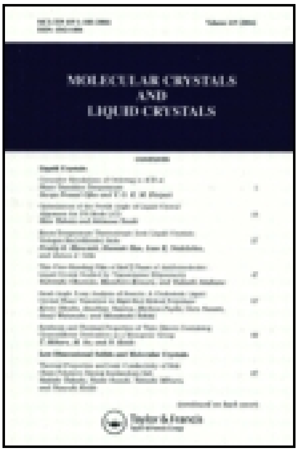

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Nematic Film Under Electric Field: Total Internal Reflection, Surface Tilt Angle and Anchoring Energy

M. Warenghem [a] & S. Peralta [a]

[a] Laboratoire de Physico-Chimie des Interfaces et Applications (LFCIA, EA2463), Universitè d'Artois, SP 18, LENS Cedex, F.62307, France

Version of record first published: 18 Oct 2010

Mol. Cryst. Liq. Cryst., Vol. 375, pp. 553-562

1058-725X/02 $12.00 + .00

Nematic Film Under Electric Field: Total Internal Reflection, Surface Tilt Angle and Anchoring Energy

M. WARENGHEM and S. PERALTA

Laboratoire de Physico-Chimie des Interfaces et Applications (LPCIA, EA2463) Université d'Artois; SP 18; F.62307, LENS Cedex; France

Abstract

In this paper, we first analyze an existing anchoring energy measurement technique in terms of accuracy and surface tilt angle value as an electric field is applied to the nematic cell initially planarly aligned. We thus perform a simulation of the film behavior using a pure elastic model and derive from it a possible new method for polar anchoring coefficient measurement, based on the surface tilt angle dependence on the applied voltage. We propose an experimental setup to perform this measurement. The reported preliminary experiment (5CB nematic film aligned using a polyimid layer) shows on one hand the feasibility of the measurement and in an other hand that – in that specific case – the pure elastic model is too restrictive and extra surface phenomena have to be accounted for.

Keywords : Anchoring energy, nematic liquid crystals

INTRODUCTION

In Liquid Crystal (LC) displays, the applied electric field reorients the director throughout the bulk of the nematic pixel cell, however the effect is less pronounced next to the interface. As one considers using the LC reorientation capability to tune any wave-guide functionality, it is compulsory to have a director reorientation that occurs next to the interface, where the evanescent field is located, to modify the guiding conditions. It is then worthy to look for a weak polar anchoring energy. As such condition is meet, an experimental control of the interfacial reorientation due to an electric field can be necessary, together with a measurement of the anchoring energy. Amongst the different methods to measure the anchoring energy [1], the "dynamic" ones [2, 3], involving an applied field look suitable to that control. However, they do not allow a surface tilt angle measurement, also the actual accuracy is questionable. We present here a brief reminder of these methods, their drawback in term of accuracy (part 1); then, from the simulations of the actual solution of the elastic problem, we suggest a different method to measure the polar anchoring energy based on the surface tilt angle measurement (part 2) and also on the fact that a good accuracy cannot be reached anyway. We thus propose an experiment to check the results obtained by simulation (part 3) and finally a discussion is developed.

I. ANCHORING ENERGY MEASUREMENT

It is beyond the scope of this paper to present a comprehensive critical analysis of all the existing methods to measure the polar anchoring energy. Since we plan to work on nematic under electric field and weak anchoring energy, we naturally selected few methods including an electric field, namely the Yokohama – VanSprang (YVS)[2] and the Nastishin – Lavrentovich (NL) [3]. They are both based on the measurement of the cell birefringence with respect to the applied voltage. They mainly differ from each other in the data analysis. The first one (YVS) requires the measurement of the capacitance of the cell, whereas the second don't. In both cases, the data to be exploited concern the birefringence measured as the applied voltage is large enough to ensure a maximum reorientation ($\pi/2$) to be achieved in the middle of the cell.

The geometry considered in these methods and in the work reported in the next parts is depicted on the Fig. 1. It is a planarly aligned nematic film as there is no applied field and which experiences an in-plane distortion as the field is switched on.

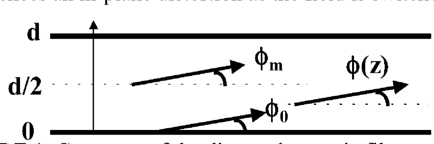

FIGURE 1. Geometry of the distorted nematic film under an electric field.

