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A Tool to Control the Nematic Surface Alignment: Anchoring Competition

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The problem to obtain a suitable surface texture for a nematic liquid crystal is dealt by means of the fine control of the anchoring properties of independent surface aligning attractors. This approch allows to obtain monostable oblique and planar surface directors and even bistable anchoring conditions. Both cases of azimuthal and zenithal anchorings are considered. Experimental observations are made using composite surfaces with thin superposed different aligning layers. Phenomenological models are used to describe the experimental results and to suggest new applications of this point of view, that can be easily extended to all mesomorphic materials.

Keywords: liquid crystals; nematic; anchoring

1. Introduction

The experimental study of physical properties of mesogenic materials often requires the confinement of these liquids in a cell and, in this case, the equilibrium texture assumed by the material, in absence of external fields, mainly depends on the properties of the boundary surfaces. This is particularly true for the nematic phase, which is the simplest mesophase: nematic liquid crystals (NLC) are in fact just anisotropic

liquids with a common alignment direction for their elongated molecules[1]. The practical making of a defined NLC specimen hence requires the knowledge of specific surface treatments to control the interaction between the NLC molecules and a solid substrate[2].

The pioneer work of Mauguin and Grandjean about the liquid crystal alignment on solid crystal substrates showed that the distinct orientations of the optical axis were in simple relation with the symmetry of the crystal substrate[3][4]. Later on, Berreman examined the aligning effect of glass surfaces rubbed with diamond paste on leather and observed micro-grooves along the rubbing direction. By assuming that the molecular alignment was locally parallel to the profile of the grooves, his calculations showed that the minimum of the elastic energy due to the distortion induced by the surface morphology corresponds to the NLC alignment along the grooves themselves[5]. This is the model also invoked to explain the NLC alignment induced by rubbed polymer films, even if it is known that, in this case, other interface properties play a role in the final macroscopic alignment. For instance, when a polystyrene film is unidirectionally rubbed, the NLC aligns perpendicularly with respect to the rubbing direction[6], in contrast with the Berreman elastic model. To explain the NLC alignment on rubbed polymer films, Geary and Goodby proposed a model in which the reorientation of the polymer chains due to the rubbing process is considered[7].

Other methods developed to obtain an uniform surface NLC alignment are the oblique vacuum-deposition technique[8] and the "optical buffing"[9]. The first one allows to obtain anisotropic surface roughness that can induce planar or oblique monostable anchorings and the very interesting bistable oblique surface alignment[10][11][12]. The second one is based on the optically induced surface anisotropy. Photosensitive polymer films can be, for instance, photopolymerized by means of linearly polarized light, then inducing uniform planar NLC alignment[13]. This effect is explained by means of irreversible photochemical reactions inside the polymer layer[14].

In general, when a nematic material is in contact with a solid substrate, several sources of anchoring can act at the same time to define the state of the interface. Short range interactions, as the steric one, and long range interactions, as anisotropic van der Waals forces[15], can be present in the surface nematic layer. Moreover, ion-absorption, surface polarizations, elastic deformations and order variations can influence the state of the nematic interface, drastically changing its

properties with respect to the bulk ones on distances that range from a few tens to several hundreds of Angstroms[16].

In this paper, we present a new approach to the fine control of the surface state of a nematic. The basic idea is to generate different anchoring sources that can be independently controlled to obtain a well defined surface alignments. In this sense, we can refer to this technique as the result of a kind of "anchoring competition"[17].

Let us consider a solid substrate in contact with a nematic and let us imagine the possibility to have two different anchoring sources *1* and *2* characterized by two alignment directions $\mathbf{n}_1$ and $\mathbf{n}_2$ and two associated anchoring strengths W_1 and W_2. If $W_1 >> W_2$, the nematic molecules will follow the surface direction imposed by the anchoring field *1*. While, in the opposite case, $W_2 >> W_1$ the nematic adopts the alignment imposed by the anchoring field *2*. The situation becomes more interesting when W_1 compares with W_2. Now, the final orientation cannot be easily foreseen. In principle, the delicate balance of energy could result in any reasonable solution: final alignment along $\mathbf{n}_1$ or along $\mathbf{n}_2$ or in any intermediate direction.

