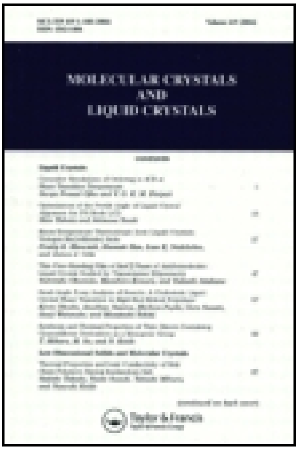

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Orientational Transitions in Nematic Liquid Crystals on Substrates with Controlled Topography

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Version of record first published: 24 Sep 2006

To cite this article: Rodica Moldovan, Traian Beica, Stefan Frunzã & Mihaela Tĭntaru (1999): Orientational Transitions in Nematic Liquid Crystals on Substrates with Controlled Topography, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 329:1, 43-49

To link to this article: http://dx.doi.org/10.1080/10587259908025924

Mol. Cryst. Liq. Cryst., 1999, Vol. 329, pp. 43-49
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Orientational Transitions in Nematic Liquid Crystals on Substrates with Controlled Topography

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Orientational transitions induced by temperature variation, in cells with nematic liquid crystal having limiting substrates with controlled topography, are presented. The variable topography was obtained by SiO_x deposition in vacuum at an incidence angle around 85°, or by depositions of polyvinyl alcohol (PVA) with different thicknesses, on glasses with the same SiO_x deposition.

The experimental results are explained by a phenomenological model based on the Landau-de Gennes free energy expansion, taking into account the anisotropy of the substrate.

Keywords: liquid crystals; surface transitions

1. INTRODUCTION

The surface orientation of a nematic liquid crystal limited by a solid substrate is a function of the physical properties of the solid substrate, in particular of its topography, and of the liquid crystal. Our experiments were performed in homogenous cells with boundary surfaces obtained by obliquely SiO_x deposition at high incidence angles and by PVA deposition on glasses with SiO_x obliquely evaporated in vacuum. By using different concentrations of the PVA solutions for sample preparation, we obtain different anchoring angles[1]. As is shown by electron microscopy, the deposited films display an inclined columnar growth structure arranged in a row-like order[2], structure that is maintained, but attenuated[1] in the PVA coverage process.

The surface orientation may be stable or not with respect to the temperature variation. If it is temperature dependent, the nematic sample shows a temperature dependent average molecular orientation[3-8] explained by a phenomenological model[9-12]. The phenomenological theory applied to a surface with microtopography[12] introduces a surface free energy expression, which takes into account the surface anisotropy induced for example, by an oblique deposition of a dielectric layer:

$$\begin{aligned} f_s = {} & \frac{3}{2}\alpha + \frac{3}{2}\beta_1 S(p^2 - \frac{1}{3}) + \frac{3}{2}\beta_2 S^2(p^2 + \frac{1}{3}) + \frac{9}{4}\beta_3 S^2(p^2 - \frac{1}{3})^2 + \\ & + \frac{3}{2}\gamma_1 S(p^2 - \frac{1}{3}) + \frac{3}{2}\gamma_2 S^2(p^2 + \frac{1}{3}) + \frac{9}{4}\gamma_3 S^2(p^2 - \frac{1}{3})^2 + \\ & + \frac{9}{4}\mu_1 S(p^2 - \frac{1}{3})(q^2 - \frac{1}{3}) + \frac{9}{4}\mu_2 S^2 p^2 q^2 \end{aligned} \tag{1}$$

In Eq. (1) $p=\cos\theta$ and $q=\sin\theta\cos\phi$ where θ and ϕ are the tilt and azimuthal angles, respectively, measured in a rectangular co-ordinate system with the (x-y) plane in the glass surface and the (y-z) plane chosen parallel with the deposition one. β_i, γ_i, μ_i are temperature independent phenomenological coefficients. The temperature dependence of f_s is contained in the surface order parameter, S.

Following ref.[12], the temperature variation of the tilt angle θ is given by:

$$\cos^2\theta = r + t/S \tag{2}$$

where r and t are combinations of the phenomenological coefficients.

