Novel Measurement Method for Difference of Flexo-coefficients (e_{11}-e_{33}) by Using Disclination Lines in HAN Cells with Concentric Rubbing Treatment

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ABSTRACT

We propose a novel evaluation method for the difference of flexo-coefficients 'e_{11}-e_{33}'. A HAN cell with in-plane electrodes treated concentric rubbing is used. Positions of disclination lines which occur due to the flexo-polarization under applying the dc electric field are used for evaluating e_{11}-e_{33} with fitting of numerical calculated results.

1 INTRODUCTION

Several problems have been reported such light leakage or flicker at the pixel edge as tinier pixel size for the high resolution especially in an IPS mode or an FFS mode. As the most influential cause, a flexoelectric effect is suspected. [1] There are two kinds of flexoelectric coefficients e_{11} and e_{33}, correspond for splay and bend distortion, respectively, with the director orientation. [2] To evaluation method for flexo-coefficients has been proposed and tried by lots of research groups, however, no methods are received as a canonical evaluation method. Even today, LC materials with flexo effect are selected / developed from past experiential rules, indirect experimental data, etc. Then, the development of a method for easily and reliably evaluating flexo-coefficients is desired. Incidentally, the difference value 'e_{11}-e_{33}' (e_n) or the additional value 'e_{11}+e_{33}' (e_p) are evaluated because it is difficult to independently evaluate e_{11} and e_{33} due to the continuity of the director distribution. [3-5] It is derived from the theoretical formula that e_n is dominant in the in-plane electric field. Therefore, e_n is greatly related to the defect phenomenon influence of flexo effects in the IPS or FSS modes. That is, it is significantly to be able to evaluate e_n.

In this report, we propose a novel evaluation method for e_n. The border of the difference of LC director rotation direction between the dielectric effect and the flexo electric effect under applying the dc electric field to the hybrid aligned nematic (HAN) cell with in-plane electrodes is observed as a disclination line (DL). And, the position of DLs are used. Where, a concentric rubbing treatment is carried out on the substrate with the horizontal orientation side in the HAN cell. And, for the determination of e_n, the position of the DL in the experimental result is compared with the calculated results.

2 MEASUREMENT PRINCIPLE

2.1 Theoretical Background

One dimensional model of the continuum theory for nematic LC is used for numerical calculations. We assume that the deformation of lines of electric force is neglect and inside of the cell is uniformity electric field. The electric field is applied in the y direction in Fig. 1. A HAN cell which has the distortional director orientation is used for inducing the flexo polarization.

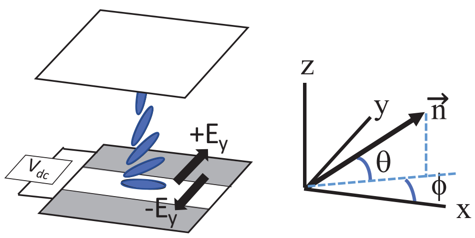

Fig. 1 HAN cell with in-plane electrodes and coordinate system.

The theoretical equation expands to the Euler-Lagrange equation, and it can be seen that the term of 'e_{11}-e_{33}' is included in the azimuthal term, as shown in Eq. 1, *i. e.*, there is a possibility that the influence of 'e_{11}-e_{33}' can be detected by applying the in-plane electric field. [4]

$$2g'(\theta)\left(\frac{\partial\phi}{\partial z}\right)\left(\frac{\partial\theta}{\partial z}\right)+2g(\theta)\left(\frac{\partial^2\phi}{\partial z^2}\right)+\Delta\varepsilon\cos^2\theta\,\sin(2\phi)E_y^2$$
$$+2(e_{11}-e_{33})\cos^2\theta\,\cos\phi\left(\frac{\partial\theta}{\partial z}\right)E_y=0 \qquad (1)$$

where,

$$g(\theta)=\cos^2\theta(K_{22}\cos^2\theta+K_{33}\sin^2\theta)$$

As shown in Fig. 2, ϕ_0 is the pretilt angle at the in-plane direction. LC directors are received two directions of forces (F_{diel} and F_{flex}) under applying the dc voltage, where F_{diel} and F_{flex} are forces to rotate directors induced by the dielectric polarization and the flexo-polarization, respectively. When e_n is zero of the using LC material, as the applied voltage increases from zero, the director rotates in the direction of ϕ_0 by the force of F_{diel}

