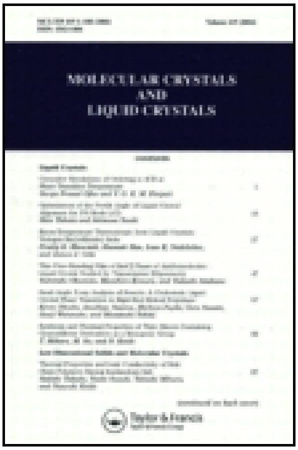

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# Textures in Thin Free Suspended Nematic Liquid Crystal Film

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# Textures in Thin Free Suspended Nematic Liquid Crystal Film

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In this paper we are concerning the orientational properties of free suspended nematic liquid crystal films. The experiments showed that orientation can be either homeotropic or planar. It is found that the orientation depends on the time during which the film was cooling from isotropic state to the liquid crystal one. For the slow cooling the liquid crystal had always homeortopic orientation, for the fast cooling the resulting structure is planar. The analysis shows that the realized structure depends on a defect created in the film during cooling from isotropic state.

*Keywords:* freely suspended films; hybrid orientation

## INTRODUCTION

The liquid crystal molecules have a preferred orientation on a bounding surface. The angle, $\theta$, that they form with the surface in the absence of applied field defines the easy orientation of the average molecular axis (director $\mathbf{n}$) and is important measure of the liquid crystal - surface interaction. The interfaces at which orientation has been mostly studied are those with solid substrate (see for example review [1]). However, a full understanding of the physical mechanisms responsible for the easy orientation of the director at these interfaces has not yet been reached. The problem can be greatly simplified if one consider the case of the interface between a nematic liquid crystal (NLC) and its vapor (free surface). In this case the only polar angle of the director orientation are fixed at interfaces and the molecular interactions do not fix the azimuthal orientation. There was considerable activity in experimental and theoretical studying of an nematic layer with one or two free surfaces [2]. The observed phenomena at an air-nematic liquid crystal interface can be summarized as follows [3-9]: i) the easy director orientation of 5CB nematic liquid crystal is orthogonal at the free surface [9]; ii) the free suspended liquid crystal films of MBBA exhibit the both planar or orthogonal orientation depending on the thickness of the film as well as on the temperature [7,8]. In this work we will consider the special case of the thing free suspended nematic liquid crystal 5CB films. The films exhibit two type of molecular distribution within the layer in dependence on the time during which NLC was cooled from isotropic state to the nematic one. For the slow cooling the resultant stationary state is homeotropic one with uniform director distribution along the normal to the surface. For the fast cooling the stationary state of liquid crystal layer becomes highly birefringent with random distribution of director.

## EXPERIMENT

To suspend liquid crystal films the copper foil 10 μm thick was used with a square holes of 450 μm and distance between neighboring holes is 50 μm. The 5% solution of liquid crystal 5CB in hexane was dropped on the foil. When hexane evaporated, the liquid crystal forms uniform films within the holes. After this the foil with liquid crystal films was placed in the microscope heating stage (HS1-i, Instec, Inc.). The temperature was changed with the accuracy of 0.03 K. The thickness of the liquid crystal films was determined by interference microscopy method.

## RESULTS AND DISCUSSION

The orientation of molecules in freshly prepared free suspended liquid crystal films was homeotropic. The typical profile of the films is shown on Figure 1. The nematic film profile doesn't change during the heating to isotropic state and cooling back wile the director distribution within the liquid crystal layer suffers the drastic change. To perform the experimental measurements, the temperature of liquid crystal films on

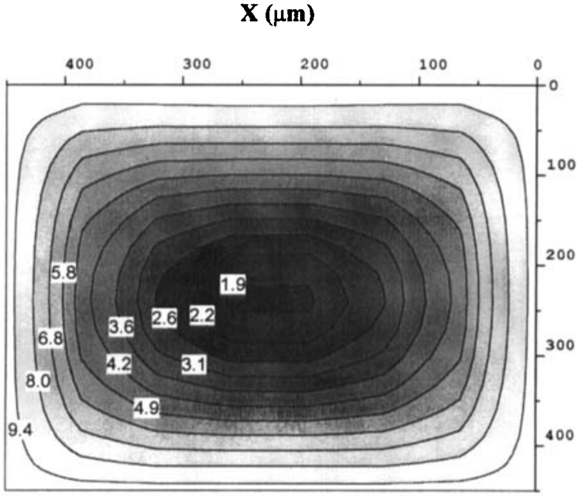


FIGURE 1 Thickness profile of free standing nematic liquid crystal film.

the copper foil was set slightly above temperature of nematic - isotropic transition, $T_{NI}$. In our case the $T_{NI}$ is 34.6 °C and temperature we began was 50 °C. Gradually decrease the temperature with the range of 0.01 °C per second one can observe the phase transition and then the process of setting of director alignment in the layer. The textures we observed are represented on Figure 2a. In the final state the director is uniform aligned along the normal to the surface. Increasing the rate of cooling up to 0.5 °C per second one can observe that some of the liquid crystal layers exhibit highly birefringent texture that can be classified as a schlieren texture. The textures that appear during cooling with the rate of 0.5 °C/s are shown on Figure 2b. In this case of fast cooling, cooling rate is 3 °C/s, schlieren texture becomes dominated final state, see Figure 2c. Additional heating or cooling within the nematic phase does not influence on already obtained structure.

To understand this phenomena, let us consider the nematic layer with the profile shown on Figure 1 in the right-handed coordinate system were the **z** axis coincides with the normal to the layer.

