7- 4: Alignment of Ferroelectric Liquid Crystals with Photoanisotropic Azodye Aligning Layers

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Abstract

The photo-induced alignment quality of a ferroelectric liquid crystas (FLC) onto a photochemical stable azodye film was studied for various procedures of the azodye film photo-treatment and the FLC structure. The alignment quality of FLC depends mainly on the order parameter of the azodye film, however the structure of FLC layer is also important. So, the photo-aligned deformed helix ferroelectric (DHF) liquid crystal exhibits the contrast ratio CR>500:1, while for the helix free FLC the contrast ratio CR>1500:1.

1. Introduction

Nowadays practically all liquid crystal displays are aligned mainly by mechanical buffing of thin polyimide films. However the impurities and electrostatic charge together with mechanical damage of the surface are produced in this case, which has to be completely avoided for the new types of LCDs with active matrix (AM) addressing and high resolution.

FLC display cells are extremely sensitive to dust particles that induce nucleation centers for dislocations especially at very small cell gap (less than 2μm) which provides the best optical transmission of the cells [1]. Moreover, as we understood previously through our experiments, buffing non-uniformity very often results in the appearance of large domains with opposite FLC directors (typical dimension is about 0.5÷3 cm). The domain formation leads to a poor reproducibility in manufacturing of FLC display devices. The phenomenon of the bistability degradation in FLC cells aligned with ordinary rubbing technique has been already discovered many years ago [2]. This is why the photoalignment FLC technology, which enables to avoid mechanical brushing, looks very promising [3].

At least two approaches to the photoalignment of FLC's have been discussed [1,4]. A hybrid of linearly photopolymerized photoalignment (LPP) with liquid crystal polymer (LCP) layers provides a very good alignment of deformed helix ferroelectric (DHF) FLC with the contrast ratio more than 200:1 as well as the electrooptical response time less than 200 μs [1]. Photoanisotropic azodye films were used for the alignment of FLC in order to increase the bistability steadiness, but this approach does not prevent the bistability degradation [4]. A new azodye, called SD-1 dye, had been recently synthesized and successfully tested for the alignment of nematic liquid crystals [5].

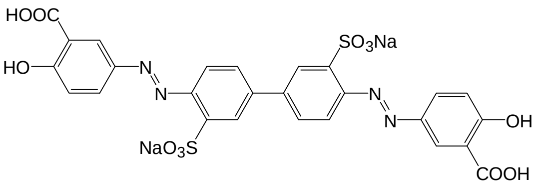

Figure 1. Chemical structure of SD-1 dye.

A remarkable property of this azodye is the pure reorientation of the molecular absorption oscillators perpendicular to the UV light polarization, which is not practically accompanied with photochemical transformations [6]. This property gives a good chance to provide a high photoalignment quality of FLC using the azodye SD-1 layer.

2. Experimental

Asymmetric boundary conditions of the FLC layer have been arranged in the framework of our present investigation as shown in Fig. 2.

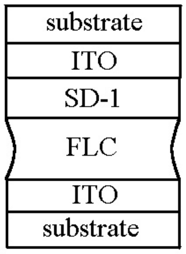

Figure 2. Schematic drawing of a cell, which provides asymmetric boundary conditions for the photoalignment of ferroelectric liquid crystals.

So, only one ITO surface of all prepared FLC cells was covered with SD-1 layer but another ITO surface was simply washed in N,N-dimethylformamide (DMF). The azodye SD-1 layer onto ITO surface has been formed as follows. First, the dye was dissolved in DMF in concentration of 1.3%. The solution has been spin coated onto ITO electrode at 2000 rpm or at 3000 rpm, and dried at 50°C. The SD-1 layer thickness was 8÷10nm at 3000 rpm, and 13÷15nm at 2000 rpm, as it was evaluated through the AFM technique. UV light was irradiated onto the surface of the layer using a super-high pressure Hg lamp, interference filter at 365 nm, and a polarizing filter. The light intensity on the surface of layer was 6 mW/cm^2 for the polarized light.

