17.3: OCB-WV Film for Fast-Response-Time and Wide-Viewing-Angle LCD-TVs

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Abstract

We have successfully developed and commercialized an OCB-WV film, which maximizes the viewing angle performance of the OCB mode while maintaining a high on-axis contrast ratio. The OCB-WV film consists of a 45degree-rubbed discotic layer and a high Rth biaxial TAC film, which are suited for a roll-to-roll polarizer manufacturing process. This OCB-WV has brought out the excellent features that OCB intrinsically has, making next-generation fast-response LCD-TVs possible and free from image blurring in conjunction with an impulsive driving scheme.

1. Introduction

The response time of liquid crystal displays (LCDs) used for note-book PCs and monitors is not fast enough for TV applications. Conventional LCDs are inferior to CRTs in displaying motion pictures because, whereas a CRT displays pictures in a series of pulse light-emission, an LCD has slow response time and a hold-type driving scheme, resulting in blurring over consecutive frames. It is known that LCDs with an impulsive-type driving scheme improve blurring[1)] but require LC response time of less than 5 ms.

The OCB mode is the only nematic-type LCD mode known, so far, to have the fastest response time. OCB-LCDs have long been reported mainly in academic conferences for many years[2)~6)]. It was not until quite recently that OCB-TVs were commercialized.

Some of the main reasons are follows: OCB is sensitive to retardation fluctuation of the cell and the optical compensation films because of a birefringence mode. OCB-LCDs require a complicated structure of optical compensation to obtain a wide viewing angle. To develop the compensation films, we had to overcome the following difficulties:

(1) Optical control of the TAC film, which plays an important role in optical compensation, as well as a protective film.

It is well known that TAC films tend to have a low Rth value, and that it is very difficult to control the birefringence.

(2) Suitability to roll-to-roll process in polarizer production lines.

A new rubbing method was necessary to align the PDM (polymerized discotic material) layer to make an angle of 45 degrees with the longitudinal direction of the film roll.

We have successfully developed a novel optical compensation film for OCB-LCDs, which realizes yield up without changing the polarizer production process.

2. Optical design of OCB-WV

Figure 1 shows the structure of an OCB-LCD in the black state. The OCB mode has a bend alignment of LC. The novel optical compensation film, the OCB-WV film, as a whole was designed to 3-demensionally compensate the bend alignment structure of the LC layer of the OCB-LCD. The OCB-WV requires a high Rth value for the biaxial TAC film with the slow axis parallel to the transmission axis of the polarizer and a hybridly-aligned PDM layer with the alignment direction parallel to the cell rubbing direction. By optimizing the cell and film parameters, light leakage from cross-nicole polarizers at oblique incidence can also be minimized.

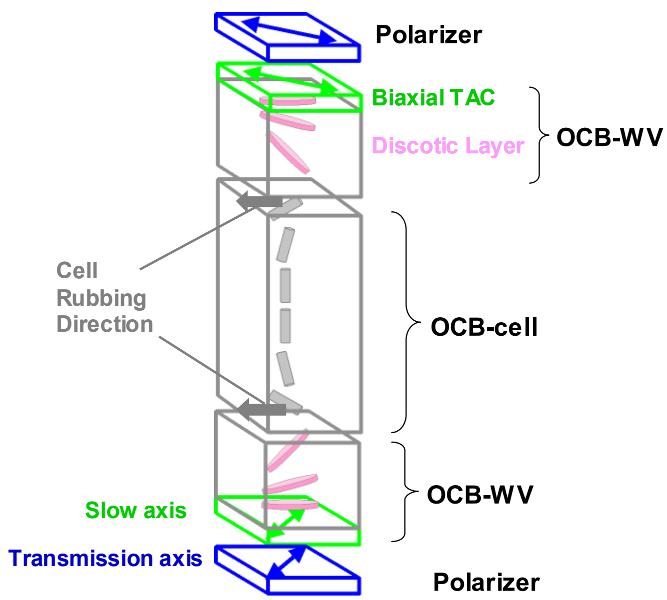

Fig. 1 Structure of an OCB-LCD with OCB-WVs

To determine the optical parameters of the OCB-WV film, a numerical simulation approach was employed, as explained below.

First of all, Δnd of the OCB-LC cell was optimized. At given optical parameters of the OCB-WV film, light leakage at oblique incidence in the black state was minimized (Figure 2).

