

Surface anchoring breaking in smectic C liquid crystals

M. PETROV*, B. KATRANCHEV, H. NARADIKIAN

Institute of Solid State Physics, Bulgarian Academy of Sciences, 72 Tzarigradsko Chaussee Blvd., 1784 Sofia, Bulgaria.

The surface anchoring in a smectic C (S_C) liquid crystal, in contrast to that in nematics, has been studied very scantily. Here we present the angular dependence of the surface anchoring energy of the S_C with a temperature independent tilt angle (8OBA) on two surfaces: $SiO_x/ITO/glass$ and a holographic diffraction grating. This dependence was measured using a twist – cell method. The S_C single local monocrystal (SML) rotation, starting at a critical bulk twist, reveals surface anchoring breaking. A model for the bulk twist influence on the S_C SLMs is suggested.

(Received November 28, 2006; accepted December 21, 2006)

Keywords: Liquid Crystals, Smectic C, Single monocrystal, Surface anchoring

1. Introduction

The main problem in forming smectic C (S_C) liquid crystals (LCs) (grown upon cooling the nematic (N) LC) is the co-ordination of both the layer and the molecular orientations.

One strong constraint on the layers during S_C growth is to make a cone of angle, that of the S_C tilt angle, around the imposed orientation. The existence of orientating boundary plates favours an orientation of the layers, which reduces the conical degeneracy.

Obtaining large single local monocrystals (SLMs) (LC medium, where the layer's planes are identically situated, and the molecules inside the layers are approximately equally oriented) is very important for the experimental study of S_C .

We applied controllable bulk twists to determine the surface anchoring in S_C for various surface coatings. The balance of the surface and bulk torques, considered as action and counteraction, can give rich information on the surface anchoring conditions and the surface stability, expressed by the polar (zenithal) and azimuthal surface energies. These anchoring energies are very scantily studied in S_C . However, the relaxation times in this smectic phase are comparatively short (the response time is 2-3 ms), which is very important for display techniques.

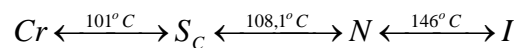
The goal of the present paper is to estimate the surface anchoring and the anchoring breaking by imposing a controllable bulk twist. This is the first surface anchoring energy estimation in the S_C phase.

2. Experimental results

2.1. LC materials and cell preparation

We used two kinds of liquid crystal cells (LCCs) according to the substrates: (i) SiO_x obliquely evaporated on glass previously covered with ITO ($SiO_x/ITO/glass$); and (ii) a sinusoidal holographic diffraction grating. The

phase transition temperatures of the used LC substance 8OBA were:



The $SiO_x/ITO/glass$ treated plates were obtained at two oblique evaporations with evaporation angles α equal to 60° and 82° , with SiO_x nominal thicknesses of $\delta = 4.5$ and 107 nm respectively, ensuring planar (perpendicular to the evaporation plane) and tilted (in the evaporation plane) orientations respectively.

We used direct information about the surface topography of the gratings from AFM measurements. The surface wave form of the grating was approximately sinusoidal: $z = A \sin 2\pi x / \Lambda$, where Λ is the wavelength of the surface undulation and A is the amplitude.

2.2. Microtextural polarization analysis

The director (n_s) in the S_C near to the surface is constrained to lie on the surface circular cone of angle $\pi/2 - \theta$, coaxial to the surface normal K , and it should lie on the layer cone of angle ω (between the director and the layer's normal N), as indicated in Fig. 1. Simultaneous application of these two constraints, and for $\pi/2 - \omega < \theta < \pi/2$ in general, determines four allowed values of the azimuthal angle at each of the orienting substrate surfaces. The degrees of intersection of the two cones are very important. At $(\pi/2 - \theta)$ close to zero, the surface cone collapses to a plane and the allowed states reduce to two. We note that the S_C phase of 8OBA characterizes, with a small latent heat, N- S_C , allowing a domination of the surface forces over the bulk ones and a flat layer structure. Neither chevrons nor uniform tilt layer distortion were observed in this material (for details see [1,2]).

