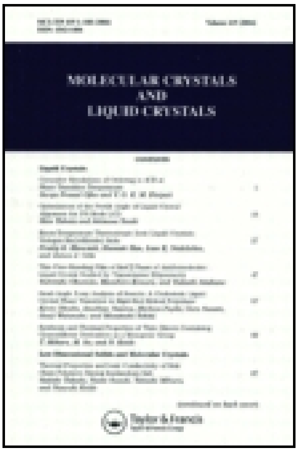

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Orientation of Nematic Liquid Crystals on Random Anchoring Surface

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Orientation of Nematic Liquid Crystals on Random Anchoring Surface

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We report on the studies of LC orientation on random aligning surface. We developed a method of obtaining a surface with random distribution of the easy axis orientation. Alignment of 5CB LC in a cell consisted of a reference regular aligning surface and a random aligning surface was studied. We recovered angular distribution of the domains' orientation for different cell thickness. We observed a transformation of initially uniform random angular director distribution to the anisotropic distribution with a preferable axis along rubbing direction on the reference substrate as the cell thickness decreases.

Keywords liquid crystal; random anchoring; alignment

INTRODUCTION

Bounding surfaces play a crucial role in liquid crystals behaviour in confined geometry. In particular, the surface aligns director along a particular 'easy' direction. Depending on the symmetry of molecular interactions at the interface, the easy direction can be a unique axis or it can be degenerate with respect to rotations around the normal to the substrate.

The present paper takes a fresh approach to the research and development of alignment layers for liquid crystals. Previous research focused on strong, uniform anchoring of liquid crystals, where spatial fluctuations of the orientation of the liquid crystal were negligible. Only recently alignment of liquid crystal on untreated or weakly anchoring materials has been explored[1]. In this paper we present studies of liquid crystal orientation on randomly aligning surface.

RANDOMLY ALIGNING SURFACE

We studied an orientation of nematic LC 4'-n-penthyl-4-cyanobiphenyl (K15, Merck) on an untreated photoaligning polymer. The experiments were carried out in combined cells, where LC is sandwiched between reference and tested surfaces.

Reference surface - glass substrate covered by the rubbed polyimide - provides a strong anchoring along the rubbing direction. The other substrate was covered with para-pentoxy-cinnamate cellulose, which provides a degenerated planar alignment of K15.

LC was injected into the cell in isotropic phase state (T=50°C) to avoid flow influence on the director orientation. After filling the cell was placed onto a cooler with the tested surface facing it to create temperature gradient across the cell. Nematic phase nucleated at the tested surface, which was colder, and then propagated towards the upper substrate. In this way, alignment of the LC at the tested polymer layer was determined mainly by anchoring properties of the tested surface, namely, by a spatial distribution of the easy axis on the surface.

To reveal initial distribution of easy axis orientation a thick cell (60 microns) was assembled first. Polarising microscopy demonstrated spotted inhomogeneous pattern at the bottom plate: there are domains of the same director orientation (figure 1). The boundaries of the domains are either smooth with a continuous director reorientation or sharp with director singularities at disclinations.

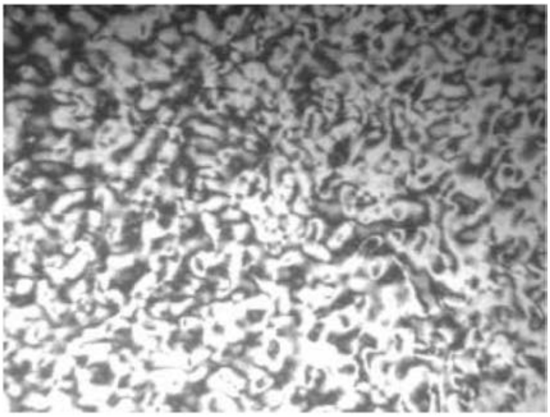

FIGURE 1 Texture of liquid crystal on randomly aligning surface in polarising microscopy