In the following, we will present some experimental results that can be analyzed in terms of anchoring competition, with the related phenomenological description. Both cases of zenithal and azimuthal anchorings will be considered and finally a novel method to obtain a true bistable nematic anchoring will be presented.

2. The screening effect

In this section, we will present the properties of the zenithal alignment of a nematic in contact with a thin layer of a rubbed polyimide film deposited on a solid substrate inducing a degenerate planar anchoring. The influence of the solid substrate on the zenithal anchoring properties is studied by investigating the variation of the nematic pretilt angle as a function of the polymer film thickness.

Our system may be considered as a junction of three different media: a solid substrate, a polymer layer of thickness *l* and a nematic (Fig. 1).

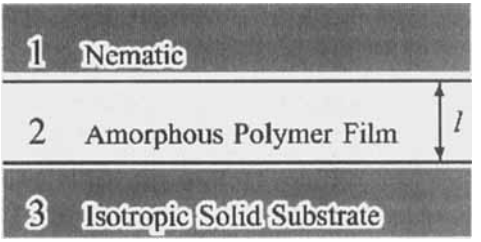


Figure 1: Solid substrate covered by a polymer layer of thickness l. The system nematic liquid crystal-polymer film-solid substrate may be considered as a junction of three different media.

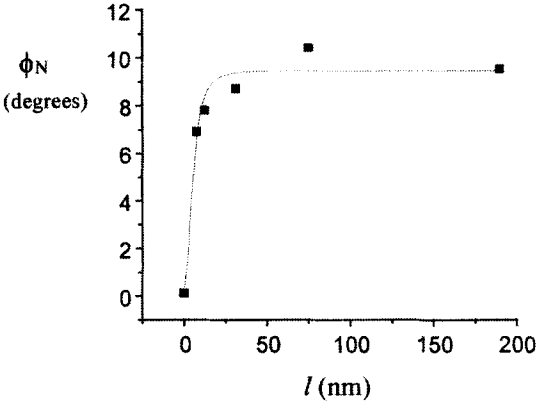


Figure 2: Experimental results for the nematic oblique orientation *vs* the polymide thickness and the best fit obtained by means of the model presented in section 2. The observed anchoring transition, from the planar orientation to the tilted one, can be explained by means of the screening effect of the polymer film on the anisotropic Van der Waals interaction from the lower substrate.

Figure 2 shows the experimental values of the nematic pretilt angle ϕ_N versus the polymer thickness [18]. ϕ_N is observed to increase from a planar orientation ($\phi_N = 0$), in absence of polymer film, to the typical tilted alignment given by the rubbed polyimide ($\phi_N \approx 10°$) when l grows to a few hundred Angstroms.

The total free energy for unit surface of this junction is

$$f = f_{12} + f_{13} + f_{23} \tag{1}$$

The term f_{23}, corresponding to the polymer-substrate interaction, can be neglected as it is expected to be independent of the nematic orientation. The term f_{12} takes its origin from the steric-like interaction between the nematic and the polymer and has the form:

$$f_{12} = \frac{u_{13}}{2} \sin^2(\phi_N - \phi_P) \tag{2}$$

where ϕ_p is the anchoring attractor for the polymer.

In a first approximation, f_{13}, that is due to the anisotropic van der Waals interactions between the nematic and the solid substrate, can be written in the form:

$$f_{13} = \frac{u_{13}}{2l^3} \sin^2(\phi_N - \phi_S) \tag{3}$$

where ϕ_N is the actual nematic easy axis, ϕ_S is the anchoring attractor for the substrate and u_{13} is a constant connected to the material polarizability. Note that the anchoring strength of f_{13} scales with l^3, taking into account the screening effect of the polymer layer.

Minimizing f with respect to ϕ_N, one obtains:

$$tg(2\phi_N) = \frac{w_{13}(l)\sin(2\phi_S) + u_{12}\sin(2\phi_p)}{w_{13}(l)\cos(2\phi_S) + u_{12}\cos(2\phi_p)}, \tag{4}$$

where $w_{13}(l) = \frac{u_{13}}{l^3}$.

Figure 2 shows also a fit $\phi_N(l)$ of the experimental values. This fit is made using equation (4). It can be seen that this simple model is in quite good agreement with the experimental values. It seems that such anchoring transition can be explained just by means of the growing

screening of the van der Waals-like interactions between the nematic and the solid substrate due to the increasing thickness of the intermediate polymer layer.

