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Liquid Crystals

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Flow induced bistable anchoring switching in nematic liquid crystals

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To cite this Article Barberi, R. and Durand, G.(1991) 'Flow induced bistable anchoring switching in nematic liquid crystals', Liquid Crystals, 10: 2, 289 — 293
To link to this Article: DOI: 10.1080/02678299108036432
URL: http://dx.doi.org/10.1080/02678299108036432

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LIQUID CRYSTALS, 1991, VOL. 10, NO. 2, 289–293

PRELIMINARY COMMUNICATION

Flow induced bistable anchoring switching in nematic liquid crystals

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(*Received 15 February 1991; accepted 11 April 1991*)

A hydrodynamically controlled switching of orientations of a nematic bistable surface anchoring is observed. A viscous torque moves surface lines between domains corresponding to bistable anchoring. An observed threshold for this viscous torque is attributed to relative spatial inhomogeneities of surface energy ($\sim 10^{-2}$).

Nematic liquid crystals present, on some particular surfaces, a multistable surface anchoring [1]. A well-known case is the bistable anchoring given by a controlled grazing evaporation of SiO on glass surfaces [2]. This anchoring is characterized by two energetically equivalent surface easy directions for the surface directors $\mathbf{n}_s$. A surface with this bistable anchoring will present two possible easy orientations with the same probability. External agents can privilege one of the two surface easy directions with respect to the other one. The selection between the two competing anchoring positions has been studied in wetting experiments [3]. It has also been experimentally demonstrated that the orientational surface states can be changed and controlled by external electric fields [4, 5]. In this preliminary communication, we demonstrate that hydrodynamic flow can also control this bistable surface anchoring.

The two surface easy directions of this bistable anchoring are symmetrical with respect to the normal plane P, which contains the direction $\mathbf{e}$ of the SiO evaporation [2]. We indicate the two surface easy directions with two surface directors $\mathbf{n}_1$ and $\mathbf{n}_2$, with the same polar angle θ_s between $\mathbf{n}_1$ or $\mathbf{n}_2$ and the z axis and two opposite azimuthal angles $\pm\varphi_s$, on both sides of P.

To describe the flow of a nematic, one needs to determine the velocity and director fields $\mathbf{v}(\mathbf{r}, t)$ and $\mathbf{n}(\mathbf{r}, t)$, where $\mathbf{r}$ is the position and t the time. These two fields are viscoelastically coupled [6]. In the bulk, a velocity gradient exerts a viscous torque on the bulk director and a local change of the director orientation can induce a flow. At the solid surface, the nematic orientation is bistable, but not defined: the anchoring directions are influenced by the flow and *vice versa*.

To observe the effect of the flow on the bistable anchoring, we built a sandwich cell with the lower glass plate which presents the twofold degenerate anchoring and the upper plate which gives a usual oblique orientation on P. The two glass plates are antisymmetrically oriented with respect to $\mathbf{e}$. The cell is filled with MBBA (p-methoxy-

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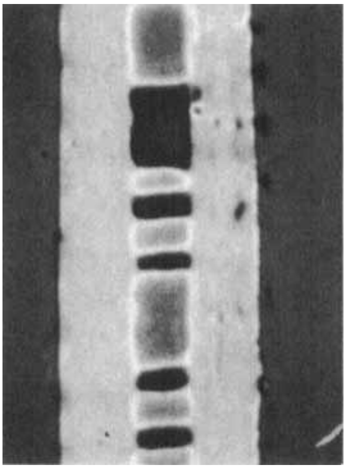

Figure 1. Upper view of the sample observed at rest between twisted polarizers. Grey regions on the left- and right-hand sides are the gold electrodes. The bistable anchoring is realized only in the central region between the electrodes, where dark domains correspond to the $+\varphi_s$ orientation ($\mathbf{n}_1$) and light domains to the $-\varphi_s$ orientation ($\mathbf{n}_2$). These domains are stable.

