Advanced wideband coatable LCD retarder with anomalous dispersion of optical anisotropy

A. Geivandov*, A. Lazarev, A. Manko*, 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

Crysoptix has introduced B_A-type plate coatable retarder as an efficient tool for optical compensation of IPS and VA-LCD modes. Today we demonstrate the improved retarder possessing anomalous dispersion of optical anisotropy. A new method of tuning material properties using dye additives allows significantly suppressing colour shift during the LCD switching.

1. INTRODUCTION

Crysoptix KK developed a new class of thin birefringent films (TBF^{TM}) providing LCD optical compensation with a single-layer retarder [1]. A method for TBF^{TM} manufacturing is based on molecular engineering of self-assembling organic compounds. The first product – BA-LT-1000 – biaxial B_A-type plate coatable retarder is scheduled for mass production in 2009.

The optical properties of modern stretched polymer retardation films enable good viewing angle compensation to LCD. The B_A-type plate coatable retarder reported earlier [1-3] provides high-performance compensation for IPS and VA LCD modes. However, both stretched and coatable retardation films require improvement of spectral performance in whole visible range.

2. BACKGROUND

Typical retardation films exhibit normal spectral dispersion of both principal refractive indices and optical anisotropy (birefringence Δn). Due to this property it is difficult to provide optimal compensation of a wide dynamic range of gray scale levels and wide viewing angles, in the entire visible spectral range. As a result, a distortion of colour of a displayed image can appear.

Usually the optimization of an LCD optical stack is performed for the maximal sensitivity of the human eye wavelength range, particularly for the wavelength of 550 nm (green part of the light spectrum). Therefore, the maximal distortions appear in the red and blue parts of the light spectrum. It results in an undesirable colour shift and a displayed image distortion. Ideally, for LCD compensation in red spectrum part, a higher birefringence is required as compared to optimal one at λ = 550 nm, while for shorter wavelengths of blue part, a lower optical anisotropy results in less distortions of colour of the displayed image. Thus, an ideal retardation film should possess anomalous dispersion of the birefringence, when the optical anisotropy increases while increasing the wavelength.

3. WIDEBAND RETARDER

In the current paper we present a new Crysoptix proprietary method [4] which is used for correcting birefringence dispersion and thus reducing undesirable colour shift in LCD. The experimental results showing the anomalous dispersion are shown in Figure 1. The biaxial B_A-type plate TBF^{TM} possesses normal dispersion of birefringence in the entire visible spectrum (a). After dispersion correction the biaxial B_A-type TBF^{TM} exhibits anomalous dispersion of birefringence in the wavelength range 460-570 nm (b).

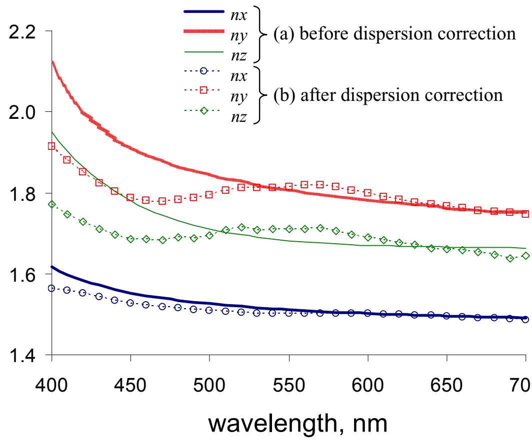


Fig. 1 Spectra of refractive indices of Crysoptix B_A-type plate TBF^{TM} (a) before and (b) after dispersion correction

3.1 COATABLE RETARDER TECHNOLOGY

The method of TBF^{TM} film deposition is based on slot-die coating technique of lyotropic liquid crystal (LLC) solutions. This method employs the shear force that orients LLC molecules along the coating direction. Slot-die technique allows obtaining the highly uniform films exhibiting anisotropic properties such as TBF^{TM}.

The flat-bed slot-die technique is preferable for coating a retarder material onto a glass substrate. This type of retarders is suitable for in-cell application. The roll-to-roll technique is used for manufacturing of the coatable TBF^{TM} retarder on plastic substrates. The laboratory samples can be hand-coated with the Mayer Rod technique. The general requirement for manufacturng the TBF^{TM} is high shear-rate.

3.2 BIREFRINGENCE DISPERSION CORRECTION

The principle of dispersion correction is based on precise control of the retarder spectral properties via material formulation, such as mixing of the B_A-type plate retardation material with anisotropic dye molecules. The mixture forms a guest-host system and possesses an integrated spectrum, wherein the birefringence spectrum is controlled.

The optically anisotropic film prepared from the "Bordeaux" dye (bisbenzimidazo[1,2-c:2',1'-i]benzo [lmn]-3,8-phenanthroline-6,9-dione disulfonic acid water solution), which is further referred to as guest *G1*, can be characterized as a uniaxial negative A-type retarder (when coated according to methods described in 3.1).

