Effects of polarization azimuth in dynamics of electrically assisted light-induced gliding of nematic liquid-crystal easy axis

A.V. Dubtsov,1 S.V. Pasechnik,1,2 Alexei D. Kiselev,3,2 D.V. Shmeliova,1 and V.G. Chigrinov2

1Moscow State University of Instrument Engineering and Computer Science, Stromynka 20, 107846 Moscow, Russia
2Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong
3Institute of Physics of National Academy of Sciences of Ukraine, prospekt Nauki 46, 03028 Kiev, Ukraine
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We experimentally study the reorientation dynamics of the nematic liquid crystal easy axis at photoaligned azo-dye films under the combined action of in-plane electric field and reorienting UV light linearly polarized at varying polarization azimuth, $\varphi_p$. In contrast to the case where the light polarization vector is parallel to the initial easy axis and $\varphi_p = 0$, at $\varphi_p \neq 0$, the pronounced purely photoinduced reorientation is observed outside the interelectrode gaps. In the regions between electrodes with non-zero electric field, it is found that the dynamics of reorientation slows down with $\varphi_p$ and the sense of easy axis rotation is independent of the sign of $\varphi_p$.

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INTRODUCTION

It is well known that external electric, magnetic or light fields may produce deformations of liquid crystal (LC) orientational structures initially stabilized by anisotropic boundary surfaces (substrates). There is a variety of related Fréedericksz-type effects that are at the heart of operation of the vast majority of modern liquid crystal devices [1, 2].

Among the key factors that have a profound effect on behavior of the field induced orientational transitions are the boundary conditions at the substrates. These conditions are determined by the anchoring characteristics such as the anchoring energy strengths and the easy axis, $n_e$, giving the direction of preferential orientation of LC molecules at the surface.

In contrast to traditional description of the Fréedericksz-type transitions, it turned out that reorientation processes induced by external fields may additionally involve slow rotation of the easy axis. Over the past few decades this slow motion — the so-called easy axis gliding — has received much attention as a widespread phenomenon observed in a variety of liquid crystals on amorphous glass [3], polymer [4–12] and solid [6, 12] substrates.

Slow reorientation of the easy axis also takes place on the photosensitive layers prepared using the photoalignment (PA) technique such as poly-(vinyl)-alcohol (PVA) coatings with embedded azo-dye molecules [5], polymer compound poly (vinyl methoxyxynamate) [6], and the azo-dye films [12]. The PA technique is employed in the manufacturing process of liquid crystal displays for fabricating high quality aligning substrates and uses linearly polarized ultraviolet (LPUV) light to induce anisotropy of the angular distribution of molecules in an azo-dye containing photosensitive film [12].

In PA method, the easy axis is determined by the polarization azimuth of the pumping LPUV light, whereas the azimuthal and polar anchoring strengths may depend on a number of the governing parameters such as the wavelength and the irradiation dose [15]. So, in a LC cell with the initially irradiated layer, subsequent illumination with reorienting light which polarization differs from the one used to prepare the layer can trigger the light-induced easy axis gliding. Such gliding may be of considerable interest for applications such as LC rewritable devices [16].

Recently, it has been found experimentally that a more complicated effect of electrically assisted light-induced azimuthal gliding of the easy axis takes place on photoaligned azo-dye layers when irradiation of nematic LC (NLC) cells with LPUV light is combined with the application of an in-plane electric field [17]. It was observed that, at certain combinations of the parameters such as the amplitude of electric field $E$, the light intensity, $I_{LPUV}$, the exposure time, $I_{exp}$, and the dose of the initial UV irradiation, $D_p$, the switching off relaxation considerably slows down to few months. The switching on dynamics of the gliding for both the linearly polarized and the nonpolarized reorienting light was studied in [18]. In particular, the results of the papers [17, 18] demonstrate that the combined effect may be used as a tool to tune technical parameters of LC memory devices.

