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Effect of Frcition Conditions on Pretilt Angle of Liquid Crystal

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Abstract: The response time of the liquid crystal determines the display quality of the material. Pretilt angle is one of the basic characteristics of liquid crystal, which affects the response time of liquid crystal. In this paper, the equipment of Newton Ring Laboratory is used to measure the birefringence of liquid crystal, the pretilt angle of the liquid crystal cell is measured, and the pretilt angle of the liquid crystal cell is measured by the crystal rotation method. When the transmission direction of the linear polarizer is parallel to the scratch, the polarization direction of the incident light is also parallel to the scratch direction, and different liquid crystal prediction angles are obtained by different fractionation conditions. The experimental results show that there is a qualitative relationship between the rubbing direction and the pretilt angle. As the friction depth increases, the friction value of the friction layer surface also increases. When it is necessary to change the pretilt angle of the liquid crystal cell, changing the friction depth has become a new and reasonable choice.

Keywords: Liquid crystal pretilt angle; Fractionatio; Friction direction

1. Introduction

The response time of liquid crystal can determine display quality of the material. The pretilt Angle is a basic property of Liquid Crystal, which can influence its response time. The angle between the liquid crystal molecules and the orienting surface and time follows Erickson-Leslie equation [1]:

$$K_{33}\frac{d^2\theta}{dz^2}+\varepsilon_0\Delta\varepsilon E^2\theta=-\gamma_1\frac{\partial\theta}{\partial t} \quad (1)$$

Until now, People have explored several possible influencing factors of the pretilt angle of liquid crystal, such as polymer stabilisation [2] and preparation conditions of PI solutions. However, the relationship between friction conditions and the pretilt angle has not been reported thoroughly yet. For the first time, we changed friction depth of both surfaces when making liquid crystal cells and measured their pretilt angles by crystal rotation method, and got quite reasonable relationship between them.

2. Experiment and Results

2.1. Measurement of the birefringence of the liquid crystal

Liquid crystal is a kind of birefringent crystals, with the alignment direction of the molecule being its long axis, while the vertical direction being its short axis. To measure its pretilt angle, we need to know the direction of its long axis, while the pretilt angle is just the angle between its long axis and the responding surface. To know the long axis, we need to measure the birefringence of the material. We use the equipment of Newton's ring laboratory to accomplish.

We put a piece of A4 paper between the two surfaces of the liquid crystal box. The friction directions of both surfaces are parallel to each other.

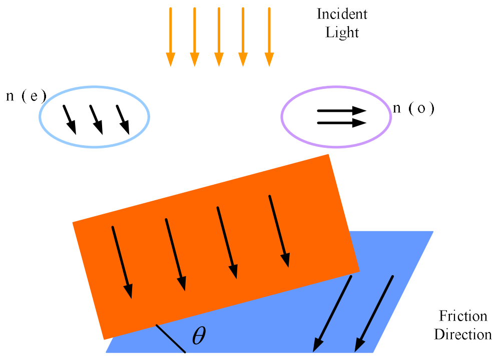

Figure 1. Parallel graphs of two surface friction directions

The wavelength of the incident light is 589nm, with the arrows on the surface refers to the friction direction of the surface. The ellipse is linear polarizer, while when its direction is parallel to the friction direction, we get n(e) , and when vertical to it, we get n_e .

When the transimission direction of the linear polarizer is parallel to the scratch, the polarization direction of the incident light is also parallel to the scratch direction, which is the same as the optical axis of the liquid crystal. On such occasion, the incident light is parallel to the principal plane, which means it's ordinary light and using the fringe spacing we can calculate $n(e)$,where n_e is the refractive index of the extraordinary light, x and d verifies the location of each interference fringe and the corresponding thickness of the air in the slope. d' represents the thickness of the paper, l is the length of the slope.

$$\delta = \frac{2\pi}{\lambda} 2n_e d = 2k\pi, d = x\tan\theta, \tan\theta = \frac{d'}{l} \tag{2}$$

$$n_e = \frac{\lambda \Delta k}{2\Delta x_e} \frac{l}{d'} . \tag{3}$$

When the transimission direction of the linear polarizer is parallel to the scratch, n_o is gotten by $n_o = \frac{\lambda \Delta k}{2\Delta x_o} \frac{l}{d'}$

The location of several interferometric fringes is shown as Table 1.

Table 1. The Location of Several Interferometric Fringes

Number of the bright fringe	Location(mm)	Deltan,(mm)	Number of the bright fringe	Location(mm)	Deltan,(mm)
0	16.415	0	0	26.51	0
2	16.48	0.065	4	26.41	-0.1
5	16.56	0.145	7	26.308	-0.202
8	16.698	0.283	10	26.201	-0.309
10	16.71	0.295	13	26.107	-0.403
12	16.791	0.376	16	26.002	-0.508
15	16.869	0.454	19	25.9	-0.61
17	16.94	0.525	22	25.798	-0.712
19	17.018	0.603	25	25.687	-0.823
22	17.105	0.69	27	25.588	-0.922

Finally, we got n_o as 1.604, n_e as 1.448, which indicates that the liquid crystal material in
the experiment is aniaxial negative crystal.