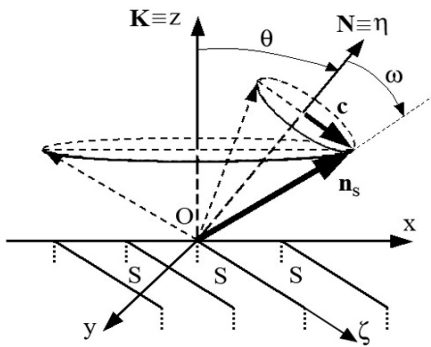


Fig. 1. The director n_s near the surface is under two constraints: it should lie on the surface circular cone of angle $\pi/2 - \theta$, coaxial to the surface normal \mathbf{K} and it should lie on the layer cone of angle ω (the smectic C tilt angle). \mathbf{c} is the S_C director, S is the layer plane.

The twisting was realized by rotation of the upper plates by a desired angle, Ω . By polarization microtextural analysis, one measures the actual twist angle φ_t , which is influenced by both the bulk elastic force and the surface anchoring force of the LC. Thus, φ_t will deviate from the angle Ω . The deviation can be expressed as $2\varphi = \Omega - \varphi_t$. After the actual twist angle in LCC is known, the deviation and the surface anchoring strength can be calculated.

The SLMs formed in the S_C phase in a planar geometry indicate that the smectic layers are vertical toward the orienting substrates and are at a $\pm\pi/4$ ($\approx\omega$) angle to the rubbing direction (x in Fig. 1). Furthermore, the SLM in the first approximation could be presented as an ellipse. The long elliptic axis direction is that of the layers' (S) direction. One can follow the rotation of this axis further, marked as l , on the orienting surface, and thus to follow the rotation of the SLM. This process must be strongly dependent on the surface anchoring, and is a possibility for correlating the simultaneously action of both the surface and bulk action applied to the S_C system.

Imposing consecutively increasing bulk twists, we found that for $0^\circ < \Omega < 70^\circ$ the long axis l , meaning the flat layer's plane of the SLM, keeps the same direction as at $\Omega = 0^\circ$. Slightly above $\Omega_c = 70^\circ$, one finds a sharp rotation of the l from $\pm 45^\circ$ to an angle $\pm \pi/2$ with respect to the 'easy' axis $n_o \equiv x$, revealing an anchoring breaking instability. The increase of the bulk twist does not change this $\pm 45^\circ$ l rotation, and until the completely ($\pm \pi/2$) bulk twist it remains the same. In Fig. 2a,b, we indicate an example of rotation of the l by $\pi/2$ with respect to the 'easy' n_o direction, implying the surface n_s rotation at an angle of $\pm 45^\circ$ with respect to n_o , as seen in Fig. 2c,d, which present the scheme of the polarization analysis. The value (Ω_c) is critical for the anchoring strength.

The Ω_c value in the LCC prepared using the sinusoidal holographic diffraction grating as an orientating surface is smaller than that prepared using $\text{SiO}_x/\text{ITO}/\text{glass}$ surfaces. We refer this to a significantly lower anchoring ability of the grating surface.

3. Discussion

Let us analyse the SLM rotation on the basis of the surface anisotropy and the corresponding balance of surface and bulk forces for the $\text{SiO}_x/\text{ITO}/\text{glass}$ case. We neglect the surface anisotropy, due to Van der Waals forces, since the imposed bulk twist does not change the θ zenithal-polar value [3-5] and concentrate on the surface elastic adaptation. As a result, one can easily control φ by the counteracting bulk twist, providing the anchoring breaking studied here.

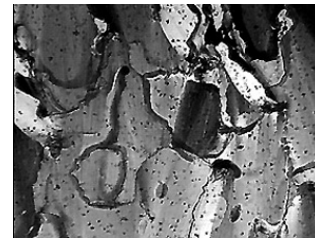
The most optimal form of the azimuthal surface energy is that proposed by Rapini-Papoular [6]:

$$F_s = -(1/2)W_{el}(n_s \cdot n_o)^2 = -(1/2)(K_{22}/L)\cos^2\varphi, \quad (1)$$

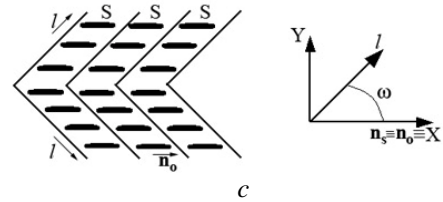
expressing the surface azimuthal energy. L is the extrapolation length [7] used as a measure of the anchoring strength.



