P-139: Investigation of the Behaviors of Liquid Crystal at the Surface under Applied Electrical Field by Reflective Measurements

Anatoli Murauski, Vladimir Chigrinov and Hoi-Sing Kwok
ECE Department, Hong Kong University of Science & Technology, Clear Water Bay, Kowloon, Hong Kong

Abstract
Variation of tilt angle on surface of alignment layer under electric field was investigated by reflection measurement in thin (2-5 μm) twisted LC cell. Dependence of tilt angle from voltage was used for determination of polar anchoring properties of two alignment materials with different polar anchoring energy. It introduces the new method for investigation of polar anchoring properties of nematic liquid crystal cell, which has twisted structure and small cell gap.

1. Introduction

Liquid crystal (LC) anchoring energy is the important parameter of LC cell, which defines the basic characteristics of LC electrooptic response, such as controlling voltage and response time [1]. Question about the correct function of the dependence of anchoring energy from deviation angle from equilibrium state was widely discussed in literature [2,3,4]. For this purpose usually people use the Rapini-Popular relation for anchoring energy. It is simple form and quite logical approximation for anchoring energy [3]. But some authors indicate that this approximation is not universal formula and exist several cases when possible find declination from it [5,6]. Most of the methods for determinations of the LC anchoring energy are based on the Rapini-Popular formula.

At present time direct methods for determination of the tilt angle on the surface do not exist. Usually LC anchoring energy is found from the dependence of the LC bulk parameters such as a retardation or capacity versus applied electric or magnetic field for LC cell with large cell gap [7-16]. The most effective method is a high voltage technique proposed by Yokoyama and van Sprang [10]. Certain modification of this method is RV technique developed by Kent University [11,12] The polar anchoring energy can be also found from electrical measurement by a capacity method [13,14,15] The method to evaluate polar (or zenithal) LC anchoring energy proposed by Vilfan et al. use the measurements of relaxation time of LC director fluctuations in a homogeneously aligned cell as a function of LC cell thickness [16,17]

The disadvantage of the "bulk" methods is the small contribution of the LC anchoring effect. It does not give possibility to investigate the form of the function for anchoring energy. In 2005 we introduced the compensation principal for minimization of volume effects on measurement of anchoring energy and investigation of surface properties: all effects, which are not related to the interaction with the surface, are automatically excluded from result of measurement. It was successfully realized in two channels capacity methods [14]. In this case the VA cell was used for the reference channel in measurement device giving possibility to increase the precision of the electrical method. In the present paper we propose to use the same compensation principal for optical measurement. For investigation of surface alignment the anisotropy of reflectivity at the boundary of isotropic-anisotropic materials (liquid crystal - alignment material) was measured. Compensation birefringence of LC in 90 degree twisted cell gives possibility to suppress the birefringence in the bulk of liquid crystal. We used the property that the reflective coefficient at the isotropic-anisotropic boundary in LC cell is determined by the LC tilt angle on the surface and the profile of the tilt angle nearest of boundary. The amplitude of reflection can be precisely measured for any applied voltage. Thus this dependence can be used for evaluation polar anchoring energy of LC.

2. Base for measurement

Reflection coefficient for boundary of two mediums is determined by the refractive indexes of these mediums. In case of liquid crystal we have ordinary and extraordinary waves, which propagate in liquid crystal. For every wave we find different amplitude of light wave reflected at the interface of LC-isotropic medium. For ordinary waves reflection coefficient can be described by Fresnel formula and ordinary refractive indexes n_{LC}^{o} of liquid crystal and refractive index n_{gl} of isotropic medium (glass substrate).. For extraordinary waves we can use same formula only for small voltages, when deformation of LC nearest of boundary is small. In common case we must include in description reflection from deformed layer of liquid crystal (amplitude reflection R_{LC}). This problem was solved analytically for next condition: 90 degree twist LC cell, applied voltage $V>6V_{th}$ (LC director oriented vertically in center of cell), input polarization has 45 degree angle with orientation LC on top substrate, output polarized crossed with input polarizer, alignment layer is not anisotropic.

$$A_{out} = \frac{1}{2} A_{in} \left(\frac{n_{LC}^{s} - n_{LC}^{o}}{n_{LC}^{s} + n_{LC}^{o}} - R_{LC}(V) \right) \quad (1)$$

where $n_{LC}^{s} = \dfrac{n_e}{\sqrt{1+\beta^2 \sin^2 \theta_s}}$, and $\beta^2 = \dfrac{n_e^2 - n_o^2}{n_o^2}$,

