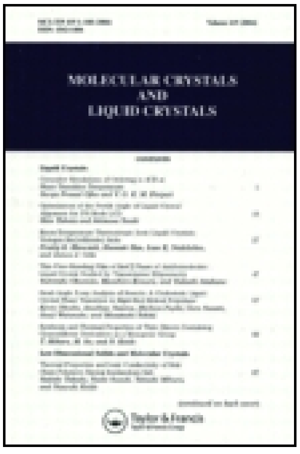

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl16

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Version of record first published: 20 Apr 2011.

To cite this article: A. Strigazzi , G. Barbero , E. Miraldi & C. Ferrero (1983): On a Periodically Grooved Nematic Cell, Molecular Crystals and Liquid Crystals, 82:10, 345-353

To link to this article: http://dx.doi.org/10.1080/01406568308247029

Mol. Cryst. Liq. Cryst. Vol. 82 (Letters), pp. 345-353
0140-6566/83/8210-0345$18.50/0

ON A PERIODICALLY GROOVED NEMATIC CELL

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(Submitted for publication October 29, 1982)

Abstract: The mean permittivity behaviour of a periodically grooved nematic liquid crystal cell has been theoretically investigated as a function of the cell geometry in the strong anchoring hypothesis, with the aim of predicting the degree of homeotropic alignment. The capacitance measurements, performed on two MBBA cells of different thicknesses, are in good agreement with our calculations.

The permittivity investigation of a thin nematic liquid crystal (NLC) cell gives information on NLC-surface interaction[1 ÷ 3], from which both the impedance and contrast behaviour of a display unit[4,5] can be found. Hence the degree of alignment of an NLC as a function of the cell thickness and of the temperature can be established by permittivity analysis.

It is well known that an oblique evaporation or ion implantation technique can ensure an average homeotropic configuration inside the cell, but it gives a certain misalignment, difficult to compute[6 ÷ 9], with respect to the ideal homeotropic sample.

In this paper we propose a model of the degree of alignment in the row-like grooves and consequently in the bulk, obtaining a good agreement with the experimental data presented.

Let us consider an NLC cell with periodically grooved bidimensional glass surfaces, coated with a thin conductive deposit of tin oxide in order to induce a quasi-homeotropic alignment in the bulk[10 ÷ 14]. By restricting ourselves to the case of strong anchoring and isotropic elasticity in the framework of the continuum theory, the tilt angle φ (x, y) between the director **n** and the y-axis normal to the cell plates - see fig. 1 - is given by a harmonic function, odd with respect to (x, y). By indicating the tilt angle in the bulk as φ_b and in the triangular zones corresponding to the grooves as φ_t, we get

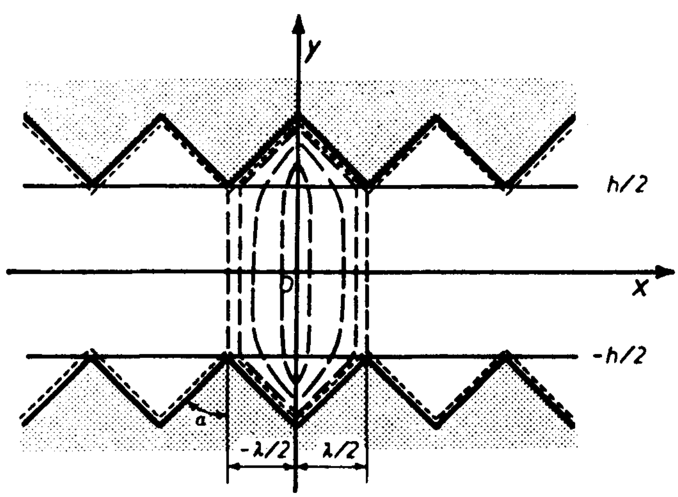

FIGURE 1 – Cell geometry and director lines pattern.

(1) $$\varphi_b(\xi, \eta) = \sum_{k=1}^{\infty} \Omega_k \sin(2\pi k\xi)\, \mathrm{sh}(2\beta_k \eta) \,/\, \mathrm{sh}\beta_k$$

$\forall\ \eta \in (-1/2, 1/2)$, where $\xi = x/\lambda$, $\eta = y/h$, and $\beta_k = k\pi h/\lambda$, λ being the carving period and h the cell thickness, as defined in fig. 1, and

(2) $$\Omega_k = -2\int_{-1/2}^{1/2} \varphi_b(\xi, -1/2) \sin(2\pi k\xi)\, d\xi$$

In order to derive the relationship between the permittivity and the geometry of the cell, the mean square tilt angle $< \varphi_b^2 >$ in the bulk needs to be calculated. From eq. (1) the following relation

(3) $$< \varphi_b^2 > = (1/4) \sum_{k=1}^{\infty} \Omega_k^2\ G(\beta_k)$$

is obtained, with $G(\beta_k)$ given by:

(4) $$G(\beta_k) = (\mathrm{sh}2\beta_k \,/\, 2\beta_k - 1) \,/\, \mathrm{sh}^2 \beta_k$$

Since $G(\beta_k)$ decreases with β_k, $< \varphi_b^2 >$ decreases with h, as might be expected. Moreover, eq. (4) becomes more simply[□] $G(\beta_k) \sim 1/\beta_k$ if $\beta_k \gtrsim \pi$, i.e. if $\lambda \lesssim h$.

