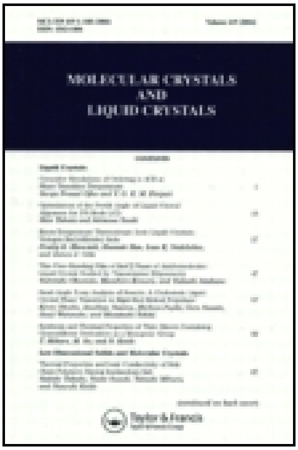

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Development of Liquid Crystalline Polymer Film “Nisseki LC Film” for Viewing Angle Compensation of Various LCD Modes

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Development of Liquid Crystalline Polymer Film "Nisseki LC Film" for Viewing Angle Compensation of Various LCD Modes

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To improve quality of images of LCDs such as their viewing angle performance and coloration, liquid crystalline retardation film technology has been developed by using rod-like liquid crystalline polymer. The resulting liquid crystalline retardation film has several advantages over conventional uni- or biaxial stretched retardation film. By using liquid crystalline polymer, the direction of the principal axis can be determined freely for roll-to-roll lamination. Optical well-controlled structures such as twisted nematic, hybrid nematic and homeotropic structures can be stabilized for ideal compensation of various LCD modes including STN, TN, ECB, VA and IPS LCDs.

Keywords: color compensation; homeotropic; hybrid nematic; liquid crystalline polymer film; twisted nematic; viewing angle compensation

1. INTRODUCTION

Since LCDs had been applied to electrical appliance in 1970's, the level of market demands toward quality of images became higher and higher. By many enthusiastic investigations on LCDs, it was found that the quality of images, such as their contrast, coloration, and viewing angle performance, can be greatly improved by using retardation films. The first generation of retardation film was uniaxial stretched films for improving the coloration of STN-LCDs. Biaxial stretched film was later developed for improving the viewing angle performance of

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TFT-LCDs. However, stretched film has intrinsic drawbacks in its principal axis direction. Usually, the principal axis of the stretched film is limited in the machine direction (MD) and the traverse direction (TD). This prevents roll-to-roll lamination of the stretched film with the polarizer or another stretched film. Furthermore, the principal axis of the stretched film is aligned uniformly even though the low-molecular-weight liquid crystalline molecules in the LC cell are aligned twisted, sprayed, and bent. This mismatch of optical axes between the LC cell and the stretched film prevents optimal compensation.

We have tried to develop the new generation of retardation films by using liquid crystalline polymer.

2. ROD-LIKE LIQUID CRYSTALLINE POLYMER FOR THE OPTICAL RETARDATION FILMS

Liquid crystal has a large optical anisotropy that is suitable for the optical film. Polymer has several advantages in a viewpoint of mass production, i.e. immobility, high stability, and high strength. Thus, liquid crystalline polymer seemed to be very suitable material for the optical retardation film. For the optical usage, the following characteristics are required for the liquid crystalline polymer;

1. that has a glassy state at room temperature, instead of crystalline phase
2. the LC phase has to be sufficiently stable over a wide temperature range
3. low viscosity to get fast domain growth.

We have developed thermotropic liquid crystalline polyesters of main-chain type that satisfy the requirement mentioned above.

Rod-like liquid crystal molecules can be aligned to form various optical well-controlled structures by introducing twist dopant and controlling an anchoring energy and an annealing condition. Various retardation films by using rod-like liquid crystalline polymer as shown in Figure 1 have been studied and some of them have already been on the market at film-roll scale, including nematic, twisted nematic, and hybrid nematic films as Nisseki LC film series since 1995.

In Figure 2, an outward and a cross section of the LC film were shown. An LC layer covered by a protection layer with the thickness of less than 15 μm was formed on the film substrate. TAC film (Tri-acetyl-cellulose film) with thickness of 40 μm or 80 μm is used for the substrate. Since 2002, we had started to provide "substrate-less type" in some grade. This type became very popular in the market because of its thin thickness. This type is the thinnest retardation film in the world now.