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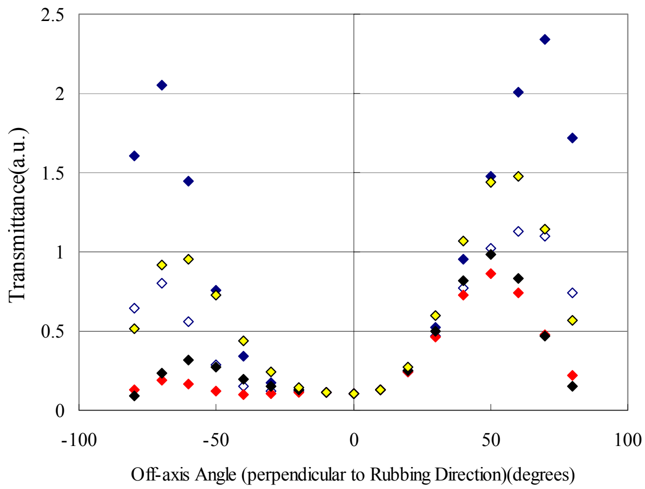

Fi g2. Viewing angle dependence of light leakage at black-state
(◆ : 4.36 μ, ◇ : 4.46 μ, ◆ : 4.56 μ, ◆ : 4.66 μ, ◆ : 4.75 μ)

Next, at temporarily determined parameters, we checked other optical characteristics, such as transmittance, viewing angle, gray scale inversion, and so on. And we found that gray-scale inversion was seen in the high transmittance region, as shown in Figure 3, if Δnd of the OCB-cell was too large. Surprisingly, white luminance is almost independent of the optical parameters of OCB-WV, considering gray-scale inversion (red broken curves in Figure 3).

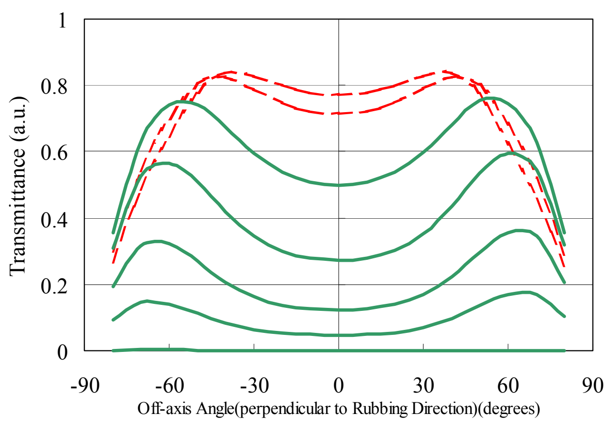

Fig. 3 Viewing-angle dependence of gray-scale luminance (Δnd of OCB-cell:770nm)

Meanwhile, light leakage in the black state is found to be lower as the in-plane Re of the OCB-cell becomes lower.

Our simulation concludes that the lowest Re of the PDM layer in the range of considered cell gaps and black voltages provides the best performance for LCD-TV applications.

Figure 4 shows an iso-contrast ratio map of the OCB-LCD with the optimized optical parameters, which shows excellent viewing angle characteristics, especially in the horizontal direction. (The rubbing direction of the cell is indicated as an arrow in Figure 4.)

We believe that OCB is a strong candidate for general purpose LCD-TVs that have a wide screen.

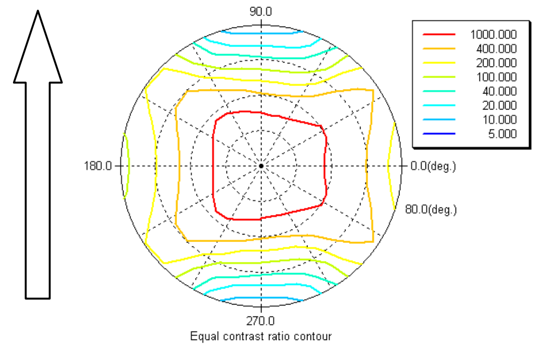

Fig4. Iso-contrast ratio map of the optimized OCB-LCD. (simulation result)

3. How to realize of its optical design

3.1 Biaxial TAC film

3.1.1 Control of Rth

OCB-LCDs need a large Rth value of the biaxial TAC film for compensation, as mentioned before. But it is well known that TAC films tend to have a low Rth value because cellulose tri acetate (CTA) molecules have three side chains perpendicular to the main chain, compared with polycarbonate that has no side chains (Figure 5). Furthermore, TAC films are inherently too brittle to stretch.

