P-140: Simultaneous Phase Retardation and Optic Axis Measurements of A- and C-Plates

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Abstract

We demonstrate a new method for simultaneously measuring the phase retardation and optic axis of a compensation film by using an axially-symmetric sheared polymer network liquid crystal (AS-SPNLC). With overlaying a tested compensation film with a calibrated AS-SPNLC cell between crossed polarizers, the optic axis and phase retardation value of the compensation film can be determined. This method is applicable to both A- and C-plate phase compensation films..

1. Introduction

Phase compensation films play an important role for improving the viewing angle and contrast ratio of liquid crystal display devices. There are two essential factors to define a compensation film, the refractive indices and optical axis. Several methods have been developed for measuring the phase retardation value of a phase compensation film [1-4]. For example, Soleil-Babinet compensator is a mechanically adjustable retardation plate. By adjusting the relative distance of two crystal wedges against to each other, we can determine compensation point and read out the phase retardation information. However, the major shortcoming of them is that they cannot determine the retardation and optical axis simultaneously.

In this paper, we develop a new method for simultaneous detection of phase retardation and optical axis of a phase compensation film using an axially-symmetric Sheared Polymer Network Liquid Crystal (AS-SPNLC) [5-6]. The AS-SPNLC exhibits two unique features: 1) its optical axis is radial in all directions, and 2) its phase retardation has a gradient distribution from center to edges. For an A-plate, we first characterize the phase retardation profile of our AS-SPNLC film. Then we overlay a phase compensation film, whose retardation value and optical axis is yet to be determined, on top of our SPNLC film. The transmitted image between crossed polarizers is recorded by a CCD camera. After analyzing the compensation pattern of the CCD image, we can precisely identify the phase retardation value and optical axis of the tested phase compensation film. For a C-plate, no matter positive or negative, it is impossible to measure the $d\Delta n$ directly, where d is cell gap and $\Delta n = (n_e - n_o)$, because the optic axis is parallel to the normal direction of the compensation film. In order to measure the phase retardation, we tilt the optic axis by 30° and 45°. By using the same method as measuring the A-plate, we can precisely obtain the phase retardation value of the C-plate. Compared to the traditional C-plate measurement method [7], our method is easier and faster.

2. Experiment and results

2.1. Axially-symmetric Sheared Polymer Network Liquid Crystal Fabrication

To prepare an AS-SPNLC cell, we mixed 15 wt % of a photopolymerizable monomer (NOA65) in a commercial Merck E7 LC mixture. The mixed LC and monomer was filled in two ITO glass substrates with the cell gap d~9 μm. In order to polymerize the LC cell, a two-step UV curing process was adopted [8-9]. After UV curing, we applied an off-axis shearing force to the top substrate while keeping the bottom glass substrate fixed. Figure shows a illustration of the off-axis shearing of the SPNLC cell. This shearing force stretches the entangled polymer networks and suppresses the light scattering completely [8-9]. If the shearing torque is large enough, the polymer networks begin to contract and form an axially-symmetric pattern owing to the restoring force. The AS-SPNLC cell is transparent after shearing process.

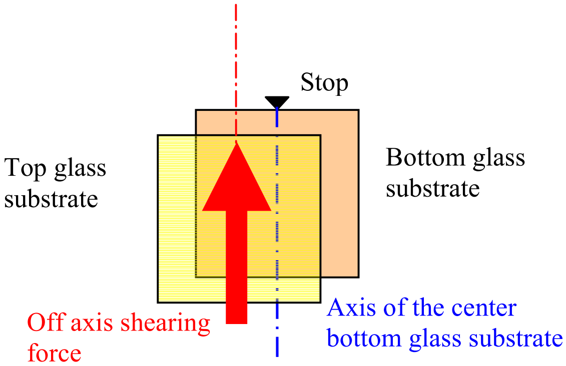

Figure 1: Illustration of the off-axis shearing of the SPNLC cell.

Figure shows the cross-hair pattern while sandwiching AS-SPNLC structure between the crossed polarizers. It is an indirect proof of the axially symmetric structure because the black cross turns while rotating the polarizer and analyzer pairs [5]. Figure shows the top and side views of the AS-SPNLC structure. Polymer network forms a radial structure and constrains the LC directors within a circle. The diameter of the structure is around 10 mm; whose size depends on the fabrication process. The top view of the structure displays a symmetric alignment of LC directors toward the center. The side view of the structure reveals a gradient distribution of the hybrid alignment from the center to the edge of the circle. The AS-SPNLC exhibits two unique characteristics. First, its optical axis is radial in all directions. Second, its phase retardation has a gradient distribution from center to edges because of the gradient distribution of the liquid crystal alignment. This radial gradient phase plate can be used for measuring the phase retardation and optical axis of an optical phase compensation film.