The order of magnitude of the screening thickness, defined as the thickness above which the solid substrate does not contribute any more to the NLC orientation, is about 100Å. It can be estimated by calculating the anchoring energy strength as a function of the polymer thickness l. In the sense of Rapini-Papoular[19], it is given by

$$w_{RP} = \left(\frac{d^2 f}{d\phi_N^2} \right).$$

$w_{RP}(l)$ is reported on Figure 3. One can clearly see that w_{RP} drastically decreases when l increases to reach a constant value, corresponding only to the interaction nematic-polymer, at $l \approx 100$Å. The saturation value of w_{RP} should correspond to the thickness limit above which the van der Waals-like interactions between the nematic and the solid substrate are no longer efficient. This thickness could be referred as a "screening length".

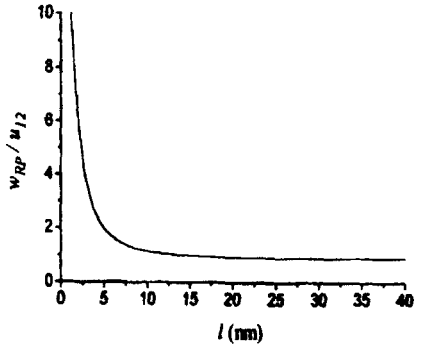


Figure 3: Anchoring energy strenght, in the case of screening effect, evaluated for ϕ_N minimizing the total surface energy per unit area (eq.1). Note that for $l \to 0$ the anchoring strenght is strong. w_{rp} reaches a constant value for $l \geq 100$ Å.

The screening length is a critical parameter in the anchoring competition frame. We have observed similar phenomena in other systems. For instance, a kind of screening effect has been clearly found by using oblique evaporated SiO plates further coated by amorphous poly-(vinyl-alcohol) (PVA). In this case, the azimuthal component of the anchoring is affected.

The SiO film was deposited under vacuum with an angle of about 75° with respect to the surface normal. Its thickness was measured by using a quartz balance perpendicular to the deposition beam: the material deposited on the balance corresponds to a film of 100Å thickness. The PVA layer was obtained by deposition of a PVA solution on the SiO substrate by spin-coating. The PVA material, from Aldrich, is 87-89 % hydrolyzed and has a molecular weight distribution between 31 000 and 50 000. We used different PVA concentrations (0.2, 0.5, 1 wt %) to vary the PVA film thickness. These films were then dried at 100°C for one hour. No further treatment was performed on the PVA layer.

To study the alignment properties of such a plate, built up with an amorphous PVA layer on an anisotropic SiO substrate, the nematic material (5CB, 4'-n-pentyl-4-cyanobiphenyl) was confined between this plate and a homeotropic one, making a hybrid cell. The homeotropic treatment was obtain by coating a clean ITO-glass plate with a solution of DMOAP (dimethyl octadecyl 3 (trimethoxysilil) propylammonium chloride) (10^{-3} wt%).

The cell was observed, between crossed polarizers, under a polarizing microscope. It turned out that for PVA concentrations lower than 0.5%, corresponding to a film thickness smaller than 100Å, a homogeneous planar NLC alignment is obtained along the orientation imposed by the SiO layer. Whereas, when the thickness increases, a degenerate planar alignment is observed.

We have to recall that when a PVA layer is deposited on an isotropic substrate, for instance a clean glass plate, the nematic takes a degenerate planar orientation, independently of the layer thickness. It appears evident that, in our case, the alignment effect of the anisotropic SiO layer on the nematic material is lost only when the thickness of the polymer layer is larger than the screening length.

3. Surface transition induced by anchoring competition

In this section, we will consider a more general case of a nematic subjected to two different anisotropic attractors. First of all, we will take into account the situation of a zenithal anchoring transition determined by submitting a starting homeotropic nematic anchoring to a destabilizing position dependent surface external field[17]. We will show that depending on the value of the surface anchoring strength, an anchoring transition can be induced from the starting homeotropic state to a planar orientation through intermediated states. In a second part, we will consider the case of an azimuthal anchoring competition[20]. The anchoring properties of a nematic on two superposed aligning layers giving distinct azimuthal anchoring directions will be analyzed. We will also show that special geometries can give true bistable anchoring conditions.