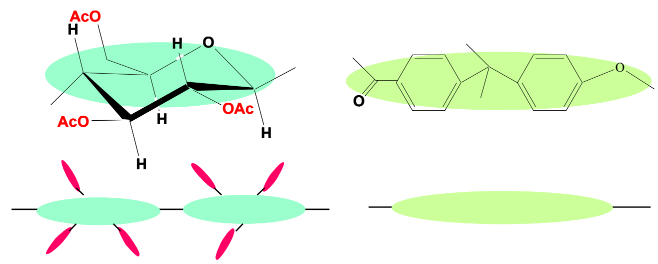

Fig5. Chemical formula of CTA (left side) and PC (right side)

A new technology of controlling the Rth value of TAC film has successfully been developed. To produce TAC films, a TAC solution is cast on a metal substrate, peeled off from the substrate, and dried. In the course of forming a film, CTA molecules tend to align in the film plane. We synthesized a new chemical compound that has large optical anisotropy and is capable of aligning parallel with CTA molecules in the TAC film. The new additive controls the Rth value of TAC films (Figure 6).

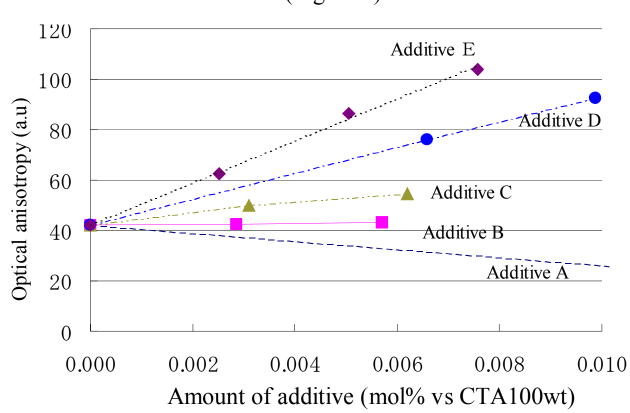

Fig.6 Optical anisotropy of TAC vs. amount of additive

3.1.2 Control of in-plane Re

The in-plane retardation of the biaxial TAC films plays an important role in improving the viewing angle of a pair of cross-polarizers. To control the in-plane retardation of the biaxial TAC film, we introduced a new inline tenter-stretching equipment, which stretches the film in the lateral direction.

One of the problems of tenter-stretching is the "bowing" phenomenon, which deviates the slow axis of the film in the shape of a bow.

When a polymer film is stretched, it is generally contracted in the orthogonal direction to the stretching direction. In the case of tenter-stretching, the center of the film tends to be contracted more than a edge of its film, as shown in Figure 7. By releasing the film from tenter clips before the film is contracted, we can avoid the bowing. (Figure 8)

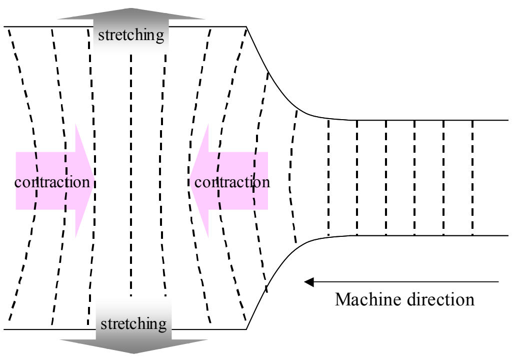

Fig7. Schematic of tenter-stretching

Fig.8 Width Span dependence of slow axis of Biaxial TAC

(Red line: previous method , green line: improved method)

3.2 PDM layer

3.2.1 Hybrid alignment

Discotic molecules must be aligned in a hybrid way to compensate the bend cell.

We developed a new additive to the PDM layer, which controls the air-surface tilt angle to fit the bend alignment structure of the LC layer[7]. The new additive forms a thin layer on the air surface of the PDM layer and changes the surface energy at the air surface[8] .

We have a list of additives, which allow us to control the tilt angle of the discotic molecules adjacent to the air surface. This can be relatively easily implemented because all we have to do is to add an appropriate additive (Figure 9).

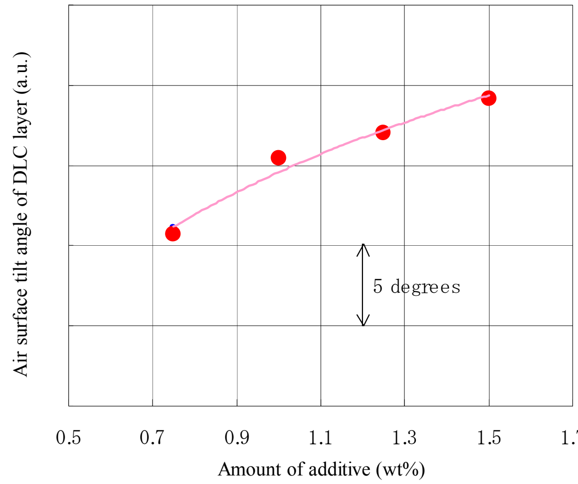

Fig.9 Tilt angle vs amount of additive

(Tilt angle was calculated from simulation analysis)

It is important to align the PDM layer to make an angle of 45 degrees with the longitudinal direction of the film roll. This makes a roll-to-roll process possible in polarizer production lines. The OCB-WV film can directly be laminated onto a stretched PVA film to make a polarizer.