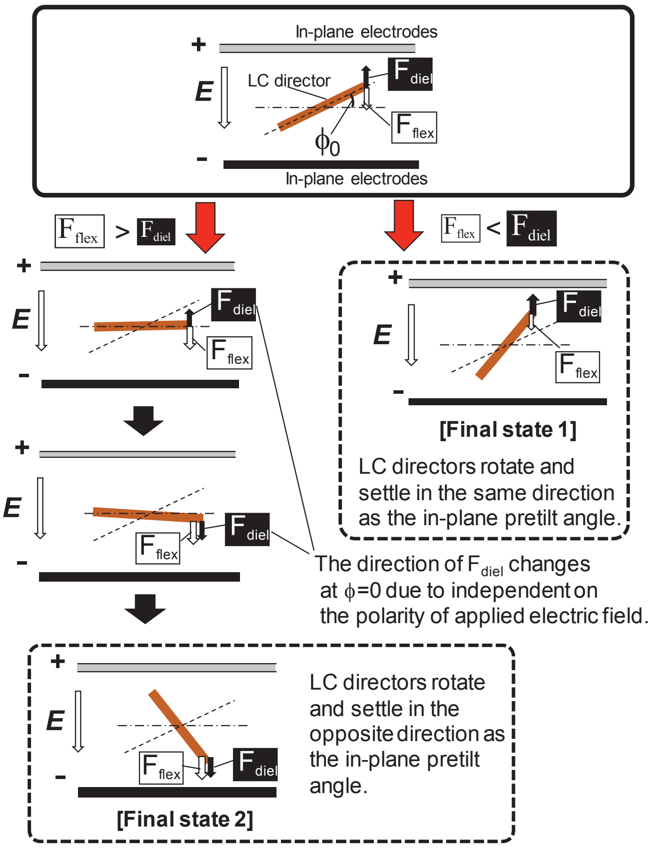

Fig. 2 Rotational direction of LC director between a pair of in-plane electrodes depend on F_{diel} and F_{flex}. (ϕ_0 is an in-plane pretilt angle, ϕ is an azimuthal angle.)

regardless of the polarity of applied voltage. In the case that the using LC material has some value of e_n (not equal zero), and the dc voltage of such a polarity that F_{diel} and F_{flex} work in the opposite direction is applied, if the applied voltage is increased from zero, two cases can be considered as follows. One is F_{diel} > F_{flex} and the director rotates in the ϕ_0 direction, the other one is F_{diel} < F_{flex} and the director rotates in the opposite direction to ϕ_0, those depend on the value ϕ_0. When the tilt angle in the plane of the director becomes once less than zero, the direction of F_{diel} works opposite direction until now. Then the director rotates as shown in Fig. 2 [Final state 2]. That is, by finding the in-plane pretilt angle ϕ_0 at this boundary, the value of e_n can be determined by means of comparison with results of numerical calculations. Under the condition of induced the flexo effects, if the cell includes whole in-plane pretilt angles continuously, we can expect to be observed the occurring of DL at somewhere in the cell set between polarizers. Thus, the HAN cell which was treated a concentric rubbing with the in-plane electrode pattern was prepared for this experiment, as shown in Fig. 3. Incidentally, there is no problem even if the center of concentric rubbing exists outside the cell.

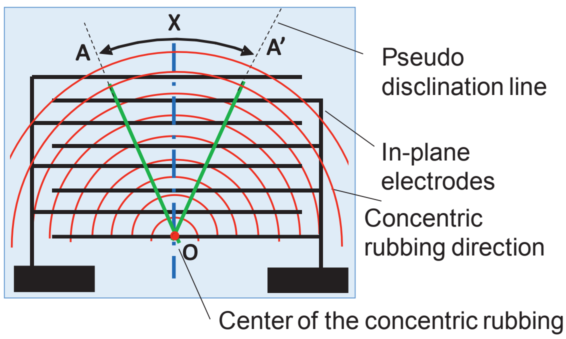

Fig. 3 Schematic model of the in-plane electrodes and concentric rubbing direction for the measurement cell.