3.1 Zenithal anchoring competition

Let us consider a nematic sample having a shape of a slab of thickness *d*. The two boundary plates give a homeotropic alignment of finite anchoring strength *w*. The NLC director is assumed to lie in a vertical plane and depends only on the *z* coordinate. The geometry of the problem is shown in Figure 4. The free energy of the nematic slab, in one constant approximation, is given by

$$F = \frac{1}{2} w \sin^2 \phi_0 + \frac{1}{2} \int_{-d/2}^{d/2} \left[k\phi'^2 - u(z) \sin^2 \phi \right] dz \qquad (6)$$

where k is the nematic bulk elastic constant, $\phi(z) = \cos^{-1}\left(\bar{n} \cdot \bar{k}\right)$ is the tilt angle, $\phi_0 = \phi\left(\pm \frac{d}{2}\right)$. The bulk term $u(z)\sin^2\phi(z)$ represents the coupling between the nematic and a position dependent external field $u(z)$. We will assume $u(z)$ to be of the form:

$$u(z) = u(-z) = u_0 \frac{\cosh(z \cdot \lambda)}{\cosh(d\ 2\lambda)} \qquad (7)$$

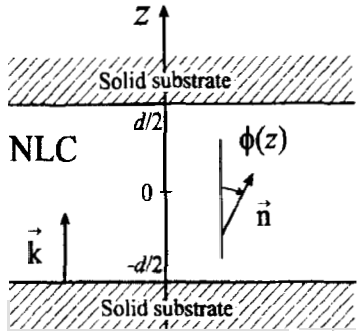


Figure 4: Geometry of the analyzed problem. A nematic slab of thickness d is considered, $\vec{n}$ is the nematic director, ϕ is the tilt angle and $\vec{k}$ is the geometrical normal to the surface.

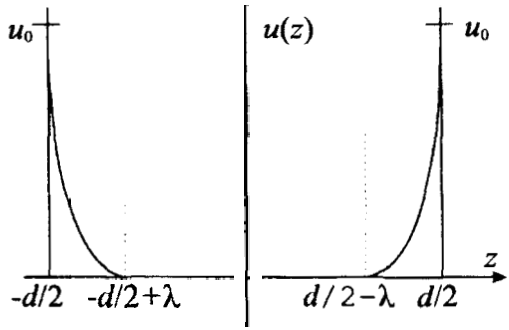


Figure 5: Dependence of the anisotropic interaction energy strenght u *vs* z. *u(z)* is different from zero in a microscopic layer of thickness λ.

Hence, the external field is present only on two surface layers of thickness λ as can be seen on Figure 5. λ is a characteristic length which is, for instance, in the order of 10^3Å in the case of van der Waals forces. In equation (6), the sign of the external field term is chosen to

destabilize the starting homeotropic orientation. This destabilizing effect will give rise to an anchoring competition with the elastic-like surface aligning field. In order to analyze the stability of the starting homeotropic state ($\phi = 0$) with respect to the other possible states, let consider the two limits $\phi \to 0$ and $\phi \to \pi/2$.

In the case $\phi \to 0$, at the second order in ϕ, equation (6) writes

$$F = \frac{1}{2} w \phi_0^2 + \frac{1}{2} \int_{-d/2}^{d/2} \left[k \phi'^2 - u(z) \phi^2 \right] dz . \tag{8}$$

Since ϕ is expected to be an even function of z and assuming a weak anchoring, one expects a significant variation of ϕ with z only in the layer of thickness λ close to the surfaces. However, we can separate out a constant value, ψ, in the bulk and a term, different from zero, only in the two layers.

$$\phi(z) = \psi + \Phi \frac{\cosh(z/\xi)}{\cosh(d/2\xi)} \tag{9}$$

where $\psi+\Phi=\phi_0 \neq 0$. ξ is a typical length characterizing the distortion and, in the following, it will be taken in the order of λ, to simplify the description ($\xi=\lambda$). By substituting equation (9) into equation (8) one obtains:

$$F = \frac{1}{2}(w - A)\psi^2 + (w - B)\psi\Phi + \frac{1}{2}(w - C + D)\Phi^2 \tag{10}$$

where

$$A = \int_{-d/2}^{d/2} u(z) dz = 2\lambda u_0 \tanh\left(\frac{d}{2\lambda}\right),$$