Two glass substrates were assembled as shown in Fig. 2 to form liquid crystal cell with a cell gap of 1.5ìm. The boundary conditions asymmetry has been provided in order to avoid a competition in aligning action of solid surfaces of FLC cells. Let us note that ITO electrode washed in DMF, provides a focal-conic, or planar degenerated alignment, where all directions in the plane of the substrate are energetically equivalent. On the contrary, the photoaligned SD-1 layer provides a preferable direction for the alignment of FLC molecules.

Our basic approach is that existence of just one preferable direction given by one solid surface minimizes the density of dislocations, if another solid surface provides the degenerated planar alignment.

FLC mixtures FLC-451A and FLC-445 (from P. N. Lebedev Physical Institute of Russian Academy of Sciences) have been injected into the cell in an isotropic phase by a capillary action. The DHF FLC-451A possesses the helix pitch p_0 =0,27μm, the spontaneous polarization P_S =150 nC/cm^2 at T=23°C, and the following phase transition sequence:

$$Cr\text{®}^{4^{\circ}C}\text{®}C^*\text{®}^{64^{\circ}C}\text{®}A^*\text{®}^{87^{\circ}C}\text{®}Is$$

The FLC-445 possesses the spontaneous polarization P_S =210 nC/cm^2 at T=23°C, but the helix pitch tends to infinity compensated in the bulk due to the interaction of the two chiral dopants with the same signs of the spontaneous polarization and opposite signs of their handedness [7]. The phase transition sequence of this FLC writes:

$$Cr\text{®}^{6^{\circ}C}\text{®}C^*\text{®}^{78^{\circ}C}\text{®}A^*\text{®}^{90^{\circ}C}\text{®}Is.$$

The electrooptical measurements have been carried out at l =0,6328μm, with registration of responses with HP Infinum oscilloscope and a photodiode.

3. Results

3.1 The FLC alignment quality for the photoalignment and buffing procedures

The linear polarized UV light was irradiated perpendicularly to the SD-1 layer during the time 10, 20, 30 and 60 minutes. A dependence of the contrast ratio on the exposure time t_{exp} (Fig.3) illustrates, in fact, the relationship between the exposure energy and the FLC alignment quality.

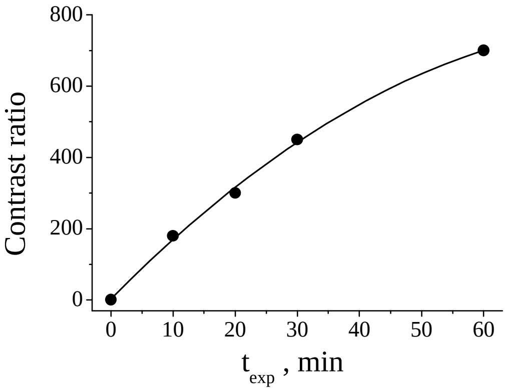

Figure 3. The contrast ratio of FLC cells filled with the FLC-451A versus exposure time t_{exp}, when SD-1 layer was illuminated with the linear polarized UV light at a normal incidence.

The contrast ratio increases up to 700:1 because of the decrease of the dislocations density with increasing of the UV light energy irradiating the surface of SD-1 layer. This point is illustrated with the photos of FLC layers textures, Fig. 4.

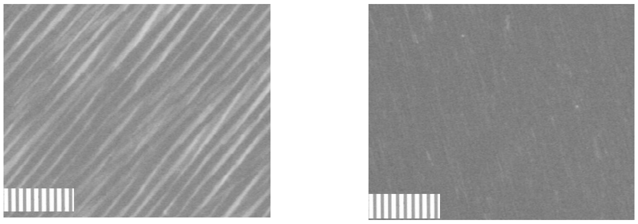

Figure 4. Polarization microscope images of the dark state of two photoaligned cells filled with the FLC-451A: left – the irradiation time of SD-1 surface is 10 minutes, right - the irradiation time of SD-1 surface is 60 minutes. The SD-1 layer thickness is 13nm. Appendices at photos illustrate a scale of images, the striped structure of appendices has a periodicity of 8μm. Photos made just after preparation of the cells, the electric field was not applied.

