Novel Coatable Negative C-plate Retarder

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ABSTRACT

We developed a new coatable negative C-plate retarder for efficient optical compensation of VA LCD. The cost effective Thin Birefringent Film (TBF™) technology can be applied to roll-to-roll manufacturing of polarizers by slot-die coating as well as in-cell retarders. The retarder properties and new LCD design are presented.

1. INTRODUCTION

The LCD market demands cost reduction. Crysoptix KK [1] has developed a cost effective technology for manufacturing thin birefringent films (TBF™) by coating technique [2]. The TBF™ is a submicron film produced from a solution of organic material by coating onto a plastic (with roll-to-roll slot-die) or glass substrate (with flat-bed slot-die) with performance and cost advantages.

Currently LCDs are compensated with stretched polymer retardation films. However, the demand for the cost reduction stimulates development of cost-effective technologies.

So far high-retardation negative C-plate films are expensive for commercial application because of technological issues. In the 1990s development of a uniaxial negative birefringent film was a major objective for LCD improvement. Several techniques have been developed. Thus, biaxial mechanical stretching of a heated polymer film in directions parallel to the film plane produces the optical films. A typical problem of this method was discussed in the technical literature [3]. Another method is based on pressing the heated polymers between two substrates. In this case the birefringence appears under cooling due to internal mechanical constraints [4].

To date the triacetyl cellulose (TAC) films are widely used in LCD polarizer stacks. The conventional PVA polarizers are laminated with TAC films. A typical 50 µm thick TAC film behaves as a negative C-plate retarder having a retardation of 50 nm. However, for typical optical compensation of LCDs a retardation value should exceed 100 nm, while the problem of high optical retardation at low cost remains unresolved.

In past there was a competitive technology based on coating of highly birefringent polymers [5-8]. Harris et al synthesized rigid-core polymers soluble in organic solvents. They were able to produce uniaxial negative birefringent film of C-plate type with controlled value of birefringence. The retardation was proportional to the film thickness. However, the technology did not meet a requisite mass production capability because of harsh and expensive post-processing of the casted coatings. As the technology required annealing at 150 °C for several hours [5] it was applicable to glass substrates only.

Recently coatable retarders have been introduced. There are various ways to produce coatable retarders: photo cross-linkable LC materials typically require alignment layer and/or photo-alignment procedure [9], polyimide coatings require curing at high temperatures and can't be applied to plastic substrates [10]. All these steps in manufacturing process increase film's production cost.

The main objective of the advanced TBF™ technology is to decrease the manufacturing cost of retardation films by factor 10 and still provide excellent viewing angle performance for modern LCD TV. We developed a set of coatable retarders based on guest-host lyotropic liquid crystals for LCD TV compensation [11]. The detailed classification of retardation films is given in [12].

In this paper we present optical properties and application of one of the types of LCD retarder – negative C-plate playing crucial role in enhancing VA LCD viewing angle performance. The simulation results are presented.

2. TBF™ RETARDER

2.1 Coating technology

TBF™ retarder is coatable from water solutions. It does not require any special measures during drying, and the birefringence of the film is not influenced by drying conditions. New CN-LT-1000 TBF™ coating material is based on block copolymer of sulfonated benzidine phthalamide derivatives. The water-soluble polymeric molecules have a rigid-core and long chain (stick-like) structure schematically presented in Figure 1.

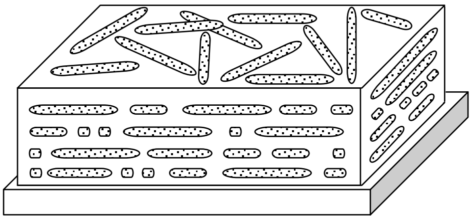

Fig. 1 Schematic molecular arrangement in the new negative C-plate TBF™

Under drying of a wet layer formed from a coating solution on a substrate, a solvent (water) evaporates and the molecules arrange in the plane of the film with their long axes parallel to the substrate plane but without any preferential orientation. This random orientation of polymer molecules leads to out-of-plane optical anisotropy as shown in Figure 2.

The TBF™ coating technology includes the following steps: 1) substrate pretreatment with plasma, corona discharge or other method for hydrophilization of the surface and providing high adhesion of coated thin film to the substrate, 2) coating of an aqueous solution with typical concentration around 5-10% onto the substrate with slot-die or spin-coating method, 3) drying of a wet layer at 25-90 °C, 4) post-treatment of the films with rare-metal salts in order to provide insolubility in water. In contrast to most commercial retarder technologies, TBF™ coating technique does not require pre-formation of alignment layers on the substrate surface, light exposure, or high temperature curing. The resulting TBF™ retarder films exhibit high adhesion to glass and plastic substrates.

