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# DYNAMIC OF SURFACE-MEDIATED DIRECTOR REORIENTATION IN A CELL WITH DYE DOPED LIQUID CRYSTAL

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*We report on investigation of a light-induced anchoring of dye-doped liquid crystal (LC) in nematic phase. Contributions of light-induced dye adsorption and desorption processes as well as of the bulk-induced reorientation effect were separated by choosing specific geometries of the light irradiation. We propose a model that explains peculiarities of light-induced easy axis producing in nematic phase which differs from one in isotropic phase due to presence of anisotropic dark-adsorbed layer and effective bulk-induced director reorientation.*

*Keywords*: adsorption; desorption; dye doped liquid crystal; light-induced anchoring; nematic liquid crystal

## 1. INTRODUCTION

Applications of liquid crystals (LCs) require both well aligned LC layers and methods to control the alignment precisely in a real time. Therefore,

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light-induced alignment and surface-mediated light-induced reorientation effects in LCs have been the subject of intense research in the last decade [1–3]. A promising method that allows to reach both requirements is surface-mediated photoalignment in the dye-doped LC [4]. The main feature of this method is the possibility of producing the easy orientation axis, $\vec{e}$, on the non-photosensitive polymer surface by irradiation with polarized laser light in the dye absorption band. It was found that the orientation of light-induced anisotropy axis on the boundary surface could be easily controlled by adjusting the polarization and intensity of incident light. Moreover, it was found that the anchoring energy associated with the light-induced easy orientation axis could be effectively controlled by the light exposure.

The nature of surface-mediated photoalignment has not been finally ascertained and still is a subject of open discussion. Ouskova *et al.* [5] found the effect of hidden photoalignment of methyl red (MR) doped LC on non-photosensitive polymer surface after irradiation of the cell in the isotropic phase. Authors observed that such irradiation resulted in the appearance of uniform director orientation in the irradiated area after cooling down the sample to the nematic state. Light-induced easy orientation axis could be either parallel or perpendicular to the polarization of the incident beam depending on the light intensity. It was assumed that an isotropic "dark-adsorbed" layer of dye molecules grows on polymer aligning surface after filling of the cell. Additionally the easy axis appearance has been attributed to the two processes: light-induced anisotropic adsorption of dye molecules on aligning surface that produced the easy axis, $\vec{e}$, parallel to the incident light polarization, $\vec{E}$, and light-induced desorption of dye molecules from the isotropic "dark-adsorbed" layer that produced $\vec{e}$ perpendicular to $\vec{E}$. The resulted orientation of easy orientation axis was determined by competition of these two processes. At low intensity regime ($I < 1\,\mathrm{W/cm^2}$) the light-induced desorption prevailed, and $\vec{e} \perp \vec{E}$. At high intensity regime ($I > 1\,\mathrm{W/cm^2}$) the light-induced desorption dominated giving $\vec{e} \| \vec{E}$.

Recently in [6,7], Lucchetti *et al.* proposed to investigate the dynamic of easy axis appearance in dye-doped LC using geometries, where desorption and adsorption processes could be distinguished. If the polarization of the pump beam is perpendicular to the initial director state ($\vec{d} \perp \vec{E}$), only director orientation toward $\vec{E}$ can be detected, namely a measured signal would correspond to reorientation caused by light-induced adsorption, which produces easy orientation axis parallel to $\vec{E}$. On the contrary, if the polarization of the incident light is parallel to the initial director ($\vec{d} \| \vec{E}$), only the director reorientation outward vector $\vec{E}$, due to desorption, can be observed.

