Wavelength Dispersion Control of Three-Dimensional Birefringence in Retardation Film for VA-LCD

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ABSTRACT

We developed a method to independently control the wavelength dispersion of in-plane birefringence and vertical birefringence of phase retardation film used in displays. By using acetylcellulose polymer with reverse wave dispersion and nanoparticles with normal wave dispersion, we showed how to independently control the wavelength dispersion of birefringence in the in-plane and thickness directions. As a result, we realized new retardation film with reverse wave dispersion in the plane and flat wavelength dispersion in the thickness direction. By applying this retardation film to VA-LCD, we confirmed that it can reduce the dark state light leakage at the oblique angle.

1 Introduction

Liquid crystal display(LCD) used for large TVs is mainly In-plane switching(IPS) mode or vertical alignment(VA) mode LCD. IPS-LCDs mainly use Z-TAC, biaxial retardation film, or combination of 2 retardation films, +A-Plate and +C-Plate[1][2]. By using the retardation film, light leakage in the diagonal direction at the black state can be suppressed. Further, the use of retardation film with reverse wavelength dispersion reduces light leakage over the entire wavelength range. In the case of IPS-LCDs, it is sufficient to compensate for the light leakage of Cross-Nichol polarizers, and therefore, reverse wavelength dispersion is suitable. It has been reported that the Halo phenomenon can be suppressed by realizing optical compensation over the entire wavelength range using retardation film with reverse wavelength dispersion characteristics even when performing local dimming by controlling the backlight[2][3].

In the optical compensation of VA-LCD, in addition to the compensation of the polarizing plate, the optical compensation of the vertically aligned liquid crystal is required[4]. Regarding the wavelength dispersion characteristics, the polarizer arranged in Cross-Nichol can be compensated by retardation film with reverse wavelength dispersion, but the thickness direction retardation of the vertically aligned liquid crystal is normal wavelength dispersion in the liquid crystal alone. However, in actual LCDs, the wavelength dispersion is changed by cell gap control.

In this study, we developed a method to independently control the wavelength dispersion characteristics of the in-plane birefringent and out of plane birefringent of the retardation film, and investigated the effect of applying the method to VA-LCD.

2 Wavelength Dispersion Control Method

We tried to adjust the birefringence by mixing polymer with reverse wavelength dispersion and smectite as nanoparticle with normal wavelength dispersion. Fig. 1 shows the index ellipsoids of composite polymer in uniaxially oriented film [5][6][7].

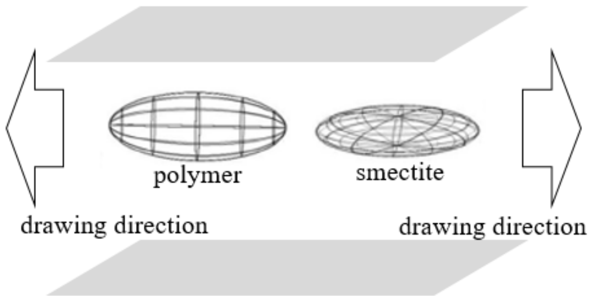

Fig. 1 Index ellipsoids of polymer material and smectite nanoparticles in the drawn film.

As shown in Fig. 1, when films are stretched, polymer is oriented in the stretching direction, and smectite disks are oriented parallel to the film surface.

The birefringence index (in-plane is ΔN and vertical is ΔP) of composite polymer, which is a mixture of polymer and nanoparticle with concentrations of [poly] and [nano], respectively, is expressed by the following equation.

$$\begin{gathered} \Delta N_{poly}[poly] + \Delta N_{nano}[nano] = \Delta N, \\ \Delta P_{poly}[poly] + \Delta P_{nano}[nano] = \Delta P, \quad (1) \\ [poly] + [nano] = 1 \end{gathered}$$

Because the smectite shows a disk shape, $\Delta N_{nano}=0$.

Furthermore, birefringence index is different for each wavelength. When polymer shows reverse wavelength dispersion and nanoparticles show normal wavelength dispersion, the values of birefringence indices of polymer and nanoparticles are inversely related to the wavelengths 450 nm, 550 nm and 650nm.

$$\Delta N_{450nm,poly} < \Delta N_{550nm,poly} < \Delta N_{650nm,poly},$$
$$\Delta P_{450nm,poly} < \Delta P_{550nm,poly} < \Delta P_{650nm,poly}, \quad (2)$$
$$\Delta P_{450nm,nano} > \Delta P_{550nm,nano} > \Delta P_{650nm,nano}$$

Therefore, regarding ΔP in (1), the magnitude relationship changes between 450 nm, 550 nm and 650nm depending on the ratio of polymer and nanoparticles. This means that the wavelength dispersion of ΔP can be controlled by the amount of nanoparticles added.