$$B = \int_{-d/2}^{d/2} u(z) \frac{\cosh(z/\lambda)}{\cosh^2(d/2\lambda)} dz = \frac{u_0}{2} \frac{d + \lambda \sinh(d/\lambda)}{\cosh^2(d/2\lambda)},$$

$$C = \int_{-d/2}^{d/2} u(z) \frac{\cosh^2(z/\lambda)}{\cosh^2(d/2\lambda)} dz = \frac{u_0 \lambda}{6} \frac{\sinh(3d/2\lambda) + 9\sinh(d/2\lambda)}{\cosh^3(d/2\lambda)},$$

$$D = \frac{k}{\lambda^2} \int_{-d/2}^{d/2} \frac{\sinh(z/\lambda)}{\cosh^2(d/2\lambda)} dz = \frac{k}{2\lambda^2} \frac{\lambda \sinh(d/\lambda) - d}{\cosh^2(d/2\lambda)}.$$

Minimizing F, one obtains that the homeotropic state ($\psi = \Phi = 0$) is stable when

$$w > w_1 = A \qquad \text{if } D < C$$

or

$$w > w_2 = A + B^2/(D-C) \qquad \text{if } D > C$$

For D>C, the homeotropic state becomes instable when $w^* = w_2$. This means that some other state begins to have lower energy, leading to an anchoring transistion.

For D<C, the anchoring transition occurs for $w^* = w_1$.

In the other limit, $\phi \to \pi/2$ (planar orientation), we can write $\phi = \pi/2 - \theta$ and consider $\theta \to 0$. Now, equation (6) becomes:

$$F = \frac{1}{2}(w - A) - \frac{1}{2} w \theta_0^2 + \frac{1}{2} \int_{-d/2}^{d/2} \left[k\theta'^2 - u(z)\theta^2 \right] dz \qquad (11)$$

By taking

$$\theta(z) = w + \Theta \frac{\cosh(z/\lambda)}{\cosh(d/2\lambda)} \qquad (12)$$

where $w + \Theta = \theta_0$ and by minimizing F, one obtains that the planar orientation state $w + \Theta = 0$ is stable when

$$w < w_3 = A - \frac{B^2}{D + C} \qquad (13)$$

We obtain that, for $w > w^{**} = w_3$, the planar state begins to be unstable. Note that $w^{**} < w^*$.

We can then stress that two second-order transitions[17] appear at anchoring strengths w^* and w^{**}, which are, in general, different from $w_1 = A$. In fact, when lowering the surface anchoring strength w, a first anchoring transition occurs at $w = w^*$ from the starting homeotropic orientation to a distorted state, then a second transition, from the distorted state to a planar one, is present at $w = w^{**}$. We have to underline that the distorted state can be stable in a quite narrow region of the anchoring strength values. In practice, for $w^{**} < w < w^*$, all the oblique orientations between the homeotropic and planar ones are possible.

This calculation shows that a zenithal anchoring competition could be created when a nematic is submitted to two anchoring sources: in the described case, the starting homeotropic anchoring could be due to short range NLC-substrate interactions, while the destabilizing position dependent external field could be due to long range anisotropic NLC-substrate interactions. The actual nematic state is tightly dependent on the surface anchoring strength.

3.2 Azimuthal anchoring competition.

Obviously, the anchoring competition could be also used to control the azimuthal anchoring. For instance, the case of nematic alignment on rubbed polystyrene films, cited in the introduction, could be the effect of a kind of competition between two different sources of azimuthal alignment: the rubbing direction and the polymer chain alignment. The eventual orientation of the polymer chains may lead to an anisotropic distribution of the phenyl side groups which implies strong steric and/or anisotropic van der Waals interactions between the nematic and the polystyrene surface. Such interactions may dominate to the detriment of the fact that the minimum elastic deformation of the NLC slab is obtained with an alignment along the micro-grooves due to rubbing, according to the Berreman model.

In our laboratory, attempts to create an azimuthal anchoring competition, using polymer films twice rubbed in two distinct directions, usually fail because the second rubbing treatment always seems to determine the final nematic surface orientation. Save the fact that rubbing is a very hard mechanical treatment, we think that a factor useful to get an actual anchoring competition mechanism is to use anchoring fields generated by different sources. For example, short range NLC-surface interactions against long ranges ones as demonstrated in the previous section.

