Printable Thin Birefringent Film Retarders for LCD

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ABSTRACT

Crysoptix Ltd. has developed Thin Birefringent Films (TBF^{TM}) retarders with negative C-plate and biaxial plate functions for manufacturing via printing technology from liquid self-assembling materials. The new coatable sub-micron retarders exhibit high optical anisotropy, low depolarization, high temperature stability, and environmental durability. The commercialization of TBF^{TM} retarders on-TAC and as in-cell LCD retarders is discussed.

1. INTRODUCTION

Crysoptix Ltd. has developed Thin Birefringent Films^{TM} (TBF^{TM}) for production of retardation films by printing of liquid self-assembling materials based on low molecular weight organic compounds. Molecular design allows adjusting the chemical structure of organic components for printing techniques (roll-to-roll slot die, extrusion coater with moving head) to produce the coatable sub-micron TBF^{TM} with the required three principal refractive indices. Coatable retarders are less expensive than existing stretched polymer materials. Furthermore, the coating on requisite display substrate may provide additional cost savings. For wider viewing angle in LCD TVs the cost of polymer stretching grows with the size of the film (because of industrial difficulties in manufacturing of highly uniform retardation plates over a large area), while the cost of printing actually decreases with the size of the film along with a baseline cost reduction due to the cheaper printing technology instead of the more expensive stretching process.

It is known that thermal stability of conventional retarders is typically limited by a maximum temperature of 80 °C. The new coatable retarders can withstand up to 240 °C for several hours that is necessary for LCD manufacturing process and in-cell retarder application. Besides the overcome of the above mentioned technological issues of stretched polymers, the TBF^{TM} coatable retarders can compensate LCDs to provide an excellent contrast at wide viewing angles [1].

2. TBF^{TM} TECHNOLOGY

In general, a preferable method for TBF^{TM} film manufacturing is based on slot-die coating technique. Extrusion of lyotropic liquid crystal (LLC) from the slot under the pressure provides external shearing impact any alignment of self-assembling supramolecules along the coating direction. This technology does not require and alignment layer or rubbing of the substrate. Slot-die technique allows producing anisotropic films of high uniformity, e.g. thin birefringent films (TBF^{TM}).

For in-cell LCD application the retardation film can be printed onto inner surfaces of one of the LCD panel substrates in sequence with necessary functional layers. However, in this case the film should possess the high temperature stability. We have developed high-temperature (HT) retardation films.

On the other hand, for application in conventional stretched polarizers the TBF^{TM} can be coated (printed) onto TAC (Triacetyl Cellulose) using slot-die technique and laminated with polyvinyl alcohol (PVA) film using conventional roll-to-roll process (Fig.1). In this case, in order to avoid destructive processes caused by water permeability, the film should exhibit high environmental durability. We have developed low-temperature (LT) wet-stable retardation films described below.

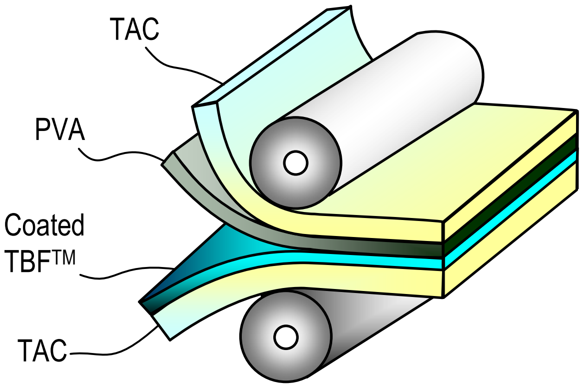
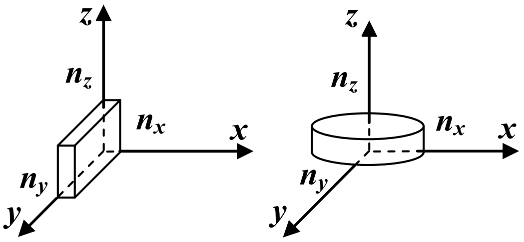


Fig. 1 Retarders on-TAC Application in Stretched PVA Polarizers (The TBF^{TM} is coated onto TAC and then the stretched PVA is laminated between the TAC and the TBF^{TM}-coated TAC.)