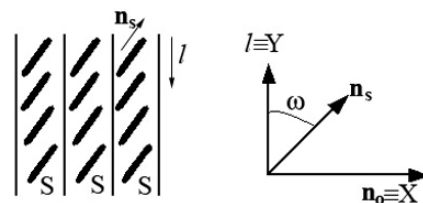
a



b



c



d

Fig. 2. The SLM orientation: a) $\Omega = 0$ and $n_o \wedge l \approx 45^\circ$; b) The SLM rotation on $\pi/4$ ($n_o \wedge n_s = 45^\circ$) for $\Omega > \Omega_c$. The second possible disposition of the SLM long axis l is parallel to the n_o ; c) The scheme for $\Omega = 0$; d) The scheme for $\Omega > \Omega_c$.

Using the polarization microtextural analysis as indicated above, we analyse the balance between the surface and bulk torque. In the cases $\Omega = 0-70^\circ$ for the $\text{SiO}_x/\text{ITO}/\text{glass}$ case and $\Omega = 0-39^\circ$ for the holographic grating, the topographic and corresponding elastic adjustment are enough to balance the bulk torque and to keep the equilibrium between the surface and bulk forces. Imposing, however, a higher Ω_c value, an anchoring instability, equivalent to a surface transition, sets in.

The bulk free energy at the twist reads [7]:

$$F_b = (B/2d)(\varphi_t)^2. \quad (2)$$

We take into account the tilt angle ω dependence of the elastic constants:

$$\begin{aligned} B_1 &\cong K_{22} \sin^2 \omega \cos^2 \omega + K_{33} \sin^4 \omega; B_2 \cong K_{11} \sin^2 \omega; \\ B_3 &\cong K_{22} \sin^4 \omega + K_{33} \sin^2 \omega \cos^2 \omega. \end{aligned} \quad (3)$$

In our case for 80BA, $\omega \approx 50^\circ$ and therefore:

$$\begin{aligned} B_1 &\cong 0.68 \times 10^{-11} \text{ J m}^{-1}; B_2 \cong 0.41 \times 10^{-11} \text{ J m}^{-1}; \\ B_3 &\cong 0.56 \times 10^{-11} \text{ J m}^{-1}. \end{aligned}$$

For simplicity, we assume:

$$B_1 = B_2 = B_3 = B = 0.55 \times 10^{-11} \text{ J m}^{-1}.$$

Since $\varphi_t = \Omega - \varphi$, then the n_s deviation can be expressed as $\varphi = \Omega - \varphi_t$.

To obtain the torque balance (between the surface torque and counteracting bulk torque), implying torque equilibrium, we present the surface torque as $\frac{\delta F_s}{\delta \varphi} = \frac{B}{2L} \sin 2\varphi$ and the bulk one as $\frac{\delta F_b}{\delta \varphi} = \frac{B}{d}(\Omega - \varphi)$. After this minimization, the torque equilibrium reads:

$$(2B/d)(\Omega - \varphi) - (B/L) \sin 2\varphi = 0. \quad (4)$$

From this equation, the surface anchoring strength $W_s = B/L$ is expressed as:

$$W_s = 2B(\Omega - \varphi)/(d \sin 2\varphi) \quad (5)$$

or

$$1/L = 2(\Omega - \varphi)/(d \sin 2\varphi). \quad (6)$$

Consequently, from the last two equations, two limiting cases follow: when φ approaches Ω , W_s tends to zero and L tends to infinity. On the contrary, when φ tends to zero (diminution of the twist), L tends to zero (W_s tends to infinity). Certainly these are unavailable, but we can conclude from these limiting cases that the stronger the surface anchoring the smaller will be the deviation.

The trend $W_s = f(\varphi)$ is clearly shown in Fig. 3. The experimental data were well fitted to an exponential decay.