In this section, we present a new technique which allows to reach controllable surface anchoring transitions for the azimuthal alignment. The basic idea is to use surface anchoring competition conditions between two superposed aligning films. We take advantage of the screening phenomenon described above. We already know that for a polymer thickness lower than the screening length, the nematic molecules feel the anchoring properties of the solid substrate onto which the polymer film is deposited. In the section describing the screening effect, we considered an isotropic solid substrate coated by a

thin polymer film: the zenithal anchoring transition occurred by varying the polymer layer thickness. Now, instead of an isotropic substrate, one can use an anisotropic solid surface coated by a polymer with a thickness smaller than the screening length: the condition of the anchoring competition could be created by treating the polymer film to induce an azimuthal alignment direction different from that imposed by the anisotropic substrate.

Our experiment has been done by using a low roughness SiO coated glass plate as lower anisotropic substrate. The SiO layer alone gives a monostable planar nematic orientation perpendicular to the SiO deposition beam. The upper second film is a very thin layer of photosensitive polymer which can be linearly photopolymerized (LPP)[13]. Figures 6a and 6b show the geometries of our system. Two cases are considered. In the first one, the x-axis coincides with the planar orientation P induced by the SiO coating, the y-axis identifies the planar nematic orientation L given by the LPP and hence P is perpendicular to L. In the second one, P is always oriented along the x-axis, but L is in the plane x-y at 45° with respect to P. The z-axis is always directed towards the bulk of the nematic material.

The SiO film was chosen to present a low surface roughness in the order of a few tens of Angstroms, to allow an uniform deposition of the upper polymer film. The photopolymer used in this work is poly-(vinyl 4-methoxy-cinnamate) (PVMC), by Rolic. It was dissolved in NMP (n-methyl pyrrolidone) and deposited by spin coating. The thickness of the photopolymer layer was varied by changing the PVMC concentration.

The LPP process was achieved by exposition to the wide spectrum UV light of three 15 W HNS-OFR fluorescent lamps by Osram, with samples placed at a distance of about 10 cm from the lamps.

The incident light was linearly polarized by means of a UV dichroic polarizer Oriel 27320.

We observe that, for a PVMC concentration of 0.2%, the nematic follows the alignment direction imposed by the SiO surface, while for a PVMC concentration of 0.3% the nematic aligns along the direction given by the LPP. The critical thickness l_c corresponds to a PVMC concentration of 0.25 % and it is about 30 Angstrom[20].

We found that the final azimuthal surface orientation ϕ strongly depends on the UV exposure time. Figure 8a shows the measured ϕ values versus the UV exposure time t in the case $P \perp L$. Two distinct and equivalent orientations directions, symmetric with respect to the y-axis are obtained. Such experimental results are not so surprising, because of

the symmetry of the investigated anchoring competition ($P \perp L$) which allows both left and right rotations of the surface director during the transition from P towards L.

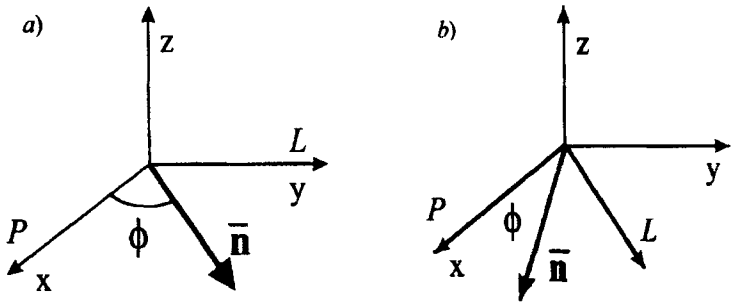


Figure 6: Geometry of the two analyzed systems. *a*) The *x*-axis coincides with the planar orientation P induced by the SiO coating, the y-axis identifies the planar nematic orientation L given by the LPP and hence P is perpendicular to L. b) P is always oriented along the x-axis, but L is in the plane x-y at 45° with respect to P. The z-axis is always directed towards the bulk of the nematic material.

This means that for each ϕ orientation, it exists also a twin director $\pi-\phi$. This anchoring is really bistable because, if such a sample is heated at a temperature about 10°C above the nematic melting point and it stay in its isotropic phase for a few minutes, when it is cooled down to the nematic phase, the local surface director can change from one to the other possible alignment directions. Two pictures of the bistable anchoring are reported in figures 7a and 7b.