3. TBF^{TM} STABILITY

3.1 Classification of Retarders

In Fig. 2 the negative C-plate and biaxial B_A-plate retarders are defined in terms of principal refractive indices. For the TBF^{TM} retarders we match the x-axis with coating direction, while the z-axis is normal to the film plane. The details of TBF^{TM} classification are described in [2].



a) $n_x < n_z < n_y$ b) $n_x = n_y > n_z$

Fig. 2 Relationship between Principal Refractive Indices: (a) biaxial BA-plate, (b) negative C-plate retarders

3.2 Temperature Stability of TBF^{TM} Retarders printed on Glass

3.2.1 TBF^{TM} negative C-plate

The TBF^{TM} negative C-plate retarder CN-HT-1000 of thickness h has been produced by coating an aqueous solution of carboxylic derivatives of bisbenzimidazole [3,4]. The refractive indices n_x, n_y, n_z, out-of-plane birefringence $\Delta n = n_x - n_z$, transmittance at normal incidence, depolarization index Di and out-of-plane retardation $R_{th} = \Delta nh$ before and after temperature stability test are shown in Table 1. The initial film thickness (h) was equal to 325 nm and decreased by 7% after the high temperature test.

Table 1 Optical Parameters of CN-HT-1000 TBF^{TM} Negative C-plate for In-cell Application as a Function of High Temperature Test Time (at λ=550 nm)

t, hours	n_x, n_y	n_z	Δn	T, %	Di, %/μm	R_{th}, nm
0	1.74	1.51	0.23	88	<0.01	75
1	1.76	1.50	0.26	90	<0.01	80
3	1.76	1.50	0.26	90	<0.01	80

As shown in Table 1, the degradation of the TBF^{TM} negative C-plate does not occur – the film remains transparent and exhibits low depolarization. At the same time, slight increase of birefringence and out-of-plane retardation takes place. The presented results confirm that the TBF^{TM} negative C-plate retarder meets the requirements for in-cell applications.

3.2.2 TBF^{TM} Biaxial B$_A$-plate

The TBF^{TM} biaxial B$_A$-plate retarder BA-HT-1000 has been formed by coating the lyotropic liquid crystal onto the glass, and dried at room temperature.

We studied the temperature stability at 240 °C for 3 hours (Table 2, Fig. 3). The initial film thickness (h) was equal to 295 nm and decreased by 8% after the high temperature test.

Table 2 Optical Characterization of BA-HT-1000 TBF^{TM} Biaxial B$_A$-plate as a Function of High Temperature Test Time (at λ=550 nm)

t, hours	Δn_{xy}	Δn_{xz}	T, %	Di, %/μm	R_0, nm	R_{th}, nm
0	0.34	0.21	88	0.58	98	62
1	0.27	0.12	90	0.35	74	30
3	0.27	0.08	90	0.35	74	24

Note: $R_0 = (n_x - n_y)h \equiv \Delta n_{xy}h$, $R_{th} = (n_x - n_z)h \equiv \Delta n_{xz}h$.

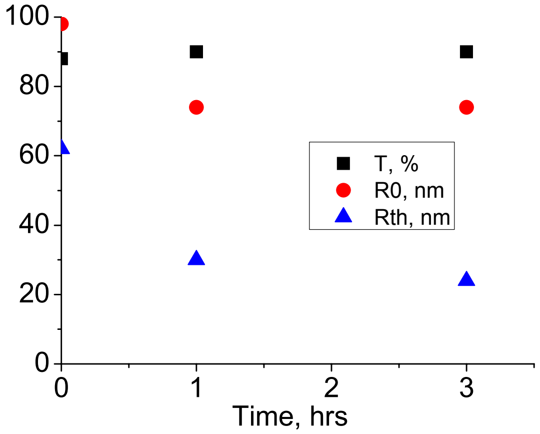


Fig. 3 Optical Characterization of BA-HT-1000 TBF^{TM} Biaxial B$_A$-plate as a Function of High Temperature Test Time (at λ=550 nm)

The measurements of the optical properties indicate that while the optical anisotropy was changing during the high temperature test process the degradation did not occur. The film remained transparent and highly birefringent. We conclude that the TBF^{TM} B$_A$-plate retarder meets the requirements for in-cell application.

3.3 Environmental Stability of TBF^{TM} Retarders

The developed negative C-plate and biaxial B$_A$-plate TBF^{TM} retarders are capable of withstanding the wet environmental test in harsh conditions (temperature is 60°C, and relative humidity - 90%).

In order to provide the film stability under harsh environment conditions the TBF^{TM} were submitted to post-treatment procedure right after the LLC wet coating [2,3].

3.3.1 TBF^{TM} biaxial B$_A$-plate

The TBF^{TM} BA-LT-1000 biaxial B$_A$-plate performance under environmental test described above is shown in Fig. 4. The measured film transmittance and retardance remain nearly unchanged after 1000-hour testing. Therefore the TBF^{TM} BA-LT-1000 biaxial B$_A$-plate retarder meets the requirements for commercial application, e.g. for compensation of polarizers based on TAC.

