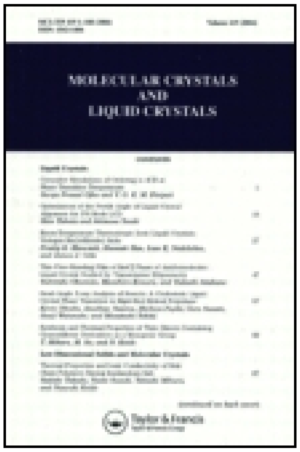

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INFLUENCE OF THE AZIMUTHAL ANCHORING ENERGY ON THE SMECTIC LAYER FORMATION IN FERROELECTRIC LIQUID CRYSTALS

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Abstract We have investigated the influence of surface treatment on the memory angle Θ_m in chevron FLC-cells. Surface anisotropy with different azimuthal anchoring energies was produced either by illumination or by rubbing of a PVA layer containing an azo dye. Due to the low pretilt angle (Θ_p<2°), we suppose that the measured value of Θ_m is governed by the tilt angle δ of the smectic layers. A model is presented which relates the equilibrium value of δ to a balance between the azimuthal anchoring energy and the bend energy of the smectic layers in the chevron structure.

INTRODUCTION

Ferroelectric smectic C liquid crystals (FLC) are an attractive subject for investigations due to their possible applications and a variety of physical properties. Especially, the investigation of the FLC behaviour in thin oriented cells is interesting because these cells are mainly used in applications and because the substrates have significant influence on the macroscopic behavior of the FLC in the cells. The most visible surface influence consists in the appearance of the chevron structure of smectic layers in the SmC* phase. To explain the chevron formation it has been suggested [1] that the smectic layers maintain their SmA anchoring location on the solid substrates. In this paper we consider another possible reason to explain the chevron formation of the smectic layers which is connected with the azimuthal anchoring interaction of the FLC molecules on the substrates.

EXPERIMENT

In the experiments we mainly used photosensitive alignment layers. In this case it is possible to obtain a smaller azimuthal anchoring energy value W_a in comparison with the value due to conventional rubbing. This is confirmed by our investigations of the nematic liquid crystal 4-cyano-4'-pentil-biphenyl (5CB, Merck Chem.Co.) anchored at alignment layers which allow both kinds of treatment. These studies show that the nematic liquid crystal molecules can hardly be reoriented by the subsequent illumination if the molecules were initially aligned by rubbing.

In order to prepare the photosensitive alignment layers, glass substrates were covered with an aqueous solution of poly-(vinyl alcohol), PVA, containing the azo dye Congo Red (Aldrich Chem.Co.). The solution consisted of 0.3wt.% PVA, 0.3wt.% the azodye, and 99.4wt.% distilled water and was spread on the substrate by spin coating at the velocity 3500rpm during 30 seconds. The substrates were dried at the temperature T=100°C for 30min. The prepared cells with a thickness of 2-3 μm were filled with the FLC mixture ZhKSM-1008 (NIOPIK; Moscow) which shows a tilt angle $\Theta=22^{\circ}$ (at T=25°C) of the molecules with respect to the smectic layer normal, and the phase sequence Cr-5°C-SmC*-52°C-SmA-59°C-N*-69°C-I. Subsequently, the samples were illuminated, being kept at T=100°C, i.e. in the isotropic temperature range of the liquid crystal. The linearly polarized radiation from a Xenon arc lamp without any filters was used for this purpose. The power in the UV region (320nm-390nm) was 0.8mW/cm^2. All the measurement were made at room temperature, T=25°C.

The purpose of our experiments was to study how the azimuthal anchoring strength of a FLC at the substrates influences the memory angle[2] Θ_m , which is the angle between the easy axis at the surface and the extinction position of the FLC director. In order to characterize the anchoring strength of differently treated substrates, we measured the anchoring energy of the nematic liquid crystal 5CB on these substrates. In these previous studies[3] we obtained a smooth dependence of the the azimuthal anchoring energy of 5CB on the UV exposure time. Moreover, we found that a second illumination with the plane of polarization perpendicular to the plane of polarization during the first illumination leads to a continuous decrease of the azimuthal anchoring energy. Thus, we conclude that the following kinds of the surface treatment result in an increasing anchoring strength:

(1) no UV illumination of the azo dye containing PVA layer or one short illumination with linearly polarized UV radiation (Figure 1); (2) two subsequent UV illuminations with the planes of polarization perpendicular to each other and limited time of the second illumination; (3) one illumination with linearly polarized UV radiation; (4) conventional rubbing.

