

# Manufacturing of coatable guest-host retarder for LCD

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## ABSTRACT

Crysoptix developed a guest-host lyotropic liquid crystal material for manufacturing coatable LCD retarders. The biaxial B<sub>A</sub>-type birefringent films (retarders) contain, as a host component, supramolecules based on Crysoptix sulfonated aromatic compound. We enhanced guest-host system by NZ-factor adjusting agents that allow producing retarders with desired optical and good mechanical properties.

## 1. INTRODUCTION

Crysoptix developed a new class of thin birefringent films (TBF<sup>TM</sup>) providing efficient optical compensation of various LCD designs (TN, STN, VA and IPS modes) [1-13]. Crysoptix KK technology allows producing printable retarders with functions of (i) uniaxial negative A-, negative C-, and positive A- plates; and (ii) biaxial B<sub>A</sub>-type and A<sub>C</sub>-type plates. A method for TBF<sup>TM</sup> manufacturing is based on molecular engineering of self-assembling organic compounds. The TBF<sup>TM</sup> retardation films are produced by solution-processed technology such as roll-to-roll, slot die or spray coating, using proprietary lyotropic liquid crystalline (LLC) coating materials. The TBF<sup>TM</sup> biaxial retarder manufacturing involves a chemical modification step (chemical synthesis and formulation of LLC material), substrate pretreatment, coating (deposition of LLC onto a glass or plastic substrate with the action of shear force), and drying (evaporation of solvent, which converts the LLC into a solid birefringent film). The solid TBF<sup>TM</sup> is converted into water-insoluble form within a post-treatment dipping process.

Our target was to develop a cost efficient material and manufacturing process for retardation films with tunable optical and mechanical properties required for LCD market. The retarder features which are critical for LCD performance include biaxiality (characterized by the NZ-factor), retardation, depolarization index (DI), processability, durability, uniformity, adhesion and hardness.

Thus, a cost-efficient solution for optical compensation of IPS LCD mode requires an application of a biaxial B<sub>A</sub>-type plate retardation film characterized by NZ-factor less than 0.45. Specifically, we have been focused on producing of TBF<sup>TM</sup> of B<sub>A</sub>-type of sufficient mechanical strength, low DI and tunable NZ-factor in the range of  $0 < NZ < 0.45$ .

## 2. RESULTS AND DISCUSSION

### 2.1 Materials and methods

We used Crysoptix sulfonated aromatic material A053.S as a major component of an LLC coating system [1, 2]. We produced LLC coating material by dissolution of

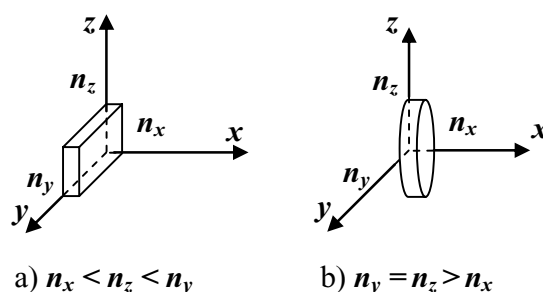
the A053.S compound in water and subsequent neutralization by CsOH or LiOH aqueous solution to obtain Cs<sub>2</sub>(A053.S) or Li<sub>2</sub>(A053.S) salt solution, respectively.

The biaxial B<sub>A</sub>-plate and uniaxial negative A-plate TBF<sup>TM</sup> retarders (depending on counterionic form [2, 3]) have been formed by coating the LLC material onto a glass substrate, and subsequent drying [1, 2,12].

The TBF<sup>TM</sup> biaxial B<sub>A</sub>-plate and negative A-type retarder are defined in terms of principal refractive indices in Figure 1a and 1b, respectively. For the TBF<sup>TM</sup> retarders the coating direction coincides with the x-axis, and the z-axis is along the normal to the film plane [13]. The biaxiality of resulting TBF<sup>TM</sup> is controlled by different ratio of biaxial and uniaxial components and it is numerically expressed by the value of NZ-factor calculated as:

$$NZ = \frac{R_{th}}{R_o} = \frac{\Delta n_{th}}{\Delta n_o} = \frac{Max(n_x, n_y) - n_z}{Max(n_x, n_y) - Min(n_x, n_y)} \quad (1),$$

where  $R_{th}$  and  $\Delta n_{th}$  are through thickness retardation and birefringence correspondingly,  $R_{th} = \Delta n_{th} \cdot d$ ;  $R_o$  and  $\Delta n_o$  are in plane retardation and birefringence respectively,  $R_o = \Delta n_o \cdot d$ , and  $d$  is physical thickness of the dry retardation film.



**Fig. 1. Relation between principle refractive indices of (a) biaxial B<sub>A</sub> plate and (b) uniaxial negative A plate**

We used Crysoptix sulfonated polymer material (hereinafter referred as P01.S) as an additive that allows to produce the retarder with required mechanical strength. For this purpose the Cs<sub>2</sub>(P01.S) salt was prepared.

The LLC coating materials were produced by traditional weight-and-mix method.

