Evaluation of Flexoelectric Coefficient by Means of Transmission Ellipsometry: Three compartments Measurement

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ABSTRACT

To determine two flexoelectric coefficients, improved method based on transmission ellipsometry that allows single cell to complete a series of measurements on device parameters including cell gap and surface anchoring energy is experimentally demonstrated.

1 INTRODUCTION

Flexoelectric effect seems to be one of an unmanageable phenomenon on liquid crystal (LC). However, at the same time, it may be the last undeveloped phenomenon for high speed driving by external field [1]. To develop novel flexoelectric polarization driven mode, it is first important to establish a method for measuring flexoelectric coefficients. Electro-optical methods and pyroelectric method had been proposed as a measurement method of the flexoelectric coefficient [2, 3]. Neither method, unfortunately, can determine two flexoelectric coefficients (e_{11} and e_{33}) simultaneously. Indeed, flexoelectric coefficients are measured in separate samples or measurement methods in the form of $e_{11} + e_{33}$ and $e_{11} - e_{33}$, where e_{11} and e_{33} correspond to splay and bend deformation, respectively. In order to reduce a systematic measurement error, it is better to measure single sample with single measuring instrument. Previously, we have continued to develop an integrated measurement method for $e_{11} + e_{33}$ and $e_{11} - e_{33}$ by means of transmission ellipsometry [4]. The reproducibility of our measurement technique has been confirmed, however, we have not systematically investigated LC materials. In this paper, we report the measurement reproducibility using various nematic LC (NLC) materials.

2 EXPERIMENT

2.1 LC Sample Preparation

Sandwich typed NLC sample cell with indium tin oxide (ITO) thin film as transparent electrodes with specific pattern is prepared, as shown in Fig.1. Inside the sample cell is divided into three compartments; one compartment is used for the determination of fundamental cell parameter such as cell gap based on the electrically controlled birefringence (ECB) mode driving. One hand, when the dielectric anisotropy of the subject NLC is positive, planar (homogeneous) alignment should be prepared (measurement spot A in Fig.1(b)), and cell gap of each sample cells is precedingly determined. On the other hand, when the dielectric anisotropy of the subject NLC is negative, vertical alignment should be prepared inside this compartment (measurement spot A in Fig.1(c)), and cell gap is precedingly determined. The fundamental cell parameters are firstly determined by original SOITE (symmetric oblique incident transmit-