Now let us suppose that the director configuration in the ($\eta =$ $= \pm 1/2$)-planes gives a step distribution in the tilt angle of the form:

(5) $$\varphi_b(\xi, \pm 1/2) = \begin{cases} \mp\alpha & \forall\ \xi \in (-1/2, 0) \\ \pm\alpha & \forall\ \xi \in (0, 1/2) \end{cases}$$

(□) The maximum error with respect to eq. (4) is $\sim 2\%$, occurring for the minimum value of $\beta_k \sim \pi$.

resulting from the strong anchoring on the groove's facets with carving angle α. Consequently, the expansion coefficients are given by $\Omega_{2k} = 0$ and $\Omega_{2k+1} = 4\alpha / \pi(2k+1)$.

Hence, the mean square tilt angle in the bulk is derived from eq. (3), obtaining

$$(6) \qquad < \varphi_b^2 > = (4\alpha^2 / \pi^2 \beta_1) \sum_{k=1}^{\infty} (2k-1)^{-3}$$

Finally, by taking into account the bidimensional grating of the substrate, we get

$$(7) \qquad < \varphi_b^2 > = 8.416\, \alpha^2 / \pi^2 \beta_1$$

On the other hand, the triangular-shaped zone contributes as

$$(8) \qquad < \varphi_t^2 > \sim \alpha^2$$

and the weighted average of the mean square tilt angle in the whole cell is found to be

$$(9) \qquad <\varphi^2> \sim <\varphi_b^2> / ((\lambda/2h\, \mathrm{tg}\alpha) + 1) + <\varphi_t^2> / (1 + 2h\, \mathrm{tg}\alpha/\lambda)$$

Now, it is well known that the mean permittivity in a non dissipative NLC cell is given by $< \epsilon_{\eta\eta} > = \epsilon_{\parallel} - \epsilon_a < \sin^2\varphi >$ (15 ÷ 17), ϵ being the permittivity along the long axis of the molecule and ϵ_a the permittivity anisotropy.

The approximated expression

$$(10) \qquad < \epsilon_{\eta\eta} > \sim \epsilon_{\parallel} - \epsilon_a < \varphi^2 >$$

leads to an error of only ~ 10% if $\varphi \sim 30^{\circ}$ in the whole cell: consequently we assume that eq. (10) is valid in our case, the alignment being quasi-homeotropic in the bulk.

With the aim of testing eqs. (9) and (10), we performed measurements of capacitance *vs.* temperature(□□) in the nematic range on two MBBA cells with the previously described substrates and different thicknesses ($h_1 = 10\ \mu m$, $h_2 = 50\ \mu m$), with area $A = 21.6\ cm^2$, $\lambda = 10\ \mu m$ and $\alpha = 44^o$. The cells have been conveniently sealed by araldyte and then filled through a hole with anhydrous MBBA in a controlled atmosphere, in order to prevent the NLC unstability and the shift of its transition temperature. The cells thicknesses have been controlled by examining the frings in yellow light.

A bridge method[10] has been used, with the bridge driven by a sinusoidal voltage (~ 1500 Hz, ~ 0.1 V), the bridge output being amplified by a lock-in in order to improve the null sensitivity (~ 10^{-4}).

Hence this capacitance method results to be a sensitive measure of the mean square tilt angle, since its resolution is given by $\Delta < \varphi^2 > \sim$ $\sim 10^{-3}$ for MBBA.

The experimental data $< \epsilon_{\eta\eta} >$ for both cell *vs.* the reduced temperature $\tau = T/T_{NI} - 1$ are reported in fig. 2, expressed as a percentage of the permittivity ϵ_{NI} at the nematic-isotropic transition. The data may be compared in the same figure with the MBBA bulk parameter $\epsilon_{\parallel}(\tau)$, as measured by Rondalez[18] and Diguet et al.[19].

The $< \epsilon_{\eta\eta} >$-behaviour can be explained by the expected temperature dependences of the principal values $\epsilon_{\parallel}$, $\epsilon_{\perp}$ of the permittivity,

(□□) A thermostat ensured the temperature stability within $\pm 0.1^oC$.

