TAC Film as a Key Component for LCDs

Hiroyuki Mori
FPD Materials Res. Labs., Fuji Photo Film Co., Ltd., Minamiashigara, Kanagawa, Japan

Abstract
TAC film is an indispensable optical component that protects the polarizing PVA (polyvinyl alcohol) film from being deteriorated and gives high durability, due to its unique features. The newly developed technology of controlling the birefringence of TAC film, together with the coating technology of a discotic material layer, enables excellent viewing angle characteristics and a cost-effective roll-to-roll polarizer manufacturing process.

1. Introduction
Since TAC (tri-acetyl cellulose, or CTA: cellulose tri-acetate) films are characterized by their high light transmittance, low birefringence, relatively high moisture regain and moderate mechanical strength, they have been used for photographic film applications as a substrate for more than 50 years[1]. These features were found to be best suited for a protective film for polarizers. Widely used plastic polarizers made of a stretched PVA (polyvinyl alcohol) film doped with iodine or dyes usually employ a pair of TAC films on the both sides to give high durability.

Although low birefringence of the TAC film was thought to be excellent as a protective film for polarizer, we recently succeeded in giving controlled birefringence to the protective TAC films, which optically compensates the birefringence of the liquid crystal layer, achieving a wide viewing angle of LCDs. Additional optical layers can be coated onto the TAC film to obtain better optical functions. One of the examples is the WV film, which consists of a polymerized discotic material (PDM) layer coated on a TAC film[2]. The WV film significantly improves the viewing angle characteristics of the TN mode TFT-LCDs. This technology was recently applied to the fast response OCB-TVs[3]. Another examples are anti-reflection films, made of a multi-layer coating of different refractive indices.

This paper describes TAC film related technologies and discusses applications to optical compensation films.

2. Structure and Properties of TAC
TAC is a polymer synthesized from natural materials, such as cotton linter or wood pulp, and is bulky and rigid. The molecular structure is shown in Fig. 1. The bulky acetyl groups give a large intermolecular free volume, leading to relatively high moisture regain compared with synthetic polymers.

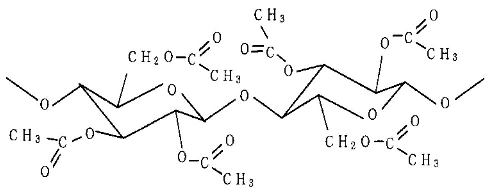


Figure 1. Structure of TAC molecule.

To produce a TAC film, a solvent casting method is commonly used. Figure 2 shows a typical band-casting machine. TAC molecules are dissolved in a solvent, which mainly consists of dichloromethane. And the polymer solution is cast onto a metal band, dried and then peeled off from the band. In the following drying zone, residual solvent is dried, and the film is wound to make a roll. The obtained TAC film is very uniform with a very small fluctuation of thickness and retardation.

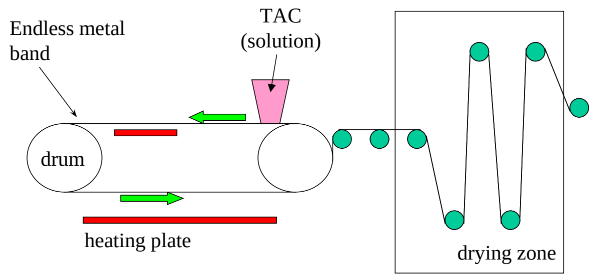


Figure 2. Solvent casting process of manufacturing a TAC film.

On the metal band, the film is difficult to shrink, which results in the in-plane orientation of the TAC molecules. After peeled off, the film is ready for stretching. The orientation of the TAC molecules influences the mechanical and optical properties.

TAC molecules easily form microcrystallites in the course of forming a film. The microcrystallites act as junction points of polymer network. The crystallite and orientation of TAC molecules strongly affect the physical properties of the film. The acetyl carbonyl groups almost perpendicular to the polymer backbone are presumed to be the origin of the small birefringence of TAC.