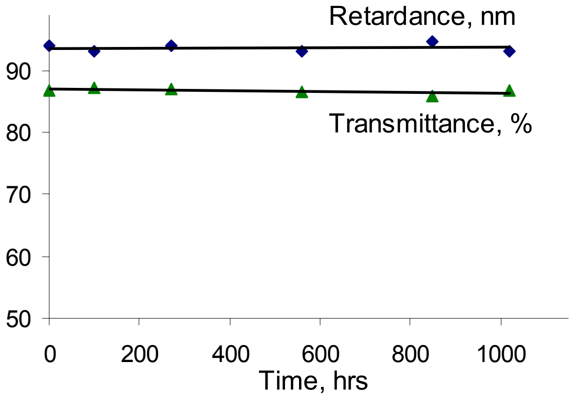


Fig. 4 Transmittance and Retardance (at λ =550 nm) of BA-LT-1000 TBF™ Biaxial B_A-plate during Wet Environmental Test (at T = 60°C and RH = 90%)

3.3.2 TBF^{TM} negative C-plate

The TBF^{TM} CN-LT-1000 negative C-plate was also submitted to the environmental test as described above. The omitted figures are similar to the Fig. 3. The film remained transparent and birefringent. We conclude that the TBF^{TM} CN-LT-1000 negative C-plate retarder meet the requirements for commercial application, e.g. for compensation of polarizers based on TAC.

4. OPTICAL DESIGN OF VA LCD

4.1 LCD Compensation by In-cell Retarder

As an example we present here an application of TBF^{TM} in-cell retarders for optical compensation of VA LCD design. The simulation results for IPS LCD with in-cell retarders are presented in [5].

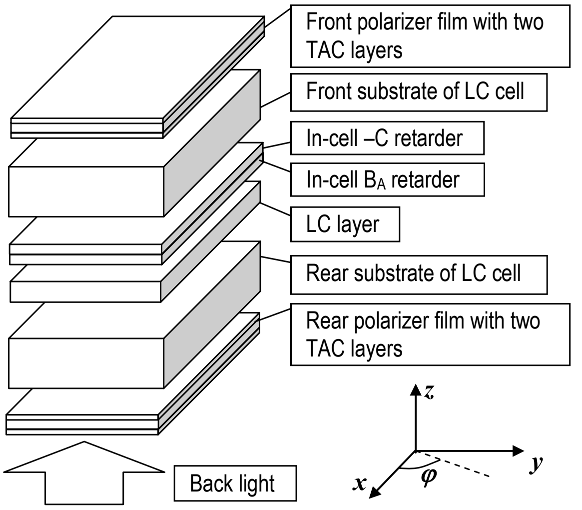
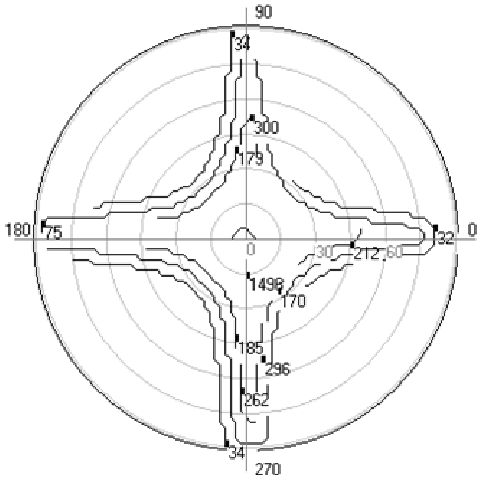


Fig. 5 Scheme of VA LCD Design Compensated by Negative C- and Biaxial B_A-plates TBF^{TM} Retarders

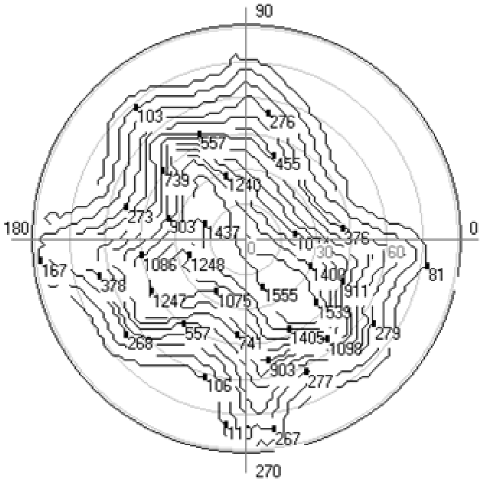
A general scheme of optically compensated VA LCD is shown in Fig. 5. In this scheme we show only principal components of the designs and do not show such elements as LC alignment layers and color filters, which are assumed to be optically isotropic and not influencing the optical compensation effect. A low thickness of retardation films and their insolubility in liquid crystal materials allow films to be coated directly onto the inner substrate surfaces, which might be in contact with a liquid crystal layer. Thus, the film retarder becomes a part of the LC cell unit.