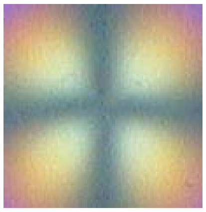

Figure 2: AS-SPNLC image under crossed polarizers

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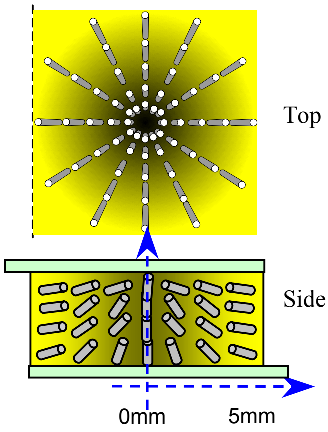

Figure 3: The top and side views of the AS-SPNLC structure.

2.2. A-plate Measurement

Then we overlay a phase compensation film, whose retardation value and optic axis are yet to be determined, on top of our SPNLC film. Figure depicts the experimental setup. To demonstrate this powerful technique, we used a quarter-wave plate with an arbitrary axis as an example. Figure shows the concept of our measurement methods. We put our sample and SPNLC film under an optical microscope and took images from a CCD camera. All we need to do is to look for the compensated dark spots of the stacked SPNLC and λ/4 films. Since our SPNLC has continually varying retardation values, we can always find a point that would cancel the phase of our measured object. At the same time, we can also determine the optical axis of the tested object.

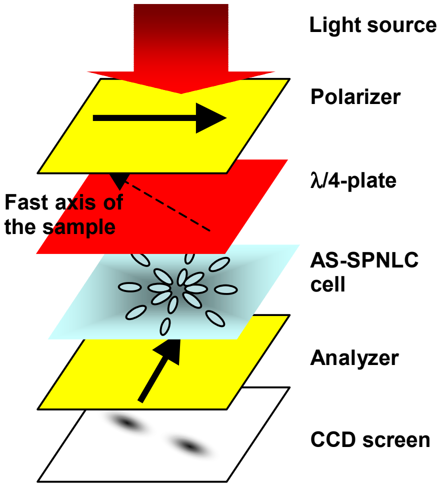

Figure 4: Compensation film measurement setup.

For example, Figure shows that the slow axis of the SPNLC is compensated with the fast axis of the λ/4 film. After analyzing the CCD image, we obtain the direction of the fast axis of the object under study. Furthermore, we can obtain the phase retardation value of the measured object by comparing the location of the dark spots with respect to the SPNLC phase retardation chart plotted in Figure .

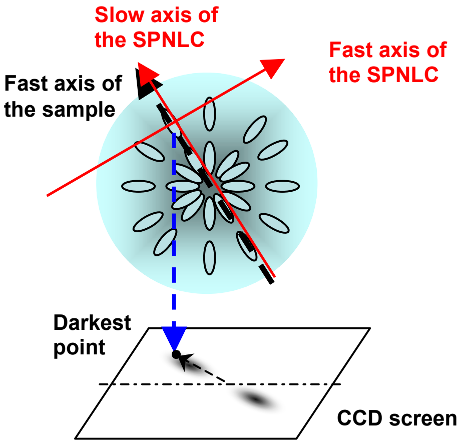

Figure 5: Illustration of the measurement methods.

To extract the phase retardation value and optic axis of the compensation film from Figure , we need to find the fast axis and the distance of the transmission minima from the center, as illustrated in Figure . From Figure , the fast axis (white dashed lines) is at 135° with respect to the horizontal axis. That means the optical axis of the uniaxial compensation film is oriented at 135^o with respect to the horizontal axis. Next, we need to determine the dΔn value of the compensation film. To do so, we measure the distance of the transmittance minima from the center. From Figure , we find that these two dark spots are quite symmetric; their distance to the center is ~399 μm.

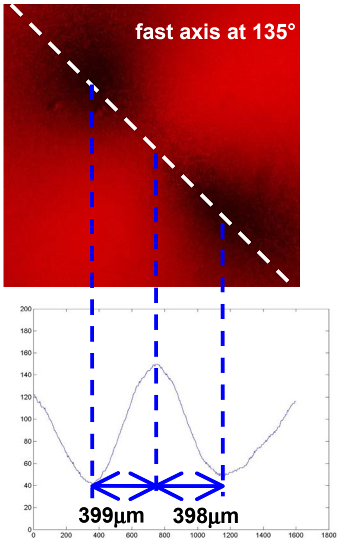

Figure 6: The relative distance of the two transmission minima recorded by a CCD camera.