2.2. Measurement of the pretilt angle of the liquid crystal cell

The pretilt angle is measured by the crystal rotation method. A schematic diagram is show below. Suppose that the incident light reaches at the front face of the liquid crystal cell at point S, while the line AA' represents the front face. Based on Huygens-Fresnel principle, S is a new wave source. According to the fact that $n_o > n_e$ the propagation speed of the ordinary light is lower than that of the extraordinary light. As a result, the hemisphere is the wave surface of the ordinary light, while the ellipsoid is the wave surface of the extraordinary light. Connect point S with the tangent point of both hock faces, we got line SB. Due to the consistence of the propagating speed between the both lights in a typical birefringence crystal, we can know that SB is the principal axis. The angle(α) between line SB and the front face is the pritilt angle.

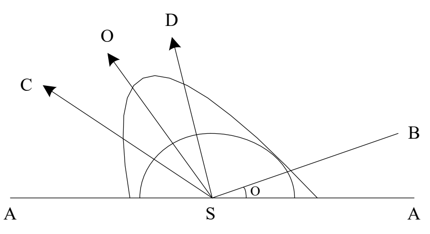

Figure 2. Ordinary light surface diagram

Now that the intensity of coherent lights is a function of the phase difference, if the incident angle is changed, the intensity of the emergent light will be changed as a result of the variable phase difference between the ordinary light and the extraordinary light. Once the phase difference is similar, the intensity of the interference light will be similar. Because the phase difference distribution is approximately axial symmetric about line SO, if the incident light is on the trace of line SO, the two divided light of the same beam will differ most hardly, as the figure shows, and the distribution of the intensity of the emergent light will be symmetric about line SO.

The phase difference between the ordinary light and the extraordinary light when they reach the bottom face of the liquid crystal cell obeys the formula below [3] :

$$\delta(\phi) = \frac{2\pi d}{\lambda}\left(\frac{n_e^2 - n_o^2}{n^2}\cos\alpha\sin\alpha\sin\phi + \sqrt{n_o^2 - \sin^2\phi} - \frac{n_e n_o}{n^2}\sqrt{n^2 - \sin^2\phi}\right) \tag{4}$$

$$n^2 = n_o^2\cos^2\alpha + n_e^2\sin^2\alpha \tag{5}$$

$\delta(\varphi)$ is the phase difference, $\lambda = 689.5\text{nm}$, α is the pretilt angle, ϕ is the incident angle. Taking the symmetry into account, near line SO, $\left.\frac{d\delta(\phi)}{d\phi}\right|_{\phi=\phi m} = 0$, As a result, we get the relationship between the pretilt angle and the symmetry incident angle ϕ_m :

$$\frac{n_e^2 - n_o^2}{n^2}\cos\alpha\sin\alpha + \sin\phi_m\left(\frac{n_e n_o}{n^2\sqrt{n^2 - \sin^2\phi}} - \frac{1}{\sqrt{n_o^2 - \sin^2\phi_m}}\right) = 0 \tag{6}$$

When making cells, the friction direction of the two surfaces of the cell should be Anti-parallel but not parallel, as the figures 6-9 display. In all of the three figures, the coordinate System is shown in Figure 3.

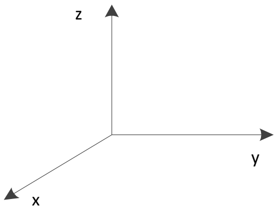

Figure 3. The coordinate system

While rubbing, the alignment of the liquid crystal molecule is not known, two possible situations are shown in Figure 4.

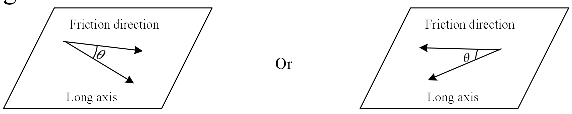

Figure 4. Two possible alignments of the liquid crystal molecules after rubbing is shown

Suppose that when rubbing the lower surface of the overlying plane in accordance with +y direction, the molecules' z ordinates are in negative correlation with their y ordinates, then when rubbing the upper surface of the underlying plane in accordance with +y direction, the molecules' z ordinates are in positive correlation with their y ordinates. Thus, the optical axes in the upper part and lower part are not unanimous, which makes it impossible to measure the direction of the optical axis, as Figure 5 shows.

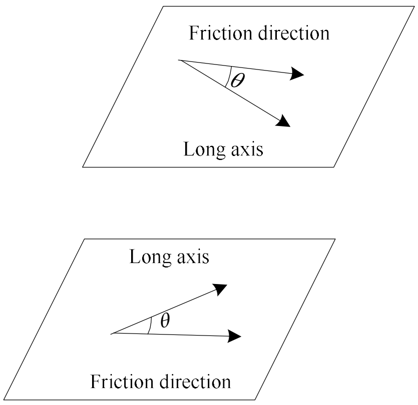

Figure 5. The alignment of the molecules when the friction directions of the two surfaces are parallel.

