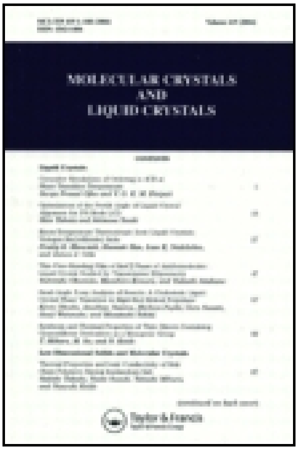

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Studies of the Anchoring Energy of Nematics on Grooved Surfaces

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Studies of the Anchoring Energy of Nematics on Grooved Surfaces

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Previously we developed optical method enabling measurements of the liquid crystal twist angle in the cells with grooved surfaces. In this work azimuthal anchoring energy of a liquid crystal to a surface is estimated by measuring the deviation of the twist angle of the liquid crystal from the angle defined by direction of liquid crystal alignment on one rubbed and one grooved surfaces substrates. It was found that the twist angle in the cells depends not only on the parameters of the grooves, but also strongly depends on the material covering the grooves.

Keywords: surface anchoring; twist angle; liquid crystals; grooved substrates

INTRODUCTION

Behaviour of liquid crystals (LC) on profiled substrates is interesting from both applicatory and fundamental points of view. It is known that liquid crystals are aligned by surfaces having microgrooves[1], but the character of this alignment is non-trivial[2]. Combining LC with gratings one can produce high-pretilt surfaces[2] and surfaces possessing

bistability, gratings help to modify molecular structure of mesogens[3]. From practical point of view one can be interested in making electrically controllable diffraction elements (gratings, Fresnel lenses)[4], or to use microgrooves made by stamping method[5] or the photolithographic method [6] for aligning LCs in active matrix displays where conventional rubbing is undesirable. To predict the properties of LC electrooptic devices with grooved surfaces exactly it is necessary to measure rather precisely such parameters as twist angle of the liquid crystal and its anchoring energy.

Recently, an accurate optical method based on spectral analysis for measuring twist angle in twisted LC cells has been proposed[7,8]. Basing on the analysis of deviation of the measured value of the twist angle for different orientations of TN cells and polarizers it has been shown that the method allows to determine twist angles with a high accuracy for cells not only with rubbed, but also with corrugated surfaces for various cell thickness. Phase shift can be simultaneously determined without preliminary determination of the angle between LC director and polarizer axis.

In the present study we use this method to investigate the twisting power of the corrugated substrates with various period of the grooves, as well as anchoring energy of a liquid crystals to corrugated surfaces covered with various materials.

THEORETICAL BACKGROUND AND EXPERIMENTAL METHOD

The method for measuring a LC twist angle is base on registering the transmittance spectrum of the LC cell between polarizers (see Figure 1). As it has been shown elsewhere[9], Jones optical propagation matrix 2x2 can be used to describe optical transmission of such TN structures and neglecting a small ptetilt angle in TN cell one can write:

$$T=\left(\frac{1}{\sqrt{1+u^2}}\sin\left(\theta\sqrt{1+u^2}\right)\sin\left(\theta+\varphi_p-\varphi_a\right)+\cos\left(\theta\sqrt{1+u^2}\right)\cos\left(\theta+\varphi_p-\varphi_a\right)\right)^2+$$

$$+\frac{u^2}{\sqrt{1+u^2}}\sin^2\left(\theta\sqrt{1+u^2}\right)\cos^2\left(\theta+\varphi_p-\varphi_a+2\varphi_c\right)=\left(K_1A+B\right)^2+K_2C^2 \quad (1)$$

where

$$u = \frac{\pi d \Delta n}{\lambda \theta} \qquad (2)$$

Here θ is the LC twist angle, λ is the wavelength of light, ϕ_p and ϕ_a are angles of polarizer and analyzer orientation, ϕ_c is the angle between the LC director at the front surface of the TN cell and polarizer axis, d is the LC thickness.

In equation (1) ϕ_c is contained only in the third term K_2C^2, so for any two orientations of the front polarizer the difference of the transmittance spectra depends only on this term and one can find the zeros of the function straightforward. These zeros correspond to the control wavelengths λ_c for which equation (1) is considerably simplified and twist angle θ can be determined by fitting experimentally measured transmittance for variable orientation of analyzer with simple formula

$$T = \cos^2\left(\theta + \varphi_p - \varphi_a\right) \qquad (3)$$

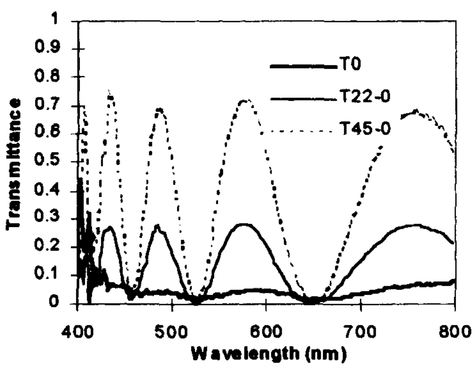

FIGURE 1 Transmission spectra (both, absolute and differential) of the cell with the gap d=9.9 μm for various cell orientations relative to polarizer.