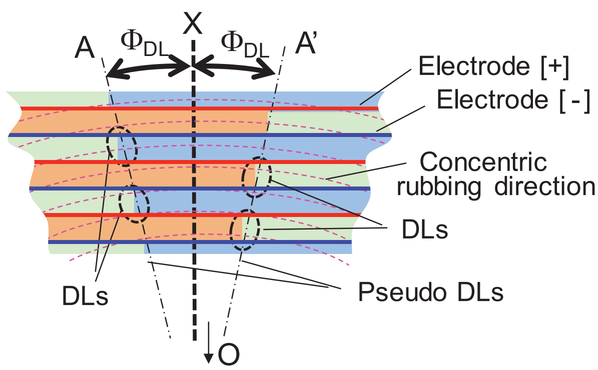

Fig. 4 Schematic model for DLs, pseudo DLs, and Φ_{DL} in the cell.

In Fig. 3, a line segment OX shows zero of the pretilt angle in the plane based on the stripe direction with in-plane electrodes. The in-plane pretilt angles are smoothly varied for increasing from the line segment OX to right and left directions with symmetry.

The applied dc field should be gradually increased from zero volts for measurements. Where, the occurring DL with the flexo effect depends on the polarity of the applying electric field, then, DL is observed at every other pair of electrodes, that is, DL occurs alternately left and right with respect to one electrode pair, as shown in Fig. 4.

After appearing the DLs, the applied dc electric field is further increased to observe clarify the DLs. If the applied electric field is significantly high, positions of each DL do not change with switching the electric field from dc to ac. Under applying the ac electric field, it is possible to settle and observe positions of DLs without considering the influence of impurity ions in the cell.

When a sufficiently high frequency of ac electric field is applied or flexo coefficients are zero, DLs due to reverse twist due to difference in the in-plane pretilt induce among all electrodes. Further, the position of DLs move toward the line segment OX with the increase of the applied voltage, and shortly, two DLs converge to the line segment OX. This is obviously different from the above-mentioned state where DL occurs every other one.

2.2 Advantages in This Method

Advantages for using our measurement method are as follows;

✓ In our method, the DL is induced at each pair of electrodes and to determine e_n using the average of those DL naturally, then, the elimination of experimental errors can be expected. That is, same as preparing a lot of sample cells to obtain the average such in conventional methods.

✓ The polarity of e_n can be also determined by paying attention to how DL induced at a pair of electrodes, such the direction of electric field and the in-plane pretilt direction.

✓ The measurement of the electro-optical characteristics such T-V curves is not necessary, so no need to use refractive index (n_e, n_o) of using LC materials nor a monochromatic light source. And also, the setup direction of each polarized axis of the polarizer and the analyzer does not affect measurement results when DLs are observed.

✓ In the case of the purpose is to compare the magnitude of e_n for some LC materials, it can be realized by comparing the state of DL for each material's cell, no need to carry out any numerical simulations.

✓ Under the condition of the sufficient magnitude of the electric field is applied to the cell and the director rotation directions are clearly separated, the position of the DL is hard to be affected even if the magnitude of the electric field is varied a bit by means of the electric double layer induced with impurity ions in the cell,

✓ Since the director rotation direction is determined when the director deformation is small, that is, under applying the small electric field, the disturbance of the electric field maybe negligible. Then, we can be handled a one-dimensional numerical model.

✓ In generally, the azimuthal anchoring energy is important in the IPS or FSS modes, however, the director rotating direction is just opposite and symmetrical at the DL position. Furthermore, the determination of the direction of rotation is determined early in the deformation of the director and the director does not rotate so much. Then, it seemed that the consideration of the azimuthal anchoring strength is not severe in the numerical calculation.

3 EXPERIMENTS

A glass substrate (25mm x 20mm) with in-plane electrodes (L / S = 10μm / 10μm) (E.H.C.) for the horizontal alignment side and a glass substrate without any electrodes for the vertical alignment side were used and assembled for the measurement HAN cell. A polyimide alignment film, SE-5611 (Nissan Chemi.), was used. In order to avoid an imbalance of impurity ions in the cell as much as possible, the same alignment material was used for the upper and the lower substrates and the horizontal or the vertical were realized by using different baking temperature. That is, the baking treatment was as follows; 270 °C for the horizontal alignment and 200 °C for the vertical alignment. The concentric rubbing treatment was carried out on the horizontal alignment surface, the pretilt angle for the polar angle was 2 deg. Then, HAN cells were assembled with cell thickness was approximately 3 μm. A nematic LC mixture, ZLI-4792 (Merck), was injected into the empty cell at the isotropic temperature, and cooled down to the room temperature. After that, the dc voltage of 60 V was applied to the cell, then, the angle Φ_{DL} was measured as an average of angles AOX and A'OX.