As an electric field is applied, the director distribution throughout the film can be derived from a conventional Euler minimization of the elastic energy including a finite anchoring strength. The corresponding calculation is well developed in the already quoted papers [2, 3], it can be found as well in other papers or text book [4] and will not be developed here. The formula will be resumed in the next part. For the moment, it is enough to consider that for one voltage V and an anchoring strength W or equivalently the extrapolation length L, the surface tilt angle ϕ_0 and the maximum tilt angle ϕ_m are connected via quite complex expressions as symbolized in (1)

$$z = f_z(\varphi, \varphi_0, \varphi_m) \;\; ; \;\; V = f_v(\varphi_0, \varphi_m) \;\; ; \;\; \frac{K_1}{W} = L = f_w(\varphi_0, \varphi_m) \qquad (1)$$

In the YVS method, the anchoring energy is derived from the slope of the plot CV = f(RCV), where R, C and V are respectively the phase shift, the capacitance and the applied voltage. In the NL one, it is the slope of the curve R(V-V*) = f(V – V*) which is evaluated, with V* being a parameter which depends on the material characteristics. In both cases, the slope is to be calculated using the high field values of the birefringence to insure the condition $\phi_m = \pi/2$ to be fulfilled. It is demonstrated that a deviation of few degrees for this angle induces a negligible error in the determination of the anchoring strength. The slope to be measured is inversely proportional to the anchoring strength, in other words, the higher the anchoring, the more horizontal is the part of the curve of interest, thus lowering the accuracy of the method for the strong anchoring. Being interested in the weak anchoring, it seems that the method is well suited for our purpose. However, there is still a serious drawback whatever the strength and the method: the measured phase shift R_{meas}. of the cell is actually measured within [0 π]. Thus to have the actual phase shift R which has to be inserted in the curve construction, the experimental values have to be shifted according to R_0, the phase shift of the field free cell, ($R \cong R_{meas} + R_0 - k\pi$; k depending on V). In the range of interest (high voltages), the cell is practically homeotropic, which means that the phase shift (R_{meas}) is close to zero and any deviation on the reference value R_0 becomes dramatic and induces a large change in the built curve. For instance, if, using values from an experiment we have performed, one built up a curve (in the NL method) using R_0 and we do it again using $R_0 + 1°$, we find a change of around 25 % for the final value of the anchoring strength. Again this discrepancy is due to the fact that the method works out the phase shifts around zero. It is hopeless to measure the actual R_0 with accuracy better than the 1° (0.5° can be achieved in the best cases), thus it is not so obvious to get an accurate value for the anchoring strength. It is even worse if one notice than it is necessary to enter some physical parameters of the nematic (in V*) such as the dielectric anisotropy and elastic constants, the accuracy of which are not so good. It is worth to notice that it is possible to avoid the introduction of these parameters and to get their actual values via a simulation of a full set of data. This has been proposed recently [5]. However the lack of accuracy due to the R_0 is still present. Since we are interested not only in the anchoring energy measurement but in the surface tilt angle as well, we have undertaken a numerical analysis of the solutions of the elastic equations for this problem and to look for a possible new way of anchoring energy measurement, accounting for the fact that it is useless to hope a high accuracy.

II. NUMERICAL ANALYSIS OF THE EXACT ELASTIC SOLUTION

We have developed a code to solve the elastic equation of our cell submitted to an electric field as the anchoring is supposed to be finite. The set of equations to be solved is written below, without demonstration since it has been done elsewhere [4].

$$z = \frac{d}{2}\frac{I_{(\varphi,\varphi_m)}}{I_{(\varphi_0,\varphi_m)}} \; ; \; I_{(\varphi,\varphi_m)} = \int_{\varphi}^{\varphi_m}\left[\frac{\left(1 + A_{diel}.\sin^2(\varphi')\right)\left(1 + A_{elast}.\sin^2(\varphi')\right)}{\left(\sin^2(\varphi_m) - \sin^2(\varphi')\right)}\right]^{1/2}.d\varphi'$$
$$A_{elast} = \frac{K_3 - K_1}{K_1} \; ; \; A_{diel} = \frac{\varepsilon_{II} - \varepsilon_{\perp}}{\varepsilon_{\perp}} \tag{2}$$

$$V = \frac{2}{\pi}.V_{\infty}.\sqrt{\left(1 + A_{diel}.\sin^2(\varphi_m)\right)}.I_{v(\varphi_0,\varphi_m)}$$
$$I_{v(\varphi_0,\varphi_m)} = \int_{\varphi_0}^{\varphi_m}\left[\frac{\left(1 + A_{elast}.\sin^2(\varphi')\right)}{\left(1 + A_{diel}.\sin^2(\varphi')\right)\left(\sin^2(\varphi_m) - \sin^2(\varphi')\right)}\right]^{1/2}.d\varphi' \tag{3}$$

$$\frac{W}{K_1} = L^{-1} = \left[\frac{\left(\sin^2(\varphi_m) - \sin^2(\varphi_0)\right)\left(1 + A_{elast}.\sin^2(\varphi_0)\right)}{\sin^2\left(2(\varphi_0 - \varphi_{easy})\right)\left(1 + A_{diel}.\sin^2(\varphi_0)\right)}\right]^{1/2}.I_{(\varphi_0,\varphi_m)} \tag{4}$$

