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SURFACE DRIVEN ORIENTATION EFFECT IN NLC CELL

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Abstract The surface driven effect of a director reorientation in a nematic liquid crystal (LC) cell caused by the light induced anisotropy in an aligning material is considered. The anisotropy was produced due to molecular phototransformations onto the aligning surface or into the LC bulk.

The important function of the aligning surface in the processes of LC director orientation and reorientation in a LC cell is widely known. Interaction on the LC-solid surface interface and its main parameter, the anchoring energy, determine operating characteristics of orientational effects, which are the basis for LC devices functioning.

In "volume" orientational effects, governed by external actions applied to the entire LC volume, an aligning surface only specifies the boundary conditions of the process. Recently another type of orientational effect has been demonstrated[1-4]. LC orientation control has been realized by changing the properties of the aligning surface itself. This surface driven orientational effect (SDOE) can be observed in the presence of photosensitive orientants for LC alignment[1,2]. Such orientants offered new interesting prospects both for LC orientation and LC orientation control by changing the aligning surface

through altering the light field parameters (power, wave length, polarization). It has been pointed out that induced change of the anisotropic part of the LC-aligning surface interaction defined by the anchoring energy W_0 is of primary importance in SDOE[4] .

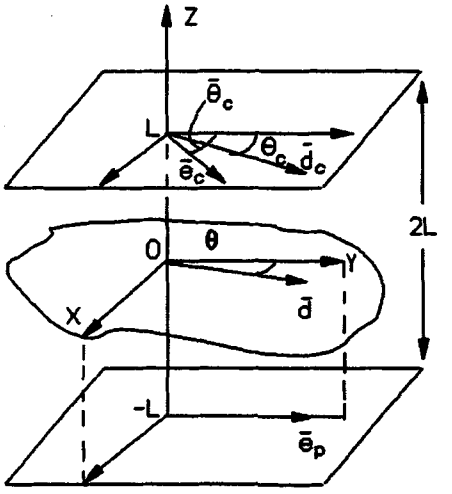

FIGURE 1

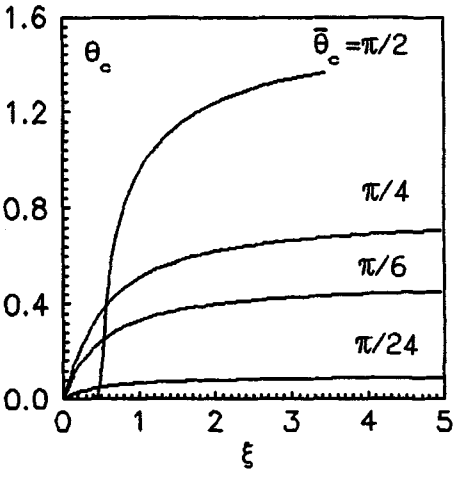

FIGURE 2

Here we present a new theoretical consideration and several experimental realizations of SDOE for LC director reorientation in a LC cell planarly aligned by photosensitive orientants. The calculation is based on a model, in which director reorientation is associated with the appearance of a new easy axis and the increase of anchoring energy. Threshold and nonthreshold SDOE are described and realized experimentally.

Let us consider the system, shown in Fig.1. A nematic LC is sandwiched between two aligning plates. The bottom plate is a passive one. Director $\vec{d}_p$ is aligned along the easy axis direction $\vec{e}_p = (0,1,0)$ on this surface and the anchoring energy W_p is supposed to be infinitely large. The top plate is the control surface. At initial state the

anchoring energy W_c equals zero. Therefore the initial directions on the surface $\vec{d}_{c,o}$ and in the volume d are determined by the orientation of the director on the passive surface ($\vec{d}_c$ is parallel to $\vec{d}_p$).