benzylidine-*p*-*n*-butylaniline) and observed by a polarizing microscope. As shown in the figure, two semi-transparent gold electrodes on the lower plate are used to create a horizontal AC electric field, perpendicular to P, which will induce the hydrodynamic motion, through electrodynamic instability. The distance between the electrodes is 40 μm. The sample has a constant thickness $d = 20\,\mu$m to meet the Mauguin condition $d \cdot \Delta n > \lambda$, where $\lambda = 0{\cdot}52\,\mu$m is the used optical wavelength and $\Delta n \approx 0{\cdot}2$ is the MBBA birefringence. In this cell, the nematic liquid crystal presents, at rest, two kinds of stable textures with opposite $\varphi_s = \pm 30°$ on the lower plate and the same $\varphi_u = 0°$ on the upper plate. The polar angle $\theta(z) = \theta_s = 75°$ can be assumed constant in all of the sample. The two kinds of surface domains on the lower plate are separated by surface lines of about 1 μm thickness. We adjust the polarizer and the analyser to have the maximum light transmission for one texture and the maximum extinction for the other one. Figure 1 shows the sample observed in these conditions. We apply a low frequency AC electric field $\mathbf{E}(t)$ to the electrodes. For $|E| < 0{\cdot}2\,\mathrm{V}\,\mu\mathrm{m}^{-1}$, there are not any optical effects. For $|E| > 0{\cdot}2\,\mathrm{V}\,\mu\mathrm{m}^{-1}$, we observe the raising of electrohydrodynamic instabilities, which tend to create convection cells parallel to the glass plates. For the sake of simplicity, we study the influence of the flow on the anchoring, in the middle region of the sample, between the electrodes, where *a priori* the velocity should present only a y component $\mathbf{v} = (0, v(z), 0)$. We determine the local flow direction by looking at the movement of small dust particles inside the nematic. The microscopical image is recorded by a videorecorder. The frame by frame analysis of the video recording allows us to determine the local flow velocity v_0. When $|v_0| > 18\,\mu\mathrm{m}\,\mathrm{s}^{-1}$, surface lines begin to move and one surface domain on the lower plate is preferred compared to the other one. We verify that the preferred state is the one for which the surface director, oriented by the glass, points along the velocity. As the surface anchoring transition between $\mathbf{n}_1$ and $\mathbf{n}_2$ is induced by the movement of defects, we do not expect a threshold behaviour. The apparent finite velocity threshold must, in fact, be connected with the surface inhomogeneity of the surface energy already observed [4]. These inhomogeneities hamper a free movement of surface defect lines. Let us consider the finite anchoring which allows us to commute from $\mathbf{n}_1$ to $\mathbf{n}_2$ or *vice versa*. This corresponds to a surface torque $|\Gamma_s| \approx K/L$, where $K = 5 \times 10^{-12}$ N is an elastic constant and $L = 0{\cdot}2\,\mu$m the measured anchoring extrapolation length [7]. We can compare Γ_s to the surface density of the viscous torque Γ_v, which acts on the bistable surface. In a first approximation, where only a φ_s variation at constant θ_s is considered, a change of the surface anchoring can be described as a simple rotation of $\mathbf{n}_s$ around the z axis. The only component of the viscous torque, relevant to obtain such a rotation is the z component, which reads [8] (per volume unit) $\gamma_z = (1/2)(\gamma_1 - \gamma_2) n_x n_z\, dv/dz$, where $n_x = \sin\theta\cos\varphi$ and $n_z = \cos\theta$ are the x and y components of the bulk director $\mathbf{n}$. As we are interested in a surface effect, γ_z must be integrated with respect to the thickness l, close to the surface, where $\mathbf{n}$ changes progressively to adjust to the stable boundary positions φ_s or $-\varphi_s$ and to the orientation in the central region of the sample (along z), where molecules tend to be aligned at the critical angle between $\mathbf{n}$ and $\mathbf{v}$ for which the viscous torque vanishes. Note that $|\gamma_1| < |\gamma_2|$ for MBBA, where γ_1 and γ_2 are two Leslie coefficients ($\gamma_1 = 0{\cdot}76$ Pa s, $\gamma_2 = -0{\cdot}078$ Pa s) [7, 9]. An estimate of l is $(K/\eta S)^{1/2}$, where $\eta = 0{\cdot}05$ Pa s is an average viscosity and S the shear rate [7]. To obtain an order of magnitude estimate of γ_z, we assume $S = v_0/l$ and a simple linear variation $\varphi(z) = ((1 + \varphi_s)/l)z - \varphi_s$ for the director distortion close to the boundary surface. Thus it results $l \approx 4\,\mu$m $< d/2$ and the surface density of the z component of the viscous torque is given by

$$(\Gamma_v)_z = \int_0^l \gamma_z\, dz \approx (\gamma_1 - \gamma_2)(\sin 2\theta) v_0/4.$$