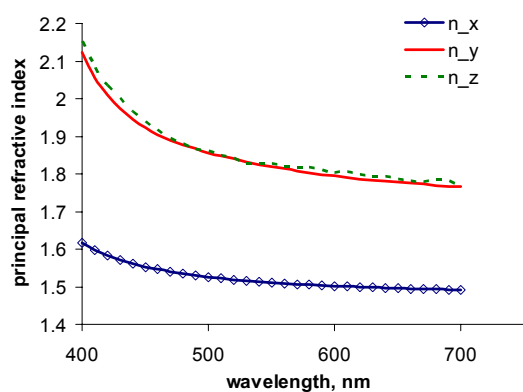
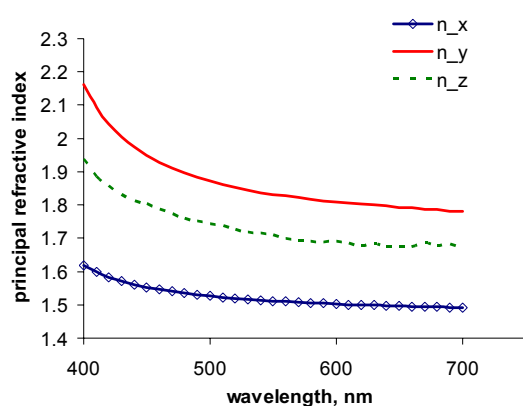
### 2.2 Biaxiality control of B<sub>A</sub>-plate birefringent films

We reported earlier about Crysoptix approach to controlling the NZ-factor (in range of 0-0.8) of optical films, which allows to design the biaxial retarders according to LCD manufacturing requirements. Specific formulation and selection of appropriate post-treatment conditions enabled to control the NZ-factor of the target optical film in a substantial range, without changing the basic chemical compounds [12]. This method allowed obtaining biaxial

retarders characterized by specific discrete values of NZ-factor. Now Crysoptix has developed an original concept of guest-host system containing biaxial ( $B_A$ -plate) and uniaxial (negative A-plate) components. The principle of the biaxiality control is based on the control of three principal refractive indices of the guest-host system. It is based on superposition of the host and guest components having different type of biaxiality. We express each of three principal refractive indices of the guest-host system via corresponding principal refractive index of individual components:

$$n \approx c \cdot n_{B_A} + (1 - c) \cdot n_{-A} \quad (2),$$

wherein  $c$  is a molar portion of biaxial component in the guest-host system. The spectral dependence of principal refractive indices for biaxial ('host') and uniaxial ('guest') components is presented in Figure 2.

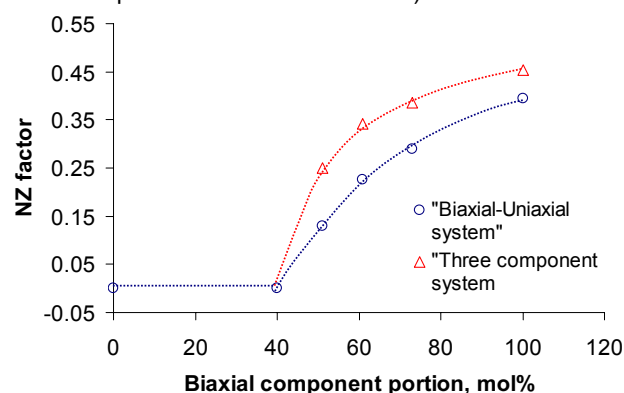


**Fig. 2. Spectra of principle refractive indices for (a) biaxial  $B_A$  plate and (b) uniaxial negative A plate**

In particular, for the wavelength of 550 nm the refractive indices of individual components were  $n_x=1.51$ ,  $n_y=1.84$ ,  $n_z=1.71$  for  $B_A$ -plate and  $n_x=1.51$ ,  $n_y=1.78$ ,  $n_z=1.78$  for negative A-plate.

LLC mixtures with different ratios between biaxial ( $B_A$ ) and uniaxial (-A) components were prepared; the optical properties of solid films on their base were investigated. The dependence of NZ-factor of a thin birefringent film on a molar portion of biaxial ( $B_A$ ) component in the LLC solution is presented in Figure 3. Experimental data are in good agreement with values calculated by equation (2).

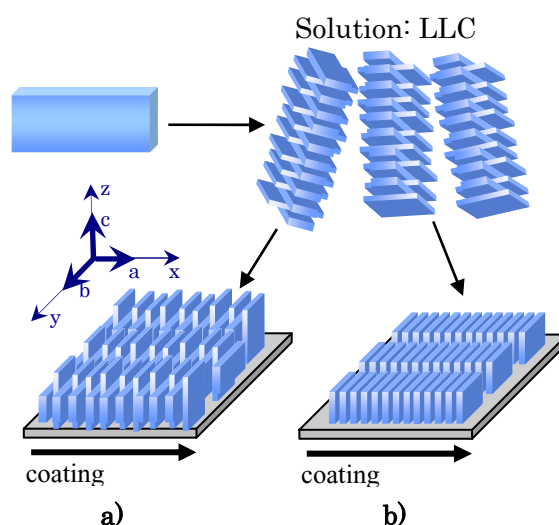
Thus, we have found that the NZ-factor of the retardation film can be controllably varied in a wide range, wherein the upper limit is defined by the NZ-factor of the individual  $B_A$ -plate component used in the mixture. At the same time the lower limit of the achievable NZ-factor can be as low as 0 (at the molar portion of  $B_A$ -plate component in the LLC mixture equal to or less than 40-mol%).