Figure 2 shows the anomalous spectral dispersion of G1 for Δn_{xz} and Δn_{xy} in the subrange from 440 nm to 575 nm.

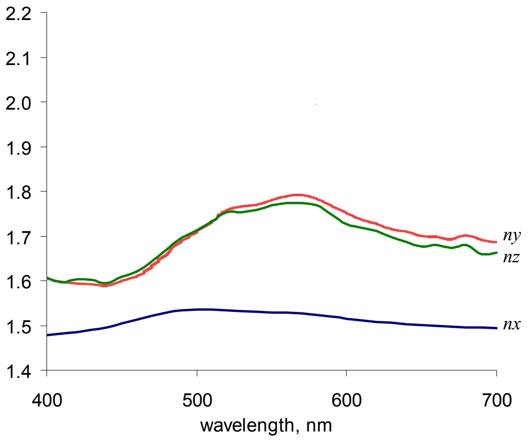


Fig. 2 Refractive indices' spectra of *G1* dye anisotropic film

The optically anisotropic film prepared from the retardation material (*4,4'-(5,5-dioxidodibenzo[b,d] thiene-3,7-diyl)dibenzenesulfonic acid water solution*), further referred to as host *H1*, can be characterized as a biaxial B_A-type plate retarder (Figure 1a).

It is known that dyes absorb light in the visible spectral range while transparent materials may absorb light in the ultraviolet spectrum region.

The continuous curve shown in Figure 3 illustrates the refractive index spectrum calculated from an absorption spectrum $k(\lambda)$ using Kramers-Kronig (K-K) relations [5]. The basic idea of using Kramers-Kronig relations is that the refraction is a consequence of the absorption. Experimental recording of the absorption spectra is substantially easier then the measurement of the refraction indices. Also the absorption spectra of a material can be modified by proper additives (for instance by making a mixture of dyes). According to K-K relation the peak of absorbance corresponds to anomalous dispersion of the refractive indices. This fundamental property of optical materials is used in one of our developed methods.

Figure 1b clearly shows that we can turn the normal dispersion into an anomalous one by introducing guest G1 to the host H1, where G1 absorbs light in the target range of wavelengths, while the host H1 itself exhibits normal dispersion in the said wavelengths range.

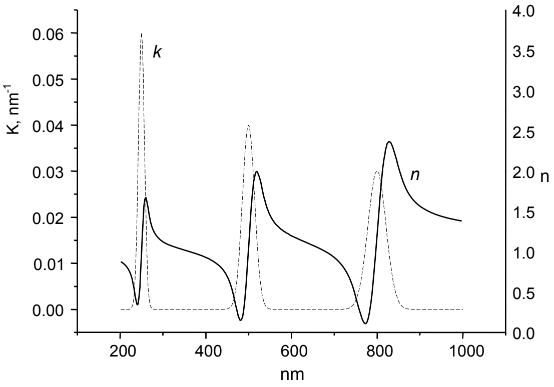


Fig. 3 Mechanism of formation of an anomalous dispersion: absorption peak corresponds to abnormal dispersion of refractive indices

It is important to note that one can adjust the refractive index spectrum of an optical film by varying its material components. Several dyes having absorption in different wavelength regions are capable of turning the optical birefringence dispersion into anomalous in the entire visible spectrum range.

The anisotropic alignment of dye molecules is also important. For instance, *G1* dye is capable of forming Lyotropic Liquid Crystal in water solutions. So the dye molecules form molecular stacks, which then can be aligned by shear stress during coating.

3.3 RESULTS

We present an example of a retarder produced from a guest-host mixture.

The TBF^{TM} has been produced by Mayer Rod technique from 10% water solution of binary guest-host mixture with a *G1*:*H1*=20:80 ratio. In the resulting anisotropic film the molecular stacks of guest dyes and host material were arranged with respect to the coating direction as shown in Figure 4. The lowest indices (n_x) of both guest and host molecules correspond to coating axis direction.

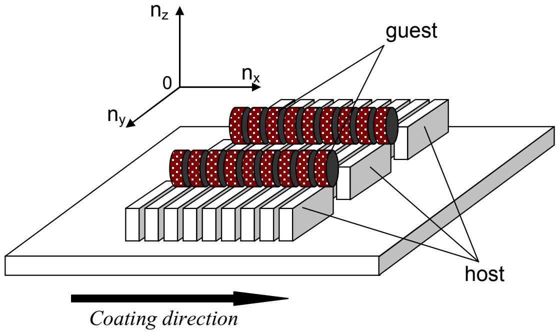


Fig. 4 Guest and host molecular stacks in anisotropic B_A-type plate TBF^{TM}

The alignment of the dye molecules shown in Figure 4 is very important, because the absorption axes of dyes must coincide with the absorption axes of the polarizer so the light transmitted through an optical stack of an LCD with such retarder is not affected by the colour of the dye guest G1.