To quantify randomness of the director alignment in the cell we measured intensity of light transmitted through the cell in the polarising microscope. The reference rubbed surface faced polariser of the microscope, with the rubbing direction being parallel to the polariser. A photodiode was placed on the polarising microscope to measure intensity of light transmitted through the cell. Rotating the analyser, we obtained angular distribution of the transmitted light intensity. Angular distribution of the intensity turned out to be uniform (figure 2)

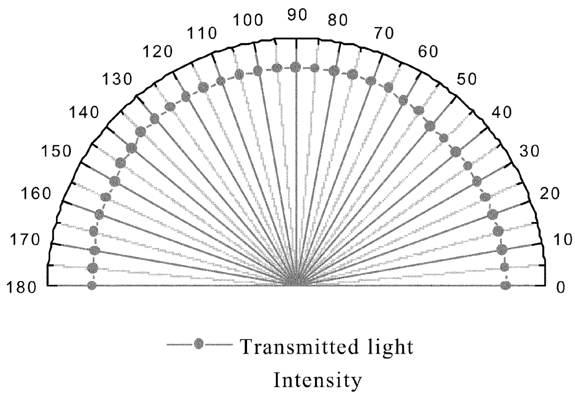

FIGURE 2 Angular dependence of the transmitted light intensity for a thick cell

The spherical symmetry of the intensity angular distribution allows us to conclude that angular distribution of domain orientation is uniform. Thus, we produced a random aligning surface, i.e. distribution function of easy axes orientation equals 1/ð.

Angular distribution of domain orientation for the constant anchoring energy

Consider nematic LC cell of thickness L. Suppose that bottom aligning substrate (rubbed surface $z = 0$ with easy axis parallel to *OY*), provides infinitely strong director anchoring. At upper substrate we have finite degenerate planar anchoring, i.e., at $z = L$ anchoring parameter $\xi = \frac{WL}{K}$

is finite and distribution function of easy axes orientation has the form $f_0(\phi_0)=\frac{1}{\pi}$.

For each domain with easy axis direction ϕ_0 at upper substrate in one elastic constant approximation, director profile satisfies the Euler-Lagrange equation

$$\frac{d^2\phi}{dz^2}=0$$

and boundary conditions

$$\phi(z=0)=0,$$
$$\left.\frac{d\phi}{dz}+\frac{1}{2}\xi\sin 2(\phi-\phi_0)\right|_{z=L}=0$$

Solution to this boundary value problem is

$$\phi=a\frac{z}{L},$$

where parameter $a=\phi(z=L)$ should be found from the equation

$$2a+\xi\sin 2(a-\phi_0)=0$$

The last equation describes mapping $\phi_0\Rightarrow\phi_1\equiv\phi(z=L)$, therefore, one can introduce the distribution function of director orientation at the upper substrate, $f(\phi_1)$.

At the upper substrate:

$$2\phi_1+\xi\sin 2(\phi_1-\phi_0)=0,$$

since $\max(\phi_0)=\pi/2$, then maximum value for ϕ_1 can be found from the following equation

$$2\phi_1+\xi\sin 2(\phi_1-\pi/2)=0,$$

$$\text{or } 2\phi_1 - \xi \sin 2\phi_1 = 0$$

Since for the constant anchoring energy all domains with easy axes lying within $d\phi_0$ around ϕ_0 will align into $d\phi_1$ area around ϕ_1, i.e.

$$f_0(\phi_0)d\phi_0 = f(\phi_1)d\phi_1$$

we find

$$f(\phi_1) = f_0(\phi_0)\frac{d\phi_0}{d\phi_1} = \frac{1}{\pi}\frac{1+\xi\cos 2(\phi_1-\phi_0)}{\xi\cos 2(\phi_1-\phi_0)}$$

$$= \frac{1}{\pi} + \frac{1}{\pi}\frac{1}{\sqrt{\xi^2 - 4\phi_1^2}}$$

On Figure 3 we plot distribution function $f(\phi_1)$ for different values of anchoring parameter ξ.