The relations (2) give the director distribution throughout the cell, the relations (3) give the link between the applied voltage V and the surface ϕ_0 and maximum ϕ_m tilt angle, the relation 4 that one linking these angles to the correlation length. The structure of the cell for a given correlation length and different voltages is calculated by successively solving the relation 3 and 4 using the distribution 2. For one value of W and all ϕ_m ranging from 0 to $\pi/2$, it is searched the associated values for ϕ_0 which satisfy 4 ; then the curve $\phi_0 = f_W(\phi_m)$ is plot. The same calculation is performed with the relation 3 and the voltage. The intersection of the two curves yields to the set of two angles (ϕ_0, ϕ_m) associated with W and V and satisfying 3 and 4. A similar operation is reproduced for any voltages and it is possible to plot out the curves $\phi_0 = f_W(V)$ and $\phi_m = f_W(V)$ for one given anchoring strength. In addition, from this set of data (ϕ_0, ϕ_m, V) it is possible to calculate the phase shift R as a function of the applied voltage V, thus totally solving numerically the problem. The obtained curves are classical and are not reproduced herein. The following step consisted in looking for some linear part of the obtained curves and some possible using in anchoring energy and surface tilt angle measurement. The computation has been performed for a set of different correlation lengths and amongst the set of curves $R_W(V)$, $\phi_{0W}(V)$ and $\phi_{mW}(V)$, only the surface tilt angle looks interesting in terms of data manipulations. The surface tilt angle linearly depends on the voltage for values ranging from around 2 to around 4 to 5 times the threshold voltage (in our case 0.75V). In addition, the slope of that curve depends on the correlation length (Fig. 2). We thus plot the slope versus the correlation length (Fig. 3). It turns out that the slope very slightly oscillates around a straight line. A linear regression performed on these data shows that the deviation from a line is very small ($R^2 = 0.998$) and accounting for the fact that it is hopeless to measure the surface tilt angle with a better accuracy than 0.5°, the linear law can be accepted in this context. In other words, the following relation can be written: $\left(\frac{d\varphi_0}{dV}\right)_L = A.L$ or equivalently: $\varphi_0 = A.L.(V - V')$, where the coefficient A depends only on the material and cell parameters. As this relationship is verified, it can become a way to measure the correlation length: derived from the slope of the curve of the surface tilt angle versus the applied voltage. The exact value of the coefficient A has first to be expressed, however it is likely a complex expression, given the initial relationships (2,3,4). Therefore, rather than trying to calculate it, it is preferable first to check whether the linear dependence of ϕ_0 with respect to V is verified. This is why in this preliminary paper we propose an experimental setup to control that result obtained from simulations.

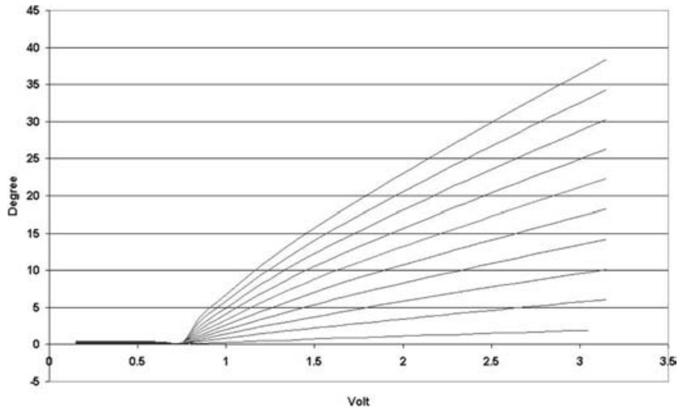

FIGURE 2. Surface tilt angle versus applied voltage for different values of L, ranging from 0.05μm (lowest curve) to 1μm (highest curve)