In the case when L is at 45° from P, we observe a single rotation of the starting anchoring direction P towards L with intermediate monostable planar anchorings. These experimental data are reported in figure 8b.

To explain this behavior, we assume that the orienting effect of the SiO film is mainly due to the elastic energy associated with the topography of the SiO. The anchoring energy related to the nematic-SiO surface interactions, according to the Berreman model is given by

$$f_{SiO} = \frac{1}{2} w_{SiO} sin^2 \phi \tag{14}$$

The orienting effect of the polymer can be connected to anisotropic van der Waals interactions and it is expressed by

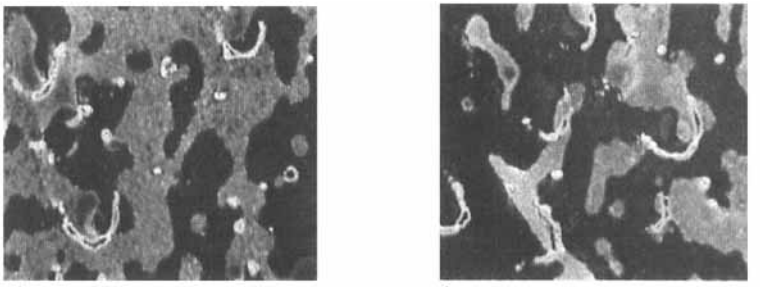
$$f_{pol} = -\frac{1}{2} w_{pol} sin^2 \phi + \frac{1}{4} b sin^4 \phi \tag{15}$$

where ϕ is the azimuthal angle of the NLC surface director taken with respect to the x-axis. The term $\frac{1}{4} sin^4 \phi$ is connected to the effect of a stochastic contribution to the surface energy coming from the random distribution of the orienting photopolymer film[21].

The total free energy per unit area of the system is then given by

$$f = f_{SiO} + f_{pol} = -\frac{a}{2} sin^2 \phi + \frac{b}{4} sin^4 \phi \tag{16}$$

where $a = w_{pol} - w_{SiO}$



a) *b)*

Figure 7: A bistable cell is observed between crossed polarizers. *a)* The optical axis of the dark region is aligned along one of the two polarizers. *b)* The sample is rotated to obtain the light extinction condition for the other region.

The minimization of the last expression with respect to ϕ leads to three possible solutions:

$$\phi = 0; \quad \phi = \frac{\pi}{2}; \quad \phi = \frac{a}{b}. \tag{17}$$

For $a<0$, the stable state corresponds to $\phi = 0$ and the nematic follows the orientation imposed by the SiO substrate.

For $a>b$, the stable state is $\phi = \pi/2$ and the NLC anchoring direction is given by the LPP.

For $0<a<b$, the nematic adopts an intermediate azimuthal orientation between the two planar attractors P and L.

There exist at least two simple ways to control this intermediate azimuthal anchoring direction: one is to vary the photopolymer thickness within a very narrow range around the critical thickness l_c, defined by the situation of equal anchoring energy of both attractors ($w_{SiO}=w_{pol}$) the other way is to vary the UV-exposure time of the photopolymer. We found that varying the UV-exposure time is more feasible with good reproducibility.

Let us consider the simple expression for w_{pol}

$$w_{pol} = R\left(1 - e^{-t/\tau}\right), \tag{18}$$

where R characterizes the highest energy strength of the photopolymer film after a sufficiently long irradiation time and τ is connected with the dynamics of orientation of the chemical bonds[13][14].

A critical exposure time τ_c is then defined by

$$R\left(1 - e^{-t_c/\tau}\right) = w_{SiO} \tag{19}$$

For $t<t_c$ the aligning SiO layer dominates and the NLC molecules lie along the P direction. While for a $t>t_c$ second critical time t_c^* is defined by $a>b$:

$$R\left(1 - e^{-(t/\tau)}\right) - w_{SiO} > b. \tag{20}$$

For $t > t_c^*$ the orienting field of the photopolymer dominates and the NLC director aligns along the L direction.

For $t_c < t < t_c^*$, from equation (17), we obtain

$$\sin^2\phi(t) = \frac{R\left(1-e^{-t/\tau}\right) - R\left(1-e^{-t_c/\tau}\right)}{C\left(1-e^{-t/\tau}\right)} \qquad (21)$$

if one consider, in a first approximation, $b \propto w_{pol}$ i.e $b=C(1-e^{-(t/\tau)})$ where C is a suitable constant.

