

## S 1-4. Temperature stable on-glass coatable retarders for in-cell LCD applications

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**Abstract:** Crysotix Ltd. has developed coatable Thin Birefringent Films (TBF<sup>TM</sup>) retarders based on molecular engineering of organic materials. The films possess negative C-type and biaxial retardation functions. The TBF<sup>TM</sup> retarders exhibiting high temperature stability meet the requirements for in-cell application and create new opportunities for quality enhancement and cost reduction of LCDs. Application of internal TBF<sup>TM</sup> retarders for optical compensation of IPS LCD is considered.

**Key Words:** retarder, coatable, printable, in-cell, internal, LCD, temperature stability, optical compensation.

### 1 Introduction

Molecular engineering of organic materials allows to develop molecular liquid formulations in water and in organic solvents coatable on a glass substrate. Coating produces molecular films with properties that are predetermined by design of molecules and formulation. Certain set of refraction indices corresponds to particular molecular alignment in the film as well as to a special symmetry of individual molecules. Structure of molecular aggregates in the liquid formulation, coating methods and drying conditions produce desirable predominant alignment of molecules.

Cost reduction and quality enhancement requirements, which are imposed on LCD products by the market, drive producers to minimize the number of components by combining different functionalities in a single component. Coatable on glass optical films create opportunity to eliminate bulk plastic films from LCD optical components. Market forces LCD industry toward on-glass coatable optical components instead of laminating plastic films. For instance, coating of the retarders onto a colour filter panel (otherwise called – in-cell application) is one of the possible ways to meet cost reduction requirements [1].

Target coatable optical films for in-cell application in LCD have to meet LCD manufacturing process requirements. One of the critical points for in-cell application is stability at the high-temperature steps of the LCD manufacturing process, in particular the alignment layer polyimide polymerization (up to 230 °C during 1-3 hours), and the cell sealing procedure.

In this paper we present a study of optical performance, and temperature stability of Thin Birefringent Films (TBF<sup>TM</sup>) retarders [2] developed by Crysotix Ltd. We present simulation data of IPS LCD design with in-cell retarder simulated.

### 2 Temperature Stability of TBF<sup>TM</sup> Retarders on Glass

We have developed a set of coatable TBF<sup>TM</sup> retarders with high retardation for VA and IPS LCD designs. TBF<sup>TM</sup> retarders with functions of negative A-plate, negative C-plate and biaxial B<sub>A</sub>-plate are produced by printing techniques (roll-to-roll slot die, spray coating) from liquid self-assembling materials based on low molecular weight aromatic compounds [3,4].

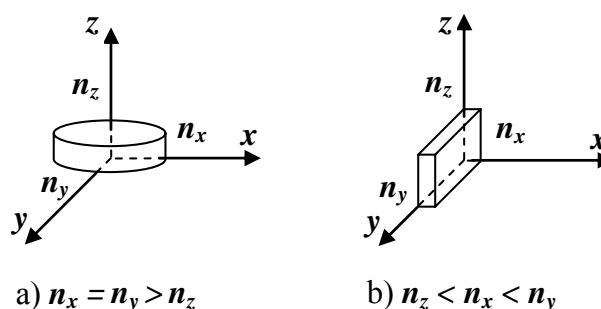
We have examined temperature stability and durability of TBF<sup>TM</sup> retarders deposited on glass substrates under 3-hours heating in air at 240 °C.

The cyclic heating procedure involved several repetitive steps. The optical parameters for not-temperature-treated samples were tested first. Then samples of TBF<sup>TM</sup> retarders were placed in an electrical oven with air atmosphere and heated to a temperature of 240 °C. After exposure to the high temperature for one hour, the samples were removed from the oven and cooled down in air to room temperature. After the optical properties were measured, the samples were placed back in the oven, and the thermal cycle was repeated. The total time of annealing was 3 hours.

This test set was aimed to simulate high-temperature operations of the LCD manufacturing process, in particular the polyimide curing and cell sealing.

#### 2.1 TBF<sup>TM</sup> Classification

In Figure 1 the negative C-plate and biaxial B<sub>A</sub>-plate retarders are defined in terms of principal refractive indices. For the TBF<sup>TM</sup> retarders we match the *x*-axis with coating direction, while the *z*-axis is normal to the film plane. The details of TBF<sup>TM</sup> classification may be found in [2].



**Figure 1** Relationship between principal refractive indices of negative C-plate (a) and biaxial B<sub>A</sub>-plate (b) retarders.