Suppose that the light illumination results in the appearance of an easy axis $\vec{e}_c$ on the control surface. Moreover, the anchoring energy W_c is the function of light exposition $E_{ex} = P_{ex}\, t_{ex}$ (P_{ex} is a light power, t_{ex} is a time of illumination). We also suppose that the director characteristic reorientation time is much shorter than the anchoring energy variation time. In this case director distribution is determined by the minimum of total free energy at each instant of time. As the director reorientation occurs in the XY-plane the total energy density per unit surface takes the form:

$$F = \frac{K_2}{2}(\theta'_z)^2 dz - \frac{W_p}{2}\cos^2(\theta(-L)) - \frac{W_c}{2}\cos^2(\theta(L)-\bar{\theta}_c), \quad (1)$$

where K_2 is the Frank's constant, $\vec{d} = (\sin\theta, \cos\theta, 0)$ and θ is the angle between $\vec{d}(z)$ and $\vec{e}_y$. The angle $\bar{\theta}_c$ is the angle between $\vec{e}_c$ and OY.

The standard procedure of the minimization of the total free energy leads to the equation, describing the director field between surfaces:

$$\frac{d^2\theta}{dz^2} = 0, \quad (2)$$

and to the following boundary conditions:

$$K_2\theta_z'(L) = \frac{W_c}{2} \sin\,(2(\theta(L) - \bar{\theta}_c)),$$

$$K_2\theta_z'(-L) = -\frac{W_p}{2} \sin(2\theta(-L)). \qquad (3)$$

The solution of the equation (2) takes the form $\theta_c = Az+B$, where A and B are the constants to be determined from the boundary conditions. In the case of fixed director orientation on the passive surface ($W_p = \infty$) we get the following equation for the constant A:

$$\sin(x - 2\bar{\theta}_c) = -\frac{x}{2\xi}, \quad x = 4AL, \qquad (4)$$

where $\xi = W_cL/K_2$ is the anchoring parameter.

The numerical solutions for θ_c at different values of $\bar{\theta}_c$ are shown on Fig.2. In all cases the angle θ_c increases with the rise of ξ, i.e. W_c is growing. When $\xi \geqslant 10$ direction of $\vec{d}_c$ does not considerably differ from that of the induced easy axis. In the case of $\bar{\theta}_c = \pi/2$ the solution of equation (4) exists only for $\xi \geqslant \xi_{th} = 1/2$, so the reorientation shows some threshold character. For every LC and cell thickness the critical parameter $\xi_{th}=1/2$ determines the anchoring energy value $W_c^{th} = K_2/2L$, from which threshold director reorientation should take place, if the forcing action is orthogonal to the initial director. "Threshold" light field intensity E_{ex} for every particular pair LC-photosensitive aligning surface is determined by the peculiarities of the interaction between LC and control surface.

Experimentally threshold and nonthreshold SDOE has been observed for the first time in a planarly aligned NLC cell with well known photoresist material polyvinylcinnamate (PVCN) as a photosensitive orientant. Experiments

were performed in a composite LC cell, which consisted of a rubbed polymer coated substrate as a passive surface and PVCN thin film coated quartz substrate as a control one. Director reorientation has been obtained for the theoretically considered conditions for different θ_c values.

Under the illumination of linearly polarized UV light, the interaction of PVCN film with LC molecules becomes anisotropic, and new easy axis $\vec{e}_c$, perpendicular to the UV light polarization direction, appears on the control surface[2]. As a result twist like reorientation of the cell director distribution is observed, if the induced $\vec{e}_c$ does not coincide with $\vec{e}_p$. Measurements were carried out using the experimental set up shown in Fig.3. The exposure light field was formed by a Hg lamp (1), a

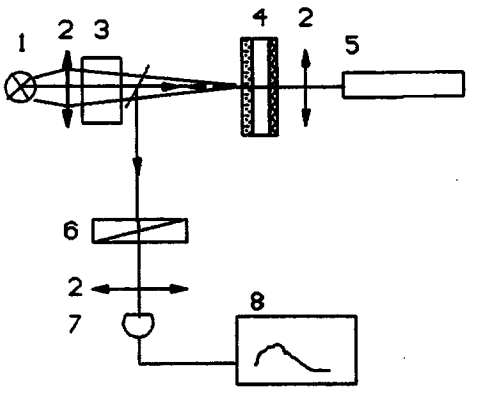

FIGURE 3

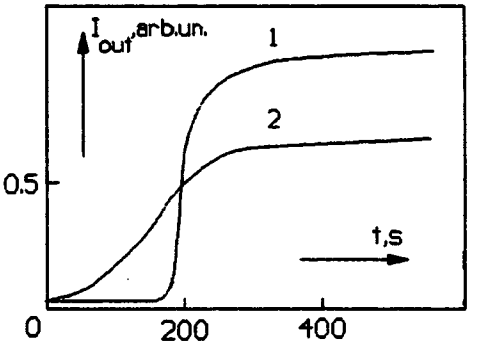

FIGURE 4

lens system (2) and a polarizing Glan-Tomson prism (3). The cell was put in the position 4 and irradiated from the side of the PVCN coated substrate. The illuminated area was tested by a weak beam of a He-Ne laser (5) (λ_t= 0.63 μm). The vector $\vec{E}_t$ of its polarization was