$R_{LC}(V)$ is amplitude reflection from deformed LC layer.

$$R_{LC} = \frac{1}{2} \int_{\theta_S}^{\pi/2} \frac{\left(n_e^2 - n_o^2\right) tg\theta}{n_o^2 + n_e^2 tg^2\theta} \exp\left(-i \frac{4 n_e d}{\lambda} \frac{V_{th}}{V} \int_{\theta_S}^{\theta} \sqrt{\frac{\left(1+\gamma \sin^2 x\right)\left(1 - a\cos^2 x\right)}{\left(1-\sin^2 x\right)\left(1+\beta^2 \sin^2 x\right)}} dx \right) d\theta \quad (2)$$

 ISSN/009-0966X/09/3903-1644-$1.00 © 2009 SID

where $\gamma = (K_{33}-K_{11})/K_{11}$, $\beta = \sqrt{\frac{n_e^2 - n_o^2}{n_o^2}}$, $a = \Delta\varepsilon/\varepsilon_{||}$, $\Delta\varepsilon = (\varepsilon_{||}-\varepsilon_{\perp})$, $V_{th} = \pi\sqrt{K_{11}/\varepsilon_0\Delta\varepsilon}$, K_{11} and K_{33} are elastic constants of liquid crystal, $(\varepsilon_{||}-\varepsilon_{\perp})$,$\varepsilon_{||}$ and $\varepsilon_{\perp}$ are dielectric constants of liquid crystal.

Intensity of output light $I_{out} = |A_{out}|^2$ can be calculated for any tilt angle of LC on boundary Fig.1.

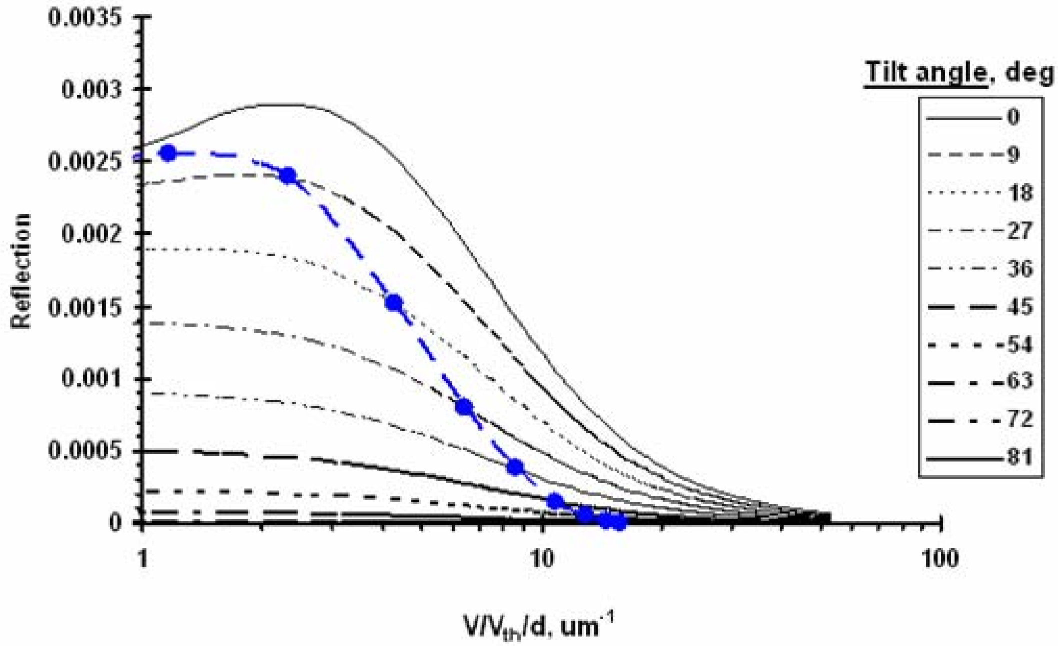

Figure 1. Voltage dependence of the reflection for different tilt angle at the boundary of liquid crystal - alignment layer. the black lines are calculated for strong anchoring condition at the boundary and the blue line for finite value of polar anchoring coefficient

When some voltage is applied to LC cell the tilt angle on boundary change in dependence of electrical strength of applied field. And reflection coefficient changes as it is shown in Fig.1 bold dash line. In this plot black points correspond the values of tilt angle LC on the boundary.