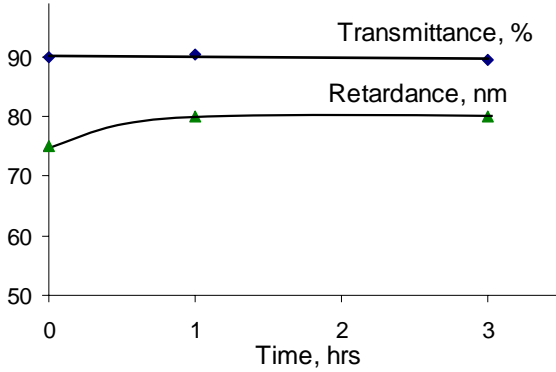
#### 2.2 TBF<sup>TM</sup> negative C-plate

The TBF<sup>TM</sup> negative C-plate retarder of thickness *h* has been produced by coating of an aqueous solution of carboxylic derivatives of bisbenzimidazole [5,6]. The refractive indices  $n_x, n_y, n_z$ , birefringence  $\Delta n = n_x - n_z$ , transmittance, depolarization index *Di* and out-of-plane retardation  $R_{th} = \Delta n h$  before and after temperature stability test are shown in Table 1 and Figure 2.

The initial film thickness ( $h$ ) was equal to 325 nm and decreased by 7% after annealing.

**Table I** Optical parameters of TBF<sup>TM</sup> negative C-plate as a function of annealing time (at  $\lambda=550$  nm)

$t$ , hours	$n_x, n_y$	$n_z$	$\Delta n$	$T$ , %	$D_i$ , %/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



**Figure 2** Transmission and retardation (at  $\lambda = 550$  nm) of TBF<sup>TM</sup> negative C-plate vs. time.

As shown in Table I and Figure 2, degradation of the TBF<sup>TM</sup> negative C-plate does not occur as 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<sup>TM</sup> negative C-plate retarder meets the requirements for in-cell application.

### 2.3 TBF<sup>TM</sup> Biaxial B<sub>A</sub>-plate

The TBF<sup>TM</sup> biaxial B<sub>A</sub>-plate retarder has been formed by coating of the lyotropic liquid crystal onto the glass, and dried at room temperature [7].

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

**Table II** Optical characterization of TBF<sup>TM</sup> biaxial B<sub>A</sub>-plate as a function of annealing time (at  $\lambda=550$  nm)

$t$ , hours	$\Delta n_{xy}$	$\Delta n_{xz}$	$T$ , %	$D_i$ , %/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:*  $R_0 = (n_x - n_y)h \equiv \Delta n_{xy}h$ ,  $R_{th} = (n_x - n_z)h \equiv \Delta n_{xz}h$ .

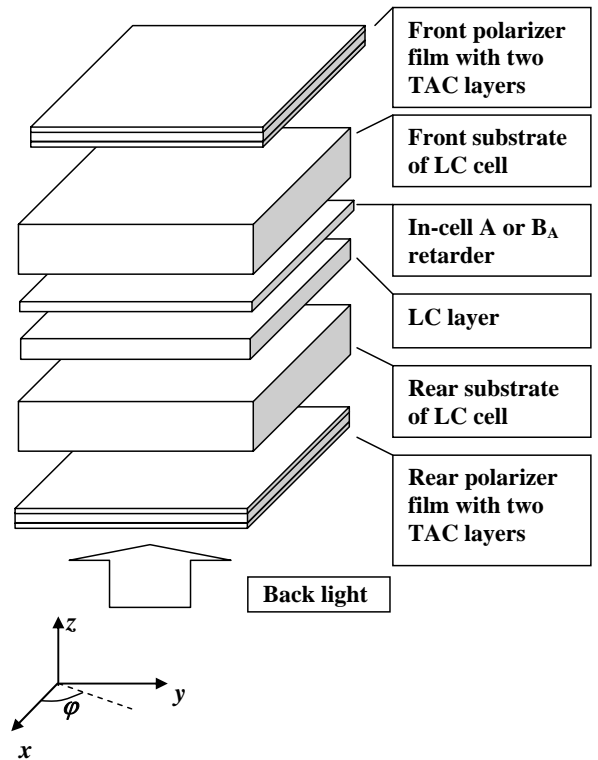
The measurements of the optical properties indicate that while the optical anisotropy was changing during the annealing process the degradation did not occur. The film remained transparent and birefringent. We conclude that the TBF<sup>TM</sup> B<sub>A</sub>-plate retarder meets the requirements for in-cell application.

## 3 Optical Design of IPS LCD

### 3.1 LCD Compensation by In-cell Retarder

As an example we present here application of TBF<sup>TM</sup> in-cell retarders for optical compensation of IPS LCD design.

A general scheme of optically compensated IPS LCD is shown in Figure 3. 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. Moreover, the temperature stability of the retarders is very important for different high temperature technological processes applied for treatment of the other cell elements (for instance, alignment layers often need high temperature annealing).