We used this idea to study the hidden photoalignment of MR doped LC pentyl-ciano-bephynil (5CB) on non-photosensitive polymer surface polyvinilcinnamate (PVCN-F) after irradiation of the cell in isotropic phase [8]. Accordingly to the previous results [5], we observed no director turn

**TABLE 1** Comparison of the Light-Induced Orientation Obtained in the Isotropic Phase [8] and in the Nematic Phase

| Geometry | Isotropic phase | Nematic phase |
|---|---|---|
| $\vec{d} \perp \vec{E}$ $I < 1\,\mathrm{W\,cm^{-2}}$ | No director turn | No director turn |
| $\vec{d} \perp \vec{E}$ $I > 1\,\mathrm{W\,cm^{-2}}$ | Director turns toward $\vec{E}$ | Director turns toward $\vec{E}$ |
| $\vec{d} \parallel \vec{E}$ $I < 1\,\mathrm{W\,cm^{-2}}$ | Director turns outward $\vec{E}$ | Director turns outward $\vec{E}$ |
| $\vec{d} \parallel \vec{E}$ $I > 1\,\mathrm{W\,cm^{-2}}$ | No director turn | Director turns outward $\vec{E}$ |

by irradiating the cell at low intensity with $\vec{E}$ perpendicular to the direction of rubbing on the reference substrate of the cell. It this case light-induced desorption led to the easy axis appeared perpendicular to $\vec{E}$, that is parallel to the rubbing direction, and a planar structure was formed. At high intensity regime a twist structure was formed that corresponded to the domination of light-induced adsorption leading to the easy axis be parallel to $\vec{E}$. According to that, when $\vec{E}$ is parallel to the rubbing direction, we obtained a twist structure at low intensity regime and a planar structure at high intensity regime. These results are summarized in the Table 1.

Recent studies of light-induced anchoring [9] showed that the orientational order in the nematic phase affected the processes controlling easy axis appearance. The aim of the present work was to investigate peculiarities of light-induced anchoring in *nematic phase* of LC doped with MR using the geometries proposed in [6].

## 2. EXPERIMENTS AND DISCUSSION

We performed our experiments using nematic LC pentyl-ciano-bephynil 5CB (Merck) doped by 0.5% weight concentration of azo-dye methyl red from Aldrich. Standard combined planar cells were made using one rubbed polyimide surface as reference one. This surface provided strong LC alignment parallel to the rubbing direction. The second, test surface, was formed by isotropic layer of fluorinated polyvinilcinnamate (PVCN-F) that was irradiated by unpolarized UV light. The UV irradiation resulted in degenerated planar alignment of LC with a weak anchoring. In opposite to not-irradiated PVCN-F, the irradiated polymer was stable against dissolving of LC. Due to the strong anchoring on the reference substrate, a homogenous planar alignment was observed in the cell. The cell thickness was determined by teflon spacers and varied in range of $25 \div 28\,\mu\mathrm{m}$.

We used an experimental set-up exploiting a standard pump-probe geometry (Fig. 1, [4]). The incident linearly polarized beam of He-Cd laser ($\lambda = 0.44\,\mu m$) was focused ($f = 50\,cm$) onto the LC layer from the side of isotropic surface. The intensity of irradiation was adjusted by filters. The irradiating region was probed by He-Ne laser beam impinging from the side of the reference surface. The probe beam polarization was fixed parallel to the initial LC director state in the cell. The Mauguin regime for the propagation of the probe beam was valid, so that the analyzer, being crossed with polarizer, blocked the test light in the absence of director reorientation. At these conditions signal appearance behind the analyzer indicated changes of LC director orientation on the test surface.

We measured the dynamic of the evolution of the easy orientation axis on the test surface in two geometries. When the polarization of the incident light was perpendicular to initial director state, $\vec{d} \perp \vec{E}$, we found a slow director turn toward polarization vector $\vec{E}$ (Fig. 2). The characteristic time of easy axis growing was about hundreds of seconds depending on the intensity of incident light. The irradiation with the intensities lower then $1\,W/cm^2$ did not produce the easy axis.

We observed different dynamics of LC director reorientation in geometry with $\vec{d} \| \vec{E}$ (Fig. 3). Just after the light switching on, there was a fast director turn outward the polarization of the incident beam, continuing in the same direction with a slower characteristic time. The characteristic time of the fast turn was about 1 ms, while the slow one was in the range of seconds.