In the case of the LC cell with grooved surfaces difference of the transmittance for different front polarizer orientations never equals zero because transmittance in this case is written as the integral over the surface of the cell

$$T = \frac{1}{S} \int \left[(K_1(d)A + B)^2 + K_2 C^2 \right] ds \qquad (4)$$

where K_i being dependent on the cell thickness after integration yields not only harmonic, but also constant term. The difference of the transmittance at two different orientations of the front polarizer again contains only the third term, but this term does not vanish for some λ_c. Therefore, fitting experimental data obtained with rotating polarizer by equation (3) one get some systematic error in so determined twist angle.

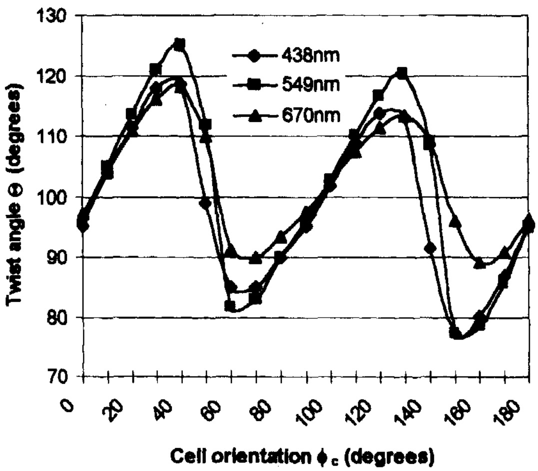

FIGURE 2 Dependence of the twist angle determined in three different spectral control points λ_c by the spectral method (fitting equation (3)) on the cell orientation (orientation of the nematic director at the front surface relative to polarizer) for the corrugated substrate covered with FP383.

A typical scan of the twist angle determined from equation (3) as a function of the orientation of the cell is presented in Figure 2. Although for flat substrates this method gives accuracy of about ± 0.5°, from Figure 2 it is seen, that for the cells with grooved surfaces errors in the twist angle determination by spectral method can be very high (more than 20°). Computer simulations of the optical properties of LC layers with periodically modulated thickness have shown, that only after averaging over $0 \leq \varphi_c \leq 180$ the errors due to non-correct choice of λ_c

vanish. Keeping this in mind, our procedure for determining twist angle of the grooved cells was as following. First we registered transmittance spectra for several orientations of the cell and from their differences found control minima. Then twist angle was determined by rotating polarizer and fitting the measured transmission by equation (3). This operation was repeatedly done for variable cell orientation and the correct value of θ was determined as its average in the interval $0 \leq \varphi_c \leq 180$.

RESULTS AND DISCUSSION

Test cells with corrugated substrates were studied experimentally. One substrate in each cell served as a reference: it was coated with JSR aligning material AL-3046 and unidirectionally buffed. (pretilt angle 1.5-2°). The opposite substrate was made corrugated photolithographically (photorezist AR4000, Allresist) with various periodicity and the height of the profile (see examples of the profiles in Figure 3). It was either left uncovered, or covered with an aligning material, but not rubbed.

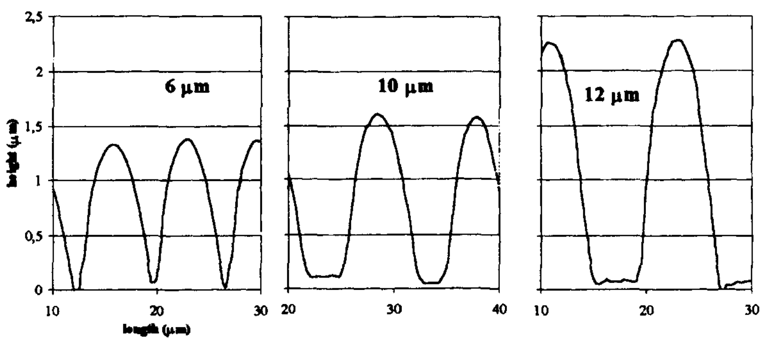

FIGURE 3 Examples of the profiles of the corrugated substrates used as aligning surfaces. The measurement is done with AFM RasterscopeTM 3000 (DME).

