that is required for high quality compensation. The coatable retarder can be laminated with polarizer or coated on glass in-cell and provide low-cost and efficient LCD optical compensation.

5. REFERENCES

[1] S. Palto, I. Kasianova, E. Kharatiyan, V. Kuzmin, A. Lazarev, and P. Lazarev, “Thin Coatable Birefringent Films and Their Application to VA and IPS Mode LCDs”, SID 2007 Digest, Long Beach, California, USA, May 20-25, 2007, pp. 1563-1566.

[2] Composition of organic compounds, optical film and method of production thereof. Patent pending.

[3] S.P. Palto, S. Remizov, I. Kasianova, N. Guselnikov, A. Lazarev, "Vertically Aligned LCD Designs Optically Compensated by Thin Birefringence Films", Proceedings of The 13th International Display Workshops IDW'06, Otsu, Japan, December 6-8, pp. 311-314 (2006).

[4] Compensated In-Plane Switching Mode Liquid Crystal Display. Patent pending.

[5] Liquid Crystal Display Operating In A Vertically Aligned Mode, PCT Publication WO2007/141025.

[6] A. Lazarev, A. Geivandov, I. Kasianova, E. Kharatiyan, S. Palto, “Modeling and Prototyping of Optically Compensated VA LCD”, SID 2008 Digest, Los Angeles, California, USA, May 18-23, 2008, pp. 1881-1884.

[7] A. Lazarev, A. Geivandov, A. Manko, S. Palto, “Advanced wideband coatable LCD retarder with anomalous dispersion of optical anisotropy”, IDW’08 Digest, in print.

[8] Color Liquid Crystal Display and Compensation Panel. Patent pending.