Increasing of the irradiation time results in a total disappearance of dislocation lines (see the right photo at Fig. 4), which become visible as bright stripes in the dark state (the left photo in Fig. 4), if the irradiation time is less than some critical threshold. Probably, the reason of the phenomenon is increasing of the order parameter of the dye film that occurs with the increasing of the exposure time [8].

On the other hand, the idea of asymmetric boundary conditions discussed above, plays very important role even if the rubbed polyimide is used instead of the azodye layer at the same FLC cell geometry which is presented in Fig. 2. The dislocation lines suppression is available in this case also, see Fig. 5.

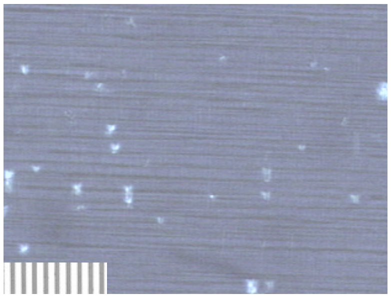

Figure 5. Polarization microscope image of the dark state of asymmetric FLC cell filled with the FLC-451A. Asymmetry of the cell means that one of ITO layers is covered with 15 nm rubbed polyimide but another is not. Appendix at the photo illustrates a scale of the image, the striped structure of the appendix has a periodicity of 8μm. The photo is made just after the preparation of cells, the electric field was not applied.

Small bright regions at the dark state here are defects related to spacers, distributed on the rubbed polyimide surface. A comparison of the photos in Figs. 4 and 5 shows that the photoalignment quality could be better or worse than the alignment quality of a cell aligned with buffing procedures (the contrast ratio related to the texture presented in Fig. 5 is 450:1), dependent on the exposure time of the azodye aligning layer. In other words, the photoalignment quality is better than the buffing alignment, if the order parameter of the azodye SD-1 layer is high enough. The asymmetric boundary conditions play a key role because in any case the suppression of dislocation lines is provided.

The photoalignment of the helix free FLC-445 reveals the same tendency as one for the DHF FLC-451A but the helix free FLC is more sensitive to aligning action of the dye layer, Fig. 6. The contrast ratio of a cell filled with the helix free FLC-445 is more than 1500:1 for the exposure time of 60 minutes and about 400:1 for the exposure time of 10 minutes. So, the photoalignment quality can be perfect independently on existence or absence of the FLC helix.

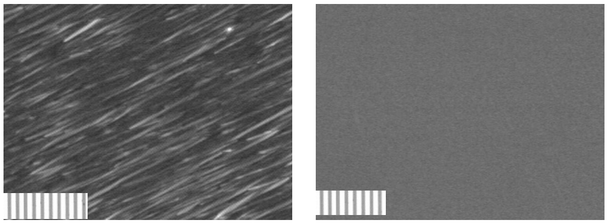

Figure 6. Polarization microscope images of the dark state of two photoaligned cells filled with the helix free FLC-445: left – the irradiation time of SD-1 surface is 10 minutes, right - the irradiation time of SD-1 surface is 60 minutes. The SD-1 layer thickness is 13nm. Appendices at photos illustrate a scale of images, the striped structure of appendices has a periodicity of 8µm. The photos are made just after the preparation of the cells, the electric field was not applied.

3.2 Electrooptics of photo-aligned FLC cell

The question arises, if the asymmetric boundary conditions could be considered as a drawback from the point of view of electrooptical properties. The bistable switching is very sensitive to the asymmetry in boundary conditions. That is why we checked the bistability of the photoaligned FLC cell (see Fig. 7) in order to evaluate if the asymmetry manifests in electrooptical operation of the cell.