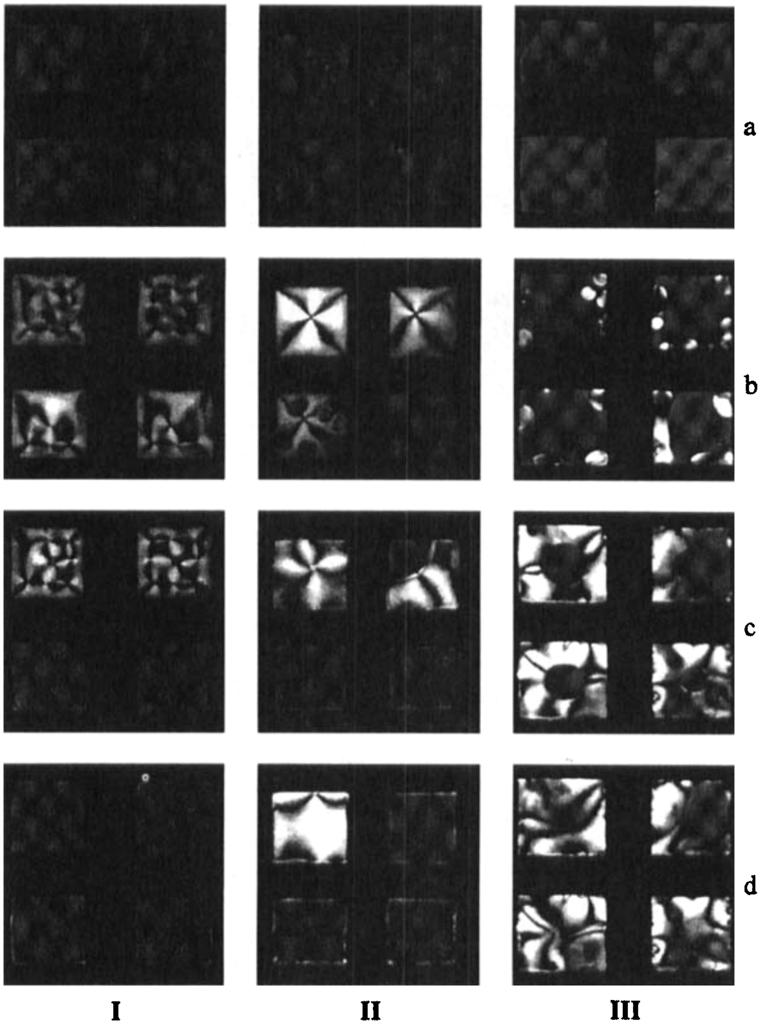


FIGURE 2 Textures observed in freely suspended nematic liquid crystal films during cooling from isotropic state to nematic one. Cooling rates are: I) 0.01 °C/s; II) 0.5 °C/s; III) 3 °C/s.

The behavior of the nematic liquid crystal layer is described by the total free energy [10]:

$$F_d = \frac{1}{2}\int d\mathbf{r}\left\{K_{11}(\nabla\mathbf{n})^2 + K_{22}(\mathbf{n}\nabla\times\mathbf{n})^2 + K_{33}(\mathbf{n}\times\nabla\times\mathbf{n})^2\right\}, \quad (1)$$

were $K_{11}$, $K_{22}$, $K_{33}$ are elastic constants, $\mathbf{n}$ is the director. For a general case one can define director in the form $\mathbf{n} = (\sin\theta\cos\varphi, \sin\theta\sin\varphi, \cos\theta)$, were $\theta = \theta(\mathbf{z})$ is the angle that describes the tilt of the director along $\mathbf{z}$ axis, and $\varphi(\mathbf{z})$ is the azimuthal angle in the plane of the cell. Taking the $\frac{\partial\theta}{\partial z} = \frac{\theta(d)-\theta(0)}{d}$, for the homeotropic orientation of liquid crystal one can obtain free energy per unit area as follows:

$$F_H = K_{33}\left(\frac{\theta_0}{d}\right)^2 d + W\theta_0^2, \quad (2)$$

were $d$ is the thickness of the cell, W is the anchoring coefficient for nematic-air interface, $\theta_0$ is the angle that describe the inclination of nematic layer [11]. Taking into account $K_{11}$= 6.2 $\times 10^{-12}$ N, $K_{33}$= 8.25$\times 10^{-12}$ N [12], W= 4$\times 10^{-6}$ J/m$^2$ [9], d = 8 μm and $\theta_0$= 0.02 rad. (see Figure 1), we can find from (2) that $F_H = 12.25\times10^{-10} J/m^2$. This energy is minimal and corresponds to homeotropically aligned liquid crystal layer. Any other structure will possess higher energy [13]. The schlieren texture, we observe during fast cooling, is more likely double hybrid [14,15], since the complete violation of surface anchoring is not energetically preferable. To transform from double hybrid structure to hopmeotropic one the liquid crystal layer should overcome the state with higher free energy. It can be domain walls for $d < b$ or surface lines for $d > b$ [16], where $b = K/2W$ is the extrapolation length. The total energy for the wall is equal to $E_W = \pi\sqrt{2dK_{22}W} = 4.3\times10^{-5} J/m^2$ [16], where $K_{22}$= 3$\times 10^{-12}$ N [17]. The total energy for the surface line is equal to $E_L = 2\pi K_{22} = 1.9\times10^{-5} J/m^2$ [16]. In this case to realize homeotropic alignment, the liquid crystal layer should overcome the state that has higher free energy.

To summarize, in free suspended nematic liquid crystal layer two stable texture can be observed, homeotropic or schlieren. The main reason of such behavior is cooling rate. For the sharp cooling of free suspended liquid crystal film from isotropic state, a number of crystallization centers will be created. Thus, one can expect the existence of domain walls or surface lines. Since the schlieren texture has intermediate value of free energy between homeotropic structure and defects, this texture becomes energetically preferable.

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