The angular orientation of principal axes of the optically anisotropic elements shown in Fig. 5 is as follows:

- transmission axes of the front and rear polarizers are at φ=90° and φ=0° respectively, and
- LC alignment is at an azimuth of 45°, while biaxial B_A-plate retarder coating direction is at φ=0°.



(a) Non-compensated design



(b) Compensated design

Fig. 6 Contrast Ratio vs. Viewing Angle at λ =550 nm for VA LCD Designs: Non-compensated (a); Compensated by Negative C- and Biaxial B_A-plates TBF^{TM} In-cell Retarders (b)

In VA mode LC molecules have vertical alignment characterized by high pretilt angle (~89°) in the vertical plane oriented at an azimuth of 45°

with respect to the x-axis. 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 out-of-plane electric field the liquid crystal should have a negative value of the dielectric anisotropy ($\varepsilon_{||}$-$\varepsilon_{\perp}$ < 0). The electric field applied along the *z*-axis reorients the LC molecules preferably in plane at an angle of 45º with respect to the x-axis. The last state corresponds to an optically bright state of the design.

4.1.1 Simulation results

In Fig. 6 we present the results of numerical simulations performed using special software (LCDTDK 3.0 by S. Palto).

The use of the in-cell TBF^{TM} negative C-plate retarder together with biaxial B_A-plate retarder provides magnificent compensation effect and drastically improves the viewing angle performance (Fig. 6b).

The n_x-axis of B_A-plate retarder is oriented at 90° with respect to transmission axis of the PVA.

4.2 LCD Compensation by Retarder on-TAC

The conventional VA LC cell can be also compensated by retarders on-TAC. Let's consider performance of the optical design. The general scheme of front polarizer is shown in Fig.7.

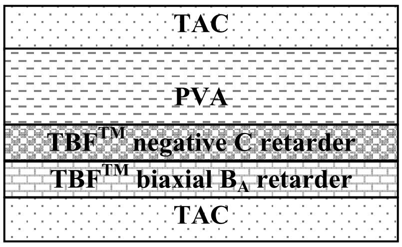


Fig. 7 Polarizer with Retarders on-TAC for VA LCD Compensation

In simulation we used the TBF^{TM} compensated front polarizer and conventional TAC compensated rear polarizer.

4.2.1 Simulation results

In Fig. 8 we present the results of numerical simulations performed using the mentioned software. As one can see the contrast ratio at oblique angles is also very high.

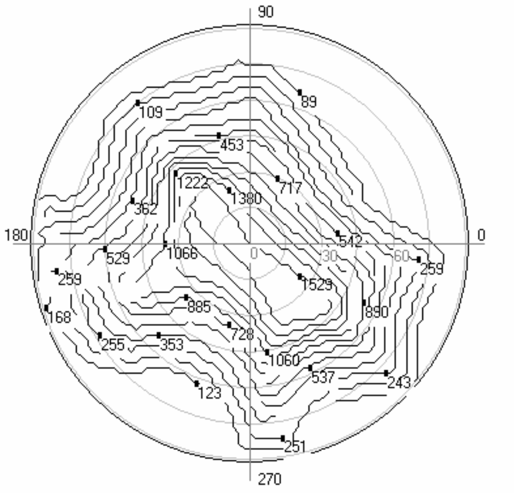


Fig. 8 Contrast Ratio vs. Viewing Angle at λ=550 nm for the VA LCD Compensated by Negative C- and Biaxial B_A-plates TBF^{TM} Retarders on-TAC

5. CONCLUSIONS

Advanced technology for manufacturing of coatable high-efficiency TBF^{TM} retarders opens up new opportunities for LCD design, optical performance improvement, and cost reduction of LCD.

6. 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 Digest, pp. 1563-1566 (2007).
[2] PCT publication WO2007042788.
[3] WO2007080419.
[4] PCT publication WO2007080420.
[5] A. Geivandov, I. Kasianova, E. Kharatiyan, A. Lazarev, P. Lazarev, and S. Palto, "Temperature stable on-glass coatable retarders for in-cell LCD applications" Proc. Eurodisplay'07 (2007), in print.