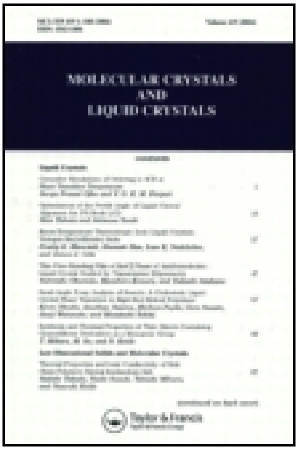

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

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Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2000, Vol. 352, pp. 19-26
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Strength of Memory-Induced Anchoring of 5CB on Bare Untreated ITO

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We realize uniform planar alignment of 5CB on isotropic untreated ITO substrate. The counterplate orientation is "imprinted" on ITO and memorized by adsorption of an oriented nematic layer. We measure the azimuthal and the zenithal anchoring energies. We show that the memory induced anchoring strength is similar to the one usually found for substrates with high anisotropy. Studying rubbed ITO substrate, we show that in this case also the azimuthal anchoring is mainly due to memory effect.

Keywords: nematic 5CB; azimuthal anchoring; zenithal anchoring; anchoring memory

INTRODUCTION

The nematics are anisotropic fluids with long range orientational order. Their molecules are in average oriented along the local nematic director **n** which is very sensitive to external field and to boundary constraints. On contact with a solid substrate, the nematic director on the surface $\mathbf{n}_s$ is usually oriented along some preferred direction $\mathbf{n}_0$ called easy axis, corresponding to a minimum of the anchoring energy $W(\mathbf{n}_s,\mathbf{n}_0)$.An useful approximation is to separate $W(\mathbf{n}_s,\mathbf{n}_0)$ into two parts, allegedly independent, zenithal $W_\theta(\theta_s,\theta_0)$ and azimuthal $W_\varphi(\varphi_s,\varphi_0)$, functions respectively only of the zenithal and azimuthal angles of $\mathbf{n}_s$ and $\mathbf{n}_0$. These energies are periodic functions and can be expanded in Fourier series. Taking only the first term in the expansion gives us the simplest form compatible with the symmetry of the surface, proposed by Rapini and Papoular[1] :

$$W_\theta = 1/2A_\theta \sin^2(\theta_s-\theta_0)$$
$$W_\varphi = 1/2A_\varphi \sin^2(\varphi_s-\varphi_0)$$

where A_θ and A_φ describe respectively the strength of the zenithal and the azimuthal anchoring energy. Comparing A_θ and A_φ with the bulk elastic constant, respectively K_{11} and K_{22}, we obtain the de Gennes[2] zenithal and azimuthal extrapolation lengths $L_\theta = K_{11}/A_\theta$ and $L_\varphi = K_{22}/A_\varphi$. For weak anchoring L is of the order of 1 μm, while for strong anchoring L can be as short as 10 nm. Usually L_φ is much longer than L_θ.

It is commonly accepted that anchoring is due to anisotropic interactions between the nematic and the surface. Zenithal anisotropy always exists, because of the different chemical composition of the nematic and the substrate. On the contrary, to induce an azimuthal anchoring, the surface must be treated. Different anisotropic surface treatments have been used to induce alignment: mechanically rubbed mineral[3,4] or organic substrates[4], ruled or holographic gratings[5] or grazing angle SiO evaporated films[6]. However, the well known flow alignment of the liquid crystals[7,8,9] can not be explained by the substrate anisotropy or the surface topography. In fact, on most of the isotropic or slightly anisotropic substrates the nematic anchoring is completely defined by weak perturbations during the first contact of the nematic with the substrate. After that, this anchoring is rapidly memorized and remains unchanged for a long time, even forever. A strong azimuthal anchoring can be obtained in this way by an adsorption of the nematic molecules on the substrate surface - keeping the initial local orientation, the adsorbed layer serves as a new highly anisotropic substrate[10]. On a longer time scale, an easy axis gliding has been observed[11,12] while an external torque is continuously applied. This easy axis reorientation can be understood as an adsorption-desorption process.

The purpose of this paper is to study the anchoring induced by memory on isotropic substrate. Planar homogeneous orientation of nematic 5CB was obtained on bare indium-tin-oxide (ITO) substrate, that enables us to measure the zenithal and the azimuthal anchoring strength.

The stability of the memory-induced anchoring is verified on one year time scale. We compare the anchoring on untreated and on rubbed ITO layer and we discuss the dependence of the anchoring strength on the surface treatment.

MEMORIZATION OF THE ANCHORING

We prepare thin cells with one plate coated with bare untreated ITO layer (thickness 100 nm) and a counterplate covered with SiO evaporated layer, inducing a good uniform nematic alignment with the strongest possible anchoring (incidence angle 82°5, thickness 14 nm for tilted alignment; incidence angle 60°, thickness 23 nm for planar alignment). The counterplate can be a flat plate or a lens with a weak curvature. The plate and the counterplate are placed in a precision mechanical holder which enables us to vary the thickness of the cell, and to rotate the plate and the counterplate in order to twist the cell.