3. Result of experiment

3.1. Samples and equipment for measurement

Two alignment materials were used in experiment. One is commercial alignment material PIA-3744 from Chisso and other new alignment material B-15 developed for deposition on plastic substrates from BSU, Belarus [18]. Materials was deposed by spin coating method PI material was baked at temperature 230°C for 1 hour and rubbed before assembling LC cell. B15 material need low temperature treatment (100°) and solved in non-aggressive solvent butyl-acetate.

For measurement was prepared several cells with cell gap 2 μm in twist configuration. Glass substrates had pattered ITO electrode which has in LC cell overlapping area 5x5 mm.

For reflective measurement was used the polarized microscope "Olympus BX40". For spectral measurement the high resolution spectrometer HD2000 from Ocean Optics was used. Spectral resolution of spectrometer was 1.5 nm

Voltage dependence of tilt angle of LC at the surface received for two different alignment materials is presented on Fig.2.

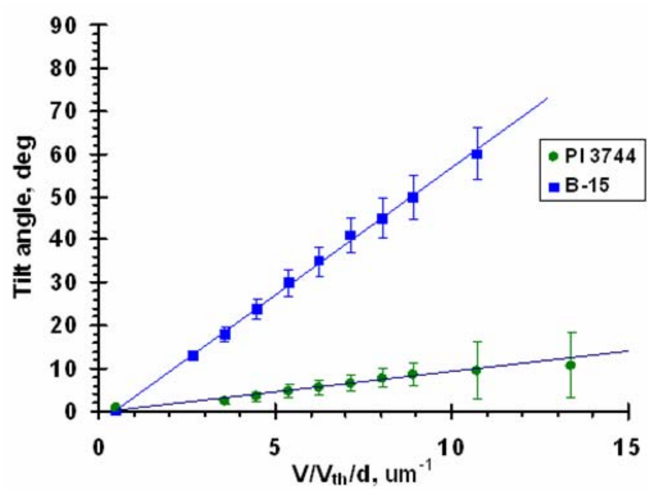

Figure 2. . Tilt angle in dependence on applied voltage. Cell gap 2 μm, LC BN-104

3.2. Results

Dependence of tilt angle on applied voltage is completely determined by the form of the potential $F_s(\theta_s)$ for polar anchoring interaction of liquid crystal with alignment material.

$$\frac{dF_s(\theta_s)}{d\theta_s} = \pi K_{11} \frac{V}{V_{th}\,d} \frac{\sqrt{1+\gamma \sin^2\theta_s}}{\sqrt{1-a\cos^2\theta_s}} \cos\theta_s \quad (3)$$

If the potential for polar anchoring energy is taken in the form of Rapini-Popular, then formula (2) has simple form:

$$F_s(\theta_s) = \frac{1}{2} W \sin^2(\theta_s) \quad (4)$$

$$\sin(\theta_s) = \pi \frac{K_{11}}{W} \frac{V}{V_{th}\,d} \frac{\sqrt{1+\gamma \sin^2\theta_s}}{\sqrt{1-a\cos^2\theta_s}} \quad (5)$$

For small values of tilt angle θ_s it is linear function

$$\theta_s = \pi \frac{K_{11}}{W} \frac{V}{V_{th}\,d} \sqrt{\frac{\varepsilon_{\parallel}}{\varepsilon_{\perp}}} \quad (6)$$

From Fig.2 the polar anchoring coefficient, W, can be easily found. In our experiment we used LC BN104 from Merck. Parameters for this materials: $\Delta\varepsilon = 26.6$, $\varepsilon_{\perp} = 7.5$, $\Delta n = 0.163$, $K_{11} = 7.5 \cdot 10^{-12}$N, $K_{22}/K_{11} = 0.75$, $K_{33}/K_{11} = 1.63$. Result of the measurement is $W = 1.4 \cdot 10^{-3}$ J/m^2 for PIA-3744 and $W = 2.6 \cdot 10^{-4}$ J/m^2 for B-15.

4. Conclusions

In this paper we show how the behavior of liquid crystal on the surface of alignment material was investigated under the electrical field. The values of tilt angle can be measured for any applied electrical field by reflection from twist nematic LC cell. In this method the cells with small cell gap (2-5 μm) can be used, and low voltage (up to 20-30V only) is sufficient for reliable measurement.