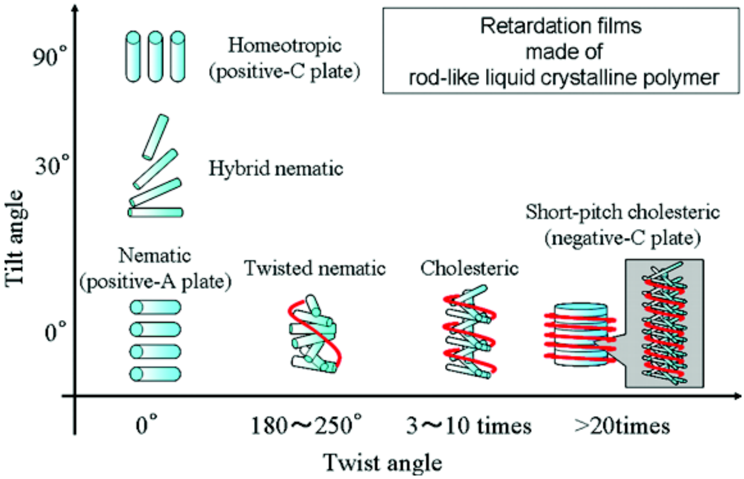

FIGURE 1 Variation of retardation films made from rod-like liquid crystalline polymer. Films with tilting and twisting structures are made from rod-like liquid crystalline polymer.

2.1. Nematic Film and Twisted Nematic Film for STN-LCDs [1–4]

Liquid crystalline retardation films using rod-like liquid crystalline polymer are based on a nematic film. The optical performance of the nematic film is equivalent to that of uniaxial stretched film. However, the nematic film has freedom of the principal axis direction that enables roll-to-roll lamination of the film with the polarizer.

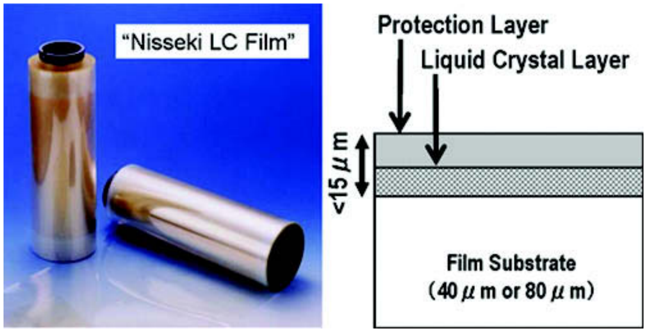

FIGURE 2 Outward and cross section of liquid crystalline retardation film "Nisseki LC film."

Introducing chirality into a nematic liquid crystal yields a twisted nematic phase that functions both as an optical retarder and as an optical rotator. The twisted nematic film can control not only the ellipticity but also the azimuth angle of elliptical polarized light by adjusting the twist angle and retardation independently. Any polarized light can be converted into the desired elliptical polarized light by using the twisted nematic retardation film. The Nippon Oil Corporation provides this nematic and twisted nematic liquid crystalline film under the product name "LC film."

In STN-mode, the cell has twist structure of about 240 degrees and optical retardation of 600 nm to 800 nm. In case of no compensated STN-LCD, black tends to be bluish and white tends to be yellowish because of the difference of birefringent effect (i.e., retardation, azimuth angle of elliptical polarized light) between lights in visible wavelength region. Thus, "color compensation" is indispensable to make good quality color image.

To solve this problem, the twisted nematic film can work drastically as shown in Figure 3. LC film that has same retardation, same twist angle and opposite helical sense with the cell can compensate the coloration. LC film works like a mirror of the STN cell, so that it can "neutralize" the unfavorable birefringent effect.

2.2. Negative-C Plate for VA-LCDs

Increasing the twisting power of chirality in twisted nematic phase yields a cholesteric film. When the cholesteric helical pitch is less than about 150 nm, the pitch is sufficiently shorter than the wavelength of

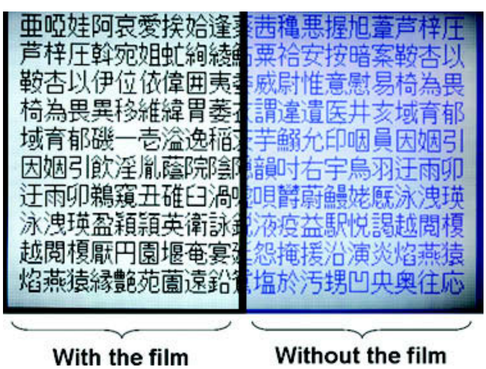

FIGURE 3 Effect of color compensation for STN-LCD by twisted nematic film (left: compensated with a twisted nematic film, right: without the film).