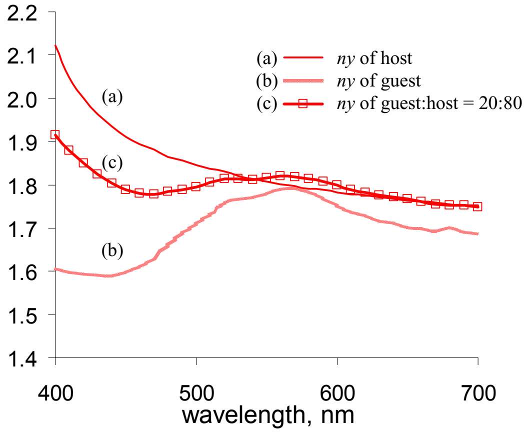


Fig. 5 Spectra of n_y refractive index of the anisotropic films of (a) B_A-type plate host, (b) dye guest, and (c) guest-host system with a *G1*:*H1*=20:80 ratio

Table 1 shows the optical parameters measured for the experimental B_A-type retarder.

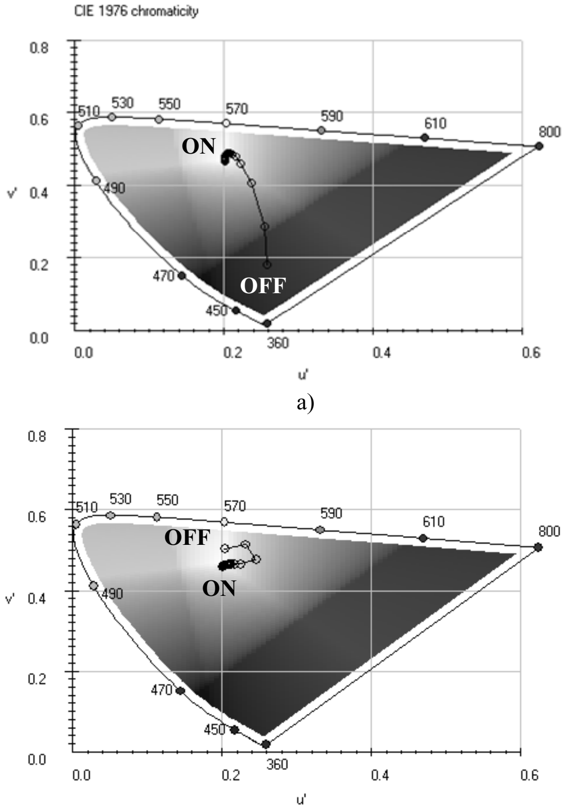
Table 1 Optical parameters of B_A-type plate TBF^{TM} sample film with a *G1*:*H1*=20:80 ratio at λ=550 nm

d, nm	Δn_{xy}	Δn_{xz}	$T_{@550\,nm}$, %	R_0, nm	R_{th}, nm
194	0.34	0.24	90	65	47

3.4 COLORSHIFT SIMULATIONS

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

The simulated colour shift for normally black IPS mode LCD compensated with a single B_A-type TBF^{TM} with its original dispersion is shown in Figure 6a. One can see a strong blue colour shift that takes place during LCD switching from OFF to ON state.



a)

b)

Fig. 6 Typical colour shift during switching from Black to White state in IPS mode LCD compensated with B_A-type retarder: (a) conventional TBF^{TM}, and (b) TBF^{TM} with dispersion correction; points correspond to the simulated LCD grayscale shown in CIE 1976 chromaticity diagram

Correction of a refractive index spectral dispersion in TBF^{TM} allows to significantly suppressing colour shift during LC switching as shown in Figure 6b. Luminance ratio at 60° viewing angle is good (approximately equal to 420), while the variation in colour is small ($\Delta u'v'$=0.06) even at low levels of output intensities. In the simulated LCD design the thickness of the experimental B_A-type plate was 0.7 microns, and the absorption coefficient k_y~2 μm^{-1} resulted in significant absorption (T~15%) along the *y*-axis at normal incidence. However, in this design the absorption axis of the guest G1 coincides with the absorption axis of the output polarizer and the resultant absorption was affected only by k_x, which is small and provides transmission of approximately 90%. Even at large incidence angles of around 60° the transmission remains at levels higher than 70%.

4. CONCLUSIONS

The described method of optical anisotropy dispersion correction of retardation film is fundamental for optical films. It can be applied to the coatable film materials as well as to the stretched optical films.

The introduction of guest dye molecules to a host retardation material provides a significant LCD colour shift suppression. The described method allows improving colour rendering of the displayed image.

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] Liquid Crystal Display Operating in a Vertically Aligned Mode, PCT Publication WO2007/141025.

[3] Patent pending.

[4] Patent pending.

[5] J. D. Jackson, *Classical Electrodynamics*, 2nd ed., John Wiley & Sons, Inc., New York, Sec. 7.10 (1975).

[6] A. Lazarev, A. Geivandov, I. Kasianova, E. Kharatiyan, P. Lazarev, S. Palto. Single-layer retarder for LCD, IDW’08 Digest, in print.