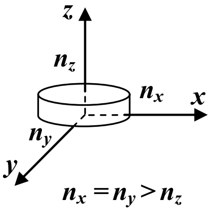

Fig. 2 Relationship between principal refractive indices for the uniaxial negative C-plate retarder

The thickness of dry negative C-plate coating exhibiting retardation R_{th}=200 nm is around 1.5 µm. It is noteworthy that the TBF™ technology enables one-step coating manufacturing of high efficiency transparent retarders with good adhesion to substrates.

2.2 Optical properties

The TBF™ retardation linearly depends on the film thickness. We have a possibility to tune the viscosity and concentration of coating solution via tailoring the polymer length. The polymer molecular weight is controlled at the chemical synthesis stage and can be established with gel-permeation chromatography (GPC) method of high-performance liquid chromatography (HPLC).

As shown in Figure 3, the out-of-plane birefringence Δn_{xz} is around 0.12 at a wavelength of 550 nm.

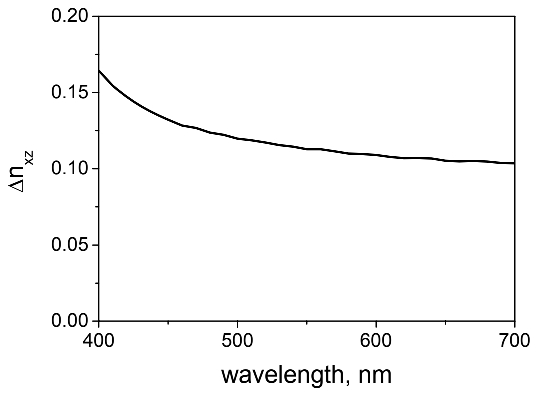

Fig. 3 Out-of-plane birefringence spectrum of the negative C-plate TBF™ retarder

As shown in Figure 4 the TBF™ birefringence is a function of polymer molecular weight.

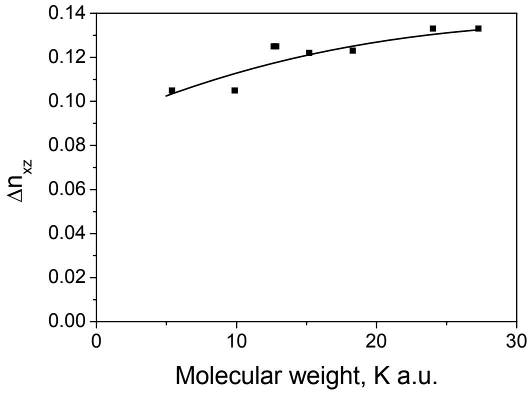

Fig. 4 Birefringence as a function of polymer molecular weight of the negative C-plate TBF™

The negative C-plate is highly transparent, which is confirmed by spectrum shown in Figure 5.

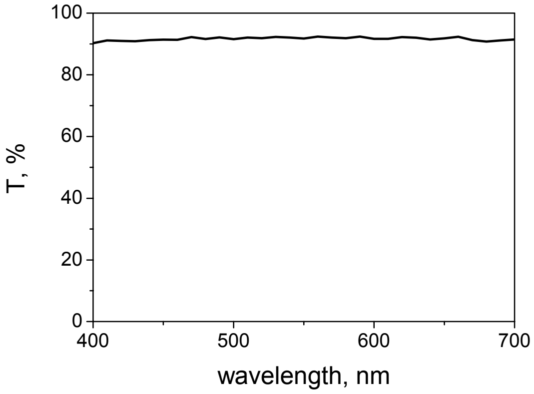

Fig. 5 Transmittance spectrum of the negative C-plate CN-LT-1000 TBF™ retarder

The color shift and the depolarization index were measured with Konica Minolta CS-1000 spectroradiometer. Colorshift of D65 was (Δx, Δy)=(0.002, 0.002) in CIE 1931 XYZ color space, which is in good correlation with polymer absorption spectrum (Figure 6). The depolarization index was less than $5x10^{-5}$, haze less than 0.3%. Colorshift, depolarization index and haze match the commercial target for LCD TV applications.

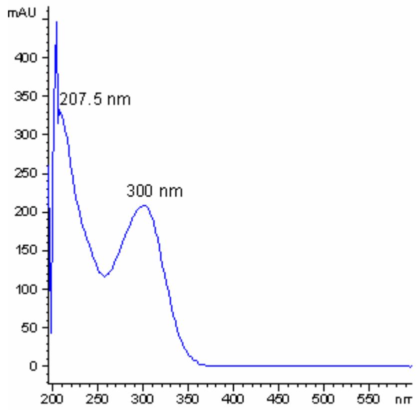

Fig. 6 Absorption spectrum of the negative C-plate coating material

2.3 Roll-to-roll manufacturing

The durability of coated retarder meets requirements of LCD components manufacturing. The TBF™ film laminated with TAC and glass substrates holds 1000 hours of the environmental wet (90% RH and 60 °C) and dry (80 °C) durability tests without significant change (less than 5%) of optical properties.