We also investigated the intermediate geometries when the angle between director and polarization of incident light was in a range from $\vec{d} \perp \vec{E}$ to $\vec{d} \| \vec{E}$. The dynamics of the director reorientation at different angles $\varphi$ between $\vec{E}$ and $\vec{d}$ at the intensity $4\,W/cm^2$ is shown in Figure 4. When $\vec{d}$ was not parallel or perpendicular to $\vec{E}$, at first the director turned outward

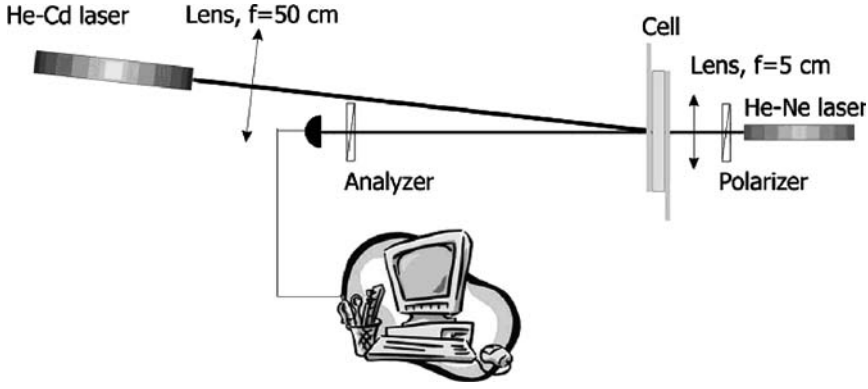


**FIGURE 1** Experimental set-up.

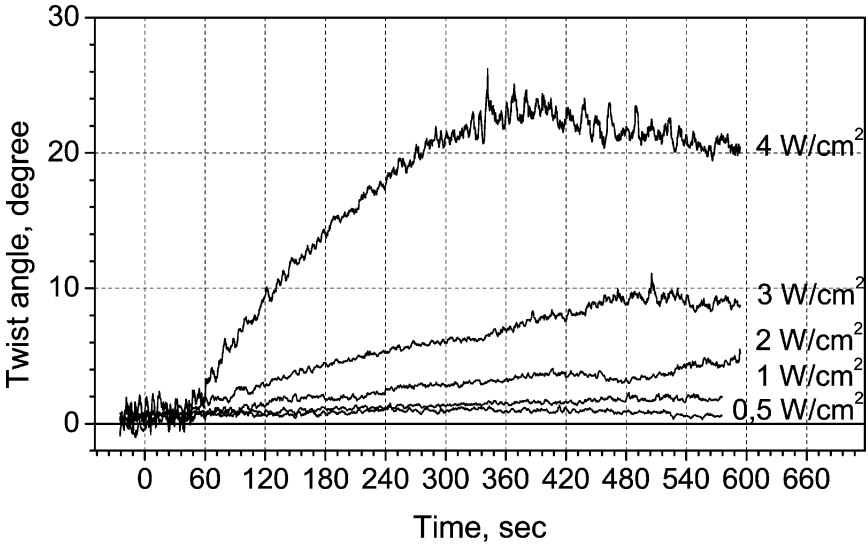


**FIGURE 2** Dynamics of director reorientation for different intensities of incident light in geometry $\vec{d} \perp \vec{E}$.

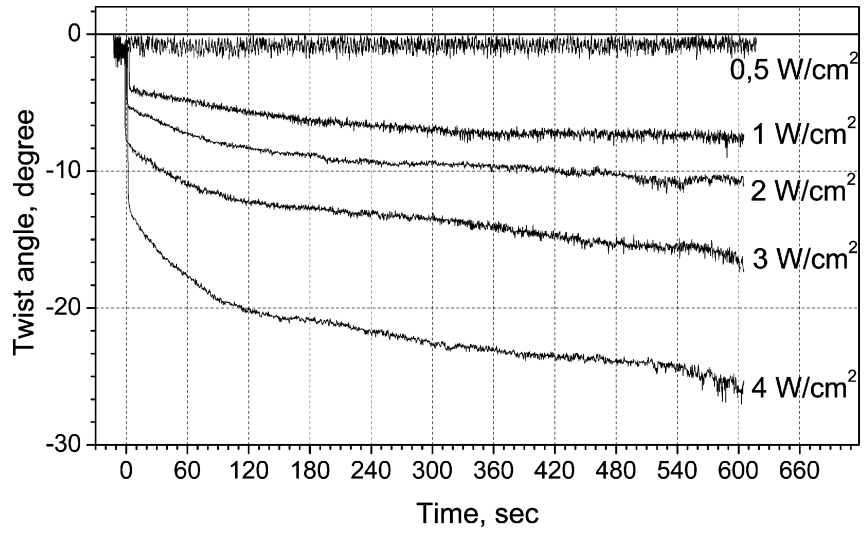


**FIGURE 3** Dynamics of director reorientation for different intensities of incident light in geometry $\vec{d} \| \vec{E}$. Negative angles of director's turn mean reorientation outward $\vec{E}$.