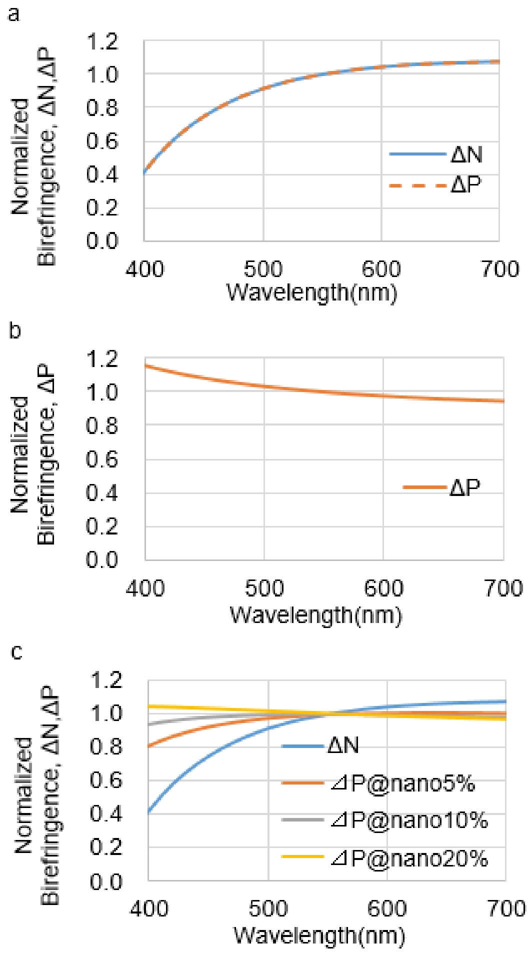

Fig. 2 Birefringence wavelength dispersion (a) polymer (b) nanoparticles (c) mixtures.

Fig. 2 shows the simulation values of ΔN and ΔP when polymer and nanoparticles are mixed in different proportions. Fig. 2(a) shows the wavelength dispersion characteristics of polymer in the ideal uniaxial state, showing the reverse wavelength dispersion. And Fig. 2(b) is the wavelength dispersion characteristic of the nanoparticle smectite oriented as -C-plate, which has normal wavelength dispersion. Fig. 2(c) shows wavelength dispersions of mixtures. As shown in Fig. 2(c), it can be seen that the slope of ΔP decreases as the amount of nanoparticles increases. This is because the magnitude relationship of ΔP changes depending on the wavelength from equations (1) and (2). Therefore, if the amount of nanoparticles added is small, wavelength dispersion becomes reverse. Then, increased further, wavelength dispersion becomes flat. If it is increased much further, wavelength dispersion becomes normal. On the other hand, wavelength dispersion of ΔN is as same as the original slope of polymer regardless of the amount of nanoparticles. This is because nanoparticles do not have in-plane birefringence. Although ΔN decreases with the percentage of nanoparticles added, there is no change in the slope of the wavelength dispersion characteristic of ΔN due to its constant decrease at any wavelengths.

Thus, using this method, wavelength dispersion of ΔP can be controlled by the amount of nanoparticles added. On the other hand, since the wavelength dispersion of ΔN is not affected by the wavelength dispersion of nanoparticles which has ΔN_{nano} =0, it can be determined by selecting the polymer material. Therefore, wavelength dispersion of in-plane and out of plane can be controlled independently.

3 Experiments and Results

In this time, the above theory was experimentally verified using acetylcellulose as polymer and smectite as nanoparticles.

Table 1 In-plane retardation (Re) of polymer

DAC	TAC	Re(nm)	Re450/ Re550	Re650/ Re550
100%	0%	107	0.94	1.03
0%	100%	8	0.23	1.60
50%	50%	83	0.90	1.05
30%	70%	55	0.85	1.07
20%	80%	50	0.75	1.12

Mixtures of diacetylcellulose (DAC) and triacetylcellulose (TAC) from Daicel Co. were used as polymer. Table 1 shows in-plane retardation values of the stretched films of single DAC, TAC and their mixtures. The thickness is about 60 µm. Re450 means retardation at 450nm, and the others mean the same thing. As shown in Table 1, DAC has a large retardation but a small slope of wavelength dispersion, and TAC has a small retardation but a large slope of wavelength dispersion. Then, mixtures of these two materials can change the slope of wavelength dispersion depending on the ratio. When the ratio of DAC and TAC is 2:8, Re450/Re550 is 0.75 and Re650/Re550 is 1.12, which is close to the ideal wavelength dispersion, is obtained, as well as Re=50nm suitable for the retardation film of VA-LCD.