Roll-to-roll manufacturing of retardation films is feasible with Crysoptix negative C-plate TBF™ coating materials.

A coating process includes 2 steps: 1) the TBF™ application and post-treatment, and 2) coating of a pressure-sensitive adhesive (PSA). The main steps of the process are shown in Fig. 7.

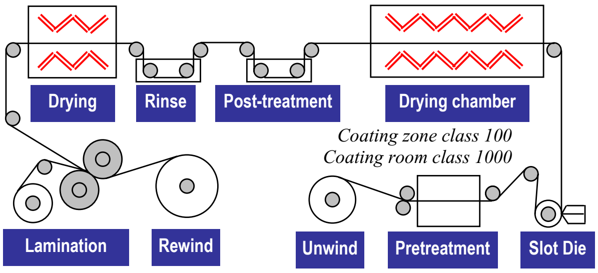

Fig. 7 Roll-to-roll manufacturing line for lamination of TBF™ retarders

The most important parameters for high quality coatings are uniformity of both thickness and shear force, which provide the alignment necessary to orient the liquid crystal phase. Recent production uses a slot die (slit nozzle) method. This provides simultaneously a good thickness control and efficient shear force. A resulting water based coating is environmentally friendly.

2.4 Durability of coated in-cell retarder

The most important requisite for in-cell retarder application is the thermal stability. The polyimide alignment layer produced during LCD manufacturing process is annealed at 200 °C. The negative C-plate retarder is stable even after heat treatment at 250 °C for 1 hour.

3. VA LCD simulation

It is known that optical compensation of VA LCD requires the use of positive A-plate and negative C-plate [13]. We simulated such VA LCD.

We propose to replace the traditional negative C-plate films, such as TAC, with thinner negative C-plate coating. In new design, front polarizer is laminated with +A plate film having R_o around 150 nm, with its fast axis in parallel to polarizer absorption axis and coated with a 1.2 μm thick negative C-plate retarder TBF™. Rear polarizer is conventional TAC film laminated polarizer as shown in Figure 8.

The angular orientation of principal axes of the optical anisotropic elements shown in Figure 8 is as follows:

- transmission axes of the front and rear polarizers are at φ=90° and φ=0° respectively, and
- the positive A plate slow axis coincide with adjacent polarizer transmission axis, and
- LC alignment is at an azimuth of 45°.

The simulation result (performed using LCD TDK simulation software by Dr. S. Palto) is shown in Figure 8. The contrast ratio map demonstrates high quality of optical compensation.

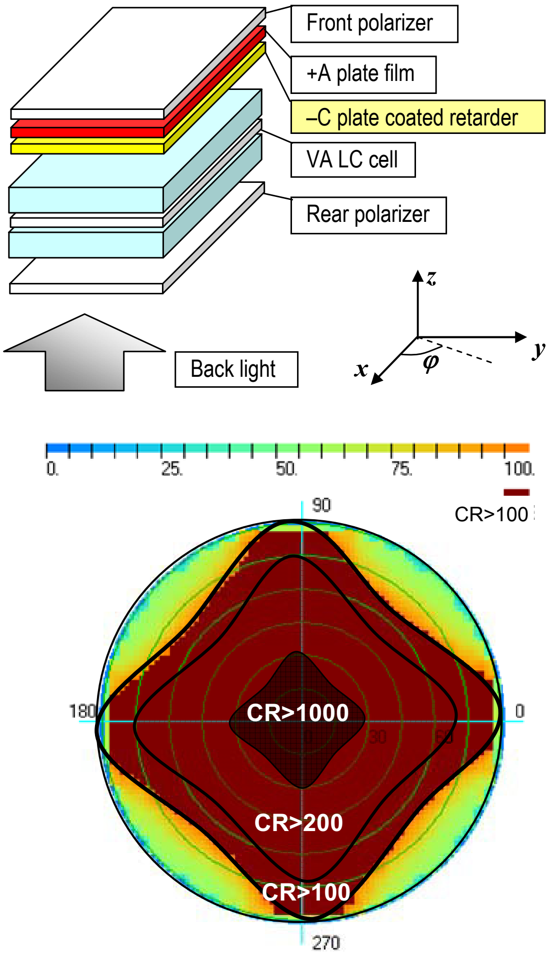

Fig. 8 Compensated multidomain VA LCD design and viewing angle performance simulation

4. CONCLUSIONS

By using TBF™ technology we produced cost efficient uniaxial negative C-plate retarder suitable for LCD optical compensation. The novel retarder material exhibits high birefringence and provides high retardation in a few micrometer thick coating.

The robust and simple low temperature coating technology is applicable to plastic substrates. The retarder withstands high temperature annealing up to 250°C, which is a requisite for in-cell application where retarder suppose to survive through alignment layer manufacturing process.

Flexibility in manufacturing, reduced number of technological operations as well as low material consumption lead to about 10 times cost reduction in large-scale production.

5. REFERENCES

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