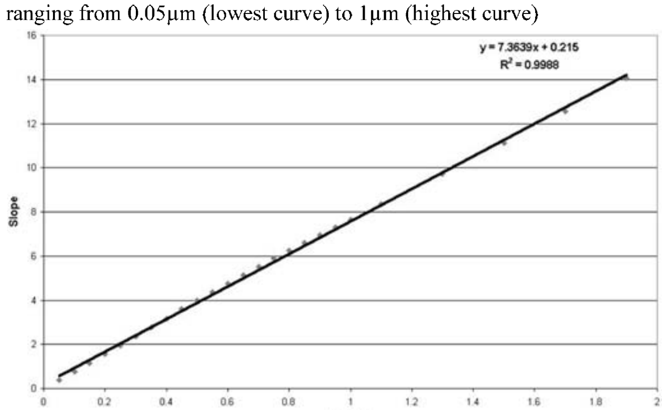

FIGURE 3. Slope of the curves in the figure 2 versus the correlation length L

III. EXPERIMENTAL: TOTAL INTERNAL REFLECTION COUPLED TO PHASE SHIFT.

The nematic film is prepared on the upper face of a dense prism, the surface of which is coated with ITO and a polyimid surfactant. The nematic is covered with a glass treated the same way as the prism in order to achieve a symmetric and homogenous planar alignment. Two mylar spacers impose the thickness of the nematic film. That sample is placed on the set-up described on the figure 4. The intensity of a beam internally reflected by the interface under study is collected by a photo sensor and recorded as a function of the angle of incidence. A comprehensive description of this set-up can be found in the reference [6]. A second linearly polarized beam impinges the sample under normal incidence and is analyzed via a Senarmont arrangement in order to measure the phase shift R as a function of the applied voltage.

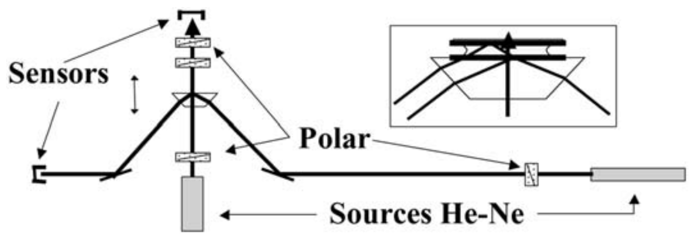

FIGURE 4. Set-up for combined Total Internal Reflection and phase shift measurement. Inset : A closer view of the sample

The reflectivity curve gives information on both the interface (around the limit angle of incidence for the TIR regime) and the bulk (for the smaller angles of incidence). A fringe pattern appears in this latter part of the reflectivity curve. It corresponds to the interference between the beam reflected at the prism/LC interface and that one at the LC / glass interface (see inset of Fig. 4.). It gives information on the bulk structure and to extract it from this fringe pattern, it is necessary to model the beam propagation in the film. Indeed, as an electric filed is applied, the nematic becomes distorted and the optical axis distribution throughout the film as well. In other words, the extraordinary beam travels through an index gradient and is bent. Moreover, since the upward and downward beams cross the optical axis under different angles, they are not just symmetrical with respect to the normal of the interface. Assuming that the optical axis distribution is only z dependent, the cell can be considered as a layered structure, the layer located at z with respect to the prism/LC interface (z = 0) has an optical axis tilted for $\phi(z)$ with respect to the layer plane. We have simulated the reflected intensity using a 4×4 matrix Berreman formalism, which in our case reduces to a 2×2 matrices since there is no coupling between ordinary and extraordinary beams (this has been carefully checked experimentally). The matrix elements being calculated after some tedious algebra, the global matrix is computed and the reflectivity curve plot out. Apart the material parameters (indices, dielectric permittivities and elastic constants), the director distribution given by the pure elastic theory (2) is included and we are left with a code which plots out the reflectivity curve, with only two input parameters, namely ϕ_0 and ϕ_m. Reflectivity curves have been recorded for different applied voltages (ranging from 0 to 3 Volts) and the phase shift under normal incidence R as well. Then, these curves have been compared with the simulated ones, looking for the best values for ϕ_0 and ϕ_m. There are several set of values for these angles that yield to a simulated curve not so far from the experimental ones: the correct couple ϕ_0 and ϕ_m is deduced from the comparison between the experimental phase shift R and the values calculated using the different possible set of tilt angle. An example of the comparison between experimental and simulation is shown on the figure 5. It is thus plotted the "experimental" curve $\phi_0(V)$ The obtained curve is shown on the figure 6. As found through simulations, the surface tilt angle has a quasi-linear dependence with the applied voltage. The small value of its slope indicates a quite strong anchoring (to be compared to the simulations of the figure 2). However, this curve has been restricted to a range of voltage lower than 1Volt since for values larger than 2Volts, the experimental curves cannot be fit using the model based on a pure elastic theory: the few first minima cannot be superimposed on that of the simulation. In that case, the pure elastic model is not sufficient. Further phenomena have to be included in the model such as flexoelectricity: this work is underway.