By the various rubbing technology steps, the surface azimuthal anchoring energy in the classic nematics (e.g. MBBA, PAA, 5CB) is usually 10^{-4} J m^{-2} [8]. Considering SiO_x at $\alpha = 82^\circ$, provoking the highest surface anchoring

energy in our case (the maximum at $\varphi \approx 2.5^\circ$ is 10^{-5} J m^{-2}), and after comparing with twisted nematics under similar boundary conditions [9] one finds that it is approximately an order of magnitude smaller.

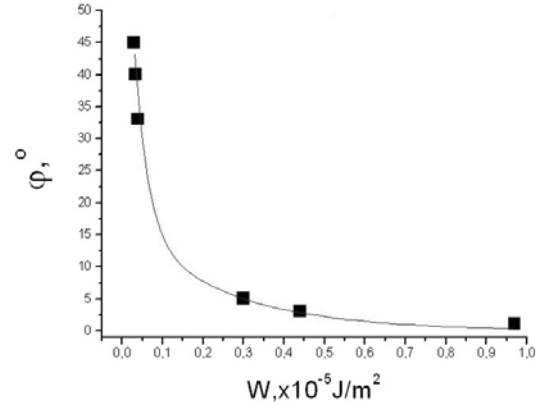


Fig. 3. The azimuthal anchoring energy $W_s = f(\varphi)$ trend of the azimuthal angle deviation on the $\text{SiO}_x/\text{ITO}/\text{glass}$ surface ($\alpha = 82^\circ$).

4. Conclusions

For the same surface coatings, the surface anchoring in S_C is an order of magnitude lower than that in the N_s . We explain this effect by the character of the S_C geometry, leading to the restriction of the director \mathbf{n} (\mathbf{c}) simultaneously to reorient around two cones: one with the substrate normal axis; and the other with the layer normal axis. The holographic diffraction grating used reveals a rather smaller anchoring strength value than those for $\text{SiO}_x/\text{ITO}/\text{glass}$, which one can find in the small imposed twist (Ω_c) causing the SLM rotation (39° versus 70°). Therefore, the SLM rotation could be more easily driven by an imposed bulk twist in the holographic grating. Furthermore, the achievement of very weak and controllable surface anchoring is that the holographic grating is one of the practical requirements.

A sufficiently high value of the n_s azimuthal deviation (φ) with increasing Ω provides limiting values of the anchoring strength parameters $W_s \rightarrow 0$ and $L \rightarrow \infty$, which means an anchoring breaking (surface instability) with the character of a 1st order surface transition. Microtextural polarization analysis shows that the l (meaning the layer plane direction S) rotates due to the imposed bulk twist from the angle range $\pm \pi/4$ with the 'easy' direction \mathbf{n}_0 to one including the an angle of 0 or $\pm \pi/2$ relative to this direction.

Acknowledgements

This study was supported by Grant No.F-1307 from the Ministry of Education and Science of Bulgaria.

References

- [1] M. Petrov, A. M. Levelut, G. Durand, *Mol. Cryst. Liq. Cryst.* **82**, 221 (1982).
- [2] M. Petrov, P. Simova, *Liq. Cryst.* **7**, 203 (1990).
- [3] H. Yokoyama, S. Kobaiashi, H. Kamei, *J. Appl. Phys.* **56**, 2645 (1984).
- [4] H. A. van Sprang, *Mol. Cryst. Liq. Cryst.* **97**, 255 (1983).
- [5] H. A. van Sprang, R. G. Harsten, *J. Appl. Phys.* **56**, 2251 (1984).
- [6] A. Rapini, M. Papoular, *J. Phys. (Paris)* **30**, Coll. 4 C54 (1969).
- [7] P. G. de Gennes, J. Prost, *The Physics of Liquid Crystals*, 2nd edition, Clarendon Press – Oxford (1993).
- [8] S. Faetti, M. Gatti, V. Pollesohi, T. Sluckin, *Phys. Rev. Lett.* **55**, 1681 (1985).
- [9] J. Min, H. Ximin, W. Zongkai, M. Kai, S. Rupeng, *Liq. Cryst.* **18**, 419 (1995).

*Corresponding author: mpetrov@issp.bas.bg