So, as compared to the case of purely light-induced reorientation of the easy axis governed by the effect of photoinduced ordering in azo-dye layers, the dynamics of the electrically assisted light-induced gliding can be additionally influenced by the electric field, $E$. Another physically and technologically important parameter is the polarization azimuth that characterizes orientation of the polarization vector of the LPUV reorienting, $E_{LPUV}$. In previous studies [17, 18], the reorienting light was linearly polarized along the initial easy axis.

In this paper, we present the experimental results on...
the reorientational dynamics of the electrically assisted light-induced azimuthal gliding of the easy axis measured at different values of the polarization azimuth. Our goal is to study how the polarization azimuth influences the surface mediated reorientation processes that occur in NLC cells under the combined action of LPUV light and in-plane electric field.

EXPERIMENT

In our experiments, liquid crystal (LC) cells \(d = 17.4 \pm 0.2 \mu m\) of sandwich like type were assembled between two amorphous glass plates. The upper glass plate was covered with a rubbed polyimide film to yield the strong planar anchoring conditions. In Fig. 1 the direction of rubbing gives the easy axis parallel to the \(x\) axis.

A film of the azobenzene sulfuric dye SD1 (Dainippon Ink and Chemicals) \[14\] was deposited onto the bottom substrate on which transparent indium tin oxide (ITO) electrodes were placed. The electrodes and the inter-electrode stripes (the gap was about \(g = 50 \mu m\)) were arranged to be parallel to the \(x\) axis.

As in \[17, 18\], the azo-dye SD1 layer was initially illuminated by linearly polarized UV light (LPUV) at the wavelength \(\lambda = 365 \text{ nm}\). The preliminary irradiation produced the zones of different energy dose exposure \(D_p = 0.27, 0.55 \text{ J/cm}^2\) characterized by relatively weak azimuthal anchoring strength. The light propagating along the normal to the substrates (the \(z\) axis) was selected by an interference filter. Orientation of the polarization vector of UV light, \(E_{\text{init}}\), was chosen so as to align azo-dye molecules at a small angle of 4 degrees to the \(x\) axis, \(\varphi_0 \approx 4 \text{ deg}\) [see Fig. 1(a)]. The LC cell was filled with the nematic LC mixture E7 (Merck) in isotropic phase and then slowly cooled down to room temperature. Thus we prepared the LC cell with a weakly twisted planar orientational structure where the director at the bottom surface \(n_0\) is clockwise rotated through the initial twist angle \(\varphi_0 \approx 4 \text{ deg}\) which is the angle between \(n_0\) and the director at the upper substrate (the \(x\) axis).

As is indicated in figure [1(b)], the director field deforms when the in-plane ac voltage \((U = 100 \text{ V, } f = 3 \text{ kHz})\) is applied to the electrodes. In addition to the electric field, \(E = 2 \text{ V/\mu m}\), the cell was irradiated with the reorienting LPUV light beam \((I_{UV} = 0.26 \text{ mW/cm}^2\) and \(\lambda = 365 \text{ nm})\) normally impinging onto the bottom substrate.

For this secondary LPUV irradiation, orientation of the polarization plane is determined by the polarization azimuth \(\varphi_p\) which is defined as the angle between the polarization vector of UV light, \(E_{UV}\), and the initial surface director \(n_0\). As is indicated in Fig. 1 we shall assume that positive (negative) values of the polarization azimuth, \(\varphi_p > 0 (\varphi_p < 0)\), correspond to clockwise (counterclockwise) rotation of the polarizer from \(n_0\) to \(E_{UV}\).

Our experimental method has already been described in \[17, 18\]. In this method, NLC orientational structures were observed via a polarized microscope connected with a digital camera and a fiber optics spectrometer. The rotating polarizer technique was used to measure the azimuthal angle \(\varphi_e\) characterizing orientation of the easy axis. In order to register microscopic images and to measure the value of \(\varphi_e\), the electric field and the reorienting light were switched off for about 1 min (see Fig. 1(c)). This time interval is short enough to ensure that orien-
tation of the easy axis remains essentially intact in the course of measurements. The measurements were carried out at a temperature of 26°C.