In our case (the director contained in the plane determined by the dielectric deposition), when q=0, which is stable for small values of β_1/β_3, we have:

$$r = \frac{1}{3} - \frac{1}{3}\frac{\beta_2}{\beta_3} + \frac{1}{6}\frac{\mu_1}{\beta_3} \quad \text{and} \quad t = -\frac{\beta_1}{3\beta_3} \tag{3}$$

We supposed a temperature dependence of the surface order parameter similar to the bulk order parameter in the vicinity of the nematic-isotropic transition point[13]:

$$S = \Delta\sqrt{1 - T/T_0} \tag{4}$$

with T the temperature in Kelvin and with the coefficients Δ and T_0 dependent of concentration.

The experimental data presented in §3 and measured as it is described in §2 were fitted by using the phenomenological theory that takes into account the surface anisotropy [12].

2. EXPERIMENTAL

The cells used in the experimental investigations were prepared from planar glass plates, separated by 15μm thick spacers. Two types of the inner surface treatment were used: (I), oblique deposition of SiO_x layer at high incidence angle, and (II), oblique deposition of SiO_x layer of the previous type followed by a PVA deposition from solutions of different concentrations. For the SiO_x deposition, the incidence angle α was high (about 85°). The film thickness corresponds to a 500Å deposition measured at normal incidence as in[14]. For the type (II) treatment, the plates were dipped into the PVA aqueous solution and withdrawn vertically at a constant speed of 1 mm/min. Solutions with the concentration of 0.25-1.5wt% were used. The coated plates were then kept for 30 min at 110°C. The two glasses forming the cell, treated in the same manner, were mounted so that symmetrical boundary conditions were obtained and tilted homogeneous cells were prepared, the tilt angle anywhere in the cell being the surface tilt angle. The cells were filled with 5CB liquid crystal (Aldrich) in the isotropic state. The nematic-isotropic transition temperatures, as measured in the samples, were 34-35°C. The tilt angle vs. temperature for the samples was measured by the null magnetic method with optical detection[15].

3. RESULTS

In Figure 1, the experimental results obtained for samples with (I) type surface are given: in cells obtained with deposition at $\alpha_1 \cong 84.7°$ (open and full circles) and at $\alpha_2 \cong 83.7°$ (open and full squares). We remark that for the samples aligned by SiO_x deposition, at an increasing of about 1° of the evaporation incidence angle in the SiO_x deposition process, the molecular tilt angle increases with about 4° at room temperature.

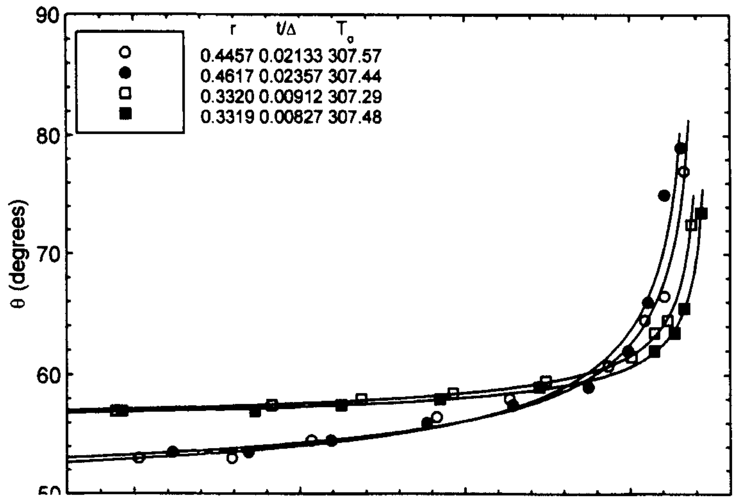

FIGURE 1 Tilt angle, vs. temperature for 5CB on type (I) surface. Experimental points for two pairs of samples: ●, ○ SiO_x deposition at $\alpha_1 \cong 84.7°$, ■, □ SiO_x deposition at $\alpha_2 \cong 83.7°$. Continuous curves are fitting curves obtained by using Eq.(2), with S given by Eq.(4). The fitting parameters are given in insert.

The results for the measured tilt angles for 5CB with the (II) type surface treatments are presented in Figure 2. From this figure, it can be seen that the tilt angle moves toward higher values when the PVA concentration increases.