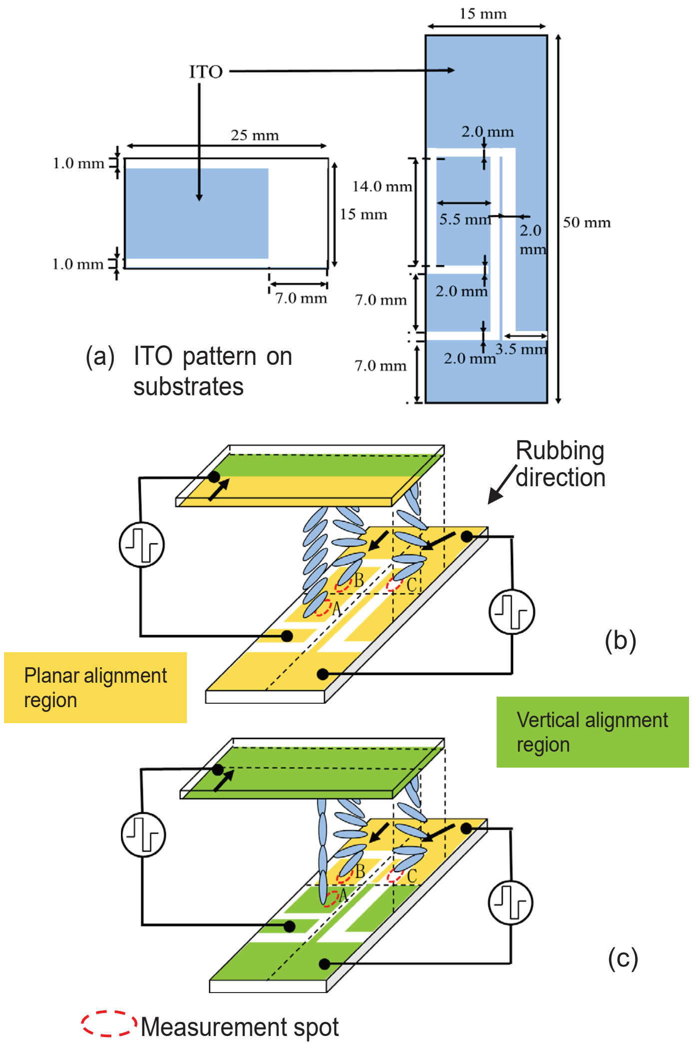

Fig.1 Illustration of sample cell. (a) Patterned ITO electrode. (b) for Δε > 0, (c) Δε < 0.

ssion ellipsometry) with applying AC electric voltage [5], and are substituted into the subsequent numerical calculation of the flexoelectric coefficient. Another neighboring two compartments in which hybrid alignment nematic (HAN) is prepared are for the determination of $e_{11} + e_{33}$ and $e_{11} - e_{33}$, respectively. Because, HAN possesses splay and bend deformation. Our technique is characterized in that two kinds of polyimide alignment films (planar alignment film and vertical alignment film) are separately coated on the specially patterned electrodes by $\Delta\varepsilon$ of LC as shown in Fig. 1 (b) and (c). Allow us to explain specifically. Figure 1(b) represents the sample structure for NLC with $\Delta\varepsilon > 0$. Measurement spot A is occupied with planarly aligned NLC whereas around the measurement spot B and C is occupied with HAN region. Second, $e_{11} + e_{33}$ is estimated by means of SOITE, where vertical DC voltage is applied around the measurement spot B [4]. Third, $e_{11} - e_{33}$ is determined by normal incident transmission ellipsometry (namely simple Δ measurement), where in-plane DC voltage is applied around the measurement spot C. The reason why we choose normal incident other than oblique incident is, as described in the prior literature, that the advantage of SOITE as such that multiple beam interference can be offset is revoked by rotating the sample cell out of the plane of incident [5]. In the case of $\Delta\varepsilon < 0$, the measurement procedure is same except for that planar alignment compartment is replaced by vertical alignment compartment as shown in Fig.1(c).

Planar alignment prepared by prerubbed polyimide film and vertical alignment without rubbing treatment were fabricated on proper glass substrates. Bead spacer was sandwiched by two glass substrates, the nominal cell gap was 10 μm. Two glass substrates were laminated by epoxy resins. Table 1 is the list of NLC materials used in our experiments. We are interested in the relationship between $\Delta\varepsilon = \varepsilon_{//} - \varepsilon_{\perp}$ and two flexoelectric coefficients. Elastic anisotropy κ is defined by $\kappa = \frac{K_{33}-K_{11}}{K_{11}}$ for $\Delta\varepsilon > 0$ and $\kappa = \frac{K_{11}-K_{33}}{K_{33}}$ for $\Delta\varepsilon < 0$, respectively.

Table 1 NLC materials used in our experiments.

	Δε @1kHz	κ @25°C
LC-1	8.4	0.43
LC-2	5.2	0.39
LC-3	4.7	0.075
LC-4	-3.1	0.12
LC-5	-4.1	0.080
LC-6	-5.0	0.24