We mixed smectite with polymer, which was a mixture of DAC and TAC at 2:8, and measured the retardation. SPN-T from Katakura&Co-op Agr Co. was used for smectite. The results are shown in Table 2. As shown in Table 2, it can be seen that vertical retardation (Rth) and wavelength dispersion change depending on the amount of smectite added, Rth increases and wavelength dispersion approaches flat as smectite is increased.

Table 2 Retardation of composite polymer (Re=50nm)

smectite	Re450 /Re550	Re650 /Re550	Rth (nm)	Rth450 /Rth550	Rth650 /Rth550
-	0.75	1.12	51	0.82	1.08
9%	0.77	1.11	127	0.94	1.03
11%	0.80	1.10	135	0.96	1.02
14%	0.81	1.09	156	0.97	1.01

On the other hand, the slope of the wavelength dispersion characteristic of Re also becomes slightly smaller as the amount of smectite increases. It is considered that this is because smectite is not optically perfect disk shape and has small birefringence ΔNnano which shows normal wavelength dispersion as well as ΔPnano when smectite has a slightly uniaxial orientation in the plane of stretched composite polymer.

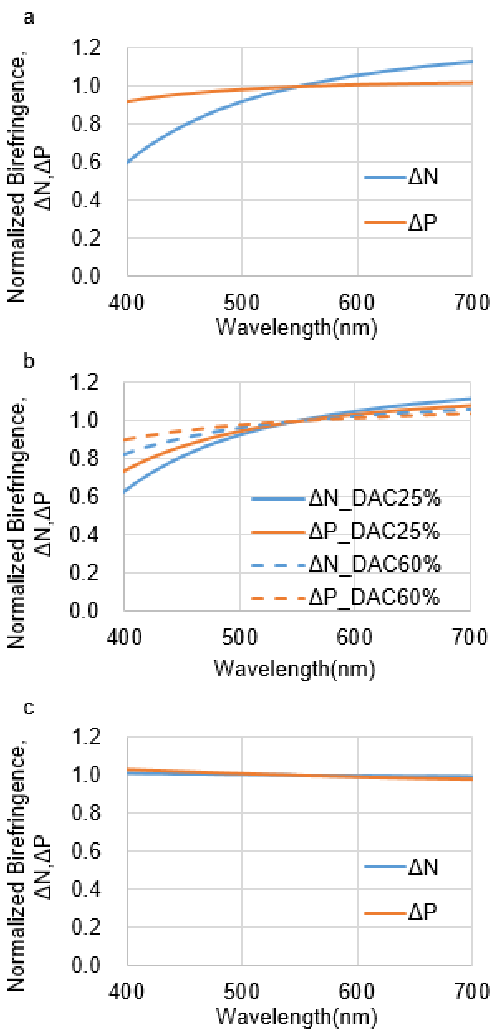

Fig. 3 Birefringence wavelength dispersion (a) New film (b) Acetyl Cellulose (c) COP.

Fig. 3 shows the wavelength dispersion characteristics of the birefringence index of a film stretched by mixing DAC20% and TAC80% with smectite 11% per polymer, films of mixtures of DAC and TAC without smectite, and COP that is commercially available retardation film for VA-LCD. As shown in Fig. 3(a), the slopes of the wavelength dispersion characteristics of Re and Rth are significantly different in this new retardation film, where Re is close to ideal reverse wavelength dispersion and Rth is wavelength dispersion characteristic close to flat. DAC 25%(TAC 75%) in Fig. 3(b) shows that Re450 / Re550 has an ideal reverse wavelength dispersion of about 0.82, and DAC 60%(TAC 40%) shows a wavelength dispersion of about 0.91 of Re450 / Re550 between the ideal reverse wavelength dispersion and flat. As for ΔP, as shown in the figure, these mixtures of DAC and TAC show slightly more moderate wavelength dispersion characteristics than Δn even without mixing nanoparticles. On the other hand, COP has almost flat wavelength dispersion characteristics for both Re and Rth.

The transmittance of this new film is around 92%. It should be the value which could be admitted for the practical displays.

4 Application for VA-LCD

We investigated the Rth of currently commercialized VA-LCD and simulated the optical properties of the combination of the VA cell with this retardation film. Fig. 4(a) shows the optical configuration of VA-LCD and Fig. 4(b) shows the Rth of VA cell.