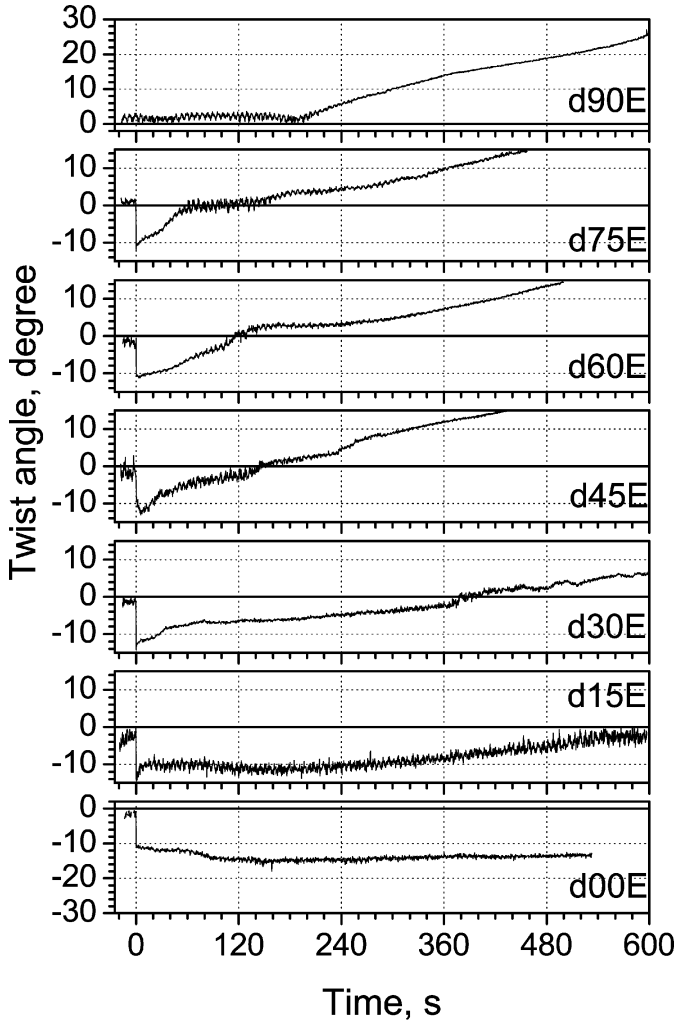


**FIGURE 4** Dynamics of director reorientation for different geometries. The insertions on each graph show the geometry of irradiation. The number between **d** and **E** indicates the angle between initial director state $\vec{d}$ and polarization of incident light $\vec{E}$.

$\vec{E}$ then with the increasing of the exposure time – toward $\vec{E}$. With increasing of the angle $\varphi$ the change of the sign of the director turn occurred at smaller exposure time.

The basic experimental results are summarized in Table 1 together with the data obtained in the studies of hidden photoalignment in isotropic

phase [8]. One can see their qualitative agreement except for the results of the geometry $\vec{d}\|\vec{E}$ for high intensity regime. We did not obtain any twist structure after the irradiation in the isotropic phase but we have observed a definite twist after irradiation of the cell in the nematic phase.

The discrepancy between the results obtained in isotropic and nematic phases is evidently connected with the orientational order in the nematic phase. Bulk ordering in the combined cell results in the appearance of anisotropic dark-adsorbed layer of MR molecules oriented along the director at the reference surface [5]. Besides, bulk-induced reorientation of the LC outward the initial direction of the director is initiated by polarized light [10]. Let us describe a picture of the evolution of the light-induced anchoring taking into account these two factors.