.

5. Acknowledgements

This research was supported by HKUST grant CERG grant 612208 and RPC07/08.EG01. The authors gratefully acknowledge the kindly present for measurement the alignment material B-15 of prof. U.V. Mahilny and A.I. Stankevich in the Belarusian State University

6. References

[1] V.G. Chigrinov, *Liquid Crystal Devices: Physics and Applications* (Artech House, 1999).

{2] L.M. Blinov, and V.G. Chigrinov, *Electrooptic Effects in Liquid Crystal Materials* (New York: SpringerVerlag, 1994).

[3] A. Rapini, and M. Papoular, "Distorsion d'une lamelle nematique sous champ magnetique conditions d'ancrage aux parois", J. Phys. (Paris) Colloq. **30**, C4–54, (1969).

[4] A.A. Sonin, *The Surface Physics of Liquid Crystals* (Gordon and Breach, 1995).

[5] A. Sugimura, R. Luckhurst, O.-Y. Zhong-can, "Director deformation of a twisted chiral nematic liquid crystal cell with weak anchoring boundaries", Phys. Rev. E, **52,** 681-689, (1995).

[6] J.-S. Hsu, M.-C. Hsieh, C.-L. Yangi, B.-J. Liangi and S.-H. Chen, "A Method to Determine the Higher Order Polar Anchoring Coefficients for the Non-Twisted Liquid Crystal Cells", Japanese Journal of Applied Physics, **44**, No.8, 6174–6177, (2005).

[7] D.-F. Gu, S. Uran, and C. Rosenblatt, "A simple and reliable method for measuring the liquid crystal anchoring strength coefficient" Liq. Cryst. **19,** 427, (1995).

[8] J.G. Fonseca, and Y. Galerne, "Local measurement of the zenithal anchoring strength", Phys. Rev. E, **61** 1550, (2000).

[9] D. Subacius, V.M. Pergamenshchik, and O.D. Lavrentovich, "Measurement of polar anchoring coefficient for nematic cell with high pretilt angle", Appl. Phys. Lett., **67,** 214, (1995).

[10] H. Yokoyama and H.A. van Sprang, "A novel method for determining the anchoring energy function at a nematic liquid crystal-wall interface from director distortions at high fields" J. Appl. Phys. **57,** 4520, (1985).

[11] Yu. A. Nastishin, R. D. Polak, S. V. Shiyanovskii, V. H. Bodnar, and O. D. Lavrentovich: J. Appl. Phys, **86,** (1999), 4199.

[12] Yu. A. Nastishin, R. D. Polak, S. V. Shiyanovskii and O. D. Lavrentovich, "Determination of nematic polar anchoring from retardation versus voltage measurements", Appl. Phys. Lett. **75,** 202, (1999).

[13] Y. Toko and T. Akahane, "Evaluation of Pretilt Angle and Polar Anchoring Strength of Amorphous Alignment Liquid Crystal Display from Capacitance Versus Applied Voltage Measurement" Mol. Cryst. Liq. Cryst. Sci. Technol., **368,** 469-481, (2001).

[14] A. Murauski, V. Chigrinov, Al. Muravsky, F.S.Y. Yeung, J. Ho and H.S. Kwok, "Determination of liquid-crystal polar anchoring energy by electrical measurements" Phys. Rev. E, **71** 061707, (2005).

[15] H. Yokoyama, and R. Sun, "Simplified High-Electric-Field Technique for Measuring the Liquid Crystal Anchoring Strength", Jpn. J. Appl. Phys., **39,** L45-L47, (2000).

[16] M. Vilfan, A. Mertelj, and M. Copic, "Dynamic light scattering measurements of azimuthal and zenithal anchoring of nematic liquid crystals" Phys. Rev. E, **65,** 041712, (2002).

[17] M. Vilfan, and M. Copic, "Azimuthal and zenithal anchoring of nematic liquid crystals" Phys. Rev. E, **68,** 031704, (2003).

[18] U.V. Mahilny, A.I. Stankevich, A.A. Muravsky and A.A. Murauski, "Novel polymer as liquid crystals alignment material for plastic substrates", to be published: J. Phys. D: Appl.Phys. **42**, 075303 (2009) .