Next, we need to convert the measured distance to phase retardation from a corresponding phase retardation chart at a selected wavelength. The procedure is shown in Figure . Figure plots the phase retardation value of the AS-SPNLC cell we fabricated. At the indicated position, we find the corresponding phase retardation value is 162.1 nm. This is in a very good agreement with the expected quarter-wave plate, whose retardation value is 163.8 nm at λ= 656 nm.

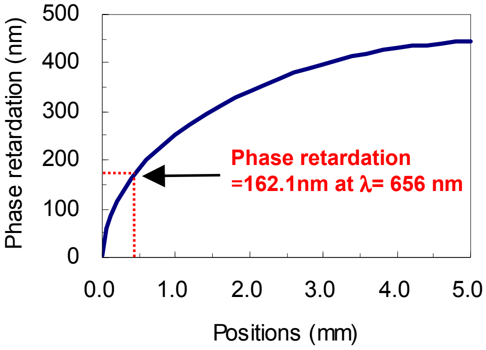

Figure 7: The corresponding phase retardation of the quarter-wave film.

2.3. C-plate Measurement

Figure shows the experimental setup for measuring the C-plate. The measurement procedures are similar to those of the A-plate. To measure the phase retardation of the C-plate, we need to obtain retardation information at the 30° and 45° tilt angles and solve the retardation values from the following equations.

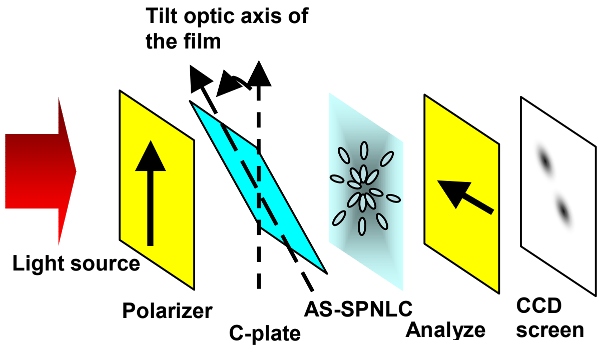

Figure 8: The measurement setup of the C-plate.

Equations (1) and (2) show the retardation values with the relation to the refractive indices (n_e, n_o) and film thickness (d) of the C-plate. Γ_{30} and Γ_{45} (in unit of nm) represent the retardation values when we tilt the C-plate to 30° and 45° with respect to the normal position.

$$\Gamma_{30} = \frac{2\sqrt{3}}{3}\left(\sqrt{\frac{4\cdot n_e^2\cdot n_o^2\cdot d^2}{3\cdot n_e^2+n_o^2}} - n_o\cdot d\right) \qquad (1)$$

$$\Gamma_{45} = \sqrt{2}\cdot\left(\sqrt{\frac{2\cdot n_e^2\cdot n_o^2\cdot d^2}{n_e^2+n_o^2}} - n_o\cdot d\right) \qquad (2)$$

To extract the retardation value R of the C-plate from Eqs. (1) and (2), we substitute n_e-n_o= Δn, R= d×Δn, and R_o=d×n_o. Equations (3) and (4) show the relationship between the phase retardation (Γ_{30} and Γ_{45}) and R. After obtaining the retardation value Γ_{30} and Γ_{45} at 30° and 45°, we can determine the retardation value R of the C-plate by solving Eqs. (3) and (4).

$$\Gamma_{30} = \frac{4\sqrt{3}\cdot(R_o^2 - R_o\cdot R)}{3\sqrt{4\cdot R_o^2 - 6\cdot R_o\cdot R + 3\cdot R^2}} - \frac{2\sqrt{3}}{3}R_o \qquad (3)$$

$$\Gamma_{45} = \frac{2\cdot(R_o^2 - R_o\cdot R)}{\sqrt{2\cdot R_o^2 - 2\cdot R_o\cdot R + R^2}} - \sqrt{2}R_o \qquad (4)$$

3. Conclusion

We have developed a new method to simultaneously measure the phase retardation and detect the direction of the optic axis of a uniaxial compensation film. By using an AS-SPNLC layer, our method is faster and easier than the traditional method to determine the phase retardation information of a compensation film. Furthermore, the compensation film measurement method is also discussed. To prove feasibility, a quarter-wave film is used as an example for demonstrating the measurement procedures. The measured results agree with reality well. This simple technique can be used for simultaneously measuring the optic axis and phase retardations of both A- and C-plates. These films have been used extensively in wide-view LCD industry. Therefore, this method will make an important impact to the LCD industry.

4. Acknowledgements

The authors are indebted to Toppoly Optoelectronics (Taiwan) for the financial support.

5. References

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