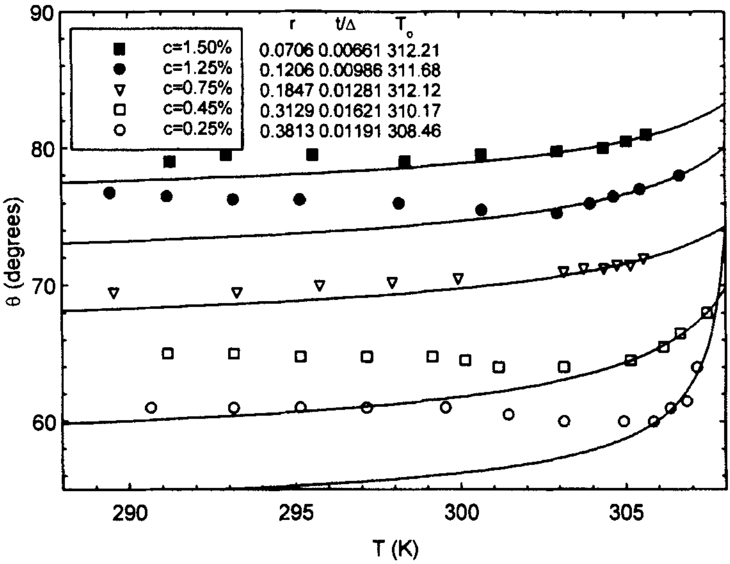

FIGURE 2. Tilt angle, vs. temperature for 5CB on type (II) surfaces. Continuous curves are fitting curves for the tilt angle θ for temperatures in the vicinity of the nematic to isotropic transition. The fitting parameters are given in insert. c is the wt % concentration of PVA solution.

Comparing the results in Figures 1 and 2, we observe that the temperature variation of the tilt angle for the SiO_x covered with PVA surfaces is less important than that of the uncovered SiO_x deposited surfaces.

The azimuthal alignment, parallel to the SiO_x deposition plane, seems to be temperature independent as the extinction position of the samples situated between crossed polarizers was always obtained when the direction of the polarisation was coincident with the evaporation plane of SiO_x.

4. DISCUSSION

The experimental results for the tilt angle dependence on temperature were interpreted by the Landau-de Gennes phenomenological theory applied to surfaces with microtopography[12]. The fit of the experimental results for the tilt angle variation with temperature is represented by continuous curves in Figures 1 and 2 and the fit parameters r, t/Δ and T_0 are given in the figure inserts.

The ratio between surface order parameters for the two studied surfaces is given by:

$$\frac{S_1}{S_2} = \frac{\Delta_1\sqrt{1 - T/T_{o1}}}{\Delta_2\sqrt{1 - T/T_{o2}}} \tag{5}$$

where the index 1 and 2 refer to the surface with SiO_x deposition at $\alpha_1 \cong 84.7°$, and $\alpha_2 \cong 83.7°$, respectively. From the fitting parameters for data in Fig.1 and taking into account that t is independent of the surface anisotropy as it can be seen from Eq.(3), we obtain $S_2 > S_1$. This is in accordance with results from literature[16,18] which show that in cells having substrates with thinner obliquely deposited SiO_x films (which are also less rough[17]), increasing order parameters are obtained.

Calculating the surface order parameter for a temperature in the vicinity of the nematic-isotropic transition, where the fit curves well-describe the experimental data in Fig.2, we obtain increasing S values for cells made with substrates drawn from solutions with increasing PVA concentrations. At increasing PVA concentration an attenuated microtopography is expected to be obtained, so that the result for S variation is in accordance with the literature[16,18].

We observe that the fitting parameters t/Δ for the data in Figs 1 and 2 have small values which, considering that Δ is of the order of unit[13], lead to small values for t, in accordance with the stability condition for the case q = 0.

From the fit coefficients in Fig.2, we observe that r (which depends on the phenomenological coefficient μ_1, connected to the presence of a surface anisotropy) is diminishing for the samples with the surface obtained using increasing concentration solutions of PVA. This is well understood supposing that in the microtopography attenuation process, μ_1 (positive) decreases.

In conclusion we can remark that the main characteristics of the temperature induced surface transitions for 5CB liquid crystal can be described using the phenomenological model in ref.[12].

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