When the electric field \((E = 2 \, \text{V/\mu m})\) in combination with reorienting LPUV light of the intensity \(I_{UV} = 0.26 \, \text{mW/cm}^2\) is applied for more than 120 minutes, we observed the memory effect. In this case, after switching off the field and light, the easy axis did not relax back to its initial state for at least few months.

Figure 2 shows the microscopic images obtained at various times of irradiation by LPUV reorienting light for four different values of the polarization azimuth: \(\varphi_p = 0, -24, -45, -65\) degrees. In this case, the initial irradiation dose is fixed at \(D_p = 0.27 \, \text{J/cm}^2\).

It can be seen that, when the reorienting light is linearly polarized along the initial surface director \(n_0\) and \(\varphi_p = 0\), the brightness of stripes within the interelectrode gaps is much higher as compared to the ones in the region outside the gaps where the electric field is negligibly small \(E \approx 0 \, \text{V/\mu m}\). So, in the case of vanishing polarization azimuth studied in Refs. [17, 18], we arrive at the conclusion that, by contrast to the electrically assisted light-induced gliding, the purely photoinduced reorientation is almost entirely inhibited.

The latter is no longer the case for the reorienting light with nonzero polarization azimuth. Referring to Fig. 2 at \(\varphi_p \neq 0\), light-induced distortions of the surface director in the zero-field region located outside the gaps are very much more pronounced. It is also evident from the curves depicted in Fig. 3(a) representing the irradiation time dependencies of the easy axis angle measured at negative polarization azimuthal angles of the reorienting LPUV light.

In the zero-field curves, the easy axis angle increases with the irradiation time starting from the angle of initial twist, \(\varphi_0\), and approaches the photo-steady state with the photosaturated value of the angle close to \(\pi/2 + \varphi_p\). The curves describing the electrically assisted reorientation within the interelectrode gaps lie below the zero-field ones and reveal analogous behavior.

The data measured at the polarization azimuths of the opposite sign, \(\varphi_p > 0\), (see Fig. 3(b)) show that, in the zero-field region, the light-induced changes of the easy axis angle are negative and correspond to the counterclockwise rotation of the polarizer. As seen from Fig. 3(b), the dynamics of the easy axis in the presence of the electric field essentially differs from the one in the regime of purely photoinduced reorientation. In the interelectrode gaps, it turned out that the electric field prevails thus suppressing the tendency for the easy axis to be reoriented along the normal to the polarization vector of light \(E_{UV}\).

**CONCLUSIONS**

In conclusion, we have experimentally studied the effects of polarization azimuth in the electrically assisted light-induced azimuthal gliding of the NLC easy axis on the photoaligning azo-dye film. It is found that, by contrast to the case where the polarization vector is oriented along the initial surface director, at nonzero polarization angle \(\varphi_0\), the purely photoinduced reorientation takes place outside the interelectrode gaps. For such field-free regime of reorientation, the easy axis reorients approaching the photosaturation limit close to the normal to the polarization vector. These results agree with the theoretical predictions of the diffusion model describing kinetics of photoinduced ordering in azo-dye films and...
the corresponding theoretical analysis will be published in a separate paper.

In the regions between electrodes with non-vanishing electric field, the dynamics of reorientation slows down with the polarization azimuth and, as opposed to the case of purely photoinduced reorientation, the sense of easy axis rotation for the electrically assisted light-induced gliding is found to be independent of the sign of polarization azimuth. The above mentioned theory [19] cannot be directly applied to this case and the work is in progress on interpreting these data using the phenomenological model formulated in [12, 17] to describe the dynamics of the electrically assisted gliding.

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* Email address: kiselev@iop.kiev.ua
† Email address: eechigr@ust.hk

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