3. Protective Film for Polarizers

Typical plastic polarizers are made of a stretched PVA (polyvinyl alcohol) film doped with iodine. The iodine in the stretched PVA film makes an ion complex, such as I_3^-, I_5^-, which aligns in the stretching direction of the PVA film and shows dichroism that covers visible wavelength[4]. Light vibrating in the stretching direction is absorbed, and thus outgoing light is linearly polarized vibrating in the perpendicular direction to the film stretching direction.

Bare polarizing PVA films are prone to shrink and to deliver iodine ion complexes, easily losing the quality of polarization. To avoid these problems and give durability to the polarizer, protective films are used. The TAC film is an excellent material as a protective film due to its high light transmittance and low birefringence, keeping the quality of linearly polarized light. A polarizing PVA film is laminated with a pair of TAC films on both sides using a roll-to-roll process, as shown in Fig. 3.

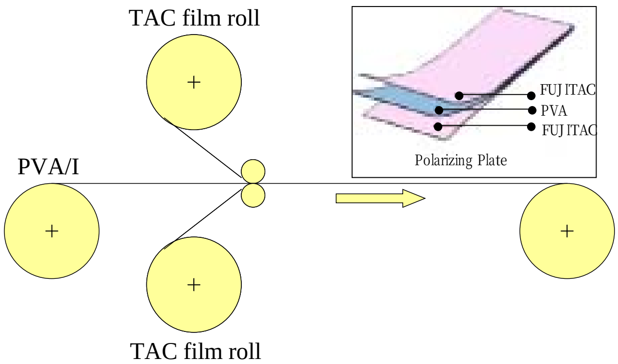


Figure 3. Roll-to-roll polarizer manufacturing process.

The TAC film gives good physical properties to the polarizer. The PVA film absorbs water in the water-based polarizer manufacturing process. Even after laminated with a pair of protective films on both sides, the PVA film contains water, which should be evaporated. As explained before, TAC is bulky and has surprisingly high water permeability, which helps absorbed water rapidly go out of the PVA film

When polarizers are attached on a glass plate of an LC cell, any curling of the polarizer could cause a problem; the polarizer cannot correctly be attached on the cell, or mura appears due to non-uniform attachment process. TAC protective films give good curl balance and greatly help the polarizer recover from curling.

Above-mentioned features make TAC indispensable as a protective film for polarizers.

4. Optical Compensation Films Based on TAC

The birefringence of TAC film is known to be low. And conventional optical compensation films were attached to the polarizer using an adhesive. But, if the protective TAC film has an appropriate retardation that compensate the birefringence of the liquid crystal layer, the additional optical compensation film can be replaced by the TAC based compensation film (Fig. 4). This protective and compensating TAC film has advantages over previous attachment-type compensation films: The number of films used is reduced, and the number of adhesive layers is also reduced. There is less chance of involving foreign articles in the film attachment process. These lead to high yield and cost reduction. It should be noted that the protective and compensating TAC film has an appropriate retardation value and the appropriate alignment direction to meet the demands that the TAC film optically compensates the liquid crystal layer and that the compensating TAC film is directly attached as a protective film onto the polarizing PVA film in the roll-to-roll process.

Additional optical compensation layers can be coated on the protective TAC film. For example, the recent TACless WV film for TN eliminated one of the TAC films. The protective and compensating TAC film basically has twice as much Rth as the attachment-type to achieve the same viewing angle characteristics as the attachment-type WV film.

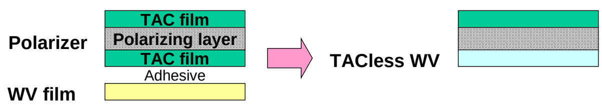


Figure 4. Performance improvement and cost reduction by simplifying the structure.