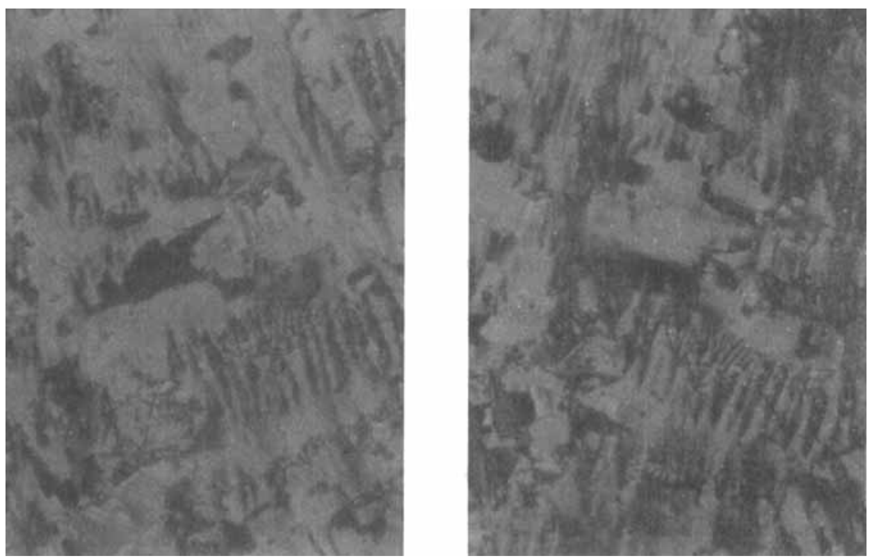

Figure 1 Extinction positions of FLC domaines for different angular positions of the cell with respect to the crossed polarizers. One can see that the angle between the extinction positions for the domains in the centre of the pictures (the angle equals to the double memory angle) nearly corresponds to the 40 degree.

(See Color Plate XII).

Figure 2 shows the influence of substrates treated with methods (1) to (4) on the memory angle Θ_m observed in the ferroelectric liquid crystal. These observations demonstrate qualitatively that the memory angle Θ_m decreases with increasing azimuthal anchoring energy.

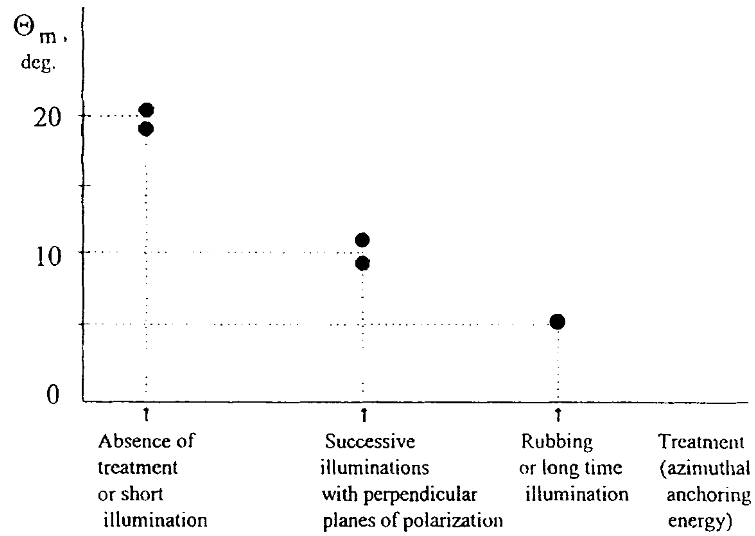

Figure 2 Dependence of the memory angle Θ_m (as defined in the text) versus relative value of the azimuthal anchoring energy W_a in the FLC cells.

MODEL

In order to explain the observed results (Figure 2), let us suppose that the forming of the chevron structure[1,4] of smectic layers is accompanied by a change of the free energy. This change may be connected with the bending of the smectic layers[5,6] at the chevron interface, with increasing of the elastic energy of the c-director deformed profile[5], with influence of the surface edge dislocations[5] or additional reasons. The first factor is, probably, the most significant because just after cooling into the SmC* phase the FLC sample first tries to avoid the chevron monodomain formation[6]. Thus, we based our model on the consideration of the layer bending althouth other factors may also be included in the model.

From the geometry (Figure 3), it follows that a decreasing of the layers tilt angle δ at fixed tilt angle Θ of the molecules in smectic layers results in an increase of the azimuthal angle α of the molecules on the substrate and thus in an increase of the FLC

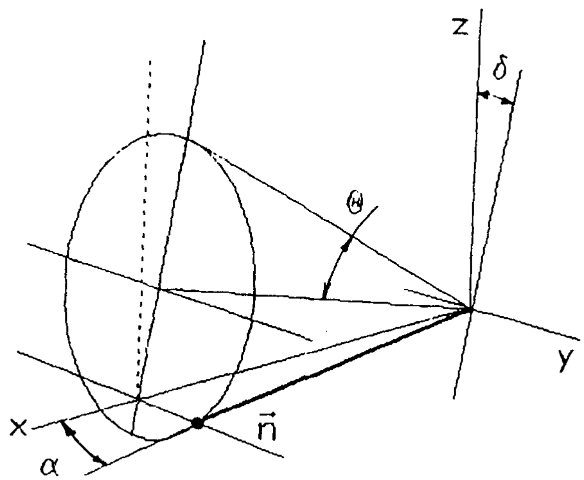

Figure 3 Intersection of the smectic cone with the substrate plane (x,y). Θ : tilt angle of the FLC molecules in smectic layers; δ : tilt angle of the smectic layers with respect to the substrates normal z; α : azimuthal angle of the FLC director n at the substrate with respect to the easy axis x.