2.2 Procedure to Determine Flexoelectric Coefficient

The outstanding feature of our measurement is all device parameter including dielectric and elastic anisotropy, cell gap, surface polar anchoring energy and flexoelectric coefficient can be determined with single monochromic ellipsometer. Instead, the measurement procedure becomes complicated. Here, necessary device parameters such as surface anchoring energy, pretilt angle, dielectric and elastic constant were separately evaluated in advance. Then, cell gap of all subject sample cell was measured by means of original SOITE under ECB mode driving. Transmission ellipsometer based on the phase-modulation technique is shown in Fig.2. The sample on the rotating stage can rotate ±45 degrees around the y-axis. The phase difference measured at the incident angle +β is expressed as Δ^{+}. Under the AC applied voltage (square waveform), after measuring Δ^{+} at the incident angle +β, Δ^{-} at the incident angle -β is measured to calculate $\Delta^{-} - \Delta^{+}$. Then the cell gap can be determined by numerical fitting procedure. The determination process of $e_{11} + e_{33}$ is as follows; a special waveform as shown in Fig. 3 is applied to the compartment B in sample cell. In order to avoid the uneven accumulation of ions, sinusoidal voltage is applied at regular intervals. Between the sinusoidal wave voltage, DC voltage is applied to the measurement spot B at certain timing, Δ^{+} and Δ^{-} is measured. Then $e_{11} + e_{33}$ can be estimated by numerical fitting against $\Delta^{-} - \Delta^{+}$. Finally, Δ at normal incident is measured around the measurement spot C under DC applied voltage as shown in Fig.3.

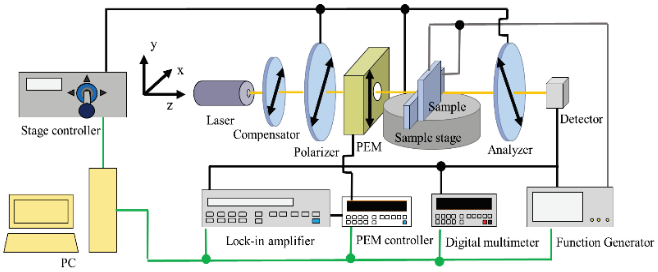

Fig.2 Measurement system based on phase-modulation type transmission monochromic ellipsometry with LC cell driving electric circuit.

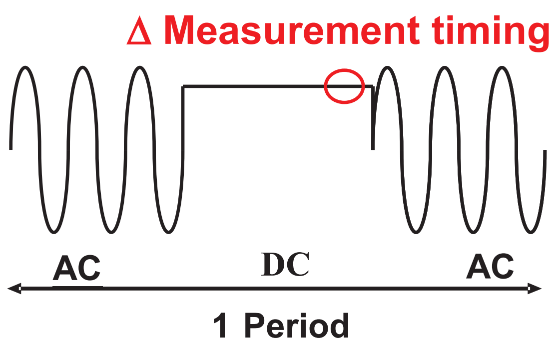

Fig.3 Timing chart of applied voltage and Δ measurement, where 1 period is 4 s.

3 RESULTS and DISCUSSION

Following the procedure described above, typical

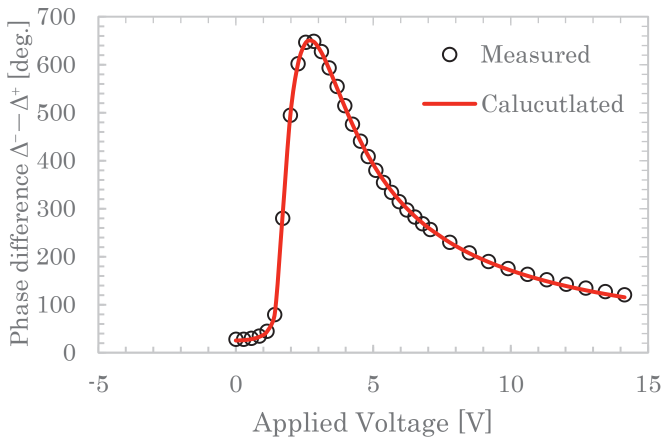

Fig.4 Experimentally measured $\Delta^{-}-\Delta^{+}$ driven with VA mode at measurement spot A.