This last result, in practice, means that, if the thickness of the polymer layer is the critical one, all possible surface orientation ϕ in the range (P, L) can be, in principle, obtained by using only the UV exposure time as a control parameter.

Fits of the experimental data, made by using equation (21), are reported in figures 8a and 8b. The agreement can be considered satisfactory.

4. Conclusion

In this paper, we presented a new approach to the solution of the practical problem to control the surface alignment of a nematic liquid crystal. By using superposed thin anisotropic films, that play the role of different anchoring sources, we obtain composite surfaces that are characterized by different anchoring attractors. By changing the relative associated anchoring strength, one can induce continuous alignment transitions between the surface attractors.

The case of zenithal anchoring is described by invoking the competition effects of short and long range surface interactions. In the simple case of an aligning substrate, coated by a thin anisotropic layer, the short range interactions are responsible of the nematic alignment effect of the upper film, while the long range interactions are written as van der Waals-like terms and their anchoring strength can be controlled by the film thickness.

The "anchoring competition" is achieved when the anchoring strengths of the two aligning sources are comparable. Experimental observations related to the fine control of a monostable oblique surface alignment are reported.

A more general model based on a position dependent destabilizing surface field is developed.

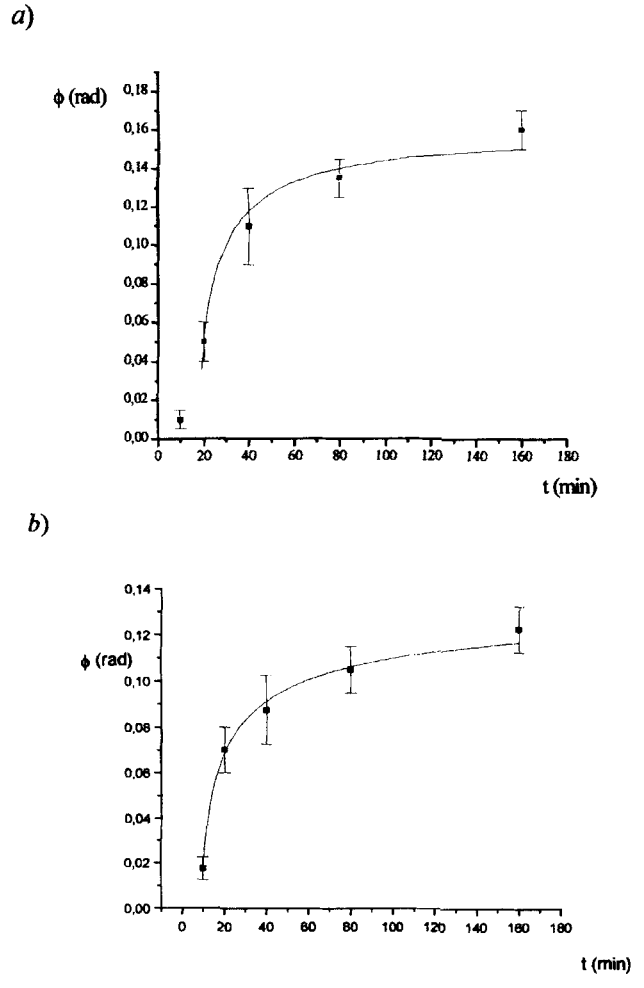


Figure 8: Experimental values of the azimuthal anchoring direction ϕ *vs* the exposure time t with a fit made by means of the theoretical curve of equation (21). *a*) in the case $P \perp L$, two distinct and equivalent orientation directions, symmetric with respect to the y-axis, are obtained. This plot shows only one of the two symmetric ϕ values. *b*) In the case when L is at 45° from P we observe a monostable planar anchoring.

The azimuthal anchoring competition is particularly interesting because this approach allows to obtain true bistable anchoring conditions. Up to now, the only way to obtain a nematic bistable anchoring was a delicate SiO under vacuum coating at grazing incidence[10][11]. The presented technique indicates a general method to achieve multistable anchorings. It is enough to obtain the correct conditions for the anchoring competition and to choose a suitable symmetry for the anchoring attractors.

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