parallel to the direction $\vec{d}_p$. After having passed the cell, the test beam went through a polarizer (6), the transparent axis of which was perpendicular to $\mathbf{E}_t$, and was detected by a photodiode (7) connected with a computer (8) through a PCLAB-807 card.

Under our experimental conditions the Mauguin regime was realized, that is the vector $\mathbf{E}$ follows the direction $\vec{d}(\theta)$ through the whole cell. Therefore the intensity of light after the polarizer (6) is determined by the Malus law:

$$I_t^{out} \sim I_t^{in} \sin^2\theta_c(I_{ex}).$$

So, there was a one-to-one correspondence at each instant of time between the detected signal and the direction $\vec{d}_c(t)$, determined by the equation (4).

The experimental curves demonstrating the kinetics of director reorientation $\vec{d}_c(t)$ in the case of threshold geometry ($\bar{\theta}_c = 90°$, curve - 1) and nonthreshold one ($\bar{\theta}_c = 55°$, curve - 2) are shown in Fig.4. Some evaluations of the light induced anchoring energy W_c can be made. At the threshold point W_c^{th} corresponds to the calculated value $\xi = K_2/2L$. In our case $K_2 \sim 5\times10^{-7}$ dyne, $2L = 50$ μm, hence $W_c^{th} = 0{,}5\times10^{-4}$ erg/cm^2. The observation in a polarizing microscope shows that the final orientation of $\vec{d}_c$ virtually coincides with the induced easy axis $\vec{e}_c$. This implies that $\xi \geqslant 10$, and a saturation value of $W_c \geqslant 2\times10^{-3}$ erg/cm^2.

Similar results on SDOE has also been obtained for the modified polyvinylcinnamate doped with dye molecules of methyl red (MR of saturated concentration, which exhibits anisotropic interaction with LC molecules under the illumination of polarized light in the blue-green spectral range (He-Cd laser beam))[5].

In the experiments described above the easy orientation axis $\vec{e}_c$ was induced through the phototransformation of molecules, inserted into the aligning layer.

However, $\vec{e}$-axis may also arise during the light action on the molecules, initially solved in the LC bulk[6].

For the first time we observed a phenomenon of this type by accident during recording polarizing sinusoidal holographic gratings in the LC bulk. LC was doped by MR molecules and planarly aligned by rubbed polyimide or illuminated PVCN layers. The formation of polarizing hologram was a result of phototransformation of MR molecules placed in the anisotropic matrix[7]. The lifetime of such a hologram is determined by the diffusion time of the phototransformed molecules for the period Λ of hologram grating and should be about 1 s in our case (Λ= 20 μm).

However, our measurements revealed that besides the reversible component characterized by the time $t \approx 1$s there is another component of a hologram which does not vanish in the absence of laser light. Apparently, the permanent grating recording may be caused only by the