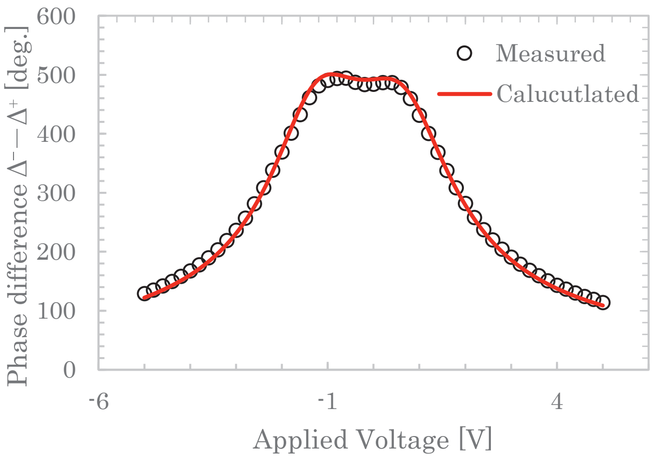

Fig.5 Experimentally measured $\Delta^{-}-\Delta^{+}$ at measurement spot B under the vertical DC voltage application.

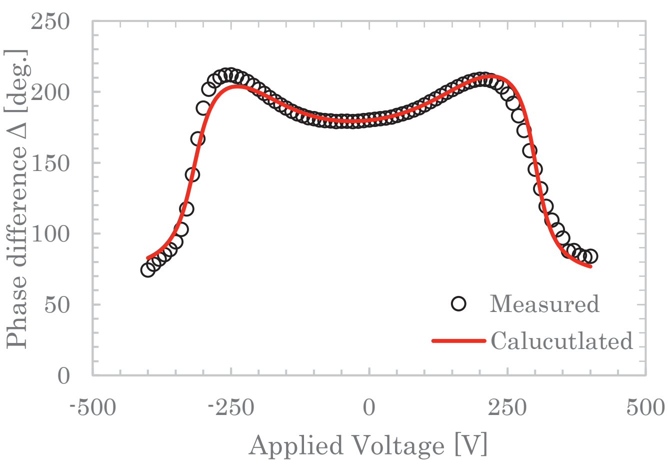

Fig.6 Experimentally measured Δ at measurement spot C under the in-plane DC voltage application

experimental results are shown for LC-1. Figure 4 shows the experimentally measured $\Delta^{-}-\Delta^{+}$ driven with ECB mode. Solid red curve represents numerical fitting, which predicts the cell gap. Resultant cell gap was approximately 10.3 μm which also matches the diameter of the spacer.

Figure 5 shows experimentally measured $\Delta^{-}-\Delta^{+}$ at measurement spot B under the vertical DC voltage application. Solid red curve represents numerical fitting. It is found that the characteristic mountain-shaped curve accompanied with two small bumps is qualitatively consistent with the experimental results. In the case of Fig.5, it was estimated to be $|e_{11}+e_{33}|$ = 22 pC/m. However, as a result, series of experiments revealed some complexity of determination of $e_{11}+e_{33}$. From the numerical simulation, the sign of the $e_{11}+e_{33}$ can be distinguished by the difference in the height of two bumps. It is confirmed that it is necessary to narrow the cell gap or weaken the anchoring energy in order to make the difference in two bumps height remarkable. It is also suggested that $|e_{11}+e_{33}|$ is ranging 15 ~ 45 pC/m and relationship between NLC and $e_{11}+e_{33}$ is ambiguous. It is also confirmed that strong surface anchoring energy is necessary to guarantee the accuracy of the absolute value of e_{11}+e_{33}.

Figure 6 also shows experimentally measured Δ at measurement spot C under in-plane DC voltage application. Resultant $e_{11}-e_{33}$ seems to be approximately 7 pC/m. As can be seen from the numerical simulation curve, the Δ response of HAN under in-plane DC voltage driving is not a monotonic curve, therefore determination of $e_{11}-e_{33}$ with enough reproducibility seems to be difficult. In order to characterize the relationship between the characteristics of LC materials and the flexoelectric coefficient, it would be necessary to perform a considerable number of sample measurements and analyze them statistically. Most of the absolute values of $e_{11}-e_{33}$ obtained in our experiment were less than 10 pC/m.

4 CONCLUSIONS

In this study, we demonstrated flexoelectric coefficient measurement method with systematic procedures. At least, it is beneficial that the effect of the cell gap of the sample as a container for LC material can be reduced properly by using single sample cell to measure two flexoelectric coefficients.

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