azimuthal anchoring energy F_a. The bend energy F_b of the smectic layers can be written as[6] :

$$F_b = \frac{2}{3}\sqrt{K_1 B}\delta^3 \tag{1}$$

where K_1, B are elastic constants of SmC* phase. Using the azimuthal anchoring energy F_a in the approximation by Rapini and Papoular[7]

$$F_a = -\frac{1}{2}W_a \cos^2\alpha \tag{2}$$

we obtain the following expression for the free energy F of the FLC cell, taking into consideration the relation[2] $\cos\alpha = \cos\Theta / \cos\delta$:

$$F = \frac{2}{3}\sqrt{K_1 B}\delta^3 - \frac{1}{2}W_a \cos^2\Theta / \cos^2\delta \tag{3}$$

According to equation (3) under the condition of small values δ, the free energy F is minimized for the following value of the angle δ :

$$\delta = W_a \cos^2 \Theta / (2\sqrt{K_1 B}) \quad (4)$$

Supposing that the pretilt angle values Θ_p of the FLC molecules at the substrates are small and writing the memory angle Θ_m as[2] $\Theta_m = \alpha$, and we finally obtain:

$$\Theta_m = \cos^{-1}(\cos\Theta / \cos[W_a \cos^2 \Theta / (2\sqrt{K_1 B})]) \quad (5)$$

According to the equation (5), the memory angle Θ_m decreases with increasing azimuthal anchoring energy W_a , as observed in the experiment.

DISCUSSION

Besides the layer tilt angle δ , there are some factors which may in principle influence the Θ_m value, e.g. the pretilt angle Θ_p of the FLC molecules on the substrate[2], the distribution of the c-director[2] in the smectic layers and the position of the chevron interface along the substrate normal. In our experimental conditions Θ_p was less then 2°, the c-director distributions were uniform and the cells are supposed to be symmetrical due to the symmetry of the substrate treatment. Thus we suppose that the observed change of Θ_m was mainly due to the change of the layers tilt angle δ . It means that there is a possibility for the FLC molecules at the surface to be shifted along the easy axis in the smectic cells. This was also confirmed by independent experiments[8]. Thus we suppose that the deviation of the FLC molecules from the easy axis is not only hindered by the fixed positions of the FLC molecules on the substrate[1], but by an additional factor. A surface viscosity γ_s of the FLC molecules may be such a reason.

From our previous investigation[9] , it follows that the surface viscosity value γ_s' in nematic liquid crystal cell may under some assumptions be described by the expression:

$$\gamma_s' = \tau(W_a' + K_{22} / \xi_E) \quad (6)$$

where τ is a time constant, $W_a^{'}$ is the azimuthal anchoring energy of the nematic liquid crystal at the substrate, K_{22} is the twist elastic constant, and ξ_E is an electric coherence length[6] . Absence of the electric field in the considered FLC cells gives us the direct connection between W_a and γ_S in the FLC sample. Thus the position of the FLC director n (Figure 3) at the substrates during such a dynamical process as the cooling of the FLC sample into the SmC* phase depends on the surface viscosity γ_s of the FLC molecules and the elastic energy of the smectic layer bending. Such a conclusion may have its consequences in phenomena, for instance, like the rebuilding of smectic layers under high electric fields[10,11] and in the appearence of different chevron states[12] C1 and C2 during the cooling process.

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REFERENCES

1. N.Clark, T.Rieker and J.Maclennan, Ferroelectrics, 85, 79 (1988).
2. N.Itoh, M.Koden, S.Miyoshi and T.Wada, Jpn. J. Appl. Phys., 31, 852 (1992).
3. V.P.Vorflusev, H..-S.Kitzerow and V.G.Chigrinov, "Azimuthal anchoring of liquid crystals at the surface of photo-induced anisotropic films", submitted to Liquid Crystals.
4. T.Rieker, N.Clark, G.Smith, D.Parmar, E.Sirota and C.Safinya, Phys. Rev.Lett., 59, 2658 (1987).
5. P.Oswald and M.Kleman, J.Phys.(Paris), 42, 1461 (1981).
6. P.G. de Gennes and J.Prost, The Physics of Liquid Crystals, Clarendon Press, Oxford, 1993.
7. B.Jerome, Rep.Prog.Phys., 54, 391 (1991).
8. M.Cagnon and G.Durand, Phys.Rev.Lett., 70, 2742 (1993).
9. V.Vorflusev, H.Kitzerow and V.Chigrinov, "Azimuthal surface switching of a nematic liquid crystal", to be published.
10. R.Shao, P.Willis and N.Clark, Ferroelectrics, 121, 127 (1991).
11. V.Vorflusev, Yu.Panarin, S.Pikin and V.Chigrinov, Liq.Cryst., 14, 1055 (1993).
12. J.Kanbe, H.Inoue, A.Mizutome, Y.Hanyuu, K.Katagiri and S.Yoshihara, Ferroelectrics, 114, 3 (1991).