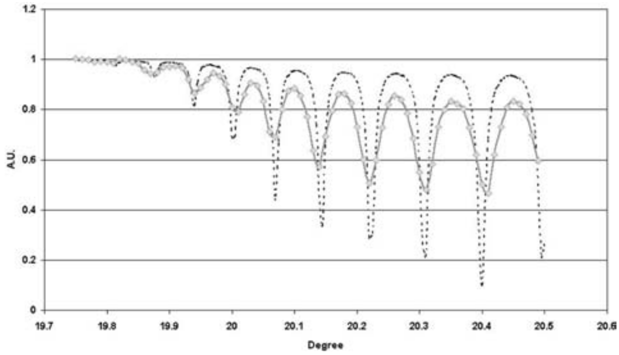

FIGURE 5. Comparison between experimental and simulation (dashed). Only the position of the minima have to be considered, the amplitude depends on the scattering losses not taken into account in the model

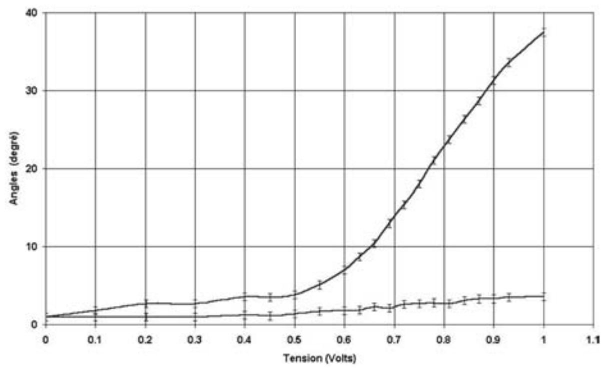

FIGURE 6. Result for the surface tilt angle (lower curve) and the maximum tilt angle (upper curve) versus the applied voltage.

IV. CONCLUSION

In this paper we have studied a planarly aligned nematic film under the influence of an electric field. A simulation has been performed in the frame of the pure elastic model, allowing the surface and maximum tilt angles of the cell to be plotted versus the applied electric field for different correlation lengths. The phase shift experienced by a beam under normal incidence crossing the film is also derived from these simulations. Looking for possible simple behavior, it has been found that the surface tilt angle depends almost linearly on the applied voltage and the slope of this linear part is proportional to the correlation length. Thus the measurement of the surface tilt angle versus the applied voltage can yield to an anchoring strength measurement. Before entering a tough calculation for a specific coefficient that enters the slope of the targeted curve, it has been decided to check first whether or not the quasi linear behavior of the surface tilt angle is a reality. A measurement of the phase shift together with the surface tilt angle has been undertaken using a Total Internal Reflection set-up coupled with a Senarmont arrangement. Reflectivity curves have been recorded for different applied voltages and compared with simulated ones allowing to derive the surface tilt angle. This angle have been found to change linearly with the applied voltage as obtained by simulation: it is therefore possible to measure the anchoring strength using the slope of this curve. However, it has been found as well that the pure elastic model is not suited for higher voltages, some surface phenomena being detectable. A more comprehensive model is underway to include others effects such as flexoelectricity.

Acknowledgments

The equipment to perform the experiments has been funded by the « Region Nord Pas de Calais ». The LPCIA participates to the « Centre de recherches sur les Lasers et Applications » (CERLA).

REFERENCES

1. A.A. Sonin.; "The surface Physics of Liquid Crystals"; Gordon & Breach Publishers, see for instance chapter 5 page 35,(1995)
2. H. Yokoyama, H. van Sprang; J. Appl. Phys. **57**(10), p. 4520, (1985)
3. Y. Nastishin, R. Polak, S. Shiyanovskii, V. Bodnar, O. Lavrentovich, J. Appl. Phys. **86** (8), , p. 4199, (1999)
4. R. Barberi, G. Barbero; "Physics of Liquid Crystalline materials", edited by I.C. Khoo, F. Simoni; Gordon & Breach, New York, p 215, (1991)
5. J. Fonseca, Y. Galerne; Phys. Rev. E**61**(2), p 1550, (2000)
6. M. Warenghem, M. Ismaili, D. Hector; J. de Phys. III, **2**, p 765, (1992)