Our data on the line motion threshold, analysed this way, correspond to an anchoring strength defined by $L \approx 10\,\mu$m, i.e. 50 times larger than the known anchoring extrapolation length $L_b \approx 0{\cdot}2\,\mu$m for the nematic bistable anchoring on a SiO film [4]. It is evident that the viscous torque cannot directly break the surface anchoring, but the comparison between L and L_b permits us to estimate the order of magnitude of the relative surface energy spatial inhomogeneity, of the order of 2×10^{-2}, comparable with the already observed 10^{-2} by the electric field switching method [4]. Let us now

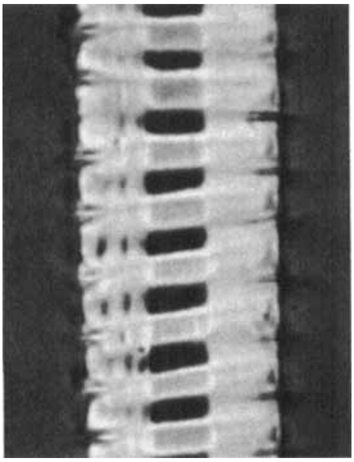

Figure 2. Convection cells in the sample for $v_0 \approx 100\,\mu$m s^{-1}. Note the regularity of the pattern created by the coupling between the flow direction and the bistable anchoring.

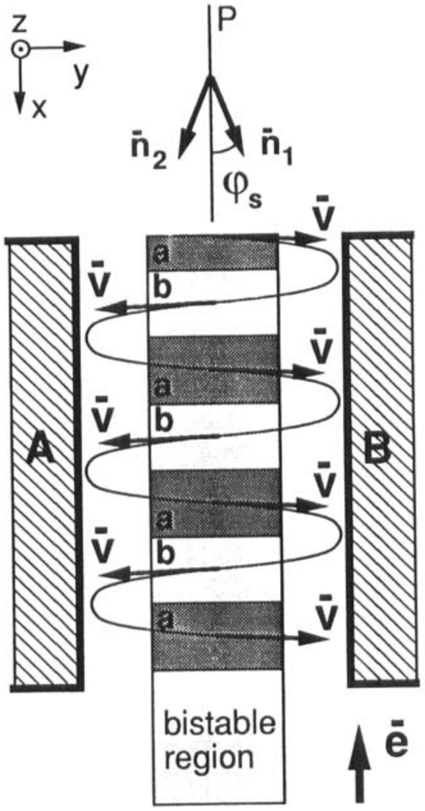

Figure 3. Schematic drawing of the flow velocity field $\mathbf{v}(\mathbf{r})$ in an upper view of the sample. $\mathbf{n}_1$ and $\mathbf{n}_2$ are the surface directors of the bistable anchoring. Dark grey regions (a) represent surface domains with $+\varphi_s$ orientation ($\mathbf{n}_1$) and light grey regions (b), surface domains with $-\varphi_s$ orientation ($\mathbf{n}_2$) on the lower plate of the sample. P is the projection of the normal plane which contains the direction $\mathbf{e}$ of the SiO evaporation. A and B are the gold electrodes.

return to the description of the flow. For weak $|E| > 0{\cdot}2\,\mathrm{V}\,\mu\mathrm{m}^{-1}$, i.e. for small v_0, the convection cells, which correspond to domains of orientation $\mathbf{n}_1$ (black) or $\mathbf{n}_2$ (white) are irregular. Then, at increasing $|E|$, i.e. increasing v_0 up to $100\,\mu\mathrm{m}\,\mathrm{s}^{-1}$, the convection cells become very regular (figure 2). It is interesting to note that the convection cells are not closed. In fact there exists a non-zero average flow component parallel to the electrodes (figure 3). This transverse flow can be explained as a Hall-like effect [10]. When, for a flow, $S = dv/dz$ is not constant or when $\mathbf{n}$ varies in space, the antisymmetric part of the Ericksen–Leslie stress tensor [7] is, in fact, not uniform in space and a volume force appears. The x component of this force is responsible for the observed transverse flow. As expected, the flow lines are deflected towards $\mathbf{n}$, for MBBA.

In conclusion, a hydrodynamic flow can determine a slow surface switching between the two stable surface positions of a bistable nematic anchoring by inducing surface defects motion. The viscous torque is not strong enough to break the surface anchoring given by an SiO film on glass plates and a flow induced uniform switching of the surface is impossible. A relative surface anchoring roughness ($\sim 2 \times 10^{-2}$) is observed.

This work was partially supported by a contract from the French Ministère de la Recherche et de la Technologie #8950006.

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