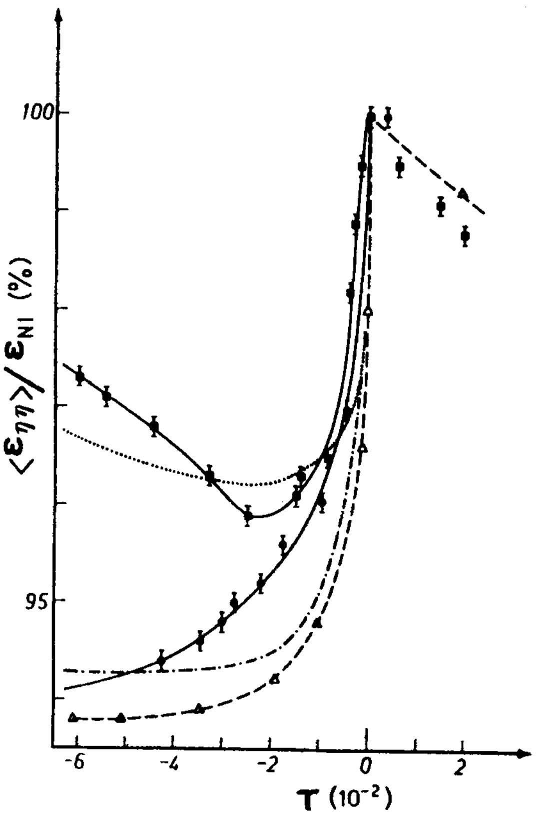

FIGURE 2 – Average permittivity $<\epsilon_{\eta\eta}>$ *vs.* reduced temperature τ : experimental curves (⧫ h_1 = 10 μm; ⧫ h_2 = 50 μm; Δ bulk) and theoretical ones (..... h_1 = 10 μm; ·–·– h_2 = 50 μm).

which express primarily the temperature dependence of the order parameter.

In fact, from eqs. [(7), (8) and (9)] we obtain the predicted values for both cells

$$(13) \qquad < \varphi^2 > \sim \begin{cases} 0.303 \\ 0.083 \end{cases} , \qquad h = \begin{cases} 10\ \mu m \\ 50\ \mu m \end{cases}$$

and we observe that the assumption (5) implies that $< \varphi^2 >$ is independent of τ.

On the other hand, a more rigorous calculation performed on the same cell in the strong anchoring hypothesis[10] shows that $< \varphi^2 >$ is τ-independent, justifying the previous assumption. In fact, by imposing the boundary condition [$\varphi = 0 \ \ \forall \ \xi = \mp 1/2, \ \ \forall \ \eta = 0; \ \ \varphi = \pm \ \alpha \ \ \forall \ \eta = = \pm \ (\xi \mp \lambda/2) \ \mathrm{ctg} \ \alpha - 1/2$], a convenient harmonic function $\varphi \ (\xi, \eta)$ could be determined by means of Schwartz-Christoffel transformation, resulting in $\varphi \ (\xi, \eta)$ independent of τ.

Hence, by ascribing the τ -dependence of $< \epsilon_{\eta\eta} >$ only to the behaviour of the permittivities $\epsilon_{||} (\tau)$ and $\epsilon_a \ (\tau)$[18, 19], we derived the theoretical curves shown in fig. 2.

We would point out that the theoretical curves are in good agreement with the experimental ones: in particular, both τ -decreasing behaviour of $< \epsilon_{\eta\eta} >$ for the thinner cell, and pratical τ-independence of $< \epsilon_{\eta\eta} >$ for the thicker one in the range $\tau < - 2 \cdot 10^{-2}$, are predicted by our calculation, the imperfect correspondence between theory and experiment being due to the impurities in the NLC and primarily to the irregularities in the bidimensional grating.

In conclusion, thick cells are characterized by mainly homeotropic alignment, $< \epsilon_{\eta\eta} >$ following $\epsilon_{||} \ (\tau)$, while in thin cells the transverse components $\epsilon_{\perp} \ (\tau)$ play a more important role, provided the temperature is rather far from the nematic-isotropic transition.

This work represents the first attempt to solve the problem of predicting the degree of homeotropic alignment inside an NLC cell with glass plates coated with a conductive deposit using either an evaporation or ion implantation technique, which gives a periodical row-like structure.

This problem is important both from a fundamental point of view, i.e. the description of a bidimensional structure, and from a practical one, i.e. the prediction of a display configuration in the off-state, so that the contrast gain can be calculated, and the quality control can be improved by means of capacitance measurements.

We would emphasize the semplicity of the model, deriving from the assumptions [(5) and (8)], which may be considered a priori as a crude approximation, but are found a posteriori to be a useful hypothesis in predicting the degree of alignment and the dielectrical behaviour of a periodic triangular grooved NLC cell.

Furthermore, this model may be used to determine the influence of the surface topography on the induce alignment. The critical angle α of the rows obtained, discriminating between homeotropic and planar orientation, is the same that can be derived by a more rigorous calculation[10].

Acknowledgments: Two of the authors (A.S. and G.B.) are indebted to the Centro Ricerche FIAT S.p.A., that has partially supported this work, and to I. Gilli for useful discussion. Thanks are also due to T.A. Savoy for some suggestion.

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