TABLE 1 Measured Results of Refractive Indexes of Nm Film and Short Pitch Cholesteric Film. In-plane Refractive Index of Short Pitch Cholesteric Film Agreed with an Average of n_e and n_o of Nematic Film

Nm film	n_e	n_o	$(n_e + n_o)/2$
	1.83	1.58	1.71
Cholesteric film	n_x	n_y	n_z
	1.71	1.71	1.59

visible light. The in-plane refractive index of such short pitch cholesteric film is an average of the extraordinary ray refractive index (n_e) and the ordinary ray refractive index (n_o) of rod-like liquid crystalline molecules. This phenomenon has been known as the "form birefringence" of layered material since at least 40 years ago [5]. This film functions as a negative-C plate, which is a suitable viewing angle compensator for the black state of VA-LCDs.

In Table 1, refractive indices of a nematic film and a cholesteric film that was composed of same nematic liquid crystal of 96 wt% and chiral unit of 4 wt% are shown. The refractive indices were measured by using Abbe refractometer (Atago 4 T). An average of n_o and n_e of the nematic film was 1.71 that was exactly the same with the in-plane refractive index of the cholesteric film with helical pitch of 170 nm. This result showed that a cholesteric film with a short helical pitch functioned as a negative-C Plate.

2.3. Hybrid Nematic Film for TFT-LCDs [6–10]

Hybrid nematic film has been created by controlling an anchoring energy in both surface of the liquid crystalline layer and an annealing condition. One of the boundaries of the liquid crystalline layer is attached to a film substrate and another is free to open to the air. The difference of the anchoring energy between the boundaries of the liquid crystalline layer yields the hybrid nematic structure. The liquid crystalline molecules are aligned homogeneously on the surface of the film substrate and are gradually tilted toward the air surface.

This retardation film works as a viewing angle compensator by forming a similar alignment structure with low-molecular-weight liquid crystalline molecules enclosed in a cell of TN mode or ECB mode. Nippon Oil Corporation provides this hybrid nematic liquid crystalline polymer under the product name "NH film."

Even in case of ON-state of the TN or ECB cell, low-molecular-weight liquid crystalline molecules near the glass substrate still keep homogeneous alignment, though the molecules in the middle part of the panel are aligned homeotropically. This is because the anchoring energy near the glass surface is stronger than the induced electric field and is the origin of the hybrid nematic alignment of liquid crystalline molecules in the cell. This asymmetric alignment makes viewing angle performance very poor which was one of the typical drawbacks of TN or ECB modes. Thus, compensating viewing angle performance by the NH film that has similar structure with the cell is very effective.

In Figure 4, iso-contrast contour maps of ECB-LCDs with/without the NH film are compared. The area surrounded by the contrast line of 10 shown by black solid line with one NH film is wider than that with no NH film. Furthermore, the area with two NH films is extremely wider than the others. Thus, the effect of viewing angle improvement by the NH film was very obvious. In Figure 5, LCD panels with/without the NH film are shown. In the panel with no NH film, gray scale inversion and solarization are observed while they are well suppressed in the panel with the NH film.

2.4. Homeotropic Film for IPS-LCDs

Viewing angle performance of IPS mode is one of the best among today's various LCD modes because liquid crystalline molecules

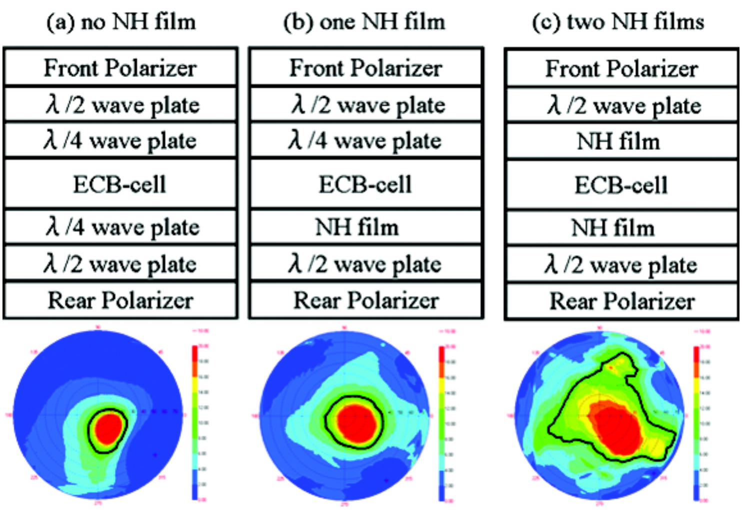

FIGURE 4 Effect of viewing angle compensation for ECB-LCD by hybrid nematic film (NH film). (a) conventional optical component of transflective ECB mode, (b) ECB mode with one NH film and (c) ECB mode with two NH films. Contrast ration of 10 is shown by black solid line.