**Figure 3** Scheme of IPS LCD design compensated by either negative A-type or biaxial B<sub>A</sub>-type retarder.

The angular orientation of principal axes of the optically anisotropic elements shown in Figure 3 is as follows:

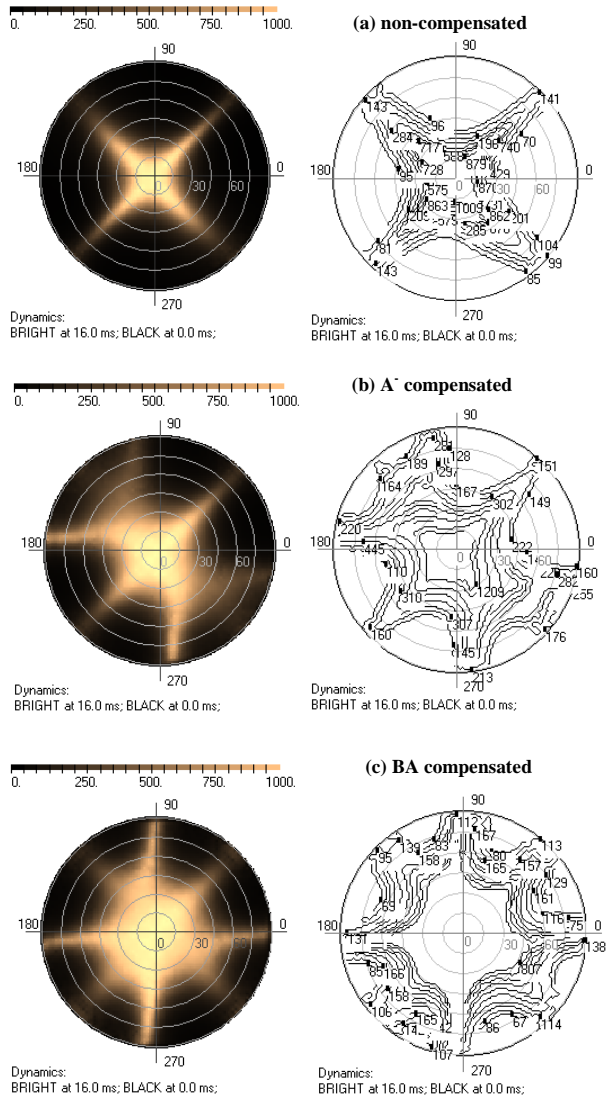
- transmission axes of the front and rear polarizers are at  $\phi = +45^\circ$  and  $\phi = -45^\circ$  respectively, and
- both LC alignment and film retarder coating directions are at  $\phi = +45^\circ$ .

In IPS design the LC molecules have planar alignment characterized by low pretilt angle ( $\sim 1^\circ$ ) 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 ( $\epsilon_{\parallel} - \epsilon_{\perp} > 0$ ). 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  $45^{\circ}$  with respect to the polarizers axes. The last state corresponds to an optically bright state of the design.

### 3.2 Simulation Results

We present here the results of numerical simulations performed using a special software (LCDTDK 3.0 by S.Palto).



**Figure 4** Contrast ratio vs. viewing angle for non-compensated (a), compensated by TBF<sup>TM</sup> negative A-type retarder (b), and TBF<sup>TM</sup> biaxial B<sub>A</sub>-type retarder (c). The data are obtained for wavelength  $\lambda=550$  nm.

Typical film polarizers are laminated between protective TAC films. The TAC films are usually optically anisotropic. They behave as C-type films (optical axis is along the  $z$ -direction) with a retardation value of about 50 nm. The inner TAC films are influencing the viewing angle optical performance of the design, so they must be taken into account

in order to define the optimal thickness of the in-cell retarders. For the present design we found that the optimal thickness of the film retarders should be close to 420 nm. With such thickness the light leakage in the black state is significantly suppressed for the oblique viewing directions compared to the non-compensated design. Suppressing the light leakage significantly increases the contrast ratio for large viewing angles, as it is illustrated in Figure 3 (a-c). Indeed, in case of optically non-compensated design when the in-cell retarder is excluded, the viewing angle performance is very low for some of the azimuth directions. The contrast ratio drops below a value of 100 at zenithal viewing angles higher than  $30^{\circ}$  (Figure 3a).

The use of the in-cell TBF<sup>TM</sup> negative A-type retarder provides significant compensation effect and improves the viewing angle performance (Figure 3b).

The use of the TBF<sup>TM</sup> biaxial B<sub>A</sub>-type retarder provides even higher optical compensation effect and wider viewing angle of the IPS LCD design (Figure 3c).

## 4 References

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## 5 Summary

- We have developed the sub-micron TBF<sup>TM</sup> retarders for in-cell application in LCD.
- The retarders are capable to withstand the temperature up to 240 °C for 3 hours. No optical degradation occurs.
- Both TBF<sup>TM</sup> biaxial B<sub>A</sub>-plate and negative A-plate retarders are found effective for the compensation of IPS LCD designs.
- In IPS LCD design the TBF<sup>TM</sup> biaxial B<sub>A</sub>-plate retarder exhibits the highest optical compensation effect.
- Coatable on glass retarders for in-cell compensation of polarizers and liquid crystal compatible with LCD manufacturing process create new opportunities for quality enhancement and cost reduction of LCDs.

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