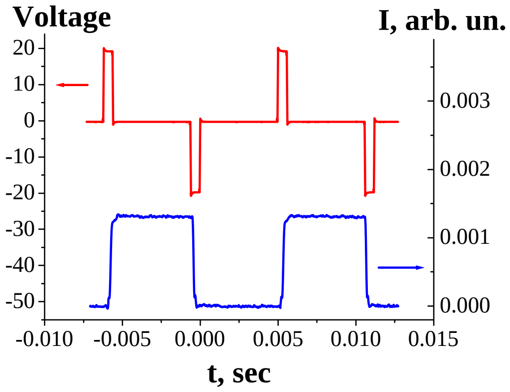

Figure 7. Bottom curve – a shape of the electrooptical response of the photoaligned cell filled with the helix free FLC-445, the exposure time is 30 min; top curve is a driving voltage waveform.

The bistability is perfect and steady, as shown in Fig. 7, and we did not observe any change in operation of the parameters at least during one month. Moreover, the multiplexing ability, which is necessary for a passively addressed FLC display cell operation also takes place, Fig.8.

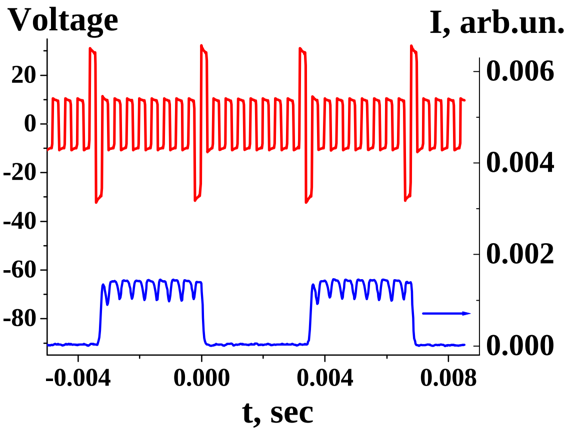

Figure 8. Illustration of multiplexing of the photoaligned cell filled with the helix free FLC-445, the exposure time is 30 min. Bottom curve – a shape of the electrooptical response; top curve is a multiplex driving voltage waveform.

So, neither bistability nor multiplex operation of photoaligned FLC cells is suppressed because of the asymmetry in boundary conditions of the cells.

There is some difference between switching on time $t^{on}_{0,1-0,9}$ and switching off one $t^{off}_{0,1-0,9}$ of the electrooptical response of cells, Fig. 9.

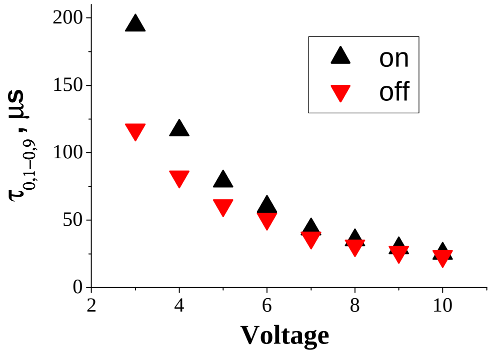

Figure 9. Switching on and off times versus the voltage. The cell is filled with the helix free FLC-445, the irradiation time is 30 min.

Nevertheless, the difference is negligible, if the voltage is higher than 5V.

4. Discussion and Conclusion

To provide a high photoalignment quality of FLC we need the following.

1.Asymmetric boundary conditions in FLC cell (Fig. 2).

2.The photochemical stable azodye photo-aligning layer with a high order parameter, obtained at a sufficiently large exposure time and/or exposure energy.

The approach covered by these ideas results in a creation of a perfect photoalignment quality of FLC cell, which is characterized by the contrast ratio 700÷1500. This value is even better in comparison with the alignment quality provided by common buffing procedures of FLC cell substrates. The new photo-aligning technology can be a decisive factor of the promotion of FLC devices to the display market.

5. Acknowledgements

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6. References

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