We start with 10 μm thick cell, filling it with the nematic 5CB in the isotropic phase. Then we cool slowly the sample through the nematic-isotropic transition, while keeping a thermal gradient between the plate and the counterplate. The nematic state appears first close to the counterplate, imposing a strong and uniform anchoring. The alignment is transmitted to the bulk. When the nematic phase touches the untreated ITO substrate, initially isotropic, this orientation is "imprinted" on ITO and rapidly memorized on the surface by adsorption of an oriented nematic layer. This alignment remains stable on one year time scale, without any degradation or gliding of the easy axis (Figure 1).

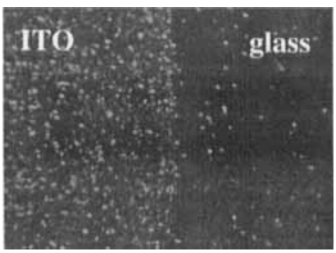

FIGURE 1: Memorized anchoring on isotropic surfaces under crossed polarizers: ITO and glass substrates. One year old sample.

CHARACTERIZATION OF THE MEMORIZED ANCHORING

Measurement of the zenithal anchoring energy

To measure the zenithal anchoring strength, we use a simple anchoring breaking technique[13]. As well known, when a strong electric field is applied on a planar anchoring (with exactly zero pretilt), the anchoring is broken and the molecules align parallel to the surface normal[14,15]. When the field is turned off sharply, hydrodynamical coupling creates half-turn domains, easily observable after the cell relaxation[13]. The condition for anchoring breaking is $L_\theta = \xi$, where L_θ is the zenithal extrapolation length and ξ the electric field correlation length ($\xi = \sqrt{4\pi K / \varepsilon_a E^2}$).

To measure the anchoring breaking threshold E_c we use a SiO evaporated counterplate, defining a tilted alignment, and cell thickness between 1 and 3 μm. For $E<E_c$ we observe short twinkles due to the bulk deformation, then the molecules come back rapidly to their initial orientation, when turning off the field. For $E>E_c$ the transition becomes uniform and sharp, the half-turn domains are easily observed after the end of the electric pulse. The dynamical anchoring breaking threshold E_c is represented on Figure 2 versus pulse duration τ. For long τ, of the order of a millisecond, we obtain the static critical field of the anchoring breaking, enabling L_θ determination. The typical measured value $E_c = 8$ V/μm corresponds to $L_\theta = 21$ nm. This anchoring strength is similar to the usual SiO values[13].

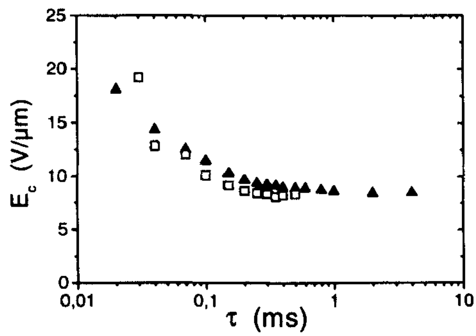

FIGURE 2: Dynamical anchoring breaking threshold versus pulse duration for cell thickness 2.9 μm (▲) and 1.6 μm (□).

Pretilt estimation

Similar technique enables us to detect a possible pretilt of the memorized anchoring. The anchoring breaking described above exists only for planar alignment, with exactly zero pretilt. On the contrary, if both plates have parallel pretilts, there is no anchoring breaking and no creation of half-turn domains. Finally, when the plates have opposite pretilts a first order anchoring breaking is possible[16] because of the topological constraints.

We use these anchoring breaking properties, based on the substrate symmetry, to demonstrate that the memory induced anchoring has no pretilt. We first measure the anchoring breaking threshold in a thin cell, made up with one memory-aligned ITO plate and one counterplate with high pretilt (≈30°). The two plates easy axes are chosen with the same azimuth, to avoid any twist in the cell. Then we rotate the ITO plate at 180° and we wait for the sample relaxation, by defects propagation, to a new untwisted texture (Figure 3). Then we measure again the threshold of anchoring breaking, if any. For planar anchoring, the two geometries are equivalent and we expect an anchoring breaking with the same threshold. For tilted anchoring we expect anchoring breaking only in one of the two geometries, corresponding to inverse pretilt on the two plates (Figure 3b).

In all the cases we observe anchoring breaking in both geometries, with approximately the same threshold. This shows that the pretilt on the plate under study, if any, is negligible (<< 0.1°). This result does not depend on the pretilt of the counterplate during the imprinting of the anchoring: only azimuthal orientation is imprinted, the zenithal one being defined by the strong intrinsic zenithal anisotropy, imposing zero pretilt.

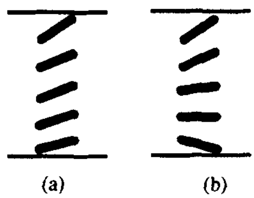

FIGURE 3: Sample geometries for measurement of the pretilt: (a) parallel pretilts, no anchoring breaking is possible, (b) opposite pretilts, first order anchoring breaking is expected.