When $\vec{d}\perp\vec{E}$ and $I < 1\,\mathrm{W/cm^2}$, no director reorientation was found because light-induced desorption prevailed at this intensity and the induced easy axis appeared to be parallel to the initial director state. Bulk-induced reorientation effect also does not induce a reorientation in this case. At irradiation with $I > 1\,\mathrm{W/cm^2}$ a slow process mediated by light-induced adsorption of MR molecules plays a leading role, and the reorientation toward $\vec{E}$ occurs. Since the anisotropic distribution function of MR molecules has a maximum along the director, then the light-induced adsorption process is not very effective at $\vec{d}\perp\vec{E}$, and the anchoring energy of the induced easy axis $\vec{e}$ grows slowly (Fig. 2).

When $I < 1\,\mathrm{W/cm^2}$ and $\vec{d}\|\vec{E}$, we observed the fast director turn followed by the slow director reorientation outward the polarization $\vec{E}$ (Fig. 3). We attribute this behavior to fast bulk-induced reorientation effect and slow desorption-mediated mechanism; each of them leads to the director turn outward $\vec{E}$. At $I > 1\,\mathrm{W/cm^2}$ the bulk-induced reorientation effect results in depressing of the light-induced adsorption due to light-induced desorption. Really, a fast director reorientation outward $\vec{E}$ damps the light-induced adsorption since the maximum of the angular distribution function of MR in the LC bulk appeared to be far from the direction of $\vec{E}$. At the same time, the distribution function of MR molecules in dark-adsorbed layer takes no changes, the polarization $\vec{E}$ is still parallel to its maximum and desorption keeps effective. Hence, in opposite to the isotropic phase, the desorption-mediated mechanism of the easy axis formation prevails in this case and reorientation of the director outward $\vec{E}$ occurs.

## 3. CONCLUSIONS

Summarizing, we found that orientational ordering essentially affected on the characteristics of surface-mediated light-induced anchoring in the nematic phase. Contributions of light-induced dye adsorption and

desorption processes as well as of the bulk-induced reorientation effect were separated by choosing specific geometries of the light irradiation. We proposed a model that explained the peculiarities of light-induced easy axis occurrence in the nematic phase, which differs from the one in the isotropic phase due to presence of anisotropic dark-adsorbed layer and effective bulk-induced director reorientation.

## REFERENCES

[1] Gibbons, W. M., Shannon, P. J., Sun, S. T., & Swetlin, B. J. (1991). *Nature* (London) *351*, 49.
[2] Dyadyusha, A. G., Marusii, T. Ya., Reshetnyak, V. Yu., Reznikov, Yu. A., & Khizhnyak, A. I. (1992). *Pis'ma Zh. Eksp. Teor. Fiz.*, *56*, 18 [JETP Lett. 56, 17 (1992)].
[3] Schadt, M., Schmitt, K., Kozenkov, V., & Chigrinov, V. (1992). *Jpn. J. Appl. Phys.*, Part 1, *31*, 2155.
[4] Voloshchenko, D., Khyzhnyak, A., Reznikov, Yu., & Reshetnyak, V. (1995). *Jpn. J. Appl. Phys.*, *34*, 566.
[5] Ouskova, E., Fedorenko, D., Reznikov, Yu., & Shiyanovskii, S. (2001). *Phys. Rev. E*, *63*, 021701.
[6] Lucchetti, L., Fedorenko, D., Francescangeli, O., Reznikov, Yu., & Simoni, F. (2003). accepted for publication in *Opt. Lett.*
[7] Simoni, F. & Francescangeli, O. (1999). *J. Phys.: Condens. Matter*, *11*, R439.
[8] Fedorenko, D., Ouskova, E., & Reznikov, Yu. (2003). *SPIE Proceedings*.
[9] Ouskova, E., Reznikov, Yu., Shiyanovskii, S., Su, L., West, J., Kuksenok, O., Francescangeli, O., & Simoni, F. (2001). *Phys. Rev. E*, *64*, 051709.
[10] Marusii, T., Reznikov, Yu., & Slussarenko, S. (1996). *Mol. Materials*, *6*, 163.