Figure 6 shows angle Φ_{DL} against the flexo-coefficient e_n using parameters of ZLI-4792 was calculated, in advance. The e_n could be determined by using the measurement angle and this graph. Incidentally, 4 μm of the cell thickness was used for the numerical calculation, however, the calculated characteristics remained almost unchanged, when confirmed with the cell thickness of 2 to 10 μm. It means that there is almost no cell thickness dependency.

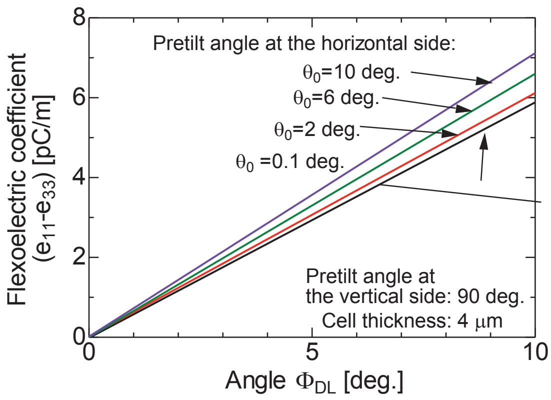

Fig.6 flexo-coefficients e_{11}-e_{33} vs. Φ_{DL} for ZLI-4792. (Calculated results.)

Figure 7 shows the observed result of the HAN cell for ZLI-4792, the set position of polarizers was shifted from the crossed position so that pseudo DLs were easy to observe. Therefore, the domain looks asymmetric. The absolute value of e_n for ZLI-4792 was guessed 1.3 pC/m from the graph (Fig. 6) due to Φ_{DL} of 2 deg.

Furthermore, the polarity of e_n was able to determine by confirming the direction of the electric field and the direction of pretilt angle in the plane for the generated DL between a pair of electrodes. As a result, we found a polarity of e_n was minus. Then, e_n of ZLI-4792 was provisionally evaluated as -1.3 pC/m.

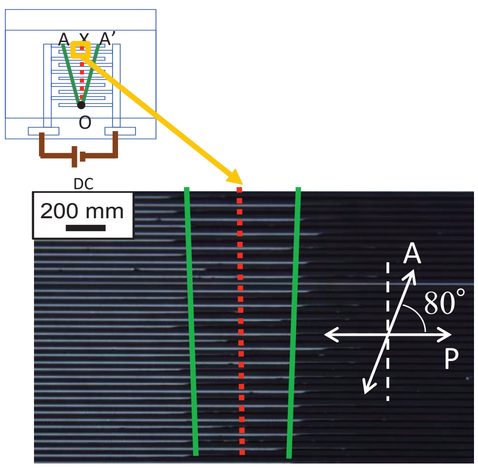

Fig. 7 Example of observation picture of the HAN cell for ZLI-4792 under applying dc 60 V.

Incidentally, ZLI-4792 is a fluorine type of LC material, since it is hard to be affected by impurity ions, the obtained value seems to be reliable. Furthermore, we carried out same experiments about non-fluorine-based LC material, ZLI-2293, however, Φ_{DL} was almost zero, that is, it seemed that the flexo-polarization did not occur. For improved accuracy, a chromatographic phenomenon during the LC injecting process in order to reduce the effect of impurity ions might also be adopted. [3]

4 CONCLUSIONS

We proposed a novel and easy evaluation method for the difference of flexo-coefficients 'e_{11}-e_{33}'. The coefficient can be concretely obtained by fitting with the calculated results, however, the fitting process is unnecessary if only a relative comparison of the properties of some materials. The influence of e_{11}-e_{33} is large in the IPS mode or the FSS mode, thus even if we do not know the value of the flexo-coefficients, we believe that it is sufficiently worthwhile to evaluate the influence of e_{11}- e_{33}.

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