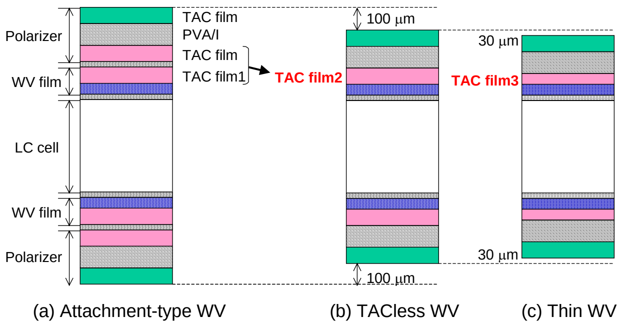


Figure 5. Thin features of the WV film.

5. Alignment Technologies

To develop the WV film, new alignment technologies for the TAC film and the PDM layer were introduced. These technologies can be applied to all LCD mode including VA and IPS as well as TN and OCB.

For the protective and compensating TAC film, the out-of-plane retardation, Rth, is controlled by adding an additive inside the TAC film, as shown in Figs. 6 and 7[3]. The in-plane retardation, Re, can be controlled by stretching of the film. To increase the Rth value, the additive should align in parallel with TAC molecules that tend to lie in the film plane when forming a film. Additives with a rigid core structure tend to give a high Rth value.

There are other additives that reduce the Rth value to almost zero. Here, the additive destroys the in-plane alignment structure of the TAC molecules.

The possible range of Rth and Re values is shown in Fig. 8. It should be noted that the solubility of the additive in the TAC film is also important for molecular design.

Figure 9 shows various alignment structures of the PDM layer that were developed. These alignment technologies allow us to develop optical compensation films for all LCD modes.

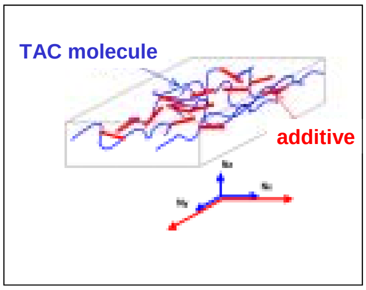


Figure 6. Alignment control of TAC film using an additive.

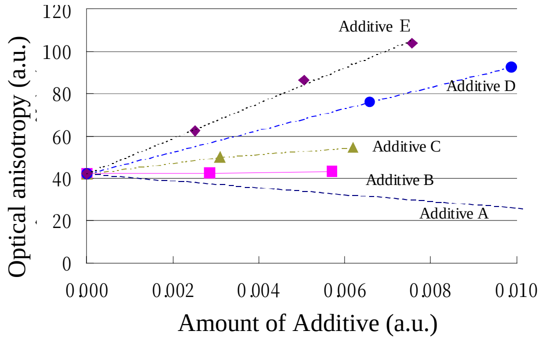


Figure 7 Effect of additive on the optical anisotropy.

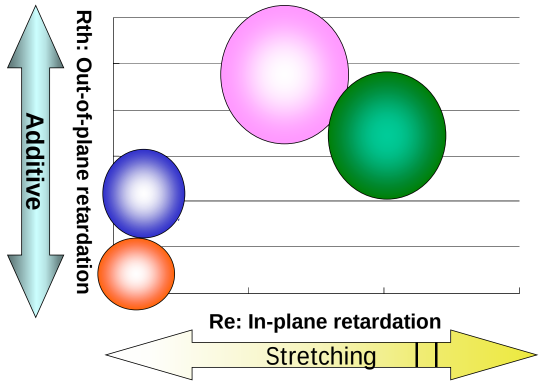


Figure 8. Re and Rth control of TAC film.