**Fig. 3. Controllable NZ-factor of  $B_A$ -plate TBF™ as a function of the biaxial component content in LLC guest-host coating system**

### 2.3 Mechanical properties improvement

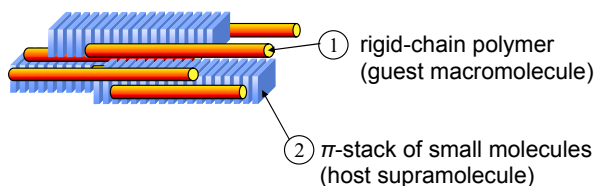
A post-treatment comprising conversion of the thin birefringent film into water-insoluble form may cause cracking in several cases. Generated cracks are oriented perpendicular to the coating direction (fast axis).



**Fig. 4. Supramolecular packing and formation of (a) negative A-plate and (b) biaxial  $B_A$ -plate**

Figure 4 schematically represents supramolecular packing in aqueous solution and in solid films for negative A-type (Figure 4a) and biaxial  $B_A$ -type components (Figure 4b) of the guest-host system. In aqueous solution the molecules are assembled in stacks (supramolecules) and can form nematic lyotropic liquid crystal phase. During the deposition process the stacks are aligned under shear force. The resulting ordered film includes stacks aligned in a substrate plane along the coating direction, which means that intermolecular bonding in x-direction is rather weak and requires an additional strengthening.

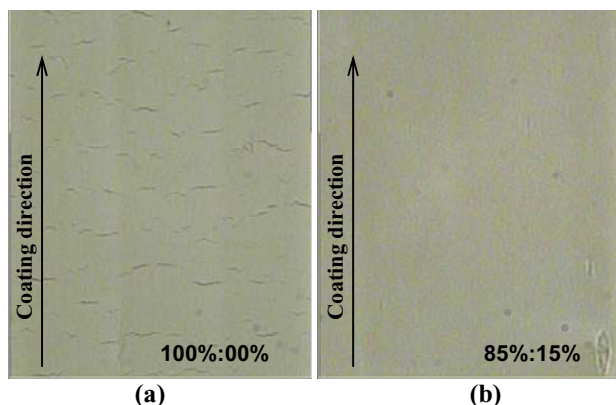
We have selected a covalently bonded polymer as a reinforcing component for a birefringent film. The mechanically improved system comprised host molecules of low molecular materials – biaxial Cs<sub>2</sub>(A053.S) and uniaxial Li<sub>2</sub>(A053.S), and guest molecules of polymer Cs<sub>2</sub>(P01.S) (see Figure 5).



**Fig. 5. Guest-host TBF™ system**

After studying a number of different polymers we came to a conclusion that the polymeric guest has to have the following features: (i) rigid polymeric chain, (ii) solubility in water, and (iii) mesogenic chain structure. The P01.S material meets all the listed requirements. We used P01.S polymer as a guest that helped to reinforce the coated birefringent film during the post-treatment procedure.

For our study we tested guest-host LLC systems with a wide range of host (low molecular component) to guest (polymer component) molar ratios: from 94%:06% to 82%:18%. No cracking was observed for TBF™ coated on glass and TAC substrates from LLC solution containing at least 15 mol % of the reinforcing component.



**Fig. 6. Improvement of mechanical properties with increasing content of reinforcing guest component:**

**100% host TBF™ (a),  
85% host and 15% guest TBF™ (b)**

The experimental results are in good agreement with calculated guest-host ratio (85% host /15% guest) for a system where one B<sub>A</sub>-plate stack alternates with one polymeric chain.

We found that introduction of the macromolecular guest component caused a certain change in optical properties of our guest-host system, namely increase of maximal level of NZ-factor. Thus, by changing the ratio of guest-host components we succeeded in broadening a range of tunable biaxiality of coated retarders:  $0 < NZ < 0.45$  and improving mechanical properties of solid films based on low molecular weight materials.

### 3. CONCLUSIONS

Crysoptix has pioneered an original concept of

“guest-host” system for LLC precursor material containing stacks of low molecular weight birefringent material and rigid polymers.

Optimization of the developed guest-host system based on one host material (A053.S) allows producing biaxial retardation films possessing a target NZ-factor ( $0 < NZ < 0.45$ ) and exhibiting high optical performance, durability and mechanical stability.

The Crysoptix coatable retarder technology is compatible with current process of polarizer manufacturing and enables mass production of low cost large-area retarder films.

### 4. REFERENCES

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