The cells (10 - 11 μm thick) were filled with MLC-6080 (E.Merck) LC material (quality of alignment achieved by such gratings can be seen in the microscope pictures in crossed and parallel polarizers in Figure 4). Transmission spectra for twist anle determination were registered with minispectrometer MMS-1 (Carl Zeiss) in the range 400-800 nm.

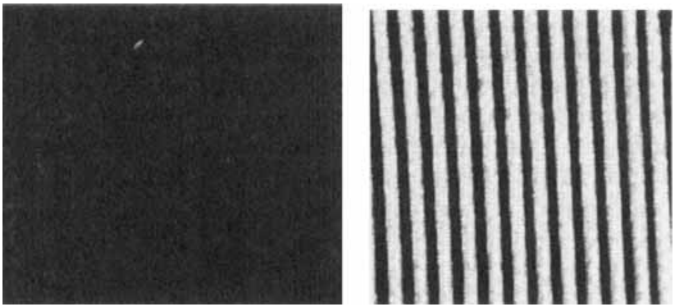

FIGURE 4 Microscope pictures of the cells with the LC aligned by the photolithographically made grating (the pitch of the grating is 10 μm) in the crossed (left part) and parallel (right part) polarizers.

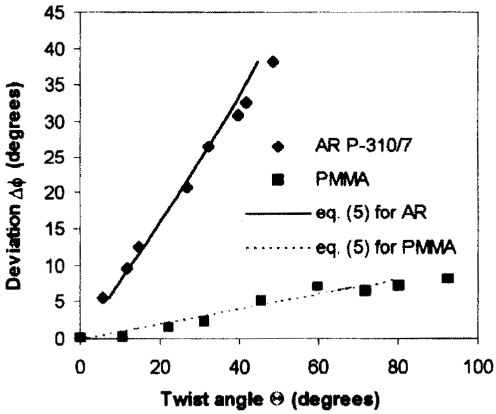

FIGURE 5 Deviations of the LC twist angle from the substrates twist angle as a function of the substrates twist angle for the grating with 10 μm period covered with different materials shown in the legend.

Periodic sinusoidal grating produced lithographically in our case were used to check theoretical predictions. Deformation of a liquid crystal material by the twisted aligning surfaces was considered theoretically[10,11] and the following relation between the deviation $\Delta\varphi$ of the LC director at the surface from the aligning direction governed by the surface and the actual twist angle θ was obtained:

$$\sin(2\Delta\varphi) = \frac{2K_2}{Ad}\left[\theta - \frac{2\pi d}{P}\right] \qquad (5)$$

where K_2 is the twist elastic constant, P is the LC equilibrium pitch, d is the cell gap and A is the surface anchoring constant. From Figure 5 it is seen that almost linear dependence of $\Delta\varphi$ on the twist angle of the aligning surfaces predicted by relation (5) is quite well reproduced experimentally. Noticeable regular deviations of experimental points are observed only for the grating covered with AR-P310/7, for which $\Delta\varphi$ is rather high. Such discrepancy may be attributed to the out-of-plane deformations of the liquid crystal by the grating which are neglected in the theory[10]. As it has been shown previously[7] dependence of the LC twist angle on its thickness even more closely follows formula (5).

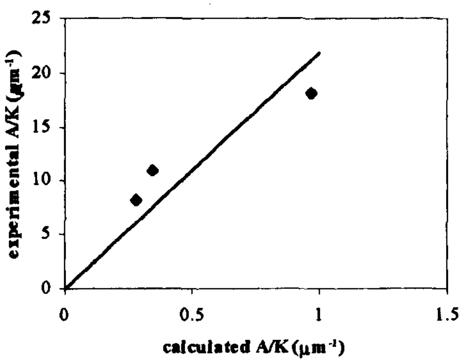

FIGURE 6 Experimental ratios A/K for the gratings with various period (Figure 3) calculated from the measured twist angle (see equation (5)) vs. calculated values with formula (6).

When alignment is produced by the periodic distortion of the LC director caused by the surface the anchoring constant A can be related to the parameters of the surface[10]:

$$A = \frac{1}{2}Ku^2q^3 \qquad (6)$$

where u and q are the amplitude and the wave-vector of the periodic distortion of the surface. K is effective elastic constant of the liquid crystal (formula (6) is derived in a single-constant approximation). If to neglect difference between K and K_2 one can relate (using (6)) experimentally determined ratios A/K_2 to the parameters of the grating. The results are compared in Figure 6 with the predictions of the theory. Although the absolute values of the ratios are about one order of value higher than according to equation (6), the general trend follows theory. It should be mentioned that experimental A/K ratios obtained in this work correlate well with the values for the rubbed surfaces[12].

Acknowledgements
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