In comparison, when the friction directions are anti-parallel, the optical axes are uniform throughout the liquid crystal cell, as Figure 6 shows.

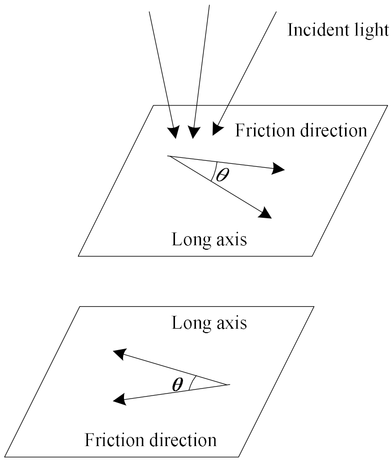

Figure 6. The alignment of the molecules when the friction directions of the two surfaces are anti-parallel

In conclusion, the friction directions of the two surfaces of the cell should be anti-parallel. We measured the incident angle and corresponding transmissivity of three liquid crystal cells with disparate friction depths, getting the computational solutions of corresponding pretilt angle whose computational defaults are limited to less than 10-3 degrees using the searching-for-solution computational method. Because the birefringence is measured under 589nm monochromatic light, a 589-nm filter chip with a 10-nm half wave bandwidth is imposed between the compound light laser and the liquid crystal cells, assuring all valid light received by the receiver is 589 nanometers. Figure 7-9 show the relationship between the transimissivity and incident angle. The apparently extreme points in three plots are the symmetry incident angles.

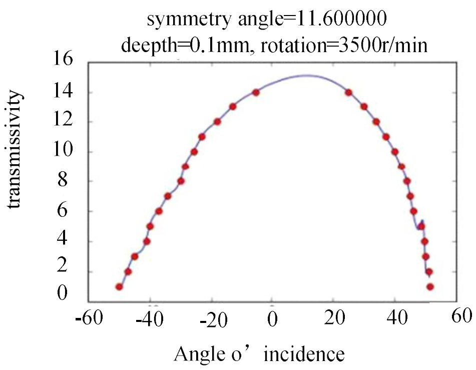

Figure 7. Transmissivity versus incident angle in the first cell.

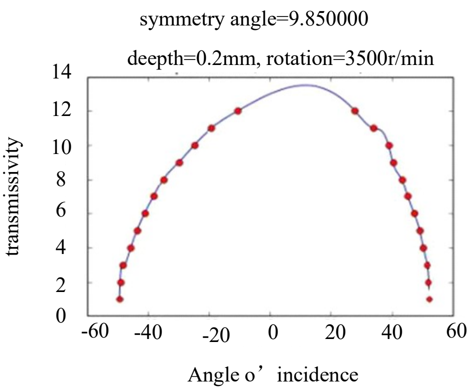

Figure 8. Transmissivity versus incident angle in the second cell.

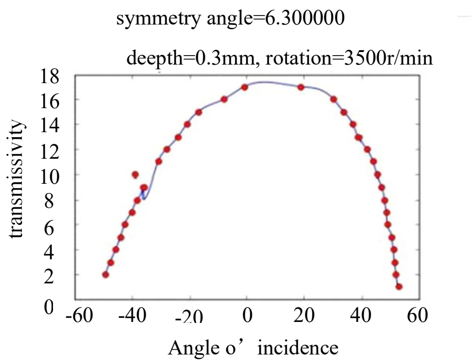

Figure 9. Transmissivity versus incident angle in the third cell.

Finally, we get the pretilt angles of the three liquid crystal cells, as Figure 10 shows, where the unit of the angle is degree.

Results:
deepth=0.1mm rotation=3500r/min:pretilt angle=5.156620
deepth=0.2mm rotation=3500r/min:pretilt angle=4.010705
deepth=0.3mm rotation=3500r/min:pretilt angle=1.718873

Figure 10. Results of pretilt angles of the three liquid crystal cells.

3. Supplements and Conclusion

The experiment is carried out when the friction directions of the two surfaces are parallel to each other, while only when the molecules near the two surfaces of the cell are vertically aligned can they perform as photoswitch. We assume that the pretilt angle is of the same quantity no matter whether the friction directions are parallel or vertical once the friction directions of each surface of the cell are same.

For the first time, we proved that there is a qualitative relationship between friction directions and pretilt angle, with the friction deepth when rubbing the surfaces of the cells increasing, the friction is "enhanced " and the molecules are more adjoining to the surface, which leads to the pretilt angle decreasing. Furthermore, the liquid rotation method in determining a uniaxial crystal has been verified effective again in our experiment. When there's a need to change pretilt angle of liquid crystal cells, altering the friction depth has surely become a new reasonable choice.

References

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[2] Lee T.R., Kim J.H., Lee S.H. Suppressing pretilt angle for enhancing black quality in diagonal viewing angle of homogenously aligned liquid crystal display. Liquid Crystals. 2017,44, 1146-1156.

[3] Scheffer T.J., Nehring J.J. Applied Physics Letter. 1977, 48, 1783.