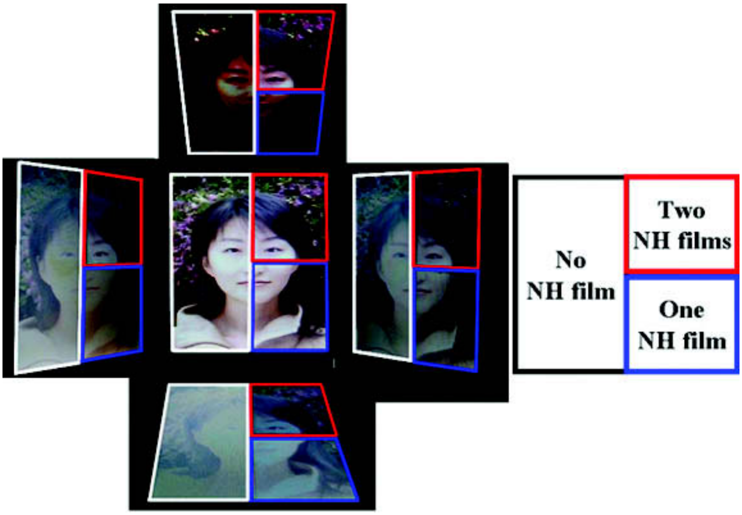

FIGURE 5 Comparison between displayed images of ECB-LCDs with/without the NH film. (left: conventional optical component of transflective ECB mode, lower right: ECB mode with one NH film, upper right: ECB mode with two NH films. These photographs are corresponding to optical components (a), (b) and (c) in Figure 4 respectively.

enclosed in an IPS cell are restricted in-plane. No tilting molecules are in the cell in any gray scale level. However, viewing angle compensation is necessary to suppress light leakage from the crossed polarizers in high viewing angle region even in the case of IPS-LCDs. Although the angle of absorption axes between a pair of crossed polarizers is 90 degrees each other when observed along the normal axis, the angle is greater than 90 degrees if it is observed from oblique angle so that light leaks at high viewing angle.

A positive-C plate that has an extraordinary ray refractive index along the normal axis is a suitable compensator to suppress the light leakage.

There are some difficulties with making a positive-C plate by the stretch process because the refractive index is increased along stretching direction. The liquid crystalline retardation film technology makes it easy to produce a positive-C plate by using a homeotropic alignment of rod-like liquid crystal.

In Figure 6, iso-contrast contour maps of IPS-LCDs with/without positive-C plate made by homeotropic film are compared each other. There is no iso-contrast line of 10 in the iso-contour map

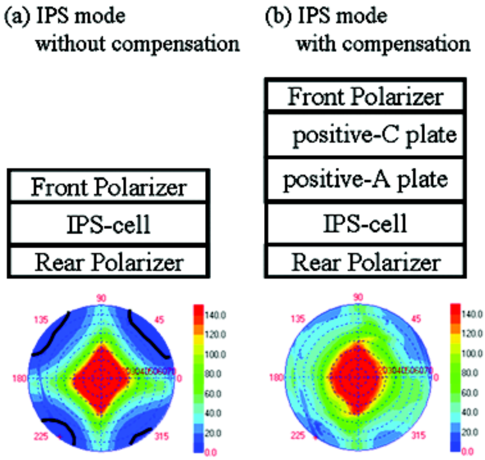

FIGURE 6 Effect of viewing angle compensation for IPS-LCD by homeotropic film. (a) IPS mode without viewing angle compensation and (b) IPS mode with viewing angle compensation by positive-C plate (homeotropic film) and positive-A plate (nematic film). Contrast ration of 10 is shown by black solid line.

of IPS-LCD compensated by the homeotropic film. This means that the contrast ratio within the viewing angle of 80 degrees is higher than 10. This result is very excellent to compare with any other LCD modes.

3. CONCLUSION

Compensating LC cells with retardation films is standard optical design used today to achieve good quality of image of LCDs. Recently, liquid crystalline retardation film has been developed as the new generation retardation film. Compared with conventional stretched film, liquid crystalline film has several advantages, including internal well-controlled structures such as twisted nematic, hybrid nematic and homeotropic alignments and freedom of the direction of principal axis, which allows a roll-to-roll process when the retardation film is laminated with the polarizer.

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