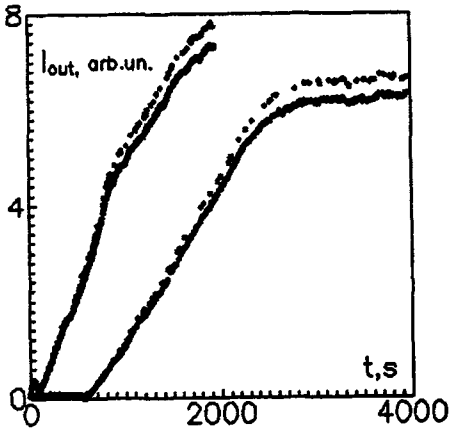

FIGURE 5

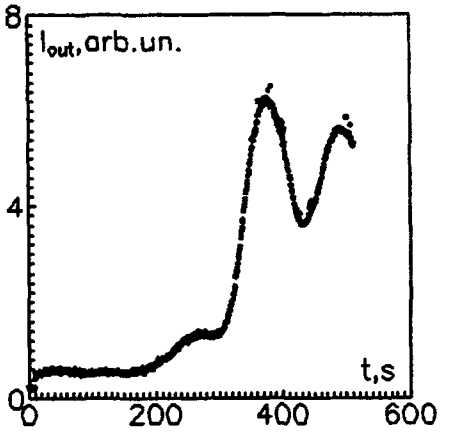

FIGURE 6

change of the boundary conditions on the aligning surface. Indeed, observations through polarizing microscope showed that the easy axis direction in the illuminated region was modulated with a spacial period of Λ = 20μm.

More detailed investigations of the light-induced bulk-surface anchoring transition were performed, using a described above experimental setup. The analogous cell was filled with the same LC but MR molecules were dissolved in the LC bulk - not in the aligning layer (weight concentration of MR molecules was 6%). The cell was illuminated with a He-Cd laser (λ_{ex}= 0.44μm, radiating power $P_{ex}\leqslant 5$ mW, beam diameter in the plane of the LC-cell $d_{ex}\approx$ 0.5 mm).

The following results were obtained:

- It was found that owing to exposure to a polarized light a permanent easy axis orientation $\vec{e}_c$ appeared on the PVCN-substrate; the direction of the $\vec{e}$-axis was parallel to the vector $\vec{E}_{ex}$. It should be mentioned that such a direction of a vector $\vec{e}$ was observed for the first time. In the publications[2-6] $\vec{e}_c$ was perpendicular to $\vec{E}_{ex}$.

- The appearance of the easy axis induces director reorientation in the LC bulk and on the control surface. In most cases the original direction of a vector $\vec{d}_p$ on the polyimide remains the same, i.e. the polyimide surface proved to be passive. Sometimes, reorientation of the vector $\vec{d}_p$ on the polyimide surface was also observed as a result of long time exposures (more than 5-10 min). Reorientation characteristics were in agreement with the theory for the case $\vec{e}_c \parallel \vec{E}_{ex}$: in the case of $\vec{E}_{ex} \parallel \vec{d}_o$ the reorientation was not observed, if $\vec{E}_{ex} \perp \vec{d}_o$ the reorientation had a threshold behavior , and it turned out to be without threshold in the intermediate situation (Fig.5).

In some cases, threshold reorientation showed an oscillating quasi-periodical behavior (Fig.6) (the same result was obtained in recording of polarizing dynamic holograms).

- Reorientation process consisted of irreversible and reversible components. Characteristic times of appearance and relaxation of the latter were roughly a few seconds, that, in turn, coincides in the order of magnitude with the lifetime of the c-isomers of MR molecules.

- Synchronous with irreversible reorientation, irreversible photobleaching of the illuminated area was observed.

- In the case of a long irradiation time (more than 5-10 min) reorientation of the easy axis was also found in the LC-cell with rubbed polyimide aligning surfaces.

The orientants which were used in the experiment and the LC-matrix were not sensitive to the illumination of a He-Cd laser. Therefore, we suppose that the reason for the appearance of the $\vec{e}$-axis was the interaction of light with MR molecules. The correlation between a photobleaching process and trans-cis isomerization with an easy axis formation shows that the $\vec{e}$-axis formation was due to the phototransformations of these molecules.

We also suppose that phototransformation products "adhere" to an aligning surface ("light-induced adsorption"). Since MR molecules are anisotropic and originally were placed in the anisotropic matrix, the light-induced adsorption also must be anisotropic and sensitive to the exciting light polarization.

Additional studies are needed for the corroboration of the model. In particular, an investigation of a photobleaching nature of MR molecules as well as a thorough analysis of possible interactions between MR and orientant molecules seem to be necessary.

Adsorption of organic molecules on a solid state surface is a quite general phenomenon. Because of that, an idea of an LC orientation control by means of a phototransformation of molecules due to changing of their adsorption parameters seems to be rather fruitful. A wide choice of orientant types as well as phototransformation products to be adsorbed on a surface enables to use a light-induced adsorption both for the purpose of a director control and for the research of general aspects of the "anchoring transition".

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