It is also important to reduce the fluctuation of the alignment direction of the PDM layer. It was found that air-flow in the heated-air drying process of the PDM layer affects the PDM alignment direction in a model experiment, as shown in Figure 10. To solve this problem, two new technologies were developed. One is to use a new compound which increases viscosity of the discotic material at the discotic nematic phase. The other is to control the air-flow by introducing a new equipment.

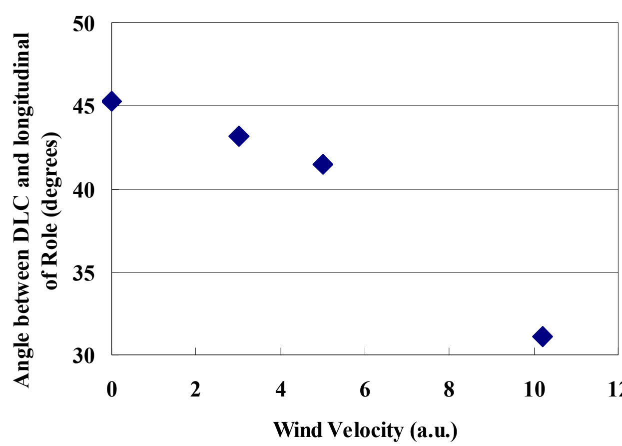

Fig.10 Air-flow Velocity dependence of PDM

4. Improvement of Mura

Mura could be a serious problem for a birefringence mode, like OCB.

We already reported that it was possible to make the thickness fluctuation of the PDM layer less than 1/3 to 1/4 compared with conventional WV films by finely-controlling airflow during the early stage of drying process and by adding a newly-developed additive to the discotic material solution [9].

Another important factor that we have found recently to be considered is the surface roughness of the biaxial TAC film, which causes other different type of " Mura" in the WV films. A newly-developed technology improved the surface roughness of the TAC film, as shown in Figure 11.

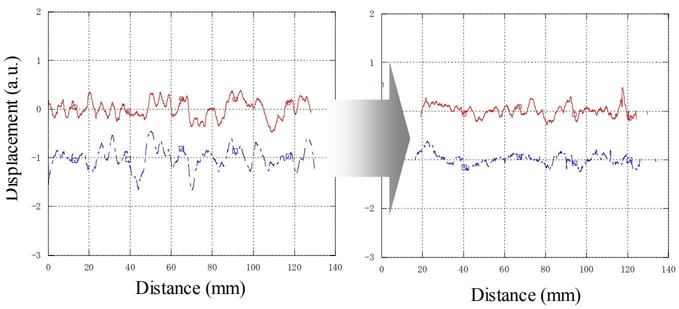

Fig.11 Surface roughness of TAC film

5. Conclusion

The novel OCB-WV film that we have developed will lead to the OCB-TV with a fast response time less than 5ms, which is an unreachable target for the VA mode or the IPS mode even if an over driving scheme is employed. The OCB-TV is free from image blurring especially when an impulsive driving scheme is combined. The development of OCB-WV film and the introduction of OCB-TVs into the market should play an important roll in the rapid growth of the LCD-TV market. The OCB-TV film developed is basically based on the technologies developed for the TN-WV film but was far difficult to realize because it should have a large Rth value for the TAC film and an optimized PDM layer. The TAC film also has a biaxial property with in-plane retardation perpendicular to the longitudinal direction. The biaxial TAC film, in combination with the PDM layer, minimizes light leakage at oblique incident angles, maximizing the viewing angle performance. The 45degree-rubbed PDM layer as well as the biaxial TAC film enables a roll-to-roll polarizer manufacturing process, leading to a very low defect level and high yield. The OCB-WV film should offer a high performance LCD-TV with a reasonable cost.

We will continue our effort to make OCB-WV more and more sophisticated and hopefully to make OCB-LCDs the de facto standard LCD-TVs.

6. Acknowledgements

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7. References

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