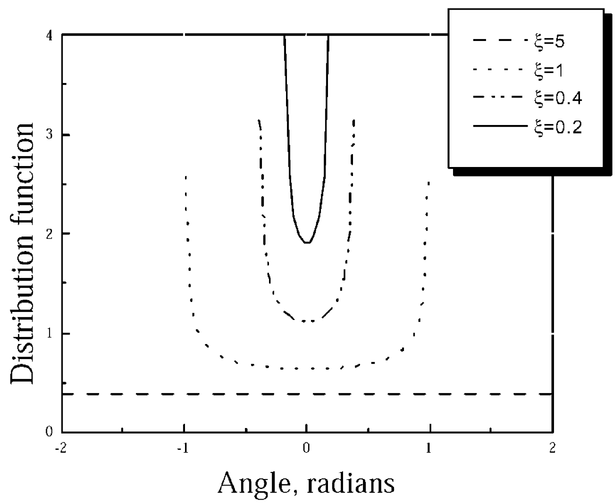

FIGURE 3 Angular distribution of domain orientation for different values of anchoring energy

EXPERIMENTAL RESULTS AND DISCUSSION

Decreasing thickness of the cell leads to increasing elastic torque, which forces domains to realign. Therefore angular distribution of the intensity changes breaking the spherical symmetry, and preferable direction along the rubbing appears.

In this case measuring intensity of the transmitted light does not allow one to recover distribution function of domain orientation since intensity we were measuring is an integral quantity

$$I(\phi) = \int_0^{\pi/2} f(x)\cos^2(\phi - x)\,dx$$

To determine the domain distribution function LC cells were studied with a digital camera through a polarising microscope. It allowed getting knowledge of the spatial distribution of the easy axis over the aligning surface. Therefore, we captured series of images corresponding to consequent analyser positions.

We developed algorithm, recovering distribution of the domains' orientation. Consequent images were stacked in 3D matrix of grey-scale intensity. Then for each domain we search through the matrix for the analyser position giving the minimal intensity value. Finding it allows us to conclude that director orientation of the domain makes up 90 degrees with the corresponding analyser position. Changing cells' thickness we could observe transformation of uniform domain distribution (for a thick cell) to a distribution with a sharp maximum along the rubbing direction (for a thin cell). Numerical processing of the digital images gives following distribution functions for different values of cell thickness (figure 4):

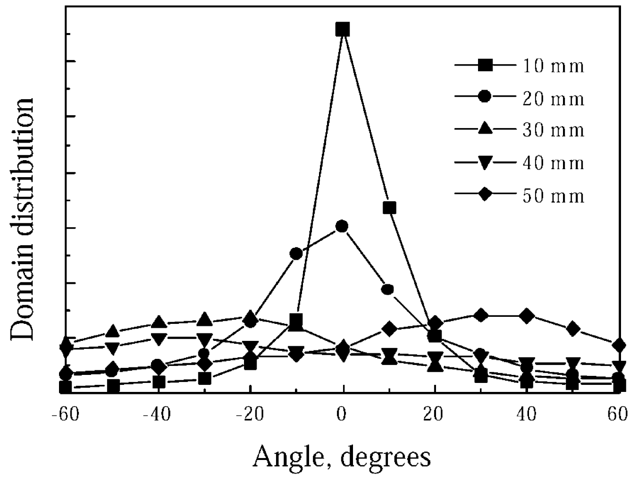

FIGURE 4 Angular distribution of domain alignment for different cell thickness

How can the discrepancy of theoretical and experimental results be substantiated?

First, theory considers the constant anchoring energy W, while there might be a certain spread of the anchoring energy values.

Second, theory assumes immediate orientation of LC on the tested substrate, while finite (and in fact unknown) time of LC molecules' adsorption onto the polymer surface would lead to drifting of the easy axis orientation. To clarify the nature of the effect additional experiments are required.

CONCLUSIONS

Untreated surface of para-pentoxy-cinnamate cellulose provides random anchoring of nematic liquid crystal.

We developed method of determining the angular director distribution, which allowed us to find out that in a thick cell domains are evenly distributed over all orientations. As the cell thickness decreases, a maximum of distribution function appears. The maximum position coincides with the rubbing direction on the opposite substrate. We believe that obtained results indicate that either easy axis is not formed instantly, or anchoring energy spreads over the certain range of values.

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