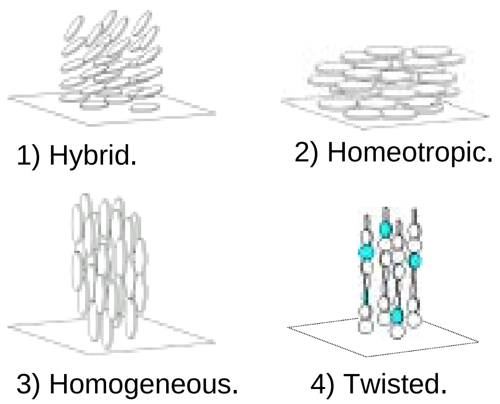
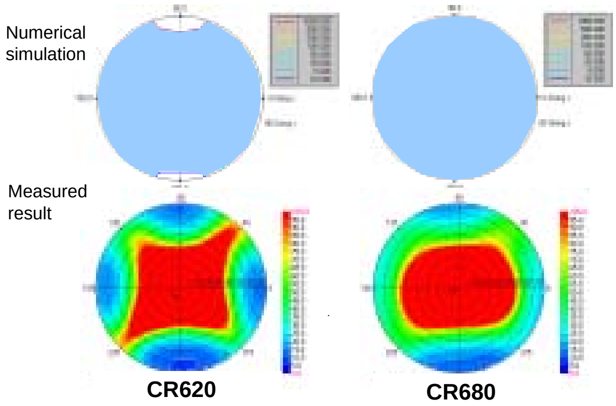


Figure 9. Alignment structures of the PDM layer (Simplified and idealized description).

6. Applications: WV Films

We have recently developed a new WV film for TN, called WV-EA (Excellent Ace), which gives a wider viewing angle than the predecessors, especially in the horizontal direction. The WV-EA film has optimized optical properties for the TAC substrate film and the PDM layer. Fig. 10 shows the viewing angle characteristics. The WV-EA also gives a higher on-axis contrast ratio and improved color shift in the horizontal direction. We believe that the WV-EA makes TN compatible with large size LCD monitors and TVs.



(a) WV-SA (b) WV-EA

Figure 10. Continuous exploration for a wider viewing angle of TN.

OCB-WV film was developed and commercialized last fall. The OCB-WV film is specially designed for the OCB mode, which is know to have a very fast optical response time suited for showing moving pictures[5]. The OCB-WV film has a biaxial TAC film and a PDM layer. The biaxial TAC film has a relatively large Rth and Re values using the alignment technology described above. The PDM layer has a controlled hybrid alignment structure with the alignment direction of 45 degrees to the slow axis of the biaxial TAC film so that a roll-to-roll polarizer manufacturing process is possible. In the case for birefringence modes like OCB, non-uniformity of retardation is especially noticeable to human eyes. A newly developed coating process technology and an additive inside the PDM layer greatly improved the uniformity of retardation to the level where human eyes cannot practically detect mura[6, 3]. The viewing angle (CR 10:1) is over 80 degrees in all directions.

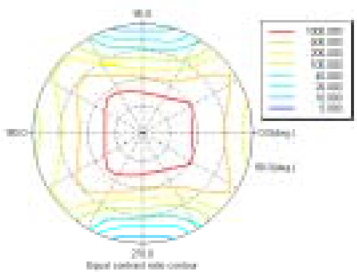


Figure 11. Calculated viewing angle performance for OCB.

7. Summary

TAC film has the advantages of high light transmittance, low birefringence, relatively high water permeability, high uniformity in thickness and retardation and better curling property. These features make the TAC film indispensable as a protective film for polarizers. We have developed novel technologies that control the birefringence of the protective TAC film by adding an additive, which controls the Rth value, by stretching, which controls the in-plane Re value, and by coating an optical function layer. As an example, we explained the technology of the WV film, which consists of a PDM layer coated on the TAC film. The WV film effectively compensates the on-state liquid crystal layer, enlarging the viewing angle. The WV film can directly be attached to the polarizing PVA layer. This roll-to-roll manufacturing process leads to yield up and cost effectiveness. We will continue our effort to develop high performance optical films based upon TAC.

8. Acknowledgements

The author would like to thank Mr. K. Mihayashi, Mr. Yoji Ito, Mr. Keiichi Taguchi, Dr. H. Sata and Dr. H. Nakayama for useful discussions.

9. References

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