Measurement of the azimuthal anchoring energy

To measure the azimuthal anchoring strength, we use a simple method, developed in our laboratory[17,18]. The 5CB is placed in a cell, made up with the ITO plate and a glass lens with strong planar anchoring (evaporated SiO). The two substrates are twisted at 90° in order to obtain a strong azimuthal torque in the sample. Due to the symmetry of the cell, we obtain the easy axis deviation $\delta\varphi = \varphi_s - \varphi_0$ on the ITO surface as a function of the local thickness simply by transmission measurements[17]. From the known applied torque and director deviation we obtain the angular dependence of the anchoring energy $W_\varphi(\delta\varphi)$. It is in good agreement with the Rapini-Papoular approximation[1]. The experimental value of the azimuthal extrapolation length $L_\varphi \approx 56$ nm reveals a rather strong anchoring, comparable to the one on the SiO counterplate[17]. However, this value of L_φ is only approximate. Our technique, as the other known azimuthal anchoring measurement methods, is not precise for strong anchorings. The memorized anchoring on the ITO remains stable even under the strong mechanical torque applied during the measurements. We do not observe anchoring gliding, at least on the 30 minutes time scale of the present experiment. The observed high strength and stability of the memorized azimuthal anchoring can be attributed to a high density of the oriented adsorbed 5CB layer on ITO.

COMPARISON OF THE ANCHORINGS OBTAINED BY RUBBING AND BY MEMORIZATION

An additional experiment enabled us to compare directly the anchoring "imprinted" on untreated ITO with the one obtained by unidirectional mechanical rubbing. We start by rubbing on velvet the ITO plate, masking half of it to leave it untreated. Then we imprint the counterplate alignment on the ITO substrate as described above, but at 45° azimuthal angle respective to the rubbing direction. On the untreated half-plate, we observe, as before, imprinting and memorizing of the alignment imposed by the counterplate. On the rubbed half-plate we observe also good uniform alignment, deviating at 20° from the counterplate easy axis and at 25° from the rubbing direction (Figure 4). The alignment is rapidly memorized and does not change further.

This intermediate orientation of the resulting easy axis shows that during the first contact with the rubbed ITO, the nematic is sensitive to both bulk torque and anchoring torque, due to the rubbing. At the first moment there is an elastic torque equilibrium. Then the adsorbed layer grows up on the rubbed ITO, oriented along the instantaneous equilibrium, and this orientation is memorized in the same way, as on the untreated half-plate. From our observations and the known sample thickness during the elastic equilibrium, we estimate the extrapolation length of the anchoring induced by the rubbing to be few micrometers. We conclude that the anchoring strength induced by the rubbing is two orders of magnitude weaker than the one obtained by memory effect.

To confirm this, we measure the anchoring strength in both regions: rubbed and unrubbed. Both azimuthal and zenithal anchoring strengths are studied by the techniques described above. The results, obtained simultaneously on the two sides of the line separating the two regions, are exactly the same, showing that the rubbing anisotropy is negligible compared to the memory.

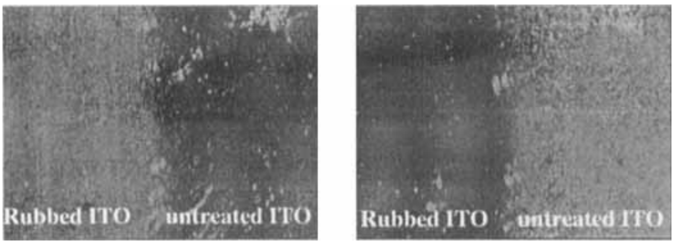

FIGURE 4: Both photographs are taken under crossed polarizers, rotated to minimize respectively the transmission of the untreated or the rubbed ITO regions.

CONCLUSION

Our study demonstrates that a strong and uniform planar anchoring can be imposed on isotropic substrate, by imprinting the counterplate alignment on the surface and memorizing it. Once memorized the anchoring remains stable at least on one year time scale. The azimuthal anchoring strength, due to the memory, is quite large ($L_\varphi \approx 56$ nm), comparable to the usual value for anisotropic substrates. The anchoring direction can be imprinted and memorized also on anisotropic substrate, in our case rubbed ITO. We observe that the resulting easy axis on ITO is defined during the first contact with nematic by the instantaneous equilibrium between the bulk torque and the rubbing induced anchoring. After memorization, the azimuthal anchoring strength seems independent from the rubbing, showing that the elastic rubbing contribution is negligible compared to the memory-induced anchoring strength[19]. The zenithal anchoring on our ITO substrates seems independent from memory effects. We do not succeed to imprint a pretilt on ITO or on bare glass. We attribute this to the strong intrinsic zenithal anisotropy of the substrates, dominating completely all the relatively weak memory effects, visible in azimuthal geometry. For both rubbed and untreated ITO we measure the zenithal extrapolation length L_θ = 21 nm. This value is in the usual strong anchoring range.

Acknowledgments

This work was supported by the European Community Grants C15CT960744 (Copernicus Program) and BRRT-CT97/5003 (SALC-NET Thematic Network).

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