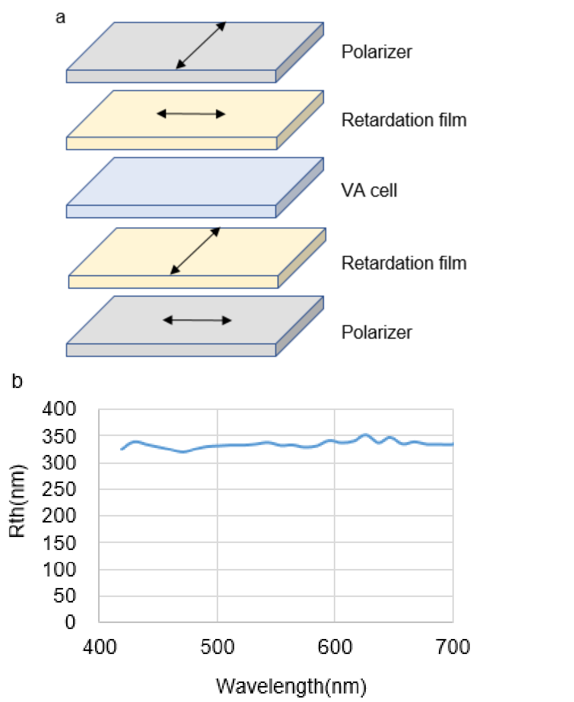

Fig. 4 Structure of VA-LCD (a) Optical configuration of VA-LCD (b) Rth of the commercial VA-LCD

As shown in Fig. 4 (a), the VA-LCD has a structure in which optical compensation is performed by upper and lower retardation films. In this case for the film retardation, Re = 50 nm and Rth = 135 nm. And the measured Rth of VA-LCD shows almost flat wavelength dispersion characteristics as shown in Fig. 4(b).

Fig. 5(a) shows the spectral transmittance of the panel when viewed in black state from an oblique angle and Fig. 5(b) shows the chromaticity change. As shown in Fig. 5(a), in the case of the conventional COP film, light leakage is suppressed in green region, but light leakage occurs in blue and red regions. This is because the wavelength dispersion of COP film sufficiently compensates only the center wavelength. As for the mixtures of DAC and TAC, the 60% DAC mixture suppresses light leakage to some extent, but the blue light leakage is large. The 25% DAC, which is close to the ideal reverse wavelength dispersion at 450nm, is even worse than the COP for blue light leakage. This is because the wavelength dispersion of the liquid crystal is flat, so when the Rth of the retardation film is close to the ideal reverse wavelength dispersion, the optical compensation does not match Rth of LCD. On the other hand, in the case of developed new retardation film, light leakage is suppressed over the entire region.

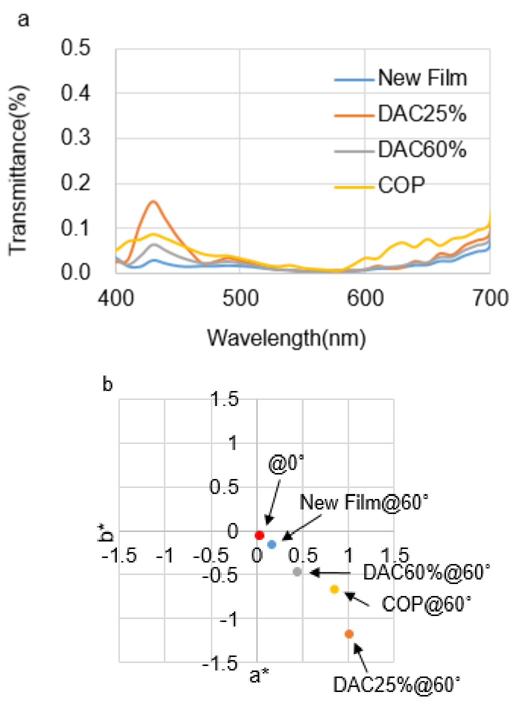

Fig. 5 Dark state light leakage of VA-LCD at the oblique angle (Azimuth 45˚, Polar 60˚) (a) Spectrum transmittance (b) Chromaticity (a*b*).

Fig. 5(b) shows the chromaticity change in the front and oblique directions. The front values @0˚ are consistent no matter which film is used. As shown in Fig. 5(b), VA-LCDs using mixtures of DAC and TAC without smectite and COP film do not compensate for the entire wavelength range, so the chromaticity changes significantly in the oblique direction. On the other hand, when the new retardation film is applied, it is compensated in the entire wavelength range, so there is little light leakage even from an oblique angle, resulting in less chromaticity change.

The transmittance of this film is higher than 92%, so the film can be applied to the practical display usage.

5 Conclusions

We developed a method to independently control the wavelength dispersion of in-plane birefringence and vertical birefringence of phase retardation film used in displays. By using polymer TAC with reverse wave dispersion and nanoparticles with normal wave dispersion, we showed how to independently control the wavelength dispersion of birefringence in the in-plane and thickness directions. As a result, we realized new retardation film with reverse wave dispersion in the plane and flat wavelength dispersion in the thickness direction. By applying this retardation film to VA-LCD, we